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PREFACE

This is the 15th International Conference on Environmental Ergonomics (ICEE2013), and the first time it has been held south of the equator. It’s actually ventured well south; Otago is the world’s second most southern university, and an apt location to host a satellite meeting on ‘Moving in Extreme Environments’. Aotearoa, New Zealand, has the dubious advantage of being formed by the juncture of the Indian/Australian and Pacific continental plates, and almost squarely intercepts ‘The roaring forties’ [southern latitude].

The evolution of the ICEE is described very well by editors of published contributions from previous meetings, e.g., in the Proceedings of the 1996 meeting (John Frim, Michel Ducharme and Peter Tikuisis), and the special issue of *Eur J Appl Physiol* following the 2007 meeting (Igor Mekjavić, Nigel Taylor and Pietro Di Prampero; 104: 127-129, 2008). Briefly, the ICEE arose from an initial gathering in England, in 1984, of people interested in factors affecting work under adverse environments, and has become a biennial meeting of such individuals. It’s a small, single-session meeting, often held over 4.5 days. Its strength is in providing a collegial forum for robust and integrative discussion on research and its application to humans working in stressful environments. Long-term attendees include exercise and environmental physiologists, clothing and equipment designers and manufacturers, physicians, modellers, and especially students – whose research development is especially considered.

We thank the Executive Committee for – in 2007 – putting their faith in us to run the 15th ICEE. The period 11-15th February was chosen after juggling several factors, but inevitably caused conflicts; we apologise especially to those unable to attend because of Chinese New Year. We also appreciate that the cost of travel prevented other regulars from attending, especially due to wider budgetary problems for scientists in Europe and North America.

The conference is only as good as the calibre, nature and number of research submissions, and to this end we thank delegates for many excellent submissions. This volume contains 128 abstracts or minipapers, all of which were both reviewed and edited by at least one independent reviewer. Amendments were requested on all but five. Ethical clearance was verified by authors, where relevant. The conference had 129 registered delegates, with 40 presenting students, 6 non-presenting students. We are very grateful for the support of WL Gore & Associates for funding almost all of the presenting students and prizes for best oral and poster student presentations. (No student with a relevant submission was denied free registration). We are also grateful to the School of Physical Education for their substantial funding of the satellite symposium, thereby providing an additional research forum for people travelling to New Zealand, and a broader range of speakers for the ICEE. Last but not least, we are grateful to the other sponsors: The new and highly-relevant, open-access journal, *Extreme Physiology & Medicine*; The Maurice & Phyllis Paykel Trust; Water Safety New Zealand, and; the trade exhibitors (Measurement Technology NW and GBC Biomed). We warmly welcome you, and hope that you find the conference and environment to be stimulating and enjoyable.
Previous Conferences

THE 1st INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Bristol, UK, 1984
Organisers: N. Thomas

THE 2nd INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Whistler Mountain, Canada, 1986
Organisers: I.B. Mekjavic, N. Kakitsuba
Selected papers in Environmental Ergonomics, Editors I Mekjavic, EW Banister and JB Morrison, Taylor & Francis, London 1988

THE 3rd INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Helsinki, Finland, 1988
Organisers: R. Ilmarinen, A. Pasche

THE 4th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Austin, Texas, USA, 1990
Organisers: E. Wissler, S.A. Nunneley

THE 5th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Maastricht, The Netherlands, 1992
Organisers: W. Lotens, G. Havenith

THE 6th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Montebello, Canada, 1994
Organisers: J. Frim, M. Ducharme, P. Tikuisis
Proceedings published by Defence and Civil Institute of Environmental Medicine, Canada.

THE 7th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Jerusalem, Israel, 1996
Organisers: Y. Shapiro, D. Moran, Y. Epstein
Proceedings published by Freund Publishing house, Tel Aviv.

THE 8th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
San Diego, USA, 1998
Organisers: J. Hodgdon, J. Heaney, M. Buono
Proceedings published Environmental Ergonomics VIII
THE 9th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Dortmund, Germany, 2000
Organisers: J. Werner, M. Hexamer
Proceedings published as Environmental Ergonomics IX.

THE 10th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Fukuoka, Japan, 2002
Organisers: Y. Tochihara
Proceedings also published as Environmental Ergonomics X.

THE 11th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Ystad, Sweden, 2005
Organisers: I. Holmér, K. Kuklane and C. Gao

THE 12th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Portoroz, Slovenia, 2007
Organisers: I. Mekjavic, R. Pisot & N. Taylor
Proceedings published as:

THE 13th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Boston, USA, 2009
Organisers: J. Castellani
ISBN: 978-1-74128-179-8 (online)

THE 14th INTERNATIONAL CONFERENCE ON ENVIRONMENTAL ERGONOMICS
Nafplio, Greece, 2011
Organisers: N. Geladas, M. Koskolou, S. Kounalakis
Proceedings published as: Proceedings of the 14th International Conference on Environmental Ergonomics, ENVIRONMENTAL ERGONOMICS XIV
Editors: Stylianos Kounalakis, Maria Koskolou, National and Kapodestrian University of Athens
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2nd  Siyeon Kim (Seoul Nat. Univ., Korea)

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Climate change is already occurring and making hot days hotter in tropical and sub-tropical areas of the world and periods of very hot days become longer. People who are carrying out physically demanding jobs are particularly affected by ambient heat as their muscle movements create waste heat inside the body, which cannot easily be transferred to the surrounding air when the air temperature is higher than the body temperature. Evaporation of sweat is then the only physiological mechanism to avoid body over-heating, and the efficiency of evaporation is less and less the more humid the surrounding air is.

These basic physiological and ergonomic facts are the foundation of our ongoing global research and action programme established in 2008. The programme focuses on impacts of occupational heat exposures, how these can be reduced and how climate change may increase the exposures in different localities around the world. Outdoor work in the sun is the most highly exposed to the increasing heat, but it needs to be remembered that most factories in hot countries, where much of the consumer products for the global market are currently produced, do not use air conditioning or other effective means for cooling the air.

The heat health hazards can create major ergonomic problems, and when the workers protect themselves from over-heating by taking more rest or working more slowly, the labour productivity is reduced, leading to lower incomes or lower economic outputs for enterprises and communities. This threat to health and the community economy has been overlooked in climate change impact analysis until now, and the most affected people are the poor and under-privileged. A new major international report, the Climate Vulnerability Monitor 2012, highlighted the importance of this aspect of climate change impacts on occupational health, as the global costs in 2030 was estimated at 2.4 trillion US$ PPP. A number of other health threats from climate change can also cause special problems for working people, creating special importance for basic occupational health services and preventive interventions as the world gets hotter.

Clearly, this issue of human reactions to environmental heat levels and the ergonomics of reducing heat stress and strain is a mainstream topic at this conference. The research on heat exposures and effects and approaches for policies and actions to reduce the health risks is highly interdisciplinary. Unfortunately the links between all relevant disciplines have not been established in the context of climate change research and impact analysis. Environmental ergonomists could take the lead in creating bridges to these disciplines in order to actively develop evidence of value for the prevention of climate change health and economic impacts. These include: Bio-meteorologists, Thermal physiologists, Industrial hygienists, Occupational medicine practitioners, Epidemiologists, Biostatisticians, Human factors psychologists, Industrial design engineers, Air cooling specialists, Social impact and health equity analysts, Productivity management experts, and economists.
The global HOTHAPS program – new analysis and action on workplace heat; a key environmental ergonomics issue during climate change

Tord Kjellström1,2*, Rebekah A.I. Lucas1, Bruno Lemke3
1 Centre for Global Health Research, Umeå University, Umeå, Sweden
2 National Centre for Epidemiology and Population Health, Australian National University, Canberra, Australia
3 Nelson-Marlborough Institute of Technology, Nelson, New Zealand
*corresponding author: kjellstromt@yahoo.com

Introduction
The High Occupational Temperature Health and Productivity Suppression (HOTHAPS) program is designed to carry out research on the direct effects of heat exposure on working people. The aim of this program is to quantify likely increases in heat exposure resulting from climate change, the subsequent effects of such changes in different geographical locations (focus on Tropical low and middle income countries) and to identify feasible ways to reduce exposures and effects.

Methods
The program has been implemented since 2008 on a shoe-string budget with support from Australia, Sweden and Norway. This research program includes studies that:
- Develop improved methods for assessing human heat exposure and effects;
- Measure and model such exposures in different parts of the world;
- Test methods to measure effects on health and human performance (particularly physical activity and work capacity) due to heat, including studies of working children and pregnant women;
- Quantify the exposure-response relationships for direct heat effects and other workplace-related effects of climate change;
- Analyse the age-specific and sex-specific impacts of heat exposures, including studies of pregnant women, working children, school children and other vulnerable groups;
- Use climate change modelling (carried out by internationally-agreed methods) to estimate future climate exposures and impacts on health and human performance of working people in specific locations and the whole planet (using globally gridded data);
- Estimate the economic consequences of these HOTHAPS impacts.

Results and Discussion
Field studies are currently implemented in Australia, New Zealand, India, Nepal, Thailand, Vietnam, Ghana, South Africa, Costa Rica and Nicaragua. The findings show the importance of workplace heat in creating health risks and in reducing labour productivity. When hourly ambient temperatures exceed 37-40 degrees C the productivity losses are at least 30% compared to cooler hours. As indicated in a recent economic analysis by DARA (see: Climate Vulnerability Monitor 2012) the resulting economic losses may be massive, and they occur mainly in low and middle income countries. There is a great need for broadened capacity building in environmental ergonomics in the affected countries.
The effect of global warming and urban heat islands on mortality, morbidity and productivity in The Netherlands

Hein A.M. Daanen1,2*, Wouter Jonkhoff1, Peter Bosch1, Harm ten Broeke1

1 TNO, Delft, Utrecht and Soesterberg, The Netherlands
2 MOVE Research Institute Amsterdam & Faculty of Human Movement Sciences, VU University, Amsterdam, The Netherlands
*corresponding author: Hein.Daanen@tno.nl

Introduction

This paper constitutes a first attempt to quantify the economic impact of increased ambient temperature due to global warming and due to urban heat islands for The Netherlands. The study is limited to the direct effects of heat on humans: mortality (how many people die), morbidity (how many people enter hospital emergency care) and productivity. Please see Stone et al. [1] for the full details of this study.

Methods - Model Construction

Mortality

Based upon an analysis of meteorological data – daily averaged temperatures from 1995 until 2010 (source: KNMI- Royal Netherlands Meteorological office) – and statistics about deaths in the Netherlands (source: Statistics Netherlands) an empirical formula was derived that best estimated the relation between ambient temperature and mortality. This was multiplied with the value of a human life lost, with was set at 18 kEur/ year [2].

Equation:

\[ M = (377 + (0.81 - 0.0511 \times T - 0.00389 \times T^2 + 0.00000964 \times T^3) \times 38.73) \times \left(\frac{18000}{365}\right) \]

<table>
<thead>
<tr>
<th>with:</th>
<th>M</th>
<th>=</th>
<th>Mortality cost per day (Euro)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>=</td>
<td>The 24-hour averaged temperature (ºC)</td>
<td></td>
</tr>
<tr>
<td>377</td>
<td>=</td>
<td>The average mortality per day (n/day)</td>
<td></td>
</tr>
<tr>
<td>38.73</td>
<td>=</td>
<td>The standard deviation</td>
<td></td>
</tr>
<tr>
<td>18000/365</td>
<td>=</td>
<td>Value of one day of life</td>
<td></td>
</tr>
</tbody>
</table>

The number of years lost before a natural death would occur was assumed to be 1 year.

Morbidity

Parsons et al. [3] have shown that in the United Kingdom, each °C rise in temperature above 18°C means an extra 0.36% of hospital admissions. Each °C lowering in temperature below 18°C means a drop in hospital admissions of 0.64%. It is assumed that these numbers can be applied to the Netherlands. In the Netherlands, the number of daily hospital admissions is about 11,000 (2838 per 10,000 inhabitants, source: Statistics Netherlands). The average costs associated with a hospital admission is about 5 K€ur.

These costs were combined with the current average 24-hour temperatures and the average temperatures resulting from the several climate-scenarios to calculate the costs in the current and (possible) future climates. The difference between the current and future costs are the extra costs caused by climate change. Also this calculation is based on the assumption that the national pattern of hospital admissions with regard to average temperature will not change if the climate changes.
\[ \text{Equation when ambient temperature} > 18^\circ\text{C:} \]
\[ \text{Mb} = (11000 \times 5000) + (T - 18) \times 0.0036 \times 11000 \times 5000 \]
\[ \text{Equation when ambient temperature} \leq 18^\circ\text{C:} \]
\[ \text{Mb} = (11000 \times 5000) + (18 - T) \times 0.0064 \times 11000 \times 5000 \]
\[
\begin{array}{|l|l|}
\hline
\text{with:} & \text{Mb} & = & \text{Morbidity cost per day (Euro)} \\
T & = & \text{The 24-hour averaged temperature (°C)} \\
11000 & = & \text{Average number of hospital intakes/day} \\
5000 & = & \text{Average cost of hospital uptake} \\
\hline
\end{array}
\]

**Productivity**

Not much is known about the effect of temperature on productivity. In a review written by Seppänen et al. [4], it was concluded that productivity within buildings drops when the temperature in the building rises above 25°C. This was adopted for our calculations.

\[ \text{Equation when ambient temperature} \leq 25^\circ\text{C:} \]
\[ P = (469817 \times 10^3)/1800 \]
\[ \text{Equation when ambient temperature} > 25^\circ\text{C:} \]
\[ P = (469817 \times 10^3)/1800 - ((469817 \times 10^3)/180000) \times T \times 2 - 50 \]
\[
\begin{array}{|l|l|}
\hline
\text{with:} & P & = & \text{Productivity per day (Euro)} \\
T & = & \text{Corrected daily temperature (°C)} \\
469817 \times 10^3 & = & \text{Corrected national turnover of The Netherlands in Euro} \\
1800 & = & \text{Workable hours in a year} \\
\hline
\end{array}
\]

The temperature was assessed of a working day between 08:00 (am) and 18:00 (pm).

In order to calculate the costs, it is assumed that high temperatures outdoors lead to indoor temperatures just as high. Loss of productivity does not occur, or hardly occurs, at low temperatures, because Dutch buildings are generally properly heated. Not all production sectors suffer from loss of productivity because of heat, however. Therefore, all sectors in which the working pace and added value per unit of time are mostly determined by machinery (agriculture, forestry, fishery, mining, industry (textile, clothing, furniture and repair of machinery excluded), energy production, water companies, waste treatment, traffic (postal services and couriers excluded)) are not incorporated in the calculation. Also, the productivity calculation is limited to shops, services and health care production in buildings that are not equipped with any cooling installation. This was established by applying penetration degrees of cooling equipment in various types of buildings in the Netherlands. The remainder has an added value of MEur 469,817.
Results and Discussion

Global warming

The calculations provide a first estimation of the yearly damage by temperature increases caused by climate change as it is expected to occur in 2050 under four different scenario’s [5], under the assumption that the economic and demographic structure of the Netherlands in 2050 is similar to the structure in 2010, and that the temperature related mortality and morbidity functions remain constant up to 2050. The numbers thus represent an order of magnitude and cannot be used in absolute terms. The results are shown in Table 1.

Table 1. Monetary damage by heat stress in MEuro / year.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>-12</td>
<td>-16</td>
<td>-23</td>
<td>-25</td>
</tr>
<tr>
<td>of which is in July and August</td>
<td></td>
<td></td>
<td>1.3</td>
<td>2.7</td>
</tr>
<tr>
<td>Morbidity (hospital admissions)</td>
<td>-103</td>
<td>-137</td>
<td>-193</td>
<td>-249</td>
</tr>
<tr>
<td>of which is in July and August</td>
<td>-5</td>
<td>-1</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Productivity losses</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>391</td>
</tr>
</tbody>
</table>

For both extra mortality and hospital admissions it seems that, under the assumptions used, global warming leads to a greater reduction of cases in wintertime, than it leads to a rise in mortality and hospital admissions during warmer summers. Therefore, the damage is ‘negative’ or, in other words, climate change will lead to a benefit in mortality and hospital admissions. The monetary gain is highest for hospital admissions.

Losses in occupational productivity occur, according to the applied calculation method, mostly in the W scenario (the W scenario assumes a 2°C rise in temperature in 2050, worldwide, compared to 1990). The (monetary) damage as a result of productivity losses increases rapidly in this scenario. Each 0.1°C above 25°C results in a loss of 0.5 MEur/h. We have used average daily temperatures for the calculations, which hide heat wave periods. It is expected that climate change will lead to more frequent and longer heat wave periods, which might mean that the effects of extreme temperatures in summer are underestimated.

Urban heat island effect

For the urban heat island effect, data were used of a meteorological station in Rotterdam Urban and compared to (rather) non-urbanised data for Rotterdam Airport in 2009. We followed roughly the approach advanced by Roodenburg [6]. The results are shown in Table 2. The presumption is that the entire Netherlands is either an urban heat island or a rural area.

It is clear that the urban heat island effect has a minor effect on mortality and morbidity costs, but leads to an enormous productivity decrease.
Table 2. Additional costs if The Netherlands would have been an urban heat island, compared to The Netherlands as a rural area (in MEuro/year).

<table>
<thead>
<tr>
<th></th>
<th>Urban Island compared to rural area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>-8</td>
</tr>
<tr>
<td>of which in July and August</td>
<td>-6</td>
</tr>
<tr>
<td>Morbidity (hospital admissions)</td>
<td>-25</td>
</tr>
<tr>
<td>of which in July and August</td>
<td>-20</td>
</tr>
<tr>
<td>Productivity losses</td>
<td>1480</td>
</tr>
</tbody>
</table>

Conclusions
Mortality in The Netherlands is higher in the cold than in the heat. The W+ scenario for global warming in The Netherlands (the worst case) would lead to a considerable reduction in mortality equivalent to about 25 MEuro due to early loss of life. Also, the cost related to hospital uptake would be about 250 MEuro less for scenario W+. The increase in summer temperature, however, would lead to a decreased productivity equivalent to about 390 MEur. The net effect of scenario W+ for global warming in The Netherlands would therefore be an additional cost of about 115 MEuro.

If The Netherlands would be one big city, the temperature profiles during the day are different than when The Netherlands would have been one rural area. Mortality and morbidity would be 8 and 25 MEuro less respectively of which about 80% is due to the months July and August only. In an urban environment, the productivity would decrease enormously because temperatures would be much higher during the day. The additional costs would be 1480 MEuro.

These numbers represent the result of a preliminary analysis using simplified functions based on available data. Future research is required to validate the functions and perform sensitivity analyses in order to substantiate the initial conclusions.

References
Climate change and occupational health - populations exposed and the sustainability of methods to avoid excessive heat in workplaces

Karin Lundgren *, Ingvar Holmér

Thermal Environment Laboratory, Department of Design Sciences, Lund University, Lund, Sweden

*corresponding author: karin.lundgren@design.lth.se

Introduction

Global climate change will increase outdoor and indoor heat loads, and may impair health and productivity for millions of working people worldwide [1]. Coping with climate change (adaptation) is already unavoidable due to past emissions. This paper attempts to evaluate how many working people are potentially already exposed to heat and therefore, climatic changes in the tropical and subtropical climate zones, in the largest countries: Brazil, Nigeria, Pakistan, India, Bangladesh, Indonesia and China. Urbanization trends in these countries were also explored as urban populations are estimated to have additional heat load exposure due to the urban heat island effect.

Methods

A literature search with targeted search terms together with grey literature was used. For some topics such as air-conditioning and urban heat load, little research have been conducted to date, hence, a variety of search words in broad databases were used. The literature search was combined with the use of the ILO LABORSTA Statistics 1999-2008 [2] based on ISCO-88 [3], the World Bank’s World Development Indicators Data (Total Population), 2012 [4] for data on labour occupation, and UN-HABITAT’s Global Urban Indicators Database from 2008 [5] was used to gather urbanization trends.

Results and Discussion

It was found that more than 700 million workers are potentially exposed to the climatic changes in these countries due to the type of work being undertaken, particularly being in the outdoors. It was also found that more than 1.4 billion people run the risk of being exposed to the extra urban heat load [5]. However, even though these numbers are large, due to underreporting, they are bound to be underestimations.

The most vulnerable groups are people in agriculture, forestry, building and construction work and small and medium sized enterprises in small as well as large cities. Simple and low cost solutions are required to mitigate the adverse effects of heat stress and reduce costs in terms of impaired work ability, lowered productivity and reduced economy. High cost solutions such as air conditioning of buildings and workplaces will only be available for a small minority of mostly wealthy and highly educated people. Climate change and indicated trends of global warming aggravate conditions in decades to come, in particular in many of the countries mentioned above [6-8]. In all countries more detailed analyses of geographic, climatic variations and susceptible professions and workplaces and urbanization effects are needed in order to quantify the effect on health, work capacity and productivity. Future research should identify methods and models for prediction of occupational heat stress from a global warming point of view. Research must also focus on preventive measures and interventions to mitigate adverse effects with a strong focus on sustainable development.

References

Electric fans: Should they be used during heat waves?

Ollie Jay1 *, Simon Hodder2

1 Thermal Ergonomics Laboratory, School of Human Kinetics, University of Ottawa, ON, Canada
2 Environmental Ergonomics Research Centre, Loughborough University, Leics, UK
*corresponding author: ojay@uottawa.ca

Introduction
On the North American continent, July 2012 was the hottest month since records began in the late 1800s. Heat waves continue to claim lives every summer, with the elderly, poor and socially isolated at greatest risk [1]. A simple and cost-effective intervention is an electric fan. However, governmental public health messaging on their use has been inconsistent, with the suggested environmental limits at which they no longer prevent heat-related illnesses historically ranging from 32.3ºC (90ºF) (35% relative humidity (RH)) [2] to the “high 90s” (96-99ºF; 35.6-37.2ºC) with no RH stated [3]. In contrast, a recent Cochrane review concluded that no empirical evidence whatsoever currently exists in the literature supporting or refuting the use of electric fans during heat waves [4]. Using a biophysical approach, we examined the environmental conditions that electric fans no longer protect against an elevated risk of cardiovascular strain and heat illness in unacclimated, sedentary adults.

Methods
We employed a conceptual human heat balance model to derive the evaporative requirement for heat balance (E_{req}) and maximum capacity for evaporative heat loss (E_{max}) with and without an electric fan [5]. Air flow profile around the body was determined using the cylindrical model proposed by Kerslake [6]. The air velocity of 4.5 m s⁻¹ was equivalent to an 18” diameter electrical fan at waist height set at maximum speed and at a distance of 1.0 m. A velocity of 0.2 m s⁻¹ accounted for natural convection without a fan. Metabolic rate was 65 W m⁻²; body surface area was 1.8 m². A mean skin temperature of 35.5ºC, and the dry insulation and evaporative resistance of clothing for a summer ensemble (including air layer effects), were used [5].

The combinations of air temperature (T_a) and RH for, a) physiological compensability (i.e., E_{req}>E_{max}), and b) exacerbated cardiovascular strain were determined. Maximum skin wettedness values were: 0.85 (adults, no fan), 0.65 (adults, fan; older adults (50+γ), no fan) and 0.50 (older adults, fan). Critical wettedness values for elevated cardiovascular strain were: 0.50 (all, no fan) and 0.35 (all, fan) [7]. Required fluid intake to offset sweat losses were determined by calculating the rate of sweat production required for heat balance [5].

Results
At a low RH (20%), the T_a limit for an elevated cardiovascular strain with a fan is 38.6ºC, whereas at a high RH (60%) this limit is 34.2ºC. Furthermore, the estimated T_a limit for an older adult at which metabolic and passive heat loads can no longer be compensated by evaporation with maximum skin sweat coverage, with a fan, is 41.9ºC at 20%RH and 35.7ºC at 60%RH. Irrespective of RH, the T_a limit for physiological compensation and the onset of cardiovascular strain is ~3-4ºC higher with a fan compared to no fan, for all groups (Figure 1). Fans do not require additional fluid intake to balance sweat losses at any combination of T_a and RH within the upper limits of physiological compensation (Figure 1).
**Discussion and Conclusion**

The protective limits of fans are greatly altered by humidity, and our model suggests that fans can provide protection from an elevated cardiovascular strain and the onset of heat illnesses at air temperatures beyond existing guidelines issued by the CDC and WHO [2, 3]. Relative to the peak outdoor conditions reported for major heat waves, fan use would be better than no fan use in all cases. With the exception of two of the highest peak temperatures in US history, physiological compensation could be possible with, but not without, a fan. However, fans alone would not provide complete protection from cardiovascular strain, and cooler and/or drier air would be needed particularly by older individuals during the hottest parts of the day, but not at night. Elevations in indoor humidity could also increase physiological strain, even with a fan. Previous concerns that fans would exacerbate fluid intake requirements [3] were unfounded under all conditions.

**References**

A software tool to identify extreme heat exposures from weather station data

Matthias Otto¹*, Tord Kjellström²,³, Bruno Lemke¹

¹ Nelson Marlborough Institute of Technology, Nelson, New Zealand
² National Centre for Epidemiology and Population Health, Australian National University, Canberra, ACT 0200, Australia
³ Centre for Global Health Research, Umeå University, Umeå, Sweden
*corresponding author: matthias.otto@nmit.ac.nz

To assess historic and current heat exposures and make projections for the future, it is vital to be able to identify patterns, extremes and possibly trends in climate data. A software tool was developed that allows rapid presentation of several key climate variables as well as two widely used heat stress indexes WBGT (Wet Bulb Globe Temperature) and UTCI (Universal Thermal Climate Index), using publicly available weather station recordings over a time period from 1980 to the present.

The output produced by the software includes customisable monthly and annual average line graphs of climate variables and heat stress indices. For threshold analyses the software can produce charts plotting the number of days a variable exceeds a specified value. Further, the data can be analysed and monthly distributions displayed in box and whisker charts. There is a variety of numeric output options for further processing and analysis.
Daily values are used for the software’s input. The user can access data from the majority of active land-based weather stations anywhere in the world. The user is able to locate stations by name, country, or identify all available stations within a specified area around a global coordinate.

The software can be used to identify extreme events in a given locality (e.g., southern cities in the US), possibly matching them to well-known historic occurrences e.g., heat waves. The monthly data distributions allow the identification of the specific month(s) and year, or period of years, in which these extremes have occurred. A threshold analysis can give an indication of a possible time trend for extreme events and the associated heat stress experienced by people at these localities.

Further applications of the software will be demonstrated during the presentation.
A physiological evaluation of shelters that might sustain life during an Australian bushfire

Benjamin J. Haberley, David J.R. Hoyle, Nigel A.S. Taylor*
Centre for Human and Applied Physiology, University of Wollongong, Wollongong, Australia
*corresponding author: Nigel_Taylor@uow.edu.au

Introduction
South-Eastern Australia experiences the most frequent and severe bushfires in the world. In 2009, bushfires in Victoria claimed 173 lives and cost more than $4 billion in structural damage. As a consequence, the establishment of building standards that might govern the construction of bushfire shelters was recommended. Since no relevant standards existed, it was suggested that if these shelters could keep the internal conditions to a maximal mean Modified Discomfort Index (MDI) of 39° for 60 min, then they could restrain the rise in core temperature to no more than 2°C. The current investigators were invited to test this hypothesis and, in this communication, provide a physiological evaluation of this recommendation across two experiments. In the first experiment, the aim was to evaluate the physiological impact of a 10°C variation in air temperature that could be encountered at a constant Modified Discomfort Index of 39°. The objective of the second experiment was to explore changes within the internal environment of an air-tight shelter containing pre-heated and sweating occupants.

Methods
The first experiment involved 96 separate trials performed using 16 healthy adults (males (n=8) and females: 19-24 y). Semi-naked subjects were exposed (at rest) to three thermal conditions, each with a Modified Discomfort Index of 38-39°, but covering a 10°C temperature range and 40% range in relative humidity: Condition 1: 40°C, 70% RH; Condition 2: 45°C, 50% RH; Condition 3: 50°C, 30% RH. These conditions were held stable throughout each exposure, and subjects were tested under two pre-heated states: mild hyperthermia (core temperature 37.5°C) and moderate hyperthermia (38.5°C). These states were induced using hot-water immersion and exercise, and each was accompanied by mild dehydration (2%). Physiological strain was quantified from heart rate, and from the core, mean skin and mean body temperature responses.

The second experiment took place in an air-tight chamber (shelter simulator: 1.2 m³) housed within a larger climate chamber (Figure 1). This inner chamber was constructed to conform with the likely requirements of a bushfire shelter. Sixteen pre-heated (core temperature 38.0°C), semi-naked males (mass >75 kg) participated. Dehydration was prevented by drinking water to match mass loss, in an attempt to optimise sweating within the shelter. Upon attaining the desired pre-experimental state, subjects entered the inner chamber, which had been equilibrated to 45°C and 50% RH (Condition 2), and commenced a 60-min resting exposure. During this time, the physical characteristics of air sealed within the simulator were free to change. Physiological strain was again quantified, as were changes in air temperature, water vapour pressure, and the fractional concentrations of oxygen and carbon dioxide within the inner chamber.

Results and Discussion
During experiment one, subjects experienced greater cardiovascular strain in Conditions 2 and 3 when moderately hyperthermic, reflecting a protracted elevation in skin blood flow. Indeed, three subjects had heart rates >170 beats.min⁻¹ in Condition 2, with six returning such values in Condition 3. Whilst cardiovascular strain was significant, this is well tolerated by healthy individuals. Core temperature data were inspected for evidence of hyperthermia. However, for
every individual, core temperature remained below 38°C at the end of each trial, and across both pre-heated states. That is, all participants lost heat to the air even though, in the hottest state (Condition 3), the air was about 11.5°C hotter than body core temperature. This observation highlights the well known power of evaporative cooling.

![Figure 1: An air-tight chamber: bushfire shelter simulator.](image)

Whilst the three conditions from experiment one were of an equivalent Modified Discomfort Index, they were not equally stressful. Across the three conditions, physiological strain became significantly greater with each increment in air temperature. Thus, when subjects were moderately hyperthermic, the respective terminal heart rates and core temperatures were (last 15 s): 96 beats.min⁻¹, 37.2°C (Condition 1); 115 beats.min⁻¹, 37.5°C (Condition 2); 119 beats.min⁻¹, 37.8°C (Condition 3). These step-wise elevations were expected since the Modified Discomfort Index is a derivation of the effective temperature scale, and, as such, it is merely a modified sensation index. The effective temperature scale was never designed to predict physiological responses or survival probabilities. Instead, its purpose was to define thermal comfort limits for people within air-conditioned spaces by identifying combinations of air temperature, air motion and relative humidity that would elicit equivalent comfort. Notwithstanding this limitation, it was clear that the suggestion for using a Modified Discomfort Index of 39° did not result in subjects experiencing unacceptable levels of physiological strain.

Within the air-tight chamber (experiment two), water vapour pressure and carbon dioxide concentration both climbed, whilst air temperature and the fractional concentration of oxygen were reduced. The carbon dioxide and oxygen concentrations changed linearly over the duration of these exposures, reflecting respiratory gas exchanges. However, both water vapour pressure and air temperature revealed curvilinear response characteristics. Over the last minute of these exposures, the following states were recorded within the inner chamber (bushfire shelter simulator): air temperature 40.5°C (SD 0.5); relative humidity 90.5% (SD 1.9); fractional concentrations oxygen 16.7% (SD 0.9) and carbon dioxide 3.88% (SD 0.77). The terminal heart rates, core and mean skin temperatures (last 15 s) were 139 beats.min⁻¹ (SD 11), 39.3°C (SD 0.2) and 38.8°C (SD 0.2).
Conclusions
From a purely thermal perspective, the first experiment provided support for the recommendation that bushfire shelters should aim to keep the internal conditions to a maximal mean Modified Discomfort Index of 39° for 60 min. These data show that core temperature will not rise excessively under these conditions, providing air temperature and water vapour pressure remain stable. However, these states cannot be expected to exist within an air-tight shelter, and this was the focus of the second experiment.

From experiment two, one may conclude that, within a sealed bushfire shelter, physiological strain will be progressively elevated. However, even under these conditions, it appeared that the resultant strain, whilst now being profound, would be tolerable within an emergency bushfire shelter, in which the anticipated occupancy should be limited to approximately 60 min.

In the third experiment within this series, trials involving Conditions 1 and 2 will be repeated, but now with the air temperature and water vapour pressure progressively rising, and tracking the average changes measured during experiment two. These trials are aimed at approximating worst-case conditions within a shelter, and will also explore the impact of pre-heating and mild dehydration, as in the first experiment. This research is currently being completed, and will be communicated at the conference.
Protecting against excessive workplace heat as an outcome of climate change – confronting the sustainability challenge from increased air conditioning use

Karin Lundgren¹ *, Tord Kjellström²,³, Ingvar Holmér¹, Bruno Lemke³, Rebekah A.I. Lucas⁴

¹Thermal Environment Laboratory, Department of Design Sciences, Lund University, Lund, Sweden
²National Centre for Epidemiology and Population Health, Australian National University, Canberra, Australia
³Nelson-Marlborough Institute of Technology, Nelson, New Zealand
⁴Centre for Global Health Research, Umeå University, Sweden
*corresponding author: karin.lundgren@design.lth.se

The use of air conditioning in workplaces has become the routine method to cope with excessively hot work environments in offices and factories. This aspect of environmental ergonomics will be one of the major challenges to developing a sustainable future society. The balance between the need for electricity to cool working environments in order to create healthy, comfortable and productive work environments, and the minimization of current and future “un-necessary” electricity use is not going to be resolved without further scientific and technical analysis. The problem is an extension of the rapidly increasing use of air conditioning in households due to affluence. For example, the number of households in the USA with air conditioning rose from 64 to 100 million between 1993 and 2009. In China 50 million air conditioning units were sold in just one year, 2010. In Mumbai, India, 40% of the total electricity consumption goes to air conditioning [1]. The most rapid increase in the future is likely to occur in South and South-East Asia, where energy demand for residential air conditioning could increase 50% by 2100 [2]. This is happening in the current climate situation, and the projected climate change will further increase demand driven by the human need for cooler living and working environments. A recent study in business areas of Japan showed that the electricity consumption goes up 5% for each °C increase of ambient temperature [3]. The paper uses this data from offices in Japan linking increased electricity use to higher levels of temperature and humidity. An exponential relationship was found between WBGT and electricity use and on this basis calculations were made on the additional costs associated with warming temperatures. For instance, in the scenario of a two degree increase (WBGT: 21, 5-23, 5), a factory with a floor space of 5000m² could face a $150 extra daily costs for air conditioning. This also translates to an additional 6 TWh electricity use in developing countries for every °C increase. This is calculated out of the estimated air conditioning use of a total of 115 TWh in 2005 [4]. Using grid cell based estimates of current and future (modeled) temperatures in different parts of the world; our analysis shows an expected additional electricity consumption of up to 15% by 2050 in places with the greatest projected increases of daily heat. There are several reinforcing systems linking the use of air-conditioning, climate change, heat and the urban heat island effect, triggering increased energy use and a hotter climate. Sustainable interventions are therefore needed to create optimum thermal conditions in future workplaces. There need to be increased attention to the social impacts of a changing climate in combination with architectural design and urban planning, as well as development of sustainable energy systems for indoor cooling technology.

References

Climate change and heat stress in the 21st century - an example from Poland

Krys Błażejczyk¹*, Anna Błażejczyk²

¹ Institute of Geography and Spatial Organization, Polish Academy of Sciences, Warsaw, Poland
² Bioklimatologia. Laboratory of Bioclimatology and Environmental Ergonomics, Warsaw, Poland
*corresponding author: k.blaz@twarda.pan.pl

Introduction

Due to the amount of research and Intergovernmental Panel of Climate Change (IPCC) reports, global climate change is becoming significant in the 21st century [3]. These changes are manifested mainly by increases in air temperature; however, other meteorological elements will change as well. The observed climate change will influence conditions of heat exchange for humans outdoors (workers, tourists, recreation etc.), and an increase in heat stress intensity and frequency can be expected.

The aim of the paper is to present possible changes in heat stress magnitude, intensity and frequency in central Poland in the 21st century. Several heat stress indicators are applied for this purpose.

Methods

Two indices were used as the measures of heat stress: wet-bulb globe temperature (WBGT) and Universal Thermal Climate Index (UTCI). The simulations of meteorological elements necessary for the calculations of indices used (i.e. air temperature, vapour pressure, precipitation, global solar radiation) were based on the MPI-M-REMO regional climate model with spatial resolution of 25x25 km. Simulations used boundary conditions proposed in ECHAMP5 Global Climate Model for climate scenario A1B. The simulations cover the period 1970-2100. They were prepared in the frame of SPA project in the Interdisciplinary Centre for Mathematical and Computational Modelling (ICM) of the University of Warsaw by Dr. M. Liszewska in the frame of KLIMADA project. In the present study, the meteorological data for central Poland were used for the calculations of WBGT and UTCI. Average maximum WBGT and UTCI values were analysed, using the calculated from daily maximums for the summer season as well as the frequencies that these maxima exceeded certain limits.

WBGT is by far the most widely used heat stress index throughout the world. It was developed by the US Navy [4]. The WBGT index consists of weighting of dry-bulb temperature (Td), natural (un-aspirated) wet-bulb temperature (Tw) and black-globe temperature (Tg):

\[
WBGT = 0.7 \times Tw + 0.2 \times Tg + 0.1 \times Td
\]

There is an habitually-used WBGT of 23 or 28°C as heat stress limits for unacclimated and acclimated people, respectively. In the present study WBGT of 26°C was used as limit of heat stress for Polish population. This limit is applied due to Polish legislation acts assessed microclimate of working spaces and is assumed as hot environment.

The second measure of heat stress used in this research is UTCI which is derived from the Fiala multi-node model. The model simulates heat transfer inside the body and at its surface. UTCI is defined as the air temperature (Ta) of the reference condition causing the same model response (in sweat production, shivering, skin wettedness and skin blood flow as well as in rectal, mean skin and face temperatures) as the actual conditions [1, 2]. The offset, i.e. the deviation of UTCI from air temperature, depends on the actual values of air and mean radiant temperature (Tmrt), wind speed (va) and water vapour pressure (vp). This may be written in mathematical terms as:
\[ UTCI = f(Ta; Tmrt; va; vp) = Ta + Offset(Ta; Tmrt; va; vp) \]

32°C is the UTCI limit of strong heat stress, 38°C – of very strong, and 46°C – of extreme heat stress.

Results and Discussion
In the present century, maximum \( WBGT \) values during summer season will increase significantly from about 24°C in the beginning to almost 28°C by the end. We must expect an increase in \( WBGT \) max of about 3.2°C during this 100 years (Fig. 1).

The expected increase in \( UTCI \) max is even greater than for \( WBGT \) max. At the beginning of the century average maximum \( UTCI \) values for summer are about 32°C compared to the last decade of the period they can be higher by about 4°C and can reach 36°C (Fig. 2).

Also of importance is information on how frequently days with heat stress occur. For this purpose two kinds of analysis were made. In general \( WBGT \) values simulated for central Poland are relatively low and only for a few days are they higher than the limit of 26°C. Therefore, we have calculated how often summer seasons with \( WBGT \) >26°C occurred in particular decades. While in the earlier decades only 2-3 years would the limit be exceeded, compared to during the later decades with 6-7 summer seasons expected for high \( WBGT \) values (Fig. 3).
Maximum UTCI values in central Poland can be higher than 32°C relatively frequently (at least strong heat stress). They can occur from May till September. In total, in the earlier decades the annual number of days with strong heat stress is about 50 compared with the last decade of century where strong heat stress can be noted during about 60 days per year (Fig.4).

Conclusions
During the 21st century significant changes in particular climatic elements will change. The greatest changes are expected in air temperature. Increased temperatures can involve increasing and more frequent occurrences of heat stress. Both indices of heat stress used, WBGT and UTCI, show significant changes in the 21st century. We must expect gradual increases in the maximum values of both indices. The frequency of days with strong heat stress is also expected to rise. All the changes can influence conditions of outdoor work and recreation activities.

References
OCCUPATIONAL HEAT STRESS

Historic developments and future challenges in applied thermal physiology

Hein A.M. Daanen1,2*, Stephen S. Cheung3
1 TNO Behavioural and Societal Sciences, Soesterberg, The Netherlands
2 MOVE research group, Faculty of Human Movement Sciences, VU University, Amsterdam, The Netherlands
3 Department of Kinesiology, Brock University, St. Catharines, Ontario, Canada
*corresponding author: Hein.Daanen@tno.nl

Introduction

Research in applied thermal physiology has changed over the years in methodology, topics under investigation, customers and locations where research took place. It is the purpose of this paper to examine historic developments and future challenges to maintain relevance and leadership in the area of thermal physiology.

History

While temperature has been a primary driving force throughout human evolution, thermal physiology as a distinct scientific discipline was largely initiated during WWII. Famous researchers in this initial period include Yas Kuno in Japan and Edward Adolph in the U.S.A. (see http://www.feverlab.net/pages/people/History.html for more information). Also, the JB Pierce lab of NASA played an important role, in particular in thermal modelling.

Thermal physiology had four major application areas at the end of the last century: 1) military performance, in particular related to clothing and equipment research, 2) sports and occupational physiology, 3) indoor climate and 4) clinical applications. USARIEM was a leader in the first application area (e.g. Ralph Goldman), Scandinavia in the second one, Povl Ole Fanger for the third and Daniel Sessler was an example for the latter area.

At the end of the last century, thermal research labs were often linked to military research, e.g. USARIEM (U.S.A.), DRDC Toronto (Canada), TNO (Netherlands), DSTO (Australia), Qinetiq and INM (UK). The recent changes in operation, budget cuts in military funding and the switching focus towards mental (e.g. post-traumatic stress disorder) instead of physical performance reduced the budgets and staffing for thermal physiology research. Most military institutes are allowed to perform research for external customers, bringing the challenge to identify new potential markets. It seems that university-based thermal research is increasing, but funding through national scientific agencies and industrial contracts remains a consistent challenge. Therefore, re-analysing the market is important to maintain high-quality thermal physiology research.

The movement away from military-relevant research to other markets is also visible when analysing publication statistics. Figure 1 shows the number of scientific papers, derived from Scopus, over the period 1960 - 1980, 1981 - 2000 and 2001 - 2012 for keywords 'human', 'temperature' and 'physiology' with the additional subcategory keywords of 'military', 'sport', or 'clinical'. Importantly, research in the 'military' subcategory has remained largely stable in absolute number throughout the years, despite the general, large proliferation of publication drive in all fields. In contrast, both 'sport' and especially 'clinical' research in human thermal physiology have shown tremendous growth through the years. Sport applications may have shown an increase as a compensation for the drop in occupational applications as work conditions improved
in the industry.

![Graph showing number of publications with keywords 'human', 'temperature' and 'physiology' with added keyword subcategories 'military', 'sport', and 'clinical'. Total publications for military, sport and clinical subcategories are 87, 337 and 2490, respectively.]

**Figure 1.** Number of publications with keywords 'human', 'temperature' and 'physiology' with added keyword subcategories 'military', 'sport', and 'clinical'. Total publications for military, sport and clinical subcategories are 87, 337 and 2490, respectively.

**Conferences**

The shift in focus can also be deduced from the organisational and content changes of conferences where thermal physiologists meet.

One of the first conferences on thermal physiology was the Thermal Physiology Symposium, with the inaugural meeting organised by James Hardy in New Haven (U.S.A.) in 1968. This was the legendary meeting known for the famous book, “Physiological and Behavioral Temperature Regulation”. Since then, the Thermal Physiology Symposium was held as a satellite meeting of the IUPS main congress.

Another conference series was the Symposium on the Pharmacology of Thermoregulation, first organised by Ed Schönbaum and Peter Lomax in San Francisco (U.S.A.) in 1972. This series of meetings arose from the increasing recognition of the strong relationship between pharmacology and thermoregulation. This symposium continued every three years, independently of the Thermal Physiology Symposium, with the last conference from this series being held in 1999 (Seville, Spain). It was decided to merge the two conferences at the Pharmacology meeting in 1999. The integrated conference would use the name: Physiology and Pharmacology of Temperature Regulation (PPTR).

A third conference series is the International Conference of Environmental Ergonomics (ICEE). After a small interest group meeting in the UK, the first conference was organised by Igor Mekjavic and colleagues in 1986 in Whistler (Canada). The 15th meeting is currently in Queenstown (New Zealand). This conference focuses on applied thermal physiology.

After the 2001 Thermal Physiology Symposium, and due also to the overlapping interests with scientists attending ICEE, it was decided to more closely align these independent conferences. Accordingly, the PPTR and ICEE conferences are generally held on alternating years: 2011 (ICEE:
Thermal physiology also is becoming an increasingly important topic in the sports conferences: American College of Sports Medicine (ACSM) and European Conference of Sports Science (ECSS).

In summary, the first conferences started in the seventies and eighties of the last century with integration and coordination of the conferences in the decades thereafter. In the current field thermal physiology is becoming increasingly important in sports applications (ACSM and ECSS), while it is relatively constant for military, clinical, pharmacological applications (PPTR and ICEE).

**The market for Thermal Physiology**

For the military, important topics are the optimal garments for operational performance in thermal extremes: how can protection be matched with comfort and performance? Although protective clothing and equipment has improved, the issue is still there, and thermal management techniques still have much room for improvement.

Thermal physiology should integrate better with thermal psychology. Thermal behaviour is essential to survive in thermal extremes considering the limited human physiological capabilities. Yet, thermal behaviour is hardly investigated. There is a market for knowledge on thermal behaviour in the military domain, with expeditionary missions, but particularly in health research.

Thermal modelling has a long tradition, and the work of Jan Stolwijk and Eugene Wissler was setting new standards. However, thermal modelling has hardly been applied outside areas of military clothing and has a high potential in sports research, forensics (e.g. to estimate post-mortem times) and in particular as a partial model for operational performance. Thermal models should be linked to models on human behaviour to make the next step. Typically, modelling dismounted soldier operations involves thermal submodels (e.g., IWars, SCOPE, CAEN).

Global warming and urban heat island effects have changed and will change our environments drastically with concomitant changes in productivity, morbidity and mortality. These effects need to be estimated and cost/benefit analysis should be performed for potential safety measures in order to support the decision makers.

Elderly over 80 years old are the most vulnerable subjects in extreme heat and cold. Yet, their ability to regulate their thermal state is hardly investigated. Generally, they live in a homogeneous climate in elderly homes, but a question may be if a more challenging environment will improve their resilience.

The costs of energy are rapidly increasing and we have to think how we as thermal physiologists can contribute to energy savings. Can we achieve the same level of thermal comfort when only the subject is heated in an office and not the entire environment? Does it help when we heat the keyboard to have sufficient manual dexterity in typing? Those kind or questions are important to address and can only be addressed with the involvement of thermal physiologists.

**Research methods**

Miniaturisation of sensor technology and wireless communication systems have improved the possibility for measuring humans and other mammals in natural environments. Field labs offer the opportunity to investigate soldiers, first responders and employees during their actual work, with high ecological validity. For example, clothing can be the future platform of integrated sensors, measuring large amounts of physiological data. With these advances in the quality and quantity of information, data mining techniques become increasingly important to process the datasets to get answers to questions.
Some topics that were difficult to address in previous times due to methodological limitations may be clarified in the near future using better techniques. New imaging techniques are promising so that real-time 3D thermal imaging may take place and this may improve our knowledge on body thermal status during rest and exercise and the presence of selective brain cooling (SBC) in humans.

Imaging techniques like PET scans and near infrared spectroscopy may elucidate the close connections between the thermoregulation centre and other centres in our brain and thus learn us more about the interaction between thermal regulation and sleep, behaviour and pain.

Traditional methods in thermal research are not taking molecular and genetic aspects into account. More research should be dedicated to heat and cold shock proteins in order to assess their impact on function in the heat and cold.

Conclusions
Applied thermal physiologists face a number of major changes in our quest to both maintain scientific relevance and innovate our research capacity. The collapse of heavy reliance on military funding requires a diverse approach to obtaining research support. While a daunting challenge, we should embrace this opportunity to create new fields of research, through applying and integrating our thermal expertise with other human factors fields, applying new methodologies. The predicted climatic changes will affect the lives of our descendants and thermal physiologists can contribute to the understanding of optimal adaptation to the challenges that we will have to face.
Work loss from heat stress in the USA: Current trends and future predictions

Bruno Lemke* and Tord Kjellström

1 Nelson-Marlborough Institute of Technology, Nelson, New Zealand
2 Centre for Global Health Research, Umeå University, Umeå, Sweden
3 National Centre for Epidemiology and Population Health, Australian National University (ANU), Canberra, Australia
*corresponding author: Bruno.Lemke@nmit.ac.nz

Introduction
The impact of heat stress on the health and productivity of the work force is substantial according to the 2012 Dara report which estimates the current $US300B loss from the loss of labour productivity due to heat will rise to $US2500B by 2030. The impact will be greater on some countries (eg India) that are already too hot now to work to one’s full potential for many days of the year. This paper explores the impact of heat stress on the USA as an example of a temperate climate.

Methods
Several heat stress indexes (HI, WBGT, UTCI) have been mapped showing the heat stress trends in the southern states of the USA from 1980 to 2009. The maps are 50kmX50km grids using climate data available from the Climate Research Unit (UK). These give averaged monthly data which was found to be unsuitable in temperate climates where cooler summer days negate the hotter days that cause heat stress. A method has been developed that allows the mapping of the heat stress on the hottest days of each month. Temperature increases predicted by global circulation models are used to model future heat stress (2030 and 2050).

Results and Discussion
Averaged monthly data shows that there is a significant increase in heat stress in the southern central and eastern regions of the United States. Using temperature extremes the increased heat stress extends right to the north of the USA on some days. Using the WBGT index and the ISO standard for maximum work that can be undertaken, the on-going loss in work time for people doing outdoor work in some regions of the USA during the hottest months is estimated to have increased by 10% in the last 30 years. This includes work in agriculture, forestry and construction. For future predictions (2030 and 2050) we estimate the work time loss due to heat stress in some regions of the USA to increases by nearly 10% per decade as shown in figure 1.

References
Average monthly work possible for moderate (300W) work in shade based on ISO standard.

Results are a 30 year average for the month of August.
Exploring the experiences and responses of heat among workers in the sheep shearing industry

Lucy Cotterill¹, Tord Kjellström²,³, Simon Hales³, Sarah Bierre³.
¹ Masters of Public Health student, University of Otago, Wellington.
² Senior Professor, Centre for Global Health Research, Umeå University, Sweden, and Visiting Fellow, National Centre for Epidemiology and Population Health, Australian National University, Canberra
³ Supervisors of Masters, Department of Public Health, University of Otago, Wellington

Corresponding authors: Sarah Bierre, Simon Hales, Tord Kjellstrom

Introduction
Heat in workplaces is a hot topic due to the projected increase in global temperatures from anthropogenic climate change. Workers have recently been recognised as another vulnerable group impacted by increased heat exposure and the potential health burden, decreased productivity and economic impact that results worldwide [1]. This is especially true in tropical, low- and middle-income countries where the effects of climate change will be most significant, yet this issue cannot be ignored in temperate countries such as New Zealand [2]. Wet bulb global temperature (WBGT) is the most widely used measure of heat stress in workplaces worldwide. It is expressed in degrees Celsius with recommendations on work to rest ratios when work exceeds a certain WBGT. WBGT maps have been generated to show the heat exposure here in New Zealand and although not a hot country in comparison to tropical and sub-tropical countries, New Zealand is still subjected to the changes in climate.

New Zealand provides a unique environment to study the impacts of heat in the workplace due to our dependence on industries such as agriculture, forestry and industry. These occupations are often exposed to heat through different sources including the environment (outdoor workers), the physical nature (metabolic heat generation) of the work and are often paid by output. One seasonal, physical occupation, paid per output that is important to New Zealand is that of the sheep shearing industry. Within the industry there has been research completed on the ergonomics of back pain, noise induced hearing loss and thermal strain but there is a lack of research on the people in the industry. There is also a lack of literature into any industry workers perceptions of how heat affects them and how they modify their behaviours to cope with working in heat. Therefore the objective of the current research is to explore the experiences and the responses of heat among workers in the sheep shearing industry.

Methods
Purposive and snowball sampling techniques were used to gain a maximum variation sample (age, sex, geographical location and experience) of knowledgeable participants. Sixteen current and ex shearers were interviewed face to face or over the phone using an in depth study guide about the experiences of heat in the workplace. The interviews were transcribed and analysed using thematic analysis of the manifest and latent content, from a constructivist outsider’s perspective to derive themes.

Results and Discussion
Five themes from the interviews were identified as influencing workers experience of heat in the workplace. These were; shearing culture, lack of control, ‘we’ll be right’, self regulation and the want for change. Workers experiences of heat stress normalised symptoms such as sweating and cramps to the extreme of fainting and heat exhaustion. The five identified themes all influence the
workers responses to heat exposure in the workplace, and have been identified from an outsider’s perspective.

This begins with the strong culture in the shearing industry which has led to stereotypes of workers in this occupation. The stereotype included very traditional, competitive workplace, with after work traditions that may be negatively associated with their work. This theme underpins the other four themes and therefore the experiences of heat in the industry. Many participants shared experiences that lived up to the stereotype, and also gives a potential insight into why the industry is so untouched in terms of unions, guidelines, regulation and protocols, especially regarding heat. The interviews leaned on a theme of lack of control of aspects that influence their job and experiences of heat for better or worse. This lack of control was over things such as climate, weather, sheep numbers in the area, working environment, access to water and market wool prices. The main aspects that affected their experiences of heat were the working environment, access to water and weather. This lack of control is dealt within the industry with the attitude we’ll be right. This theme introduces the idea that whatever the conditions, shearers interviewed felt they would be OK and that they will self regulate their behaviours to continue working. This attitude again is potentially a reason behind why there is a lack of policy within the industry, as they are able to regulate and manage their response to heat stress through self regulation. This self regulation alongside the shearing culture has underpinned the experiences of heat within the industry. This has allowed for workers to continue working in environments that are potentially detrimental to their health. It was also clear in the interviews that these situations were influenced by the paid per unit remuneration that the workers received. However the fifth theme of the want for change within the industry highlights qualities of professionalism, team work, timeliness, organisation and a want for future change in the industry. This idea challenges the shearing culture and traditions and may be a way to move forward in policies for the future of the industry but also underpins the workers want for some control within the industry.

The projected increases in temperature in New Zealand could potentially put these workers at increased risk of working environments that are beyond physiological capabilities during more days each year. This is especially a concern to those workers on the East coast of the North Island where it is projected to get hotter and drier. As identified by participants, there is a need for regulations and standards to be put in place for the working environments around maximum heat levels, work to rest ratios (based on WBGT), needs for ventilation and access to drinking water.

References
Wearing explosive ordnance disposable equipment in hot and humid environments; what are the physiological tolerance times?

Ian B. Stewart1*, Joseph T. Costello1

1 Institute of Health and Biomedical Innovation, Queensland University of Technology, Brisbane, Australia.
*Corresponding author: i.stewart@qut.edu.au

Introduction

It has previously been reported that bomb technicians have suffered from symptoms of heat illness such as irrational behaviour and altered levels of consciousness [1]. Heat illness can occur when the body becomes unable to regulate core temperature, most commonly in response to extreme environmental conditions. Prolonged exposure to extremely hot environments can lead to life threatening situations. Additionally, symptoms of heat illness such as dizziness, muscle weakness, nausea, irritability and confusion, although not fatal in themselves, have the potential for significant harm in the explosive ordnance disposal (EOD) setting. The purpose of the present study was to examine the physiological tolerance of wearing an EOD9 suit in simulated desert and jungle environments.

Methods

Eight healthy males participated in this study [age, mean ± standard deviation (SD), 25 ± 6 years, height 180 ± 7 cm, body mass 79 ± 9 kg, sum of eight skinfolds 76 ± 15 mm, VO2 max 57 ± 6 ml.kg.min-1]. The procedures carried out in this study were approved by the University Human Research Ethics Committee and participants were informed of the procedures and had any questions answered to their satisfaction prior to giving their written and oral consent to participate.

Participants attended the lab on four occasions. The first session involved aerobic power testing, body composition acquisition and a familiarisation with the EOD9 ensemble and testing procedures. In each of the following three laboratory visits participants completed three trials. During the trials participants walked on a treadmill with 1% grade at 2.5, 4 or 5 km/hr in a climatic chamber set to a Wet Bulb Globe Temperature (WBGT) of 21, 30 or 37 °C. The order of the testing was randomised using a random number generator in a controlled crossover design. These trials were completed in a climatic chamber (4 x 3 x 2.5 m; length, width, height respectively) with 4.7 km/hr simulated wind speed and a radiant heat load (two radiant heaters positioned 0.8-1.8 m from the participant). During each activity bout, standard termination criteria were applied in accordance with the ASTM guidelines [2]: (1) core body temperature reaching 39.0 °C; (2) 60 minutes of heat stress exposure; (3) heart rate > 90% of maximum; (4) dizziness, nausea, syncope; or (5) subject exhaustion.

During each trial participants wore an EOD 9 suit and helmet. This suit is designed to provide the highest degree of modular protection to withstand the pressure released from an explosive device and any projectiles the bomb may produce. The suit consisted of a jacket; trousers, groin protection and a helmet (combined weight 31.6 kg). Participants’ base ensemble consisted of a t-shirt, shorts, socks, and underwear. Athletic shoes with a soft rubber sole were also worn during testing. These base ensemble requirements are standardised in accordance with ASTM F2668-07 [2].

All variables were tested for normal distribution with the Shapiro-Wilk test. When the assumption of sphericity was violated, significance was adjusted using the Greenhouse-Geisser method. Tolerance times were analysed using a two-way (environment x speed) repeated measures
analyses of variance (ANOVA) with a Bonferroni correction where appropriate. All statistical analyses were performed in SPSS (Statistical Package for the Social Sciences), version 19.0 (SPSS Inc, Chicago, IL) with the level of significance set at $p<0.05$. All data are presented as group means and SD, unless otherwise stated.

Results and Discussion
The tolerance times (Figure 1) and termination criteria (Table 1) are displayed below. Significant main effects were observed for environmental condition and speed. Post hoc analysis showed the tolerance times for WBGT21 were significantly longer than WBGT30 and WBGT37; in addition, WBGT30 was longer than WBGT37 (45.0 ± 15.6, 37.1 ± 16.2, 30.8 ± 11.0 min, respectively; $p<0.05$). In relation to speed 2.5 km/hr trials lasted significantly longer than 4 km/hr and 5.5 km/h; similarly, 4 km/hr lasted significantly longer than 5.5 km/hr (50.5 ± 8.6, 40.1 ± 8.8, 22.3 ± 4.6 min, respectively; $p<0.05$). No significant environment by speed interaction was observed ($p=0.166$).

Based on the termination criteria applied [2] no participant completed 60 minutes of exercise at 5.5 km/hr (in any environment) and all trials at this speed were terminated based on heart rate > 90% of maximum. Interestingly, a core temperature of 39°C was only observed in one participant during one trial (WBGT30, 2.5km/h).

Table 1. Termination criteria for each of the 8 subjects in all trials.

<table>
<thead>
<tr>
<th>WBGT (°C)</th>
<th>Speed (km/hr)</th>
<th>Heart Rate</th>
<th>Core Temp.</th>
<th>Volitional Fatigue</th>
<th>Duration 60 mins</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>2.5</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>30</td>
<td>2.5</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>7</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>2.5</td>
<td>5</td>
<td>2</td>
<td>1</td>
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<tr>
<td></td>
<td>4</td>
<td>7</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5.5</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Tolerance time for the EOD9 ensemble. Values are mean ± SD (n=8).

Conclusions
The present study confirmed tolerance times, while wearing EOD9 PPE, are significantly reduced in warmer environments and when exercise intensity is increased. However, significant heat strain was not observed in this cohort; with the majority of trials terminated due to a heart rate in excess of 90% of maximum.

References

Acknowledgment
This project is financially supported by the Australian Government, managed by the National Security Science & Technology Centre within the Defence Science & Technology Organisation, and the US Government through the Technical Support Working Group within the Combating Terrorism Technical Support Office. This support does not represent an endorsement of the contents or conclusions of the project.
Heat strain evaluation of security guards wearing overt and covert body armour

Andrew Pyke¹*, Joseph T. Costello¹, Ian B. Stewart¹
¹Queensland University of Technology, Brisbane, Australia
*corresponding author: aj.pyke@qut.edu.au

Introduction
The human body can only withstand small changes in core temperature before detrimental health effects can occur[1]. In hot environments, the body needs to lose heat to the environment at the same rate it is produced. An inability to do so leads to an accumulation of heat and a rise in body core temperature. Temperature, humidity, wind speed, metabolic rate and clothing all impact the capacity for heat exchange[2]. Some occupations require that individuals wear protective clothing in order to prevent mortality. Although effective, the clothing can have a consequence of affecting the transfer of heat to the environment, increasing occupational heat-strain risk. One example of this is cash in transit security guards, who are required to wear personal body armour (PBA) in response to fatalities within the industry[4]. To date only two studies[3, 4] have examined the effects of heat strain encountered by security guards, both of which were field based studies. The purpose of the present study was to evaluate heat strain encountered wearing non-military, overt and covert PBA in a controlled laboratory environment.

Methods
Eight healthy males (age 26±6 yr, body mass 76.6±6 kg, height 178±6 cm, VO₂max 55.5±8 mL·kg·min⁻¹, sum of six folds 60±22%; mean ± SD) participated in the study. Participants attended the laboratory on four separate occasions. On their first visit maximal aerobic capacity and body composition were recorded. On the second, third and fourth visits, separated by a minimum of seven days, participants walked for 120 minutes at 22% of their heart rate reserve (HRR) in a climatic chamber heated to 30°C Wet Bulb Globe Temperature (WBGT). In a randomised order, participants wore either no armour (control), overt or covert over tactical utility pants, short sleeve shirt with collar and utility belt. The overt and covert PBA weighed 2.977 kg and 2.571 kg, respectively. Participants also wore underwear and shoes of their own choice in each trial. Core temperature (gastrointestinal CorTemp), heart rate (Polar team sport) and skin temperature (iButtons) were recorded continuously. Rate of perceived exertion (RPE) was recorded every 15 minutes. Body mass change was recorded via nude weighing pre and post trial. Post-trial body mass was corrected for the consumption of 500 mL of water consumed at 30, 60 and 90 minutes.

Results and Discussion
Core temperature, heart rate, skin temperature and RPE all increased from start to end (p<0.05). However there was no significant difference between conditions at the end of each trial (p>0.05). Covert PBA produced a significantly greater amount of body mass change than either control (p=0.009) or overt conditions (p=0.025).
**Table 1.** Physiological and subjective outcome variables at the start and end of the control, overt and covert trials.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th></th>
<th></th>
<th></th>
<th>Overt</th>
<th></th>
<th></th>
<th></th>
<th>Covert</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Start</td>
<td>End</td>
<td></td>
<td></td>
<td>Start</td>
<td>End</td>
<td></td>
<td></td>
<td>Start</td>
<td>End</td>
<td></td>
</tr>
<tr>
<td>Tc (°C)</td>
<td>37.2±0.1</td>
<td>37.6±0.3a</td>
<td>37.3±0.2</td>
<td>37.8±0.2a</td>
<td>37.3±0.3</td>
<td>37.8±0.3a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tsk (°C)</td>
<td>33.8±0.7</td>
<td>34.5±0.9a</td>
<td>33.4±0.3</td>
<td>34.8±0.9a</td>
<td>33.2±0.4</td>
<td>35.2±0.2a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HR (b·min⁻¹)</td>
<td>78±11</td>
<td>99±8a</td>
<td>84±20</td>
<td>103±13a</td>
<td>84±11</td>
<td>104±7a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BM Change (%)</td>
<td>-1.07±0.4</td>
<td>-1.27±0.4</td>
<td>-1.81±0.4b,c</td>
<td>9±0.1</td>
<td>11.8±1.5a</td>
<td>9.6±0.7</td>
<td>12.6±1.8a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPE (6-20)</td>
<td>9±1.2</td>
<td>11.3±1.3a</td>
<td>9±0.1</td>
<td>11.8±1.5a</td>
<td>9.6±0.7</td>
<td>12.6±1.8a</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tc, Core Temperature; Tsk, Skin Temperature; HR, Heart Rate; BM, Body Mass; RPE, Rate of Perceived Exertion.

a = significantly different to starting value, p<0.05.
b = significantly different to control trial, p<0.05.
c = significantly different to overt trial, p<0.05.

**Conclusion**

Although a greater amount of body mass change was observed in the covert PBA trial; based on the physiologic outcome measures recorded, the heat strain encountered while wearing non military, overt or covert PBA was negligible compared to no PBA.

**Acknowledgments**

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**References**

The summertime thermal environment in Korean agriculture

Kyung-suk Lee², JuYoun Kwon¹*, Hye-seon Chae², Hyo-cher Kim², Yong-ho Cho²
¹School of Design & Human Engineering, Ulsan National Institute of Science and Technology, South Korea
²Department of Agricultural Engineering, National Academy of Agricultural Science, Suwon, South Korea
*corresponding author: jkwon@unist.ac.kr

Introduction
Agriculture is classified as a hazardous industry by NIOSH. One of the hazardous factors would be the injury mortality related to extreme weather events. Heat-related disorders generally occur in summer and they often affect people working in construction and agriculture. Agricultural work should be conducted by periods of ripening and the work is carried out even in extreme weather condition. Many deaths occur in the farming industry due to the nature of agricultural working environments [4]. This situation is not different in South Korea, and the number of patients with heat-related illnesses during the summer in 2012 was 984 persons [2]. Heat stress is considered heat load on the human body caused by activity, air temperature, humidity, air velocity, radiant temperature and clothing [1]. Mitigation of heat stress in the farming industry is possible if the problems of the current thermal environments to which farm workers are exposed are elucidated. The aim of this study was therefore to investigate agricultural working conditions during the summer, in South Korea.

Methods
One hundred-twenty subjects (50 males and 70 females) working in nine separate regions on different days took part in this study. The average age of subjects was 61 (11) for males and 62 (12) for females. The study was conducted in the six regions of South Korea from July until September. This study was carried out in Geochang(July 18, 2012: Exp. 1), Suwon (July 27, 2012: Exp. 2), Sunchon (August 2, 2012: Exp. 3), Seongju (August 15, 2012: Exp. 4), Seongju (August 16, 2012: Exp. 5), Seongju (August 17, 2012: Exp. 6), Yeoju (August 22, 2012: Exp. 7), Andong (September 5, 2012: Exp. 8) and Andong (September 6, 2012: Exp. 9). The subjects in Exp. 1, 2, 4, 5, 6, and 7 were farmers working in a PVC green house; in Exp. 3, 8 and 9, participants worked in fields. First, the head of each village was contacted and asked when the majority of the village’s farmers work (namely, a busy period) before visiting each village. Once experimenters arrived in a region, environmental measurement equipment was set up in the working environment, i.e., a field or PVC green house. Investigators walked or drove around the region to find farmers in these environments and examined what types of working posture farm workers used as well as what types of clothing or items they were wearing. They also interviewed the farmers about why they used the items they were wearing.

Environmental conditions were measured 1.2 m heights above the ground in each region. Environmental measurements were conducted throughout work patterns. Dry (T₉) and wet bulb (Tₚ) temperatures and globe temperature (T₈) were measured by INNOVA MM0030 transducer. Wind speed (vₐ) was measured using an anemometer (INNOVA MM0038 transducer). Relative humidity (φ) was calculated from dry and wet bulb temperatures, and wet bulb globe temperature (WBGT) was calculated using Eq 1:

\[ 0.7 \times Tₚ + 0.2 \times T₈ + 0.1 \times T₉ \]  

Eq 1 [8]

The types of upper clothing and lower clothing, lengths, material properties and the types of hat, footwear and accessories were investigated while farm workers were working in the field or PVC greenhouse. Clothing insulation (clothing; clo) was estimated based on the results of the
questionnaire (ISO9920: 2007; [7]). The types of crops and subjects’ working postures were observed, and metabolic rate (activity) was estimated using ISO8996 (2004) [6].

Results
The ranges of environmental conditions for nine cases from six regions are shown in Table 1. The air temperature (T_a) was 23.4°C to 37.9°C and relative humidity was 53% to 87%. Mean radiant temperature (T_r) was 25.5°C to 42.9°C and wind speed(v) was 0.11 m s⁻¹ to 0.95 m s⁻¹. Clothing insulation was 0.53 clo to 0.74 clo and metabolic rate (M) was 170 W m⁻² to 185 W m⁻². WBGT was 20.6°C to 34.3°C. Environmental conditions for Exps. 2, 4, 5 and 6 were above the reference value by ISO7243 [5].

Table 1. Mean environmental conditions

<table>
<thead>
<tr>
<th>Exp.</th>
<th>T_a(°C)</th>
<th>α(%)</th>
<th>T_r(°C)</th>
<th>v(m s⁻¹)</th>
<th>clothing(clo)</th>
<th>M(W m⁻²)</th>
<th>WBGT(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. 1</td>
<td>26.9(0.45)</td>
<td>87.0(3.01)</td>
<td>27.5(0.57)</td>
<td>0.11(0.069)</td>
<td>0.70(0.099)</td>
<td>185</td>
<td>25.8(0.39)</td>
</tr>
<tr>
<td>Exp. 2</td>
<td>32.2(1.39)</td>
<td>64.7(5.10)</td>
<td>42.8(5.14)</td>
<td>0.75(0.268)</td>
<td>0.67(0.094)</td>
<td>170</td>
<td>29.8(1.27)</td>
</tr>
<tr>
<td>Exp. 3</td>
<td>28.7(0.68)</td>
<td>73.8(1.70)</td>
<td>31.6(2.21)</td>
<td>0.61(0.272)</td>
<td>0.64(0.131)</td>
<td>185</td>
<td>26.5(0.70)</td>
</tr>
<tr>
<td>Exp. 4</td>
<td>30.9(2.11)</td>
<td>80.0(5.41)</td>
<td>32.0(3.60)</td>
<td>0.19(0.079)</td>
<td>0.63(0.065)</td>
<td>185</td>
<td>29.0(1.66)</td>
</tr>
<tr>
<td>Exp. 5</td>
<td>37.9(7.37)</td>
<td>69.2(16.29)</td>
<td>41.2(9.88)</td>
<td>0.16(0.062)</td>
<td>0.63(0.116)</td>
<td>185</td>
<td>34.3(5.19)</td>
</tr>
<tr>
<td>Exp. 6</td>
<td>31.8(0.90)</td>
<td>78.6(2.58)</td>
<td>34.6(2.11)</td>
<td>0.12(0.037)</td>
<td>0.59(0.082)</td>
<td>185</td>
<td>30.0(0.83)</td>
</tr>
<tr>
<td>Exp. 7</td>
<td>24.0(1.72)</td>
<td>86.4(7.32)</td>
<td>25.5(3.05)</td>
<td>0.22(0.141)</td>
<td>0.53(0.227)</td>
<td>175</td>
<td>23.0(0.71)</td>
</tr>
<tr>
<td>Exp. 8</td>
<td>23.4(1.14)</td>
<td>65.8(5.20)</td>
<td>26.5(5.44)</td>
<td>0.95(0.412)</td>
<td>0.70(0.104)</td>
<td>185</td>
<td>20.6(1.39)</td>
</tr>
<tr>
<td>Exp. 9</td>
<td>23.9(1.98)</td>
<td>52.9(7.85)</td>
<td>42.5(4.44)</td>
<td>0.74(0.313)</td>
<td>0.74(0.167)</td>
<td>185</td>
<td>22.1(1.31)</td>
</tr>
</tbody>
</table>

-Environmental conditions of Exps. 3, 8 and 9 were measured in fields but others were recorded in PVC greenhouse.

-Exp. 1: harvest of flower, measurement for 3 hours from 14:45; Exp. 2: harvest of lettuce, measurement for 2 hours from 15:45; Exp. 3: harvest of various vegetables, measurement for 2 hours from 06:40; Exps. 4, 5 and 6: harvest of oriental melon, measurements for 2 hours from 16:45, for 13 hours from 06:00, and for 1 hour from 07:10; Exp. 7: weed scraping, etc., measurement for 2 hours from 16:45; Exps. 8 and 9: picking up apples, etc., measurements for 1 hour from 17:20 and for 5 hours from 08:00.

Metabolic rate
The estimated metabolic rate for an agriculture gardener was 165 W m⁻²; the metabolic rate, depending on body postures, was added from 0 to 20 W m⁻² (ISO8996:2004). The main body posture for the flower harvesting (Exp. 1) was ‘stand stooped’, and the metabolic rate was 165+20=185 W m⁻². The body postures for lettuce (Exp. 2) were ‘sitting’ and ‘standing’, and the metabolic rate was 165+5=170 W m⁻². The main body posture for various vegetables (Exp. 3) was ‘stand stooped’, and metabolic rate was 165+20=185 W m⁻². The main body posture for oriental melon (Exps. 4, 5 and 6) was also ‘stand stooped’, and the metabolic rate was 165+20=185 W m⁻². The postures for weed scraping, etc., consisted of squatting, sitting, standing and bending at the waist, and the metabolic rate was 165+10=175 W m⁻². The postures for picking up apples, etc.,
consisted of squatting, sitting, standing and bending at the waist, and the metabolic rate was 165+10=175W·m⁻².

Clothing
In terms of upper-body clothing, bras were worn by twenty five farmers, singlets by thirty eight people, short-sleeved underwear and sleeveless T-shirts by six people, short-sleeved shirts by five people, long-sleeved shirts by thirty five people, long-sleeved T-shirts without collar, short-sleeved sportswear, sleeveless vests and raincoats by two people each, short-sleeved T-shirts with collar by twenty nine people, short-sleeved T-shirts without collar by twenty three people, long sleeved T-shirts with collar by sixteen people, long sleeved T-shirts without collar by ten people, and long-sleeved sportswear by seven people. Sleeveless under wear was worn by the largest number of people, while long-sleeved shirts were worn by the second largest number of people, and then short-sleeved T-shirts with collars were put on.

In terms of lower-body clothing, all participants wore briefs and only four people wore underpants, shorts by seven people, trousers by ninety two people, sportswear by twenty three people, and raincoat by four people. Therefore, three quarters of people wore trousers.

In terms of footwear, slippers were used by nine people, rubber shoes by thirty people, loafers (made from ethylene vinyl acetate, EVA) by forty two people, running shoes by seven people, boots by thirty people, and military boots by two people. The EVA loafers were most popularly worn because of their light weight. Traditional rubber shoes were used by the second largest group of people.

In terms of accessories, gloves were worn by eighty seven people, over-sleeves by forty seven people, scarf/towel by eleven people, waist bags by five people, masks by two people and useful equipment by sixty two people.

In terms of millinery, baseball caps were worn by twenty people, bucket hats by nine people, sun caps and hats for farm work by sixteen people each, towels by five people, straw hats by six people, and one person wore a long visor bucket. Millinery was used by fifty seven people while they were working.

Discussion and Conclusions
Environmental conditions for Exps. 1 to 9 varied; air temperature was above 30°C in half of the experiments, and wind speed was under 1m·s⁻¹ for all experiments. The difference between the highest clothing insulation and the lowest clothing insulation was 0.21 clo. Environmental conditions for Exps. 2, 4, 5 and 6 were above WBGT reference values, and corresponding clothing insulations were 0.67, 0.63, 0.63 and 0.59 clo respectively. The metabolic rate of Exps. 4, 5 and 6 for harvesting oriental melon was estimated as 185 W·m⁻² due to standing stooped. The workload would be higher than current estimated values if the weight of the oriental melon was considered. The body posture of ‘bending at the waist’ was shown in this study but the reference value ISO8996 could not be found and scarf/towel and mask could not be considered for estimating clothing values. Materials could not be considered for the estimation, for example, 100% polyester sportswear which is popular in South Korea. Exps. 4, 5 and 6 had WBG Ts above the reference, and Exp 5 was even 6.3°C higher than the value. However, the mean maximum air temperature was 33.3°C and the minimum air temperature was 25°C between July 22 and August 11, 2012 [2] and it seemed that thermal environment during the summer of 2012 was worse than the current study.
Especially, August, when the Exps. were conducted, had lower environmental temperatures than in July, which was the busiest harvest time. In addition, it was surprised that oriental melon farmers worked in ‘bending at the waist’ posture which was bad for lower back with the ergonomic concerns [3]. Therefore, practical methods such as developing work uniforms and changing work patterns should be found to create a better work environment for protecting health and safety.

Acknowledgement
The authors thank young researchers in the agricultural safety engineering division for their practical support during the experiments. This study was supported by 2012 Postdoctoral Fellowship Program of National Academy of Agricultural Science, Republic of Korea (No.PJ0084202012).

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Analysis of thermal environment conditions in classrooms of the military police academic center of Cabo Branco: Case study.

Flávia B. Ramalho de Brito1*, Priscila Elida de M. Vasconcelos1, Luiz B. da Silva1
1 Departamento de Engenharia de Produção, Universidade Federal da Paraíba, Paraíba, Br
*corresponding author: flavia_britoo@hotmail.com

Introduction
Studying the environmental effects on human endeavour and welfare is important. Most studies conducted to examine the influence of thermal environment conditions on school-related performance of students reported that both elevated and reduced temperatures have affected student learning [1,2]

The sensation of thermal comfort is derived from the interaction between environmental variables and personal factors. Partly because of its subjective nature, international standards are used to judge whether a working environment offers comfort conditions or not for its users. The ISO 7730/2005 estimates thermal sensation found in a thermally moderate environment, calculating the proportion of people dissatisfied with it. However, the applicability of this standard is questioned due to the fact that been observed occupants in numerous studies have demonstrated acceptance to thermal environments that did not comply with the criteria established by that standard [3,4,5,6,7].

Therefore, this paper intends to contribute to the existing Thermal Comfort research, through the comparative analysis of thermal sensation votes, obtained by students at learning centers, against those predcited via Predicted Mean Vote, PMV, according to ISO 7730 (2005).

Methods
The experiment was performed with forty students from the Military Police Academic Center of Cabo Branco (34 males and 6 females), due to the fact that the students being approximately similar age and height, and same type of feeding, metabolism and vestment.

Environmental variables (air temperature, mean radiant temperature, air humidity and air velocity) were obtained from measurements made with a microclimatic station BABUC-A. On the other hand, metabolic rate was considered constant and equal to 70W/m² and clothing insulation value equal to 0.56 clo, according to ASHRAE[8].

Subjective parameters such as thermal sensation and thermal preference of the students were obtained from a questionnaire about perception, assessment and thermal preference of subjects, based on 7-point scales of perception and preferences of ISO 10551/1995[9].

Questionnaires and concurrent measurement sessions occurred in mid July. Data collection was conducted in three sessions, each of which was performed with different temperatures in order to evaluate the thermal conditions in moments of comfort and thermal discomfort, 24°C, 28°C, 20°C, respectively.

Measurements were held in the morning and afternoon, with the exception of one day in which data were collected in the morning only, due to the limitation of air conditioners for generating cooler temperatures at a temperature peak time. The experiment started 40 minutes after students had entered the environment. The ideal temperatures were estimated by using linear regression and polynomial, using the software R.
Table 1. Mean values and SD of temperatures observed in each session

<table>
<thead>
<tr>
<th>Session</th>
<th>Morning</th>
<th></th>
<th>Afternoon</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tbs</td>
<td>Tbu</td>
<td>Tg</td>
<td>Tbs</td>
</tr>
<tr>
<td>24°C</td>
<td>23±0,62</td>
<td>15,75±1,16</td>
<td>23,7±0,19</td>
<td>24,5±1,22</td>
</tr>
<tr>
<td>28°C</td>
<td>28,5±1,08</td>
<td>24,13±1,15</td>
<td>27,47±0,92</td>
<td>30±0,98</td>
</tr>
<tr>
<td>20°C</td>
<td>20,2±0,22</td>
<td>13,6±0,51</td>
<td>22,18±0,06</td>
<td>----</td>
</tr>
</tbody>
</table>

Results

Comparison between the calculated PMV and the feelings reported

Figure 1 shows the variations between the PMV calculated analytically by ISO 7730/2005 and the sensations declared by students at various ambient temperatures. It is observed that at temperatures of 22, 24, 28 and 30°C the PMV calculated analytically was not compatible with the responses declared by students during the experiment. In particular, the ISO estimations underestimated actual warmth sensations.

Mathematical Modeling

The thermal sensation of students in relation to the temperature of the classroom (tbs) was modeled via regression to estimate the ideal temperature to provide neutrality of thermal sensation (Figure 2). Approximately 80% of students agree with the calculated optimum temperature (23°C).
The optimal temperature according to the thermal evaluation of students was estimated using a polynomial regression model (Figure 3). The temperature that provides greater approximation to the axis of environment comfort is therefore ideally to 21°C.

Conclusions
It can be seen that different moments were obtained between results of the PMV from ISO and students’ thermal sensations. Through predictive models, it could be concluded that the activities of students in air-conditioned classrooms can be well performed at temperatures between 21 °C and 23 °C, and that the thermal comfort of the students was optimised at 21°C.

References
Comparison of firefighters and non-firefighters and the test methods used regarding the effects of personal protective equipment on individual mobility

Su-Young Son1*, Ilham Bakri1,2, Yutaka Tochihara1

1 Kyushu University, Fukuoka, Japan
2 Hasanuddin University, Indonesia
*corresponding author: sonsu@gsd.design.kyushu-u.ac.jp

Introduction
Firefighting is one of the most hazardous occupations and it is associated with exceedingly high rates of injuries [1]. Therefore, firefighters require not only good physical capability but also sufficient mobility in their active work with their firefighting at high temperature and humidity with heavy personal protective equipment (PPE). Many studies have reported that firefighters experience physiological strain when performing simulated firefighting activities with PPE in hot and humid environments [2, 3]. However, relatively few studies report about mobility with PPE in firefighting activities. There are several international standards for evaluating firefighters’ PPE, but, these standards merely describe the heat, flame, and water resistant properties of PPE [4, 5]. Furthermore, there is no test method for assessing mobility while wearing PPE has been established. Without a standard method for mobility, the comparison of several types of PPE from different research groups may lead to inaccurate interpretations. Therefore, establishing a standard method for accessing mobility of PPE is required. WE have previously reported that, a large number of firefighters suffer injuries due to failure of balance control (slips or falls) while wearing PPE. That result indicates that a balance test with PPE is necessary. Therefore, for a standard method of mobility, the physical performance and functional balance test could be used. Thus, one aim of this study was to ascertain that mobility test methods for PPE such as physical performance and balance ability test are available to investigate effects of the PPE’s weight and design on mobility. The other aim was to compare two subject groups (firefighters versus non-firefighters) to establish which is more suitable for a standard subject group.

Methods
Nine healthy Japanese professional firefighters performed a physical performance and balance test in this study. (Mean ± SD: age 28.6 ± 2.4 yrs, height 172.4 ± 5.9 cm, body mass 69.4 ± 5.5.1 kg, body mass index 23.4 ± 1.4 kg·m⁻²). The participants undertook the physical and balance test using three different PPE (Type A, B, C; Table 1) as well as a control condition (CON; T-shirts, shorts, and running shoes). The experiment protocol consisted of two types of functional balance tests prior and before a performance test. In the first, functional balance test, performance time was measured as the time take for participants to walk along and return to the start position on a straight wooden plank (3m×9cm×5cm). The participants started walking as quickly as possible, at the half way point of the plank, participants turned and walked backwards to the end on the plank. They returned to starting point immediately in the same way. If participant lost balance and, stepped on the ground, it was considered as a performance error, and added one second (per error) to the completion time of the participants [6]. The second functional balance test was a “timed up and go” test. This test started with participants sitting on a stool. After the starting signal, participants stood up and walked forward as fast as possible for 3m, and then returned to the starting point and sat on the stool again. For the physical performance test, the participants carried out the following tasks: (1) step up, (2) side jump, (3) crawling, (4) dragging an object, (5) obstacle stride, all inside of an experiment building (23.7 ± 0.7°Cand 67.5 ± 9.9% RH). Heart rate (HR) was measured every second throughout the physical performance test using a HR monitor.
(RS400, Polar Electro, Finland). At tasks (1), (3), (4), and (5), the performance of the participants was measured by their time to completion of each task, while at task (2) the performance of the participants were measured by how many steps they could do in 20 sec. Before and after the physical performance test, the participants were asked to fill in the subjective evaluation forms about comfort and mobility of the PPE. The form contained a 7-point scale to evaluate from 3 (very easy to move or comfortable) to -3 (very difficult to move or uncomfortable). The experimental protocol was approved by the Institutional Review Board of Kyushu University.

Results

Table 1 shows the results of the functional balance test, prior to and after a physical performance test. There were no significant differences in the ‘wooden plank time’ both before and after the task. ‘Timed up and go’ for FFT was significantly faster than that for ST (p<0.001). Type B was significantly higher on phase of ‘after the task’ than that of CON (p<0.05). In the ST group, there were no significant differences among conditions both before and after the task. For ‘Arm reach’ for FFT, Types B and C were significantly shorter than CON before the task (p<0.05). In contrast, there were no significant differences between either task phase, before or after the task for the task for the ST group.

Table 1. The functional balance test before and after the physical performance test (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>Firefighters (FFT)</th>
<th>Non-firefighters (ST)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wooden plank time</td>
<td>Timed up and go (sec)</td>
</tr>
<tr>
<td></td>
<td>(sec)</td>
<td>(sec)</td>
</tr>
<tr>
<td>Before task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>9.8±2.4</td>
<td>5.2±0.8</td>
</tr>
<tr>
<td>Type A</td>
<td>10.5±1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.1±0.9&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Type B</td>
<td>11.4±1.8</td>
<td>5.9±0.8&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Type C</td>
<td>11.5±1.5</td>
<td>6.1±0.8&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>After task</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CON</td>
<td>8.8±2.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.1±0.4</td>
</tr>
<tr>
<td>Type A</td>
<td>10.5±1.9</td>
<td>6.4±1.2</td>
</tr>
<tr>
<td>Type B</td>
<td>10.5±2.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.0±0.7&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Type C</td>
<td>10.1±1.6</td>
<td>6.1±0.9&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Significant differences between CON and the other conditions (*p<0.05)

<sup>a,b,c</sup> Significant differences between groups and conditions by the t-test (*p<0.05, *p<0.01, **p<0.001).

Mean physical performance times (rest time included) for FFT was shorter than ST (22.7±24.0 vs. 24.0±0.6s, respectively; p<0.001). However, significant differences of whole performance time among clothing conditions were not found in this study. Most results from all conditions for FFT were better than ST, and standard deviations of FFT were smaller than those of ST (Table 2). For stepping up, FFT had significantly lower HR in CON than while wearing Types A, B and C (p<0.001), while HR was similar between PPE types. The ST group had the same tendency with HR in CON significantly lower than that among other conditions (all at least p<0.05, Table 2). Side jumping for FFT was significantly different from CON for all PPE conditions (p<0.001). In contrast, side jumping for ST was not significantly different between CON and all PPE conditions. The crawl score for FFT in the CON condition was significantly different from Types A, B, and C (all at least p<0.05). However, there were no significant differences for ST group among conditions. For ‘object-dragging’ for FFT, significant differences were found between CON and Type A and CON and Type...
C (both $p<0.05$). For each PPE condition of ‘Obstacle striding’ of both groups, significant differences were shown between CON ($p<0.001$). For the postural balance test, there were no significant differences among conditions and between groups.

### Table 2. Summary of the physical performance test.

<table>
<thead>
<tr>
<th></th>
<th>Firefighters (FFT)</th>
<th>Non-firefighters (ST)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CON</td>
<td>Type A</td>
</tr>
<tr>
<td><strong>Step up (bpm)</strong></td>
<td>105</td>
<td>130</td>
</tr>
<tr>
<td>±5</td>
<td>±14***</td>
<td>±12***</td>
</tr>
<tr>
<td><strong>Side Jump (times)</strong></td>
<td>52.3</td>
<td>43.1</td>
</tr>
<tr>
<td>±1.9</td>
<td>±3.3***</td>
<td>±2.7***a</td>
</tr>
<tr>
<td><strong>Crawl (sec)</strong></td>
<td>12.6</td>
<td>16.7</td>
</tr>
<tr>
<td>±2.1</td>
<td>±3.2</td>
<td>±2.5*</td>
</tr>
<tr>
<td><strong>Object-dragging (sec)</strong></td>
<td>9.7</td>
<td>11.1</td>
</tr>
<tr>
<td>±1.0</td>
<td>±1.5*</td>
<td>±0.6</td>
</tr>
<tr>
<td><strong>Obstacle striding (sec)</strong></td>
<td>35.3</td>
<td>49.9</td>
</tr>
<tr>
<td>±5.9</td>
<td>±7.9</td>
<td>±4.7***b</td>
</tr>
</tbody>
</table>

Values are mean ± SD. Significantly different to CON (*$p<0.05$, **$p<0.01$, ***$p<0.001$).

$^a$,$^b$ Significantly different between groups for that condition by the t-test ($^a$p < 0.01, $^b$p < 0.001)

### Conclusions

The present study aimed to ascertain whether mobility test methods for PPE such as physical capability and balance ability tests are suitable for investigating the effects of PPE’s weight and design on mobility. We found that wearer mobility was affected by wearing PPE. We found significant differences between PPE conditions and CON for the functional balance test (‘Timed up and go’ and ‘Arm reach’), physical performance test, HR, and subjective evaluations. Thus, the test method for mobility in this study is valid. Therefore, this test method is distinguishable from test methods for mobility that considered balance and physical performance. However, the postural balance test is not suitable for evaluating mobility due to its low effectiveness and convenience. Furthermore, the other aim of the present study was to compare two subject groups (firefighters versus non-firefighters) to establish which is more suitable as a standard subject group. In this study, the subject group that had more significant and superior scores for each test on most measurements was the firefighter group. More significant results should be obtained by studying firefighters as a standard subject group.

### References


WATER IMMERSSION

A multifactoral examination of human response to sudden cold-water immersion

Chris Button1*, James Croft1, Matthew J. Graham1, James D. Cotter1, Samuel J.E. Lucas1,2

1 School of Physical Education and 2 Department of Physiology, University of Otago, Dunedin, NZ.
*corresponding author: chris.button@otago.ac.nz

Introduction
Immersion in cold water may frequently be sudden and require survivors to actively stay afloat (e.g., tread water). To date, however, the response to cold-water immersion has typically been studied in a passive and seated posture with slow rates of immersion [~28 s; (1)]. Slow-onset immersion attenuates the cold shock response, and the passivity reduces cardiorespiratory demands. Therefore, we examined the initial physiological responses and the subsequent behaviours using a more ecologically-valid model of cold-water immersion, i.e., one in which immersion was sudden (<2 s) and participants were required to tread water and then swim.

Profound hyperventilation-induced reductions in brain blood flow occur during cold-water immersion [by 25-43%, (2, 3)], and this may affect behaviour and survival chances. Given that exercise in a terrestrial environment increases brain blood flow by 10-20% (4), we anticipated that treading water while immersed would limit a reduction in brain blood flow. In addition, we tested the hypothesis that experienced swimmers would have a blunted cold-shock response given the potential habituation and the reduced anxiety that may occur as a consequence of swimming regularly compared to novice swimmers.

Methods
Following familiarisation and screening, 25 experienced swimmers (aged 23±7 y, height 173±7 cm, body mass 72±9 kg) and 9 novice swimmers (aged 21±4 y, height 171±5 cm, body mass 70±9 kg) completed a physiological and a behavioural test in both cold (10 °C) and temperate (27 °C) water conditions (order counter-balanced), with the physiology test always preceding the behavioural test by at least one day. All the testing sessions occurred in a swimming flume (StreamLiNZ, Invercargill, New Zealand). Participants wore a lightweight full body harness (Delta™ Repel™ Technology Riggers Harness, Capital Safety, Red Wing, MN) so they could be lowered (and removed) rapidly (1-2 s) into the water with a hydraulic winch, and which did not interfere with arm or leg movements in the water. Ethical approval was granted by the participating institution and all participants gave informed consent.

Physiological testing: Measures of brain perfusion [flow velocity (MCAv, Doppler), prefrontal cortical oxygenation (near infrared spectroscopy)] and cardiorespiratory variables [including: ventilation volume and rate, and end-tidal PCO2 (PETCO2)] were recorded during a rapid (1-2 s) and unsupported immersion, during which participants were required to tread water for 150 s, or to the end of their tolerance.

Behavioural testing: Participants completed a simulated survival test which required them to tread water (3 min) and then swim at 60% of their pre-determined maximum velocity (Vmax) for 2 min (or to end of their tolerance) towards an expanding object (i.e., boat) projected onto a large screen directly in front of them. Finally, participants then swam at 90% Vmax for as long as possible. Each component of the survival test was completed with minimal breaks in between to limit the
duration of time spent in the water. Participants rated their perceived exertion and completed the state portion of the State-Trait Anxiety Inventory at each behavioural testing session.

Data analysis: We used ANOVA–simultaneous component analysis (S) to determine whether swimming skill level moderated physiological or behavioural responses to sudden water immersion. Briefly, the data were decomposed into effect matrices containing the level averages for the experimental factors and an unexplained residual matrix. The effect matrix was then analysed using Principal Components Analysis (PCA) to extract the systematic variation of the measured variables. Using the method described by Zwanenburg et al. (6), individual observations were projected on the principal component subspace to graphically show the variation at levels of each factor. The significance of the effects due to the experimental factors (Water Temperature and Experience) was estimated using p-values derived from permutation testing (10,000 permutations).

Results and Discussion
The severity of cold shock was not affected by swimming experience, with novice and skilled swimmers experiencing similar peak initial changes during the sudden immersion: MCAv decreased ~20%; respiratory frequency increased to ~60 breaths·min⁻¹, and P_{ET}CO₂ reduced to ~12 mm Hg. However, the time course across the 150 s immersion was different between the groups. While the time series of all the physiological variables were similar across groups in the temperate water, in the cold water both respiratory frequency and P_{ET}CO₂ recovered from the initial transitory response faster in the skilled group (after ~45-100 s) relative to the novice group (although both were still perturbed from resting baseline). MCAv in both groups recovered from the initial decrease within the first 30-60 s of the active immersion, to increase above resting baseline measures (25-40%) during the latter part of the immersion. Thus, the previously reported maintained decrease in brain blood flow during cold-water immersion does not appear to reflect what occurs when individuals actively stay afloat by treading water.

The skilled swimmers were able to swim for longer and faster in the temperate conditions (119 ± 29 s vs. 97 ± 40 s and 1.3 vs. 0.9 m·s⁻¹; skilled vs. novice swimmers for combined 60% and 90% V_{max} swim duration and maximum swim velocity, respectively (p<0.05). The cold water reduced duration and speed by a similar extent for each group, such that these measures remained greater in the skilled group for the cold-water swim (75 ± 32 s vs. 54 ± 28 s; for the combined 60% and 90% V_{max} swim; interaction effect: p=0.99).

Multifactorial analysis revealed that discrete values of the dependent variables differed by water temperature (p< 0.0001) and by experience (p = 0.001), but there was no interaction (p = 0.99). Score plots shown in Figure 1 are a graphical representation of the component scores that correspond to each data point. The loadings of each variable on the first principal component of the effect matrices are shown by the bars in the lower plots. They indicate the relative contribution of each variable in explaining the experimental factors. As such the swimming duration and distance variables were most heavily influenced by water temperature, followed by the respiratory variables and brain blood flow velocity (MCAv) in the first 30 s of immersion. Hence the separation between the two groups occurs largely through maximal respiratory frequency (maxRF), Duration and Distance (positive contribution), and the initial drop in P_{ET}CO₂ (minP_{ET}CO₂) and MCAv (minMCAv) during the 30 s of the immersion (negative contribution).
Figure 1: Scores plot (upper) and loadings (lower) for factors (Experience, left and Water Temperature, right). The different symbols indicate the different levels of factors (Triangle = experienced; circle = novice). Level averages are indicated by heavier weight symbols. The ellipses for each group were fitted using least squares. Loadings of each variable on the first principal component of the effect matrices are shown by the bars in the lower plots.

In conclusion, treading water during cold-water immersion increases brain blood flow despite maintained cold-shock-induced hyperventilation. This study supports previous evidence that the cold-shock response appears to be a universal feature of sudden cold-water immersion (regardless of swimming skill level); yet, extends those findings by indicating that skilled swimmers typically display a less severe and shorter manifestation of cold shock. The shorter response may be attributable to reduced anxiety and partial habituation over time associated with ability to keep their head above water. Indeed the strongest predictor of altered swimming behaviour (duration and distance) was the water temperature. Moreover, physiological responses obviously linked with cold shock (e.g., hyperventilation and thus reduced brain blood flow) were also predictors of behaviour. Overall these findings indicate that reducing the severity of cold-shock response, via habituation or limit perturbations in the respiratory and cerebrovascular parameters (in addition to gaining swimming skill/experience), may potentially improve survival chances during sudden cold-water immersion.

References
Distance perception and swimming capability in an open water environment

James Croft and Chris Button*
School of Physical Education, University of Otago, Dunedin, Otago, New Zealand.
*corresponding author: chris.button@otago.ac.nz

Introduction

In some extreme environments the capacity to estimate distance in relation to movement capacity may influence the likelihood of survival (e.g., when stranded in open water). Yet surprisingly little is known about the capability of humans to estimate distance beyond their immediate egocentric space. People tend to underestimate overland distances when the viewed object is less than approximately 100 m and overestimate the distance above this threshold [1]. However, it is likely that perceptual biases may be exacerbated or altered under deteriorated viewing conditions (e.g., with limited contextual information as one might experience when in open water). Lounsberry [2] compared novice and experienced swimmers’ estimates of distances (30 m to 1700 m) from images projected on a screen whilst immersed in an aquatic flume with 10 °C water to simulate actual immersion in open water. Participants generally overestimated the distances (by 230%) and the accuracy of these estimates was not affected by swimmers’ skill levels.

An international collaborative study recently examined the relationship between real and perceived swimming competency. Moran and colleagues [4] asked 373 college students to make capability estimates and then swim non-stop for 15 minutes in a pool environment. More than half (53%) of the students estimated that they could swim nonstop for a distance of more than 300 m, and near one quarter (27%) estimated that they could swim 100 m or less. In fact only a modest relationship was found between perceived and actual swimming distance (r = 0.37) and most students tended to underestimate their actual swimming distance (e.g., 76% were able to swim more than 300 m).

Wallingford [3] examined a number of factors influencing swimming capability in a mock survival swimming test (i.e., adiposity, body cooling rate, $V_{O2}$max, and skinfold thickness). The only variable that significantly contributed to distance swam was triceps skinfold thickness ($r^2 = 0.49$). The interpretation of this finding was that swimming cessation in cold water often results from local cooling in the exercising limbs rather than exhaustion or body core cooling.

The aim of this study was to relate self-perception of swimming ability to actual ability in a cold, open-water environment. The distance swam in open-water was compared to perceptions of maximal distance and also to the distance swam in a swimming pool. We predicted that: i) the distance swam in open water would be less than that completed in a swimming pool; ii) distance estimates from two-dimensional images would be less accurate than when made from comparable distances in a boat floating in open water; iii) distances below 100 m would be underestimated, whereas larger, over-estimates would be made above 100 m, and; iv) there would be no relationship between distance perception and swimming capability in open water.
Methods
All testing procedures conformed to the ethical requirements of the participating Institution. 40 physical education tertiary students (25 female, 15 male) volunteered to participate. All participants wore their regular swimming clothes and a standard cap but were not permitted to wear goggles. The open-water testing took place in a deep channel of the Otago Peninsula (Dunedin, New Zealand) on two different days of comparable weather conditions (i.e., light breeze, broken high cloud cover, 18-20°C ambient temperature and 14 °C water temperature).

Each participant was taken individually via motorised boat from a buoy located 5 m offshore into open water. During this trip at several distances from the buoy, the boat was stopped by the experimenter and participants were asked to estimate the distance back to the buoy. The distances were selected randomly by the experimenter with at least one stop within 50 m blocks. When participants felt they had reached their maximum open-water swimming capability they were instructed to signal for the driver to stop the boat. The participant then climbed into the water. After 150 seconds of floating / treading water participants again estimated the distance, duration and confidence of swimming back to the buoy. The rescue boat then accompanied the participant as they attempted the swim using self-selected stroke/s. The location of the participant was measured at all times by a Global Positioning System watch placed snugly under a swimming cap worn by the participant (Garmin 310XT, USA). If they were unable to complete the swim and/or asked to be removed from the water, participants were immediately pulled back into the rescue boat and the stopping point was recorded. After the swim participants were asked how much further they felt they could swim or what prevented them from completing the swim (where appropriate).

Distance perception was also tested in a controlled laboratory environment either before or after the open-water swim (order counter-balanced). Participants were asked to view a selection of images projected onto a large screen [2]. Each image (n=12) portrayed an open-water environment with a circle superimposed onto the shoreline. Participants were asked to estimate the distance to the circle and their confidence associated with each estimate. The images and actual shore distances were obtained by the experimenter from the motorised boat using the GPS watch and digital camera (Olympus, S800) prior to testing.

At least 3 days following the open-water swim and distance perception testing, participants were asked to complete a 10-minute non-stop swim in a swimming pool (water temperature of 28 °C). Participants were asked to swim as far as they could within this time limit using self-selected stroke/s and without pushing off the walls of the pool.

Results and Discussion
Most participants were able to complete the open-water swim back to shore (37 out of 40 participants). Maximal swimming distance was judged quite conservatively, as most participants estimated being able to swim considerably further (81 ± 72 m) at the end of the swim. The three participants that asked to terminate the test before reaching the buoy each cited localised fatigue in their arms as the main reason for stopping [see also 3]. As predicted, the mean distance swim in open water (151 ± 56 m) was less than that achieved 3 days later in a swimming pool (400 ± 70 m).

The distance estimates made from projected images were typically underestimated and less accurate (-27% ± 56) than those made from the boat (6% ± 50). The individual variability in the data was notable although participants tended to uniformly underestimate or overestimate
regardless of distance. There was no significant relationship between distance estimation accuracy and swimming distance in open water (r=-0.19).

**Figure 1.** Scatterplot of relative estimation error (%) by actual distance. The continuous data (solid circles) were composed from the estimates taken on the boat, the discrete data (open circle and lines; mean and upper and lower quartiles) were recorded from estimates of projected images viewed in a laboratory.

Swimming capacity was reduced in open water compared to a pool swim (by 62% on average). There was no trend for underestimating distances below 100 m and overestimating above this distance, instead individuals tended to uniformly either underestimate or overestimate. Distance perception was less accurate when viewing a two-dimensional image in comparison to real-life, three-dimensional judgments. There was no relationship between distance perception and swimming capability in this open-water environment. Consistent with previous research [4], maximal swimming distance was judged conservatively presumably as a function of limited distance estimation experience and apprehension of swimming in the cold water. Distance perception was improved in a real-life open water environment (compared to two-dimensional images) where the task was also influenced by the physical requirement of swimming to safety. Individuals tend to estimate their maximal swimming capacity quite conservatively in open water presumably to reduce the risk of drowning.

References

Impact of the dive mask on users breath-hold during face immersion in cold and warm water

Kerri Ann Evely1*, Greg Harvey1, Robert Brown1
1 Marine Institute’s Offshore Safety and Survival Centre of Memorial University, St. John’s, NL
*corresponding author: kerri-ann.evely@mi.mun.ca

Introduction

Helicopters are the primary means of transportation in the Newfoundland and Labrador (NL) offshore petroleum industry. All helicopter passengers are provided with a range of equipment to improve chances of survival in the event of a ditching. Though it is not required by legislation, the NL offshore helicopter service provider supplies dive masks to all helicopter passengers. It is suggested that a dive mask may provide protection from the environment and would increase the user’s chance of survival during egress from the ditched helicopter.

Breath-hold ability is one limitation for a successful egress from a ditched, capsized helicopter. Furthermore, exposure to cold water can result in a cold shock response which can further reduce breath-hold ability. The aim of this study is to quantify the impact that wearing a dive mask has on breath-hold time during face immersion in water temperatures of 0.5°C and 33°C, worst case and thermo-neutral conditions respectively.

Methods

This research was approved in-full by the Human Research Ethics Authority at Memorial University in St. John’s, Newfoundland, Canada. Eighteen male and four female participants (age: 42.0 ± 9.6 yrs, mass: 89.1 ± 17.6 kg, stature: 174.1 ± 5.9 cm) performed four face immersions: no mask in 0.5°C (NM0), mask in 0.5°C (M0), no mask in 33°C (NM33), mask in 33°C (M33). All face immersions were performed in a prone position and each participant donned a neoprene hood similar to what is found on a helicopter transportation flight suit. Each face immersion was repeated two times with a minimum of 60 seconds between each repeat, and the best breath-hold time (BHT) was recorded for analysis. Prior to the face immersions, the subject’s forced vital capacity (FVC), forced expired volume in 1s (FEV1), and baseline BHT’s were measured in the sitting and prone position. After each breath-hold, subjects were asked to report their thermal comfort level on the 13 point McGinnis Thermal Comfort Scale [1]. BHT’s and thermal comfort data were analyzed using a two factor ANOVA test with repeated measures (2 (dive mask) x 2 (water temperature)).

Results and Discussion

Participants had an average FVC of 4.96 ± 0.59 L and FEV1 of 3.71 ± 0.47 L. Baseline BHT’s were similar for sitting (82.44 ± 23.84 s) and prone (82.70 ± 30.38 s). BHT for NM0 (27.94 ± 9.84 s) was significantly less (p<.001) compared to M0 (56.77 ± 19.27 s), NM33 (61.22 ± 18.83 s), and M33 (63.97 ± 24.20 s). The thermal comfort levels were significantly lower (p<.001) for the cold face immersions, NM0 (3.82 ± 1.74) and M0 (5.68 ± 1.32), compared to the warm face immersions, NM33 (7.14 ± 0.35) and M33 (7.23 ± 0.43).

Conclusions

The dive mask does not appear to have any significant impact on BHT’s or thermal comfort levels during face immersion in warm water. However, during face immersion in cold water BHT’s and thermal comfort levels are greater with the mask compared to without the mask. This suggests that the dive mask provides thermal protection that can reduce the likelihood of cold shock response when the face is immersed in cold water.

Is swimming in warm water actually putting swimmers in hot water?

Carl D. Bradford1,*, David F. Gerrard2, Samuel J.E. Lucas1,3, Zhifa F. Sun4, James D. Cotter1

1 School of Physical Education, 2 Department of Medicine, 3 Department of Physiology, 4 Department of Physics, University of Otago, Dunedin, New Zealand.

*corresponding author: carl.bradford@otago.ac.nz

Introduction
Thermoregulatory responses to endurance open-water swimming in warm water are largely unknown. The few studies where high-level athletes have swum at “race pace” for more than 30 min are somewhat limited in their application to open-water swimming as they have been conducted in 25-m indoor pools and have not included any radiant heat loading [1,2]. Open-water swimming events are becoming very popular and the top athletes can be working at high work rates for ~2 h while completing the 10-km race. Races in certain parts of the world may be conducted in ‘extreme environmental’ conditions, with water temperatures of 32°C coupled with high ambient air temperatures (35-40°C) and large radiant heat load from the sun; thus providing a very heat-stressful environment. Since a swimmer remains largely immersed, the ability to evaporate is greatly reduced, although there may be an increased heat loss potential through greater conduction and convection in water. Nonetheless, with water temperatures near 32°C effectively clamping the swimmer’s skin temperature (at comfortable levels), this potentially insidious environment may lead to an uncoupling between the swimmer’s actual and perceived body temperatures. With skin temperature playing a more important role in behavioural thermoregulation than for autonomic thermoregulation, competitive open-water swimmers may be at a greater risk of thermal injury/fatality since important behavioural signals may be altered in warm water conditions due to a clamped skin temperature. However, no studies appear to have evaluated psychophysical responses during endurance swimming. Therefore, the purpose of this study was to examine the physiological and perceptual responses of swimming in conditions of warm water and air, with radiant heat loading.

Methods
Twenty two competitive swimmers or triathletes (15 males, 7 females; age 27 ± 9 y; height 176.3 ± 9.5 cm; mass 75.91 ± 10.23 kg) swam as far as possible in at least one of three durations (20, 60 and 120 min) in a swimming flume at an average water temperature of 32.1 ± 0.04°C, ambient air of 30.0 ± 0.4°C and relative humidity of 56.0 ± 2.0%. Radiant heat load was generated with two 2000 W halogen lamps, situated 1.5 m above the swimmer, creating irradiance at the water surface between 400-800 W·m⁻². Swims were undertaken following an initial familiarisation swim in these conditions, and at least 4 days apart. Rectal temperature (T<sub>re</sub>), swim speed and distance, heart rate, and ratings of perceived exertion, thermal sensation and discomfort, and overall feeling state were recorded during each swim. Ethical approval for this study was granted by the University of Otago Human Ethics Committee.

Results and Discussion
A total of 16 swims were completed in the 20-min condition, 19 swims in the 60-min condition and 10 swims in the 120-min condition. Rectal temperature increased to reach a similar level in all three swim durations (20 min: 38.10 ± 0.43°C; 60 min: 38.26 ± 0.61°C; 120 min: 38.40 ± 0.75°C; p>0.05), and consequently the rate of increase in the different swim durations was greater (both p<0.01) for the 20 min (0.037°C·min⁻¹) compared to the 60 min (0.015°C·min⁻¹) and compared to the 120 min (0.007°C·min⁻¹) swims. The average distance swum in the 20-min condition was 1332
± 164 m; 60 min: 3712 ± 403 m, and 120 min: 7628 ± 810 m. This corresponds to an average pace which was significantly faster (p<0.01) in the 20-min swim (91 ± 11 s·100 m⁻¹) compared to both the 60-min (98 ± 11 s·100 m⁻¹) and 120-min swims (96 ± 10 s·100 m⁻¹), which were swum at a similar pace (p=0.10). This was also associated with a similar average heart rate in the 20 min (166 ± 9 bpm) and 60 min (161 ± 17 bpm; p>0.05) swims, while average heart rate was lower in the 120 min swim (159 ± 15 bpm; p=0.02 compared to 20 min). There was a positive linear relationship between actual Tₑ and perceptions of thermal sensation (average rating at swim completion: hot-to-very hot) and the associated thermal discomfort (uncomfortable-to-very uncomfortable) in all three swim durations (Figure 1, Panel A and B). Further, there was a negative relationship between actual Tₑ and overall feeling state (Figure 1, Panel C).

![Figure 1](image)

**Figure 1.** Relationship between the swimmers’ actual core temperature and their thermal sensation (Panel A), thermal discomfort (Panel B) and overall feeling (Panel C) during the 20, 60 and 120-min swims in warm 32°C water and 30°C air with radiant heat loading. NB. Feeling scale range (Panel C) is actually +5 to -5.

The modest increase in rectal temperatures observed following intense swimming for 20, 60 or 120 min in conditions representative of warm open-water swimming events are similar to those previously reported following indoor pool swims of ~60 min duration without radiant heat loading [1,2]. This presumably reflects an increase in skin blood flow and the large capacity of water for conductive and convective heat transfer. The linear relationship between actual and perceived body temperatures indicates that intense swimming in warm water does not impair a swimmer’s ability to accurately perceive their thermal state and thus thermoregulate appropriately (via pace selection).

**Conclusions**
Intense swimming in seemingly ‘extreme environmental’ conditions representative of warm open-water swimming events results in only modest increases in rectal temperature. Further, this modest hyperthermia is similar across three different swim durations and appears to be matched with appropriate increases in thermal sensation and discomfort, despite a clamped skin temperature. Therefore, these data indicate that no uncoupling is evident between the actual and perceived body temperatures during intense swimming in warm water which might otherwise create an insidious environment for the swimmer.

Acknowledgments
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References
Respiratory characteristics during submaximal eggbeater kick by water polo players

Yosuke Sasaki1*, Hideki Takagi2, Takeshi Ogawa3, Bun Tsuji4, Yosuke Murase2, Shozo Tsubakimoto2 and Takeshi Nishiyasu2

1 Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan
2 Institute of Health and Sports Science, University of Tsukuba, Japan
3 Liberal Arts, University of Tokuyama, Japan
*corresponding author: sasaki@lbnp.tailku.tsukuba.ac.jp

Introduction
Recently, we found that peak oxygen uptake (VO2peak) was significantly lower during eggbeater kick (EK) than cycling (CY) in male college-age competitive water polo players (48.9±6.8 vs. 53.6±4.9 ml/kg/min, p<0.05). In addition, tidal volumes were greater during EK than during CY at moderate and high exercise intensities (2530.0±819.0 vs. 1880.9±402.5 ml, p<0.05; at 49.6±10.1% VO2peak during EK, 2733.5±454.2 vs. 2311.9±220.0 ml, p<0.05; at 74.5±8.9% VO2peak during EK) but did not differ at very high exercise intensity (2706.6±345.6 vs. 2745.8±394.3 ml, p>0.05; at 98.6±5.0% VO2peak during EK). Because buoyancy in a resting vertical position increases with increases in tidal volume [1], the subjects might have increased their buoyancy during EK by increasing tidal volume. However, it is uncertain whether expiratory reserve volume and fractional inspiratory time during EK were different from those during CY. Furthermore, it is also unknown whether the work of breathing during EK was different from that during CY. The purpose of this study was to investigate the respiratory characteristics during submaximal EK compared to that during CY in water polo players.

Methods
Twelve male college-age competitive water polo players performed incremental EK and CY tests to determine the workload to elicit three VO2 levels (moderate, high and very high exercise intensity; 48.5±4.7, 72.0±9.2 and 95.1±7.8% VO2peak during EK, respectively). Then, they performed submaximal EK and CY tests at these three VO2 levels, in random order. These three relative intensities were chosen because average VO2 during the first set of a EK test is higher than that during a CY test, and average VO2peak during EK is lower than that during CY (as mentioned above). Subjects also performed three “forced vital capacity measurements” before and immediately after exercise. Twelve voluntary maximal inspiratory capacity (IC) measurements were obtained during the last 80-270 s of each set [2]. Work of breathing was defined as the integrated area of the pressure-tidal volume loop; with pressure being the difference between intraesophageal pressure and pressure at the airway opening during spontaneous breathing. This value multiplied by the breathing frequency represents the amount of work done per minute for the lungs [3]. This research conformed to the principles of the Declaration of Helsinki, and all subjects signed an informed consent form.

Results and Discussion
We found that expiratory reserve volume was greater during EK than CY at the very high exercise intensity, while expiratory reserve volume + tidal volume values were not different between the EK or CY at all exercise intensities. Fractional inspiratory times were faster during EK than CY at all exercise intensities. Work of breathing did not differ between EK and CY at all exercise intensities. Further, work of breathing between EK and CY at the same minute ventilation (VE) was not different.
Conclusions
Respiratory pattern during submaximal eggbeater kick is different from that during cycling, with increase fractional inspiratory time. This altered breathing pattern may assist with buoyancy.

References
HYDRATION AND HEAT

Water and sodium regulation and dysregulation

Simon N. Thornton
U961 INSERM, Université de Lorraine, 54505 Vandoeuvre les Nancy, France
Corresponding author: simon.thornton@univ-lorraine.fr

Regulation of body fluids in most mammals depends on the intake, distribution and excretion of water and sodium mediated by various specialised osmolality and volume/pressure detectors that control three hormone systems; anti-diuretic hormone (ADH or vasopressin), the renin-angiotensin system (RAS), and aldosterone (which can be grouped with RAS forming RAAS). This regulation can be grouped loosely under the term thirst and ensures normally the consistency of the internal milieu.

Although there is an important health debate today around sodium and its impact on many chronic diseases, especially cardiovascular, the molecule itself is essential in the regulation of thirst. Sodium is the most important ion in the extracellular fluid, principally the blood, which maintains along with water the overall volume and osmolality. This latter value is maintained within normally strict physiological limits, around 290 mosmol/kg water. An increase in osmolality (normally the concentration of sodium) of the blood (or plasma) draws water from the intracellular fluid compartment, i.e. the cells, thus activating specialised neurons, or osmoreceptors, in the hypothalamus of the brain that stimulate the search for and the consumption of water. These same receptors stimulate neurons in other hypothalamic areas to liberate ADH into the blood stream from their axon terminals in the pituitary. As its name suggests the action of ADH is to reduce urine loss of water via the kidney. This occurs just during the increased osmolality (but can occur in various stress states as well). Once the ingested water reaches the blood supply osmolality is reduced and thus the signal for ADH release decreases. On the other hand if water is no consumed, or not enough is drunk, then plasma levels of ADH remain elevated, thus reducing urine volume.

The detectors for changes in blood volume/pressure are in the cardiovascular system and the kidney. Once activated these receptors signal the brain to search for and to consume water and release ADH into the blood. In the kidney the specialised receptors release the enzyme renin that produces angiotensin I from angiotensinogen which is then acted on by converting enzyme to produce angiotensin II (AngII). The search for and the drinking of water plus the release ADH into the blood are stimulated by AngII as well as the release of aldosterone. These effects work together with the absorption of sodium from the urine induced by aldosterone and water by ADH in order to slow the losses of blood volume. With drinking and sodium intake the losses are repaired and the hormones levels decrease. In rats AngII and aldosterone have a synergistic action in the brain to stimulate a sodium appetite; once again this would be a physiologically appropriate response to recover lost volume.

In healthy humans and rats an increased sodium intake inhibits AngII production and leads to a decrease in aldosterone in the blood ie the normal physiological response. Therefore, it could be proposed that hypohydration-induced chronic extracellular dehydration could be one of the reasons why sodium poses a problem in non-healthy humans.
Dehydration and performance – an overstated concern?

Paul B. Laursen$^{1,2}$

$^1$ High Performance Sport New Zealand, $^2$ Sport Performance Research Institute New Zealand, AUT University, Auckland, New Zealand

Corresponding author: Paul.Laursen@hpsnz.org.nz

Introduction

Laboratory studies have shown that dehydration of only 2% can lead to increases in body temperature and heart rate during exercise, and decreases in cycling performance. These studies, however, have been conducted in relatively windless environments (i.e. wind speed $<$~15 km·h$^{-1}$), without participants blinded to their hydration status. In this presentation, I will reveal new data showing the effect of hydration status on cycling time trial performance in the heat using ecologically valid facing wind speed and hydration status adjusted using different volumes of intravenous saline infusion.

Methods and Results

During three experimental trials, ten cyclists were dehydrated to -3% body mass before being reinfused with saline to replace either 100%, 33% or 0% of fluid losses, leaving them 0%, -2% or -3% hypohydrated, respectively. Subjects then completed a 25-km time trial in the heat (33°C, 40% relative humidity; wind speed 32 km·h$^{-1}$) during which their starting hydration status was maintained by infusing saline at a rate equal to their sweat rate. The treatment was subject-blinded and the order was randomised. Performance variables, heart rate, rectal temperature and perceptual variables were measured.

While rectal temperature was modestly but significantly higher beyond 17 km of the time trial in the -3% vs. 0% conditions (38.91 ± 0.25°C vs. 38.61 ± 0.32°C; p<0.05), no other differences between trials were shown.

Conclusion

When well-trained cyclists were blinded to their hydration status to -3% of body mass, little-to-no influence was found for their 25-km cycling time trial performance or physiologic strain under field-simulated conditions. In context, thirst stimulates drinking to limit dehydration beyond 3% – as evidenced, for example, by this level of dehydration being common across many sports, including ultra-endurance sports. The study presented herein, along with the recent meta-analyses by Goulet[1, 2], indicates that for well-trained athletes engaging in competitive exercise, they need not be overly concerned with their hydration status, and should drink to thirst before and during exercise to maximise their performance.

References

The affects of heat strain and dehydration on cognitive function

Anne M.J. van den Heuvel1, Rodney J. Croft2, Benjamin J. Haberley1, David J.R. Hoyle1, Nigel A.S. Taylor1*  
1 Centre for Human and Applied Physiology, University of Wollongong, Australia  
2 Centre for Psychophysics, Psychophysiology and Psychopharmacology, University of Wollongong, Australia  
*corresponding author: Nigel_Taylor@uow.edu.au

Introduction  
Many groups have investigated cognitive performance during hyperthermia and dehydration, with few demonstrating convincing and unequivocal influences. Some reports show neither thermal- nor hydration-induced influences, others have found improved, whilst some report reduced cognitive performance. This confusion has arisen due to methodological limitations that have resulted in many previous experiments not being optimally designed to evaluate these effects. For instance, few studies have appropriately induced hyperthermia and dehydration, and then clamped these states during the cognitive challenge. Many investigators have used physical exercise to induce these states, yet exercise may independently affect cognitive performance. Furthermore, task difficulty has rarely been controlled across cognitive functions, with the difficulty level for many tasks being too low, whilst inter-task comparisons have often been performed across different levels of difficulty. The former introduces bias, such that only performance decrements can be observed, whilst the latter renders it almost impossible to compare either the baseline data or subsequent changes in cognitive performance during altered thermal and hydration states. As a consequence of these limitations, our understanding of the affects of these stresses upon cognitive performance is less than optimal, and this study was designed to address these design limitations.

Methods  
Eight physically active men participated in six experimental trials, delivered in a balanced order, and at intervals >7 d. Before every trial, pre-experimental preparation ensured each subject was tested in a clamped thermal state (thermoneutral: mean body temperature: ~36.5°C; moderate hyperthermia: ~38.5°C), and at one of three hydration levels (euhydration: 0%; mild dehydration: 3%; moderate dehydration: 5%). These hydration states were then investigated at each level of thermal strain, resulting in six trials, with the control state being thermoneutral and euhydrated. Dehydration was achieved using intermittent, warm-water immersion (39-41°C: 2.5-3.5 h), with the desired state maintained throughout the trial using controlled (isotonic) fluid administration. Thermal clamping, using a water-perfusion garment, water bath and insulated clothing ensured sustainment of the target body temperatures.

Hydration status was tracked throughout each trial via changes in semi-nude mass, relative to the pre-experimental body mass, which itself was the average of three consecutive daily measurements obtained from the mornings preceding each trial. Core temperature was derived as the mean of three site measurements: oesophagus, auditory canal and rectum. Skin temperatures were measured from eight sites (forehead, scapula, chest, upper arm, forearm, hand, thigh, calf), with mean skin temperature calculated as an area-weighted average. All temperatures were recorded at 15-s intervals. Mean body temperature was determined using temperature-specific weightings of mean core (thermoneutral: 80%; hyperthermia: 90%) and mean skin temperatures.

Three cognitive tasks were performed within each trial: (1) a visual perceptual task was administered at two levels of difficulty (easy and difficult); (2) a working memory (n-back) task was delivered at a difficulty level approximately equal to that of the easy perceptual task; and (3) a
letter identification task was administered to evaluate the effect of these treatments on visual acuity, since this can confound data interpretation when cognitive tasks rely upon visual cues. These tasks were administered in a counterbalanced order, which was randomly assigned to each subject. The difficulty level used for each subject for the visual perceptual tasks was determined during a preliminary experimental session. The variables recorded and analysed from these tasks were performance accuracy (percentage of correct responses) and reaction time (ms). Data were analysed using factorial ANOVA, where the independent variables were thermal status (two levels) and hydration state (three levels), and the primary dependent variable was cognitive function, with task accuracy and reaction time being compared across trials.

Results and Discussion
The target hydration states (mass changes) were achieved within every trial: thermoneutral: -0.2% (SD 0.2), -3.1% (SD 0.2) and -5.1% (SD 0.2); moderate hyperthermia: -0.9% (SD 0.9), -3.3% (SD 0.3) and -5.1% (SD 0.5). Each of these states differed significantly from one another ($F[2,14]=468.43$, $p<0.01$), and there was no interaction between hydration and body temperature ($p=0.14$). Mean body temperature was clamped at each hydration level: $36.2^\circ$C (SD 0.3), $36.2^\circ$C (SD 0.3) and $36.4^\circ$C (SD 0.3) for the thermoneutral trials at 0%, 3% and 5% dehydration (respectively); and similarly at $38.4^\circ$C (SD 0.3), $38.3^\circ$C (SD 0.3) and $38.3^\circ$C (SD 0.3) for the moderate hyperthermia trials. These thermal states differed significantly ($F[1,7]=600.35$, $p<0.01$), and without an interaction between temperature and hydration ($p=0.07$). These outcomes were interpreted to mean that previous methodological limitations had been successfully overcome by manipulating and clamping both the thermal and hydration status of every subject prior to commencing each trial, and throughout the ensuing cognitive function tests.

To distinguish between the influence of these treatments on these cognitive domains, the accuracy for the working memory and easy perceptual tasks from the thermoneutral, euhydrated trials were matched: 83.0% (SD 11.3) and 84.9% (SD 9.8), respectively. The fact that difficulty did not differ significantly verifies that the task difficulty manipulation was achieved successfully ($t(7)=-0.427$, $p=0.68$). There were no indications of differences in accuracy for the letter identification task, as a function of the thermal ($p=0.68$) or hydration manipulations ($p=0.46$), or their interactions ($p=0.31$). Thus, the following cognitive performance changes occurred independently of variations in visual acuity.

To evaluate the thermal and hydration effects on task difficulty, comparisons were made for both task accuracy and reaction time between the easy and difficult perceptual tasks, as a function of the thermal and hydration states. For performance accuracy, there was a main effect of difficulty level ($F[1,7]=8.11$, $p=0.03$), where accuracy was higher in the easy compared to the more difficult perceptual task (Figure 1), but there was no main effect for either temperature ($p=0.18$) or hydration ($p=0.89$), and no interaction ($p=0.79$). Furthermore, difficulty level did not interact with either temperature ($p=0.56$) or hydration ($p=0.41$), nor was the interaction between temperature and hydration state significant ($p=0.55$). For reaction time, there was a main effect of temperature ($F[1,7]=29.88$, $p<0.01$), with faster reaction times generally being evident when subjects were hyperthermic (Figure 1), and there was also a main effect of hydration state ($F[2,14]=7.36$, $p<0.01$), such that reaction time was faster when 5% dehydrated relative to the euhydrated ($p<0.01$) and 3% dehydrated state (Figure 1; $p=0.01$). Similarly, difficulty level did not interact with either temperature ($p=0.80$) or hydration ($p=0.83$), nor the interaction of temperature and hydration ($p=0.22$).
To evaluate the impact of these thermal and hydration states on cognitive task type (domain), comparisons were made for both performance accuracy and reaction time between the working memory task and easy-perceptual tasks, as a function of these thermal and hydration states (Figure 1). For performance accuracy, there were no main effects for task type ($p=0.58$), temperature ($p=0.11$) or hydration state ($p=0.52$), and there were no significant interactions (all $p>0.05$). However, for reaction time, there was a main effect of temperature ($F[1,7]=43.16$, $p<0.01$), with slower reactions generally being observed when subjects were thermoneutral relative to the hyperthermic state (Figure 1), but there were no main effects for task type ($p=0.06$) or hydration level ($p=0.08$), and the interaction between temperature and hydration was not significant ($p=0.13$). Furthermore, there was no interaction between task type and either temperature ($p=0.32$) or hydration state ($p=0.59$), nor was the interaction between task type, temperature and hydration significant ($p=0.21$).

Conclusions

The main findings of this study were significantly faster reaction times when subjects were moderately hyperthermic (relative to the thermoneutral), and this was independent of both task difficulty and the cognitive domain. There was also an improvement in reaction time (perceptual tasks only) with increased dehydration. Furthermore, there was no evidence of a simultaneous decrease in accuracy within any of these comparisons. Thus, there was no trade-off evident between speed and accuracy within these data, with subjects demonstrating improvement as a function of both increasing temperature and the level of dehydration. These observations imply that, under more rigidly controlled experimental conditions, neither mild dehydration nor mild hyperthermia appear to have adverse consequences for performance within these cognitive domains.
Thermoreceptors in the stomach region independently mediate transient sweating responses

Nathan B. Morris1, *, Anthony R. Bain1,2, Ollie Jay1
1 Thermal Ergonomics Laboratory, School of Human Kinetics, University of Ottawa, Ottawa, Canada
2 Centre for Heart, Lung and Vascular Health, University of British Columbia, Okanagan Campus, Kelowna, Canada
*corresponding author: nmorr041@uottawa.ca

Introduction
Previous research from our laboratory has demonstrated that warm and cool beverage ingestion during exercise causes an augmentation or attenuation, respectively, of whole-body sweat losses compared to neutral water ingestion. In order to examine how water ingestion of different temperatures influenced mean local sweat rate (MLSR), two studies were performed with the purpose of i) characterising the transient responses in MLSR following sequential ingestions of warm and cool water; and ii) determining the location(s) of the thermoreceptors responsible for mediating MLSR.

Methods
In both studies, males cycled at 50% of their VO₂ max for 75 min in a temperate environment (23.6 ± 0.6°C, 23 ± 11% RH). In study one, 13 males ingested four 3.2 mL·kg⁻¹ boluses of either 1.5°C, 37°C, or 50°C water, 5 min before, and 15, 30 and 45 min after the start of exercise. In study two, 6 males either mouth-swilled (SW) 1.5°C or 50°C water; or ingested 1.5°C or 50°C water through a nasogastric (NG) tube, thus bypassing the mouth, in three 3.2 mL·kg⁻¹ boluses after 15, 30, and 45 min of exercise. For both experiments, skin temperature from 8 sites (Tsk), rectal temperature (Tre), and local sweat rate from the forehead, forearm and upper back were measured continuously.

Results
In study one, despite similar changes in Tre and Tsk throughout exercise (p>0.05), MLSR was greater with 50°C fluid ingestion, and lower with 1.5°C fluid ingestion in comparison to 37°C, after 15, 30, 45, and 60 min exercise (p<0.05), but not after 75-min. Time (mean ± SD) to the onset of sweating was 8.5 ± 2.6, 8.2 ± 2.0, and 7.5 ± 2.4 min with the ingestion of 1.5°C, 37°C and 50°C water, respectively, with time to onset being shorter in the 50°C trials compared to the 1.5°C trials (p=0.04). In study two, Tre and Tsk were similar across all trials (p>0.05), MLSR was lower with 1.5°C compared to 50°C water in the NG trials after 30, 45, and 60 min of exercise (p<0.05). Conversely, in the SW trials, MLSR with 1.5°C and 50°C water was almost identical at all time points (p>0.05).

Conclusions
Transient alterations in sudomotor activity occurred immediately following the ingestion of warm and cool water, independently of core and skin temperatures. Additionally, the ingestion of warm and cool water altered the time to the onset of sweating. The thermoreceptors responsible for the observed changes in MLSR probably reside within the stomach region, but not the mouth.

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Cooling for exercise in the heat: Go with your gut, or do cooler heads prevail?

Rodney Siegel
High Performance Sport New Zealand, New Zealand
Corresponding author: Rod.Siegel@hpsnz.org.nz

Exercising in hot environments can raise core body temperature to a greater extent than in temperate environments; an effect associated with impaired exercise performance over a variety of modes and durations. Pre-exercise cooling is a popular strategy used to limit this impairment, with the majority of precooling manoeuvres conducted via external means, such as using cold-water immersion or cooling garments. However, such methods are often difficult to implement during the logistics of major sporting competitions. Recently, research has focused on more practical internal cooling methods, such as ingesting cold fluids or ice slurries before and during exercise. These methods have shown success in lowering pre-exercise core temperature and/or attenuating the rise in core temperature during exercise in the heat, thereby directly or indirectly being associated with enhancements in endurance performance. Interestingly, the mechanisms responsible for these performance improvements appear to be somewhat different than traditional forms of external precooling. While the precise mechanisms are yet to be fully elucidated, the performance increases in the heat shown with cold drink ingestion have been attributed to the effects that the cold fluid may have on brain temperature, internal thermoreception and sensory responses. Indeed, recent evidence indicates that sensory responses – e.g., nutritive signals from the mouth and ergogenic feedback from muscle – may play an important role in the regulation on motor output during exercise in hot environments. Further, cooling the gut region specifically may be of particular benefit during exercise in the heat, due to the sensitivity of this area to temperature [1], as well as potential effects on endotoxaemia.

References
Effects of hypohydration on plasma markers of oxidative stress

Michael Dessoulavy, James D. Cotter, Troy Merry, Rachel Kingsford, Nancy J. Rehrer*
University of Otago, Dunedin, New Zealand
*corresponding author: nancy.rehrer@otago.ac.nz

Introduction
Hypohydration can increase oxidative stress at rest and during exercise, and upregulate antioxidant capacity. The impact of longer-lasting hypohydration is unknown. Therefore, the purpose of this study was to examine effects of hypohydration over longer acute periods (> 2 h) and when repeated (across 6 d), on exercise-induced oxidative stress.

Methods
Acute hypohydration: Trained (n=6) and untrained (n=6) males completed 80 min cycling (40 min at 70% \( \dot{V_{\text{O}_2}} \text{peak} \) followed by a 40-min work trial), twice; once euhydrated and once hypohydrated by ~2%, in counterbalanced order. On the evening before testing, participants dehydrated via moderate exercise in the heat (35°C, 50% RH), with full rehydration in one trial only. Plasma samples from before and after exercise tests were analysed for oxidised proteins (AOPP) and lipids (MDA) and for antioxidant capacity (ORAC). Linear mixed models were used to analyse data. Chronic hypohydration: Seven well-trained male runners completed a 6-d fluid-controlled training protocol, twice, once euhydrated at all times, and once with daily dehydration (i.e., not drinking during training, replacing only 30% of lost mass thereafter, until evening. On day seven, runners completed 70-min treadmill running at 85% of anaerobic threshold, followed by a 3-km time trial, in warm conditions (30°C, 50% RH), mildly hypohydrated at exercise onset and without fluid replacement thereafter.

Results
No increases in oxidative stress markers were observed with acute or chronic hypohydration; in contrast, some decreases were observed. Acute: AOPP was lower when hypohydrated (Mean 39 vs. 42 \( \mu \text{mol.L}^{-1} \) for Hyphydration vs. Euhydration, resp.; \( p=0.035 \)). Chronic: Both AOPP (Mean 32 vs. 40 \( \mu \text{mol.L}^{-1} \), resp.; \( p=0.046 \)) and MDA (Mean 2.9 vs. 3.1 \( \mu \text{mol.L}^{-1} \); \( p=0.028 \)) were lower across exercise following chronic hypohydration. However, ORAC was not affected consistently.

Discussion
We observed decreased oxidative stress with both chronic and acute hypohydration, in contrast to others’ results with shorter dehydration protocols. We speculate that an increase in antioxidant capacity may have already occurred in the present hydration studies, which ultimately eliminated the expected increase in oxidative stress and could also explain the lack of change in ORAC. Manipulation of hydration and up-regulation of antioxidant capacity may potentially be useful in training for sporting performance as a means of increasing antioxidant capacity, however, this requires further evidence and would also require consideration of other more negative aspects of hypohydration.

Conclusions
Hypohydration over several hours following exercise, and chronically over several days, can reduce the typical increase in oxidative stress observed with exercise and with acute hypohydration. This may be due to an adaptive response of increased anti-oxidant capacity.
Acute mountain sickness is not reliably due to fluid regulatory or autonomic stress.

Joseph Donnelly¹, James D. Cotter¹*, Robert J. Walker¹, Keith R. Burgess², Philip N. Ainslie³, Mike Stembridge⁴, Andrew N. Curtis¹, Nia C.S. Lewis³, Aparna S. Basnet⁵, Samuel J.E. Lucas¹

¹ University of Otago, Dunedin, New Zealand.
² University of Sydney, Sydney, New South Wales, Australia.
³ University of British Columbia, Kelowna, BC, Canada.
⁴ Cardiff Metropolitan University, Cardiff, United Kingdom.
⁵ Good Samaritan Hospital, Phoenix, USA
*corresponding author: jim.cotter@otago.ac.nz

Introduction
Acute mountain sickness (AMS) is characterised by disturbances to the central nervous system - most notably evident as headache - and appears to be a mild form of high-altitude cerebral oedema. The aetiology of AMS remains only partly understood despite extensive research. Hypoxia is the primary stimulus, although hypobaria per se also contributes [1]. Speed of ascent and genetic propensity both have a role, while physiological mediators may include arterial desaturation, autonomic stress, cerebral cytotoxicity, and possibly also disrupted blood brain barrier function and altered fluid balance.

Interestingly, hypohydration and hyperhydration have both been implicated in AMS. Hypohydration is frequently considered a risk factor for AMS. Accordingly, high-altitude sojourners are advised to drink avidly to avoid dehydration. In contrast, hypoxia has also been shown to cause inappropriate increases in the secretion of anti-diuretic hormone (ADH) and thereby reduce free-water clearance, in conjunction with increased severity of AMS symptoms [3]. This fluid retention effect was evident in approximately one third of 48 volunteers exposed to eight hours of hypobaric hypoxia. To our knowledge, the role of hypohydration or stress-induced hyperhydration in AMS has not been determined in the aetiology of AMS for newcomers to high altitude. Therefore, the purpose of this study was to identify the role of hydration in AMS at high altitude.

Methods
Design
Fluid regulation, autonomic function and symptoms of AMS were assessed in up to 20 healthy, normotensive lowlanders at sea level (SL; 334 m) and on the first morning after ascending from 4200 to 5050 m (High Altitude [HA]; i.e., from Pheriche up to the Pyramid Lab at Lobuche, Nepal). Nine participants were retested after one week living at 5050 m. Standard procedures to minimise AMS were used during the ascent to 4200 m; ascending from 1400 m (Kathmandu) over 6 d, with ingestion of 250 mg·d⁻¹ of a carbonic anhydrase inhibitor (Acetazolamide) until day 5. The subsequent, rapid ascent to 5050 m was intended to induce measurable AMS in most participants, without increasing the likelihood of excessive hyponatraemia upon an acute fluid load. Written, informed consent was obtained and the study was performed according to the Declaration of Helsinki, following approval by Institutional Ethics Committees. Participants’ physical characteristics were (mean ± SD): age 30 ± 7 years; body mass 75 ± 14 kg; height 175 ± 8 cm; and none had been to high altitude in the previous six months.

Procedure and measurements
Hydration, autonomic function and AMS were assessed before testing fluid regulatory responses to a bolus ingestion of water (15 mL·kg⁻¹ body mass), shortly after waking. On the day before testing at each altitude, participants were required to abstain from caffeine-containing drinks, and
encouraged to maintain good hydration (per normal advice at high altitude), but fluid balance was not enforced because it was of interest to examine AMS under free-living conditions. Following waking, participants gave a baseline urine sample before body mass was recorded, and lay supine for ~15 min. During this supine period measures of heart rate variability were obtained from ECG during 5 min of spontaneous breathing and 5 min of paced breathing (6 breaths-min⁻¹). AMS was assessed using the Lake Louise Scoring system (LLS), Environmental Symptoms Questionnaire (ESQ) and Headache score (scale: 0-100). Arterial O₂ saturation was recorded and a baseline venous blood sample was obtained. Participants then re-emptied their bladder, drank the water bolus as rapidly as possible, and returned to supine or semi-supine rest. A second venous sample was obtained at 40 min following drinking, with the second urine sample collected at 60 min. Plasma concentrations of ADH (using RIA) and osmolality (P_{osm}, using dewpoint) were frozen and batch analysed at a later date.

Results and Discussion
AMS was mild and variable among 20 newcomers to 5050 m (Table 1), and persisted one week later in 3 of the 9 participants retested. Unexpectedly, plasma ADH was uniformly low at HA; being consistently lower than at SL despite higher Posm. Central osmoregulatory control was unable to be determined using the mathematical relation of ADH to Posm due to data skewing, and was therefore approximated as ADH / [Posm minus a baseline of 286 mosmol·kg⁻¹]. A marked suppression of ADH was evident at HA (Table 1). Only 4 of 14 participants had a P_{osm} < 290 mosmol·kg⁻¹ at SL, and none did so at HA (Table 1). In contrast, urinalysis gave no such indication of hypohydration at HA; mean USG was only 1.017 (range: 1.002 – 1.031).

| Table 1. AMS, fluid regulation and autonomic function at sea level and on the first and seventh days following arrival at 5050 m (data are means ±SD, with 95% CI’s for differences between HA and SL). |
|----------------|----------------|----------------|---------------|
| **AMS (n ≤20)** | **Sea Level (SL)** | **High Altitude (HA)** | **HA minus SL** |
| **Day 1** | **Day 7 (n=9)** | **mean (95%CI)** |
| **LLS** | 3 ±1 | 2 ±2 |
| **ESQ** | 3 ±3 | 3 ±5 | 4 (2 to 6) |
| **Headache (0-100)** | 1 ±2 | 20 ±17 | 14 ±24 | 19 (11 to 28) |
| **Fluid regulation (n ≤14)** | **Osmo_{a} (mosmol·kg⁻¹)** | 294 ±6 | 298 ±3 | 302 ±3 | 5 (1 to 8) |
| | **ADH_{a} (pmol·L⁻¹)** | 5.1 ±2.7 | 2.0 ±1.8 | 2.3 ±0.9 | -3.1 (-4.7 to -1.5) |
| | **ADH_{a}/[Osmo_{a}>286]** | 0.84 ±0.86 | 0.14 ±0.03 | 0.12 ±0.05 | -0.70 (-1.2 to -0.2) |
| **Heart Rate Variability (n ≤14)** | **Spontaneous LF (10⁻³ ms⁻²)** | 2.2 ±1.6 | 1.5 ±2.2 | 1.6 ±0.9 | -1. (-2 to 0) |
| | **Controlled LF (10⁻³ s⁻¹)** | 8.8 ±8.4 | 8.3 ±9.7 | 5.7 ±6.7 | -1.4 (-7.8 to -4.9) |
| | **Spontaneous LF/HF** | 1.2 ±1.0 | 2.1 ±1.7 | 3.2 ±2.7 | 0.8 (-0.6 to 2.1) |
| | **Controlled LF/HF** | 9.3 ±5.4 | 11.6 ±10.5 | 14.0 ±9.2 | 2.1 (-2.7 to 7.0) |

AMS was not more severe in participants with higher concentration of ADH (LLS: r=0.11). AMS was modestly related to plasma osmolality (LLS: r=0.53; Headache: r=0.40), but not to USG (all r<0.15). Drinking at HA neither worsened nor lessened the headache, relative to the change occurring across this hour in four control participants who did not drink in the corresponding period (p=0.24). At HA, haematocrit averaged 21% higher than at SL (.57 ±0.04 vs .47 ±0.03), and fell after drinking, in contrast to an equivalent rise at SL (mean and 95%CI for difference: .03 ±.02; p=0.01). Arterial desaturation on day 1 at HA was pronounced but relatively homogenous (81 ±3%; n=12)
and thus unsurprisingly was also not correlated closely with the severity of AMS (LLS: \( r=-0.13 \); Headache: \( r=0.33 \)). Arterial desaturation was just as evident after one week at HA (80 ±4%; \( n=7 \)). Sympathetic activation, as indexed from heart rate variability, was generally not apparent at HA.

Conclusions
These findings indicate that AMS was not attributable to anti-diuresis (in any of 14 participants tested here). Rather, ADH appeared to be suppressed, and urine concentration was under-representative of the marked and consistent elevations in plasma osmolality. Hypohydration (based on high plasma osmolality but not urine) was weakly related to AMS severity.

Acknowledgements
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References
THE BRAIN IN STRESSFUL ENVIRONMENTS

Regional brain blood flow during passive hyperthermia

Anthony R. Bain*, Kurt J. Smith, Nia C.S. Lewis, Glen E. Foster, Philip N. Ainslie

University of British Columbia, Centre for Heart, Lung and Vascular Health
*corresponding author: Anthony.bain2@gmail.com

Introduction
Cerebral blood flow (CBF) is markedly reduced during passive heat stress. Reductions in the partial pressure of arterial CO₂ (PaCO₂) consequent to an idiopathic hyperventilation, are responsible for the majority of the drop in CBF during passive hyperthermia [1]. However, some speculate that reductions in PaCO₂ may account for only ~50% of the reduction in CBF [2]. Furthermore, during exercise, it has been suggested that a thermoregulatory priority may also reduce CBF by shunting blood from the internal carotid artery (ICA) to the external carotid artery (ECA) [3]. However, whether a thermoregulatory priority may mediate changes in CBF during passive heat stress has not been explored. The purpose of this study was to examine the hypotheses that 1) reductions in PaCO₂ would attenuate blood flow to the anterior and posterior regions of the brain, and 2) a distribution of blood flow to the ECA from the ICA would further compromise blood flow to the anterior brain regions.

Methods
Ten healthy volunteers were passively heated in the supine position by perfusing 49°C water through a tube-lined suit until achieving a steady state esophageal temperature (Tₑₑ) of 2°C above resting. Measurement conditions included: 1) normothermic (baseline); 2) at +2°C Tₑₑ (hyperthermia), and 3) at +2°C Tₑₑ following clamping of PaCO₂ to baseline values by using an end-tidal forcing system (eucapnic hyperthermia). Blood flow of the vertebral artery (VA), ICA and ECA was measured (Duplex Ultrasound); blood velocity of the middle and posterior cerebral artery (MCAv and PCAv; via transcranial Doppler) and skin blood velocity of the cheek (SBVC) was also measured (Doppler velocimetry).

Results and Discussion
End-tidal PCO₂ was reduced (-6±2mmHg), as well as blood flow in the ICA (-14±18%) and VA (-30±20%), and MCAv (-20±10%) and PCAv (20±11%) during hyperthermia compared to baseline (p<0.05). During eucapnic hyperthermia, restoration of blood flow in the ICA (108±11%) and VA (101±15%), and of MCAv (94±9%) and PCAv (93±11%) occurred. Blood flow in the ECA and SBVC was increased (+223±132% and +622±619% respectively) during hyperthermia compared to baseline (p<0.05); however, despite restoration of ICA, no changes in ECA blood flow or SBVC were observed during eucapnia hyperthermia compared to hyperthermia. These data indicate that during passive hyperthermia, the majority of blood flow decline in both the anterior and posterior brain regions were explained by reductions in PaCO₂. Meanwhile, rises in ECA and SBVC did not influence ICA blood flow, and therefore did not compromise blood supply to the anterior brain regions.

References
Time course of force production and voluntary activation during active and passive hyperthermia using motor cortical stimulation

Julien D. Périard¹*, Sébastien Racinais¹, Wade Knez², Ryan Christian³, Martin W. Thompson²

¹ Aspetar - Qatar Orthopaedic and Sports Medicine Hospital, Research and Education Centre, Doha, Qatar
² The University of Sydney, Discipline of Exercise and Sport Science, Lidcombe, Australia

*corresponding author: julien.periard@aspetar.com

Introduction

The development of fatigue during a sustained (≥10 s) maximal voluntary isometric contraction (MVC) is characterised by a progressive decline in motoneurone firing rates and a slowing of contractile function [1]. Part of the loss in force production capacity has also been suggested to originate from a reduction in central neural drive to exercising muscles which characterizes so-called central fatigue. During normothermia, central fatigue can account for 20-30% of the loss in force production observed in a prolonged MVC [2]. During active and passive hyperthermia, central fatigue has been suggested to exacerbate the loss of force [3, 4]. However, it appears that the increased rate of force loss observed following active (i.e. exercise-induced) hyperthermia stems not from additional central fatigue, but from peripheral alterations originating in response to a rise in core temperature and prior contractile activity [5].

Interestingly, during passive hyperthermia (38.5°C) peak relaxation rate remains faster when performing a sustained MVC than in normothermia [6]. During a brief MVC, motoneurone firing rates can be transiently increased to compensate for this hyperthermic increase in contractile velocity. However during a sustained MVC it appears that these high firing rates cannot be maintained, despite the availability of additional cortical output. As a result, central fatigue may increase in response to a failure in central neural drive to compensate for temperature-induced adjustments in skeletal muscle contractile state [6]. This raises an interesting question as to the mechanism of failure within passively heated muscles, as the modified contractile condition may exceed the centrally mediated rate of activation.

The aim of this study was to isolate the progressive development of active and passive hyperthermia in adjusting peripheral contractile state and mediating central fatigue, measured via transcranial magnetic stimulation (TMS). It was hypothesized that hyperthermia-induced changes in contractile function would increase central fatigue during passive hyperthermia, while exercise-induced peripheral adjustments would attenuate this response (i.e. reduce peak relaxation rate). The attenuation could occur in response to an exercise-induced acidification of the contractile milieu, as well as changes in sarcoplasmic reticulum Ca²⁺ handling (i.e. release and re-uptake) and cross-bridge function (i.e. Ca²⁺ dissociation from troponin).

Methods

Nine active male subjects participated in this study. Their age, body mass, height and VO₂max were 33.3 ± 8.0 years, 79.1 ± 13.9 kg, 180.7 ± 8.5 cm and 4.4 ± 0.6 L·min⁻¹. Written consent was obtained and the study was performed according to the Declaration of Helsinki, following approval by the Local Ethics Committee.

Motor cortical activation was assessed at graded increases in core temperature (resting baseline, 38.5°C and 39.5°C) on separate days during exercise (ExH) and passive (PaH) hyperthermia (Figure 1). ExH was induced by cycling at 60% VO₂max in 38°C and 45% relative (RH) conditions. PaH was induced by sitting upright in a 48°C and 45% RH environment. Baseline cortical output was
assessed in temperate conditions (20°C and 50% RH), whereas the hyperthermic assessments during ExH and PaH were performed in standardised conditions of 44°C and 45% RH. During all contractions subjects were seated upright with the hips and knees flexed at 90°. Straps placed across the chest and hips secured the subjects in the chair and prevented extraneous movements. Voluntary activation was quantified using evoked single twitches using TMS: central activation (%) = [1 - (superimposed twitch / resting twitch)] x 100. To quantify cortical activation the resting twitch was estimated from the regression equation of twitches evoked during 50, 75 and 100% contractions. The y-intercept was taken as the amplitude of the resting twitch. The peak rate of relaxation during the sustained MVC was calculated immediately following motor cortex stimulation by measuring the steepest rate of decline in force during the silent period [7]. The rate was normalized to the total force evoked prior to the silent period. During all MVCs subjects were verbally encouraged to sustain maximal force and further aided by a visual display of force production. Core (rectal: T<sub>re</sub>), skin (T<sub>sk</sub>) and muscle (vastus lateralis: T<sub>mu</sub>) temperatures were recorded continuously. Body mass changes, corrected for ad libitum fluid ingestion and sweat trapped in clothing, were evaluated at the conclusion of each trial. Statistical analyses were conducted using repeated-measures ANOVA and Student’s paired t-tests, with a Bonferroni correction where appropriate. Data in the figures are presented as the mean ± SD with an α of 0.05.

**Figure 1.** Experimental protocol performed at baseline core temperature, 38.5°C and 39.5°C during ExH and PaH.

**Results**

Baseline T<sub>re</sub> (37.0 ± 0.3 and 37.0 ± 0.4°C), T<sub>sk</sub> (30.6 ± 1.1 and 30.6 ± 1.1°C) and T<sub>mu</sub> (34.2 ± 0.7 and 34.2 ± 1.0°C) were similar between ExH and PaH conditions. On reaching the first hyperthermic stimulation interval no difference was noted between T<sub>re</sub> (38.5 ± 0.2 and 38.6 ± 0.2°C) and T<sub>mu</sub> (38.7 ± 0.7 and 38.4 ± 0.2°C) in the ExH (48.1 ± 16.6 min) and PaH (50.7 min ± 13.9 min) trials. However, T<sub>sk</sub> was significantly lower in the ExH (37.8 ± 0.7°C) trial compared with PaH (39.9 ± 0.5°C) (p<0.05). At the final stimulation interval, T<sub>re</sub> (39.4 ± 0.1 and 39.5 ± 0.2°C) and T<sub>mu</sub> (39.3 ± 0.4 and 39.3 ± 0.4°C) remained similar in the ExH (93.4 ± 27.5 min) and PaH (104.4 ± 16.9 min) trials. As with the previous interval, T<sub>sk</sub> was significantly lower in the ExH (38.3 ± 0.7°C) trial compared with PaH (40.5 ± 0.7°C; p<0.05). Percent body mass losses were similar between conditions, remaining <2%.

Force production decreased throughout all MVCs (Table 1). ExH and PaH exacerbated the decrease in force production. Following ExH, the mean decline in force across 30 s was 7.5% greater relative to its normothermic baseline, than occurred in the PaH trial. Voluntary activation results are
presented in Figure 2. These indicate that both ExH and PaH induced a significant decrease in voluntary activation relative to baseline ($p<0.05$). However, the decline was not exacerbated by the development of hyperthermia, despite a trend towards lower levels of activation at the 39.5°C interval in both conditions. In addition, voluntary activation did not progressively decrease during each sustained MVC. Figure 3 displays the peak rates of relaxation during ExH and PaH. Faster relaxation rates were observed during the hyperthermic phase of each trial. While no significant difference in peak relaxation rate was noted between ExH and PaH, peak relaxation rate tended to remain faster during PaH, especially the 39.5°C interval ($p=0.058$).

**Table 1.** Force production at the three stimulation intervals during the 30-s MVC.

<table>
<thead>
<tr>
<th>Condition / Interval</th>
<th>2 s</th>
<th>15 s</th>
<th>28 s</th>
<th>2 s</th>
<th>15 s</th>
<th>28 s</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td>641 ± 168</td>
<td>534 ± 193†</td>
<td>495 ± 143†</td>
<td>645 ± 169</td>
<td>527 ± 134†</td>
<td>489 ± 127†</td>
</tr>
<tr>
<td><strong>38.5°C</strong></td>
<td>608 ± 187</td>
<td>478 ± 160*†</td>
<td>418 ± 107*†</td>
<td>636 ± 163†</td>
<td>508 ± 153†</td>
<td>482 ± 136†</td>
</tr>
<tr>
<td><strong>39.5°C</strong></td>
<td>588 ± 182*</td>
<td>460 ± 153*†</td>
<td>392 ± 105*†</td>
<td>603 ± 149*†</td>
<td>497 ± 153†</td>
<td>452 ± 138*†</td>
</tr>
</tbody>
</table>

*Significantly lower than Baseline, $p<0.05$. †Significantly lower than 2-s interval, $p<0.05$.

**Figure 2.** Voluntary activation percent, calculated using motor cortex stimulation during the 30-s MVC. *Significant main effect between Baseline and 38.5°C and 39.5°C measures, $p<0.05$. 
Figure 3. Peak relaxation rates measured during the silent period following motor cortex stimulation during the 30-s MVC. *Significantly faster than Baseline, \( p < 0.01 \). † Significantly slower than the 2 and 15-s stimulation intervals, \( p < 0.01 \).

Conclusions
The present results confirm that increasing \( T_{re} \) via ExH and PaH reduces force production capacity and induces central fatigue. The data further confirm that the loss of force is exacerbated by exercise despite similar \( T_{mu} \). The novel finding of this study is that the peak rate of relaxation during a sustained MVC remains elevated in both ExH and PaH conditions. Although our hypothesis that exercise-induced adjustments at the skeletal muscle level (i.e. peripheral fatigue) would attenuate the increased rate of relaxation did not reach statistical significance, a strong trend towards a slowing of peak relaxation rate was observed relative to PaH.

References
Improvement in force / EMG relationship limits the force loss induced by hyperthermia

Sébastien Racinais
Aspetar - Qatar Orthopaedic and Sports Medicine Hospital, Doha, Qatar
Corresponding author: sebastien.racinais@aspetar.com

Introduction
As compared to a temperate environment, self-paced exercise intensity might be reduced in hot ambient conditions in association with a decrease in electromyographic (EMG) activity [1,2,3]. However, it is difficult to interpret EMG data during dynamic exercise at different intensities as the decrement in EMG activity could be linked to a decrease in intensity itself, rather than neurophysiological failure [4]. In addition, interpretation of EMG data in different environmental conditions might be biased by a modification of the torque / EMG relationship. Therefore, the aim of this study was to investigate the effects of hyperthermia on the EMG response during isolated isometric contractions at different intensities. These contractions allow for a more accurate interpretation and analyses of the EMG response. We hypothesized that a modification of the torque / EMG relationship at elevated temperature would be partly responsible for a modification in torque output, either in conjunction or in opposition of the changes in EMG activity.

Methods
Fourteen participants (7 males and 7 females, aged 29 to 34 yr, weight 67.8 ±10.6 kg and height 174 ±4 cm) completed the study after providing written informed consent. Participants underwent two experimental trials in a counter-balanced order in temperate (CON, room set at 24°C and 35% RH) and hot (HOT, room set at 50°C and 35% RH) ambient conditions. Each trial included a controlled activity (10 min of walk on a treadmill at 4 km·h⁻¹), a resting period of ~45-60 min in a seated position (corresponding to the time needed to reach a core temperature of 39°C in the HOT trial) and a neurophysiological assessment. The assessment included isometric maximal voluntary contractions (MVC, with strong verbal encouragement) of the plantar flexors (PF) followed by submaximal contractions at 50%, 25% and 75% of MVC with EMG recordings.

Participants performed three sets of contraction (MVC followed by submaximal contractions at 50%, 25% and 75% of MVC) that were thereafter averaged for analyses. The torque was recorded over a 1-s plateau via a custom-made dynamometric pedal. Bipolar EMG signals were recorded over the muscle belly of the Soleus and monopolar EMG signals were recorded on the Gastrocnemius Medialis (GM). Myoelectric signals were amplified (gain = 1000 for bipolar and 200 for monopolar), filtered (30-1000 Hz) and recorded at a sampling frequency of 5000 Hz. During the MVCs, doublet (20 Hz) percutaneous stimulations (400 V, rectangular pulse of 1 ms) were delivered over the tibial nerve and voluntary activation (VA) was estimated as: VA (%) = (1-Superimposed Twitch/Potentiated Twitch) x 100. Rectal (probe inserted 15 cm beyond the anal sphincter) and skin (Soleus and GM) temperatures were monitored.

Data were compared between conditions using repeated-measure ANOVA. The level of statistical significance was set at p<0.05, and data are presented as mean ±SD.

Results
Core (39.0 ±0.2°C vs. 37.3 ±0.4°C) and skin (39.8 ±0.8°C vs. 29.5 ±0.4°C) temperatures were significantly higher during HOT than CON (both p<0.001). Heart rate was also higher in HOT than CON (102 ±13 vs. 60 ±11 bpm, p<0.001). There was no sign of dehydration in any of the pre- or
post-experimental recordings (Urine specific gravity: \(~1.013 \pm 0.006 \text{ g ml}^{-1}\)) and body weight did not change significantly during any trial (-0.1 ±0.3 kg in CON, -0.2 ±0.9 kg in HOT).

Maximum voluntary torque was significantly lower in HOT (102.3 ±40.8 Nm) than CON (125.7 ±46.0 Nm) \((p<0.001)\). VA was reduced in hot (91 ±10 \%) compared to CON (96 ±8 \%), as was the EMG activity of the Soleus and GM \((p<0.05)\). The changes in maximal torque were correlated to the changes in VA \((r=0.61)\).

When participants were required to produce a range of submaximal and maximal contractions, the torque values were correlated to the EMG activity of both the soleus and GM \((0.97 \leq r \leq 1.00)\). The slope of this relationship was significantly higher in HOT than CON for both the soleus \((0.77 \pm0.20 \text{ vs. } 0.58 \pm0.28 \text{ Nm} \cdot \text{µV}^{-1}\)) and the GM \((0.35 \pm0.11 \text{ vs. } 0.29 \pm0.15 \text{ Nm} \cdot \text{µV}^{-1}\)). Consequently, a higher torque was produced in HOT than in CON for a given EMG activity (Fig. 1).

**Figure 1. Relation between torque and EMG activity.** All values are normalized in percentage of the maximal values in temperate conditions. **Left panel:** Individual values during contraction ranging from 25\% to 100\% of MVC in the heat \((50°C, 35\% \text{ RH})\). Note that most values are above identity line. **Right panel:** Average relation between torque and EMG in temperate (plain line) and hot (dashed line) environments. Note that the decrease in torque \((C)\) is a function of the decrease in EMG activity \((A)\) minus the improvement in contractile properties \((B)\).

**Discussion**

These data show a decrement in maximum voluntary torque is associated with a decrease in voluntary activation confirming that passive hyperthermia reduces drive to human skeletal muscle \([5,6,7,8]\).

We hypothesized that a modification of the torque / EMG relationship at elevated temperature would also be partly responsible for a modification in torque output. Our data showed that passive hyperthermia effects the slope of the torque / EMG relationship (Fig. 1). However, this modification did not impair, but instead improved torque production. Indeed, more torque was produced for a similar neural drive in hot ambient conditions when core temperature was \(~39°C\), compared with temperate conditions at a core temperature of 37.3°C (Fig. 1).

The decrement in maximal force during passive hyperthermia therefore represents the resultant of a decrease in muscle activation and an improvement in neuromuscular efficiency.
Conclusion
The improvement in torque / EMG relationship with temperature increase limits the force loss induced by hyperthermia.

References
Effectiveness in cognitive task performance under time pressure and elevated ambient temperature

Peter Bröde1*, Gerhard Rinkenauer4, Wolfgang Jaschinski4, Martin Schütte2
1 Leibniz Research Centre for Working Environment and Human Factors (IfADo), Dortmund, Germany
2 Federal Institute for Occupational Safety and Health (BAuA), Berlin, Germany
*corresponding author: broede@ifado.de

Introduction
Climate change may not only affect the productivity of physical work performed outdoors [1], but may also, due to increased room temperatures, potentially reduce the efficiency of mental office work [2]. Several mechanisms causing reduced cognitive task performance in warm environments are discussed, e.g. thermo-physiological strain like body heat storage or dehydration [3,4], as well as psychological strain responses like distraction due to thermal discomfort [5] or a reduced level of arousal in the heat [6].

Concerning the temperature dependency of mental performance reduction, there are conflicting results in the literature with studies showing stable performance in cognitive tasks over a wide range of temperatures with a reduction only under extreme heat on the one hand [3,7], and with reports of heavily reduced productivity in office work at temperatures just outside the comfort zone on the other hand [6,8]. This heterogeneity may be partly attributable to inter-individual differences and to the low degree of comparability and control on the type and difficulty of the tasks under study [9].

This laboratory study therefore investigated the influence of elevated room temperature on processes related to target detection and decision making using functional tests that could be individually adjusted in their level of difficulty by imposing time constraints [10].

Methods
Design and procedure
All participants gave informed consent prior to the experiments in the climatic chambers at IfADo.

Figure 1 illustrates the procedure and the measurements which conformed to the principles of the Declaration of Helsinki and were approved by the local ethics committee.

Following a two-hour adaptation phase at 23 °C, three groups of eight young male participants each (18 to 35 yrs of age) were randomly assigned to one of three experimental conditions and completed a 4-h testing period under elevated air temperatures of 27, 31 and 35 °C, respectively. Another group of ten males served as controls working at 23 °C for the whole time. The clothing was standardized comprising an aramid coverall worn over a long-sleeved polypropylene shirt, cotton briefs and socks, and sport shoes with a total thermal insulation of 0.6 clo (1 clo = 0.155 K-m²/W) as determined by a thermal manikin. Mean radiant temperature equalled air temperature and water vapour pressure was 1.1 kPa in all conditions. Air velocity was 0.2 m/s at 23 °C and 0.3 m/s otherwise.

Heart rates were determined from the electrocardiogram and skin temperatures at five sites as well as humidity and temperature of the skin–clothing layer at two body sites were recorded continuously. Core temperature was indicated by tympanic temperature readings from an infrared thermometer at the start of the experiments and at 30 min intervals throughout the testing period. Subjective strain was repeatedly assessed using standardized scales, e.g. thermal sensation votes on a seven point scale ranging from -3:“cold” over 0:“neutral” to +3:“hot” [11].
In the flanker task (FT), participants had to press the left or right button of a keypad depending on the central letter of a five-letter horizontal array (HHHHH, HHSHH, SSSSS, or SHSSH) presented on a computer screen. In the lexical decision task (LDT), they had to respond corresponding to the gender of German nouns (male or female). The frequency of targets requiring responses by the left and right button was balanced within each block of 80 trials, and the mapping of the test stimuli to the response buttons was balanced across participants within each of the four groups. For each trial reaction time (RT) and correctness of the response were recorded. After each response participants received feedback on correctness and on speed by comparing actual RT to a critical value (RT\textsubscript{crit}). RT\textsubscript{crit} was deduced as percentiles from the RT distribution obtained for each individual at the end of the adaptation phase (pre). By taking as RT\textsubscript{crit} the 95\textsuperscript{th}, 64\textsuperscript{th} and 32\textsuperscript{nd} RT percentile, we defined three conditions of low, medium and high time pressure, respectively. Participants were each paid 60 €. They could earn up to one third of that fixed amount as additional bonus depending on their task performance, which was assessed by effectiveness scores.

From the total number $n$ of test stimuli and the number $ct$ of correct responses given in time ($RT<RT\text{crit}$), we calculated effectiveness scores $Eff$ corrected for guessing probability $P_g$ as

$$Eff = [(ct/n)-P_g]/[1-P_g]$$

\textit{Figure 1.} Procedure and measurements of the experimental study. The present analysis focussed on the tests under time pressure after short (yellow) and longer (light red) exposure duration.

\textbf{Cognitive tasks}

A text correction task and two different types of two-alternative choice reaction tasks were applied. The latter, outlined in detail by [10], were carried out at the beginning and end of the testing period and are the focus of the present analysis (Figure 1).
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$P_g$ was set to 0.5 for guessing the correct response in the two-alternative choice reaction tasks, with "$|\geq 0$" indicating that values $Eff<0$ were zeroed so that effectiveness could not become negative and the participants could not earn minus points for the bonus calculation.

**Data analysis and statistics**

In separate analyses for the FT and LDT data and by fitting generalised linear mixed models (GLIMM) using SAS® 9.2 [12], we analysed the influence of the between-subject factor ambient temperature (T) and the two within-subject factors time pressure (TP) and exposure duration (D) on the effectiveness scores, for which a beta-distribution was assumed. Analogous analyses were also carried out separately for the three time pressure conditions.

**Results and Discussion**

The ANOVA shown in Table 1 revealed that effectiveness of both the FT and LDT was influenced by time pressure in the expected way with effectiveness decreasing with increasing time pressure (Figure 2). LDT effectiveness was affected by exposure duration, but this effect depended on time pressure as indicated by the significant TP*D interaction. With low time pressure, effectiveness was 3 percentage points lower at the end of exposure compared to the beginning, with medium time pressure it remained unchanged and with high time pressure it was increased by 10 percentage points at the end.

In Table 1 a statistical trend ($p=0.07$) was observed for the TP*T interaction on LDT effectiveness. This interaction of temperature and time pressure is visualised for both FT and LDT in Figure 2. Detailed analyses carried out separately for the time pressure conditions revealed significant effect of ambient temperature ($p<0.05$) only for the conditions with high time pressure. However, the nature of the temperature effect varied with task type. Whereas effectiveness decreased with increasing ambient temperature for LDT, it was lower for the control condition compared to 27 °C and 35 °C for FT.

Significant correlation coefficients ($r$) between effectiveness and physiological or subjective strain parameters were only found for the LDT under high time pressure indicating decreased effectiveness with increasing thermal sensation vote ($r=-0.36$, $p=0.03$).
Table 1. ANOVA table from GLIMM models fitted to the effectiveness scores from the flanker (FT) and lexical decision tasks (LDT), respectively.

<table>
<thead>
<tr>
<th>Factor</th>
<th>ndf^a</th>
<th>ddf^a</th>
<th>FT</th>
<th>p</th>
<th>LDT</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>3</td>
<td>30</td>
<td>1.33</td>
<td>0.2832</td>
<td>0.66</td>
<td>0.5830</td>
</tr>
<tr>
<td>Duration</td>
<td>1</td>
<td>30</td>
<td>0.48</td>
<td>0.4946</td>
<td>5.04</td>
<td>0.0322</td>
</tr>
<tr>
<td>T*D</td>
<td>3</td>
<td>30</td>
<td>0.17</td>
<td>0.9182</td>
<td>0.55</td>
<td>0.6549</td>
</tr>
<tr>
<td>Time Pressure</td>
<td>2</td>
<td>60</td>
<td>145.51</td>
<td>&lt;.0001</td>
<td>272.63</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>TP*T</td>
<td>6</td>
<td>60</td>
<td>1.30</td>
<td>0.2690</td>
<td>2.04</td>
<td>0.0739</td>
</tr>
<tr>
<td>TP*D</td>
<td>2</td>
<td>60</td>
<td>0.87</td>
<td>0.4238</td>
<td>6.03</td>
<td>0.0041</td>
</tr>
<tr>
<td>TP<em>T</em>D</td>
<td>6</td>
<td>60</td>
<td>0.40</td>
<td>0.8745</td>
<td>1.37</td>
<td>0.2430</td>
</tr>
</tbody>
</table>

^a Numerator (ndf) and denominator (ddf) degrees of freedom, respectively.

Figure 2. Interaction of room temperature and time pressure conditions on means ± SE of the effectiveness scores (Eq. 1) as estimated by GLIMM models, which were separately fitted to the data from the flanker task (FT) and lexical decision task (LDT), respectively.

Conclusions
The chosen approach [10] allowed for individually adjusted levels of task difficulty showing that the effect of increased ambient temperature on the effectiveness of cognitive task performance was modified by task type and time pressure condition. Further analyses on the correlation of performance with physiological or psychological strain still have to be completed. However, the results obtained so far suggest that generalizing assertions on reduced mental performance under elevated temperatures [6] should be viewed with caution and that potential modifying factors, amongst others time pressure, deserve consideration.

References
Efficacy of a normobaric hypoxic training programme for the prevention of AMS

Gaizka Mejuto1*, José Francisco Aramendi2, Aitziber García2, Juan Carlos Samaniego2, Xabier Erro3, José Ignacio Empananza4
1 Human Performance Laboratory, Department of Physical Education and Sport Sciences, University of the Basque Country, Vitoria-Gasteiz. Basque Country-Spain.
2 Osasun Kirol Sport Clinic. Hondarribia, Basque Country-Spain.
4 Epidemiology Unit. Donostia Hospital. CASPE-CIBERESP, Donostia-San Sebastian Basque Country-Spain.
*corresponding author: gaizka.mejuto@ehu.es

Introduction
Acute Mountain Sickness (AMS) is a pathology affecting thousands of climbers every year. It is well known that rapid ascents from low, to moderate or high altitude (and thus the sudden exposures to a lower barometric pressure) make AMS symptoms appear as consequence of a poor acclimatisation. The fall in barometric pressure causes a corresponding drop in the partial pressure of oxygen, resulting in hypobaric hypoxia. The process of acclimatisation involves a series of adjustments by the body to meet the challenge of hypoxemia. The optimal acclimatisation process takes from days to weeks. Lowlanders vary in their ability to acclimatisate (independently of their fitness level, age or gender), with a few adjusting quickly, without discomfort, whereas some develop severe AMS and are unable to tolerate any physical activity at altitude. However, individual susceptibility to AMS, rate of ascent and pre-acclimatisation could influence the development of AMS [1]. It is also important to point out that physical exertion at altitude increases the severity of AMS, likely because of further reductions in arterial oxygen saturation (SaO₂). The nature of AMS is potentially fatal and if is not properly treated, it can lead to pulmonary and/or cerebral oedema. The first symptoms are usually described as headaches followed by gastrointestinal disorders, fatigue, difficulty breathing normally and disturbed sleep. These symptoms and their severity can be ranked and treated according to the Lake Louis Score (LLS) [2].

According to the guidelines of the Center for Evidence-based Medicine, Imray et al [1] summarised the following preventive strategies based on the first two levels of evidence (I, II): slow ascent (300 m·d<sup>-1</sup> > 3,000 m) (I,II); avoid exercise, especially right after arrival (II); hydrate adequately (II); oxygen supplementation (2 L·min<sup>-1</sup>) (II); Acetazolamide (250 mg·d<sup>-1</sup> daily) (I); Dexamethasone (8 mg·d<sup>-1</sup>) (I); Medroxyprogesterone (60 mg/d) (II); Theophylline (375 mg BD) (I) and Sumatriptan (50 mg once) (II). Several studies have tried to elucidate whether AMS symptoms and their severity can be reduced and ascent rate improved by acclimatisation strategies in the weeks preceding altitude exposure. This way of preparation for expeditions is becoming popular among climbers. Therefore, in a randomised, single blind, placebo-controlled trial we aimed to test the efficacy of a normobaric hypoxic training programme on improving the symptoms of AMS during expeditions to high altitude.

Methods
All the procedures were approved by the Ethical Committee of Donostia University Hospital (Donostia, Gipuzkoa. Basque Country – Spain). Eighteen healthy participants (11 male and 7 female, 49.1 ± 10.7 yr) performed 4-12 sessions (median 6) consisting of 45 min walking on a treadmill at 80% HR<sub>max</sub> and at 15% grade, and carrying a backpack weighing 20% of their body mass. During the training session, SaO₂, HR and treadmill velocity (V) were monitored in order to perform the 45 min of walking at the target HR for each individual. Immediately after completion
of the walk, blood lactate samples were taken and the rate of perceived exertion (RPE) recorded. The final training session was planned as close as possible to the departure date to altitude and elapsed time between sessions was at least 48 h. While exercising they were given a normobaric air mixture of 11.2% O₂ (corresponding to an altitude of 3,000 m) to breathe on the 1st day; the equivalent of 4,000 m on the 2nd day; and 5,000 m on the following days until completion of the training programme (HP group). A further eighteen healthy participants (11 male and 7 female, 42.16 ± 16 yr) performed the same training programme protocol under normoxic (masked) conditions (CON group). All participants were lowlanders and had not been exposed to altitudes higher than 3,000 m in the 6 months prior to the training programme. The allocation to the groups was concealed by means of opaque, sealed, consecutively numbered envelopes. All subjects performed an incremental exercise test until volitional exhaustion on a bicycle ergometer to assess the 80% of the HRmax.

At altitude, AMS was assessed using the Lake Louise Score system (LLSA, LLCL, EV) and SaO₂ was measured on arrival, after 6 and 12 h, and the following 3 consecutive mornings above 3,000 m by mountain guides (blinded to participant groupings). Clinical assessment of AMS was set as headache symptom + > 3 points score in the LLS. Participants were instructed not to take any drugs which can attenuate AMS (such as Acetazolamide, Dexamethasone or others) from 6 months prior to the training programme until their return from the expedition.

Table 1. SaO₂ and LLS at altitude in both groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>6 h</th>
<th>12 h</th>
<th>1 d</th>
<th>2 d</th>
<th>3 d</th>
</tr>
</thead>
<tbody>
<tr>
<td>SaO₂ (%)</td>
<td>HP</td>
<td>86.8 ± 4.3</td>
<td>85.8 ± 6.3</td>
<td>87.6 ± 3.4</td>
<td>85.5 ± 6.6</td>
<td>85.6 ± 5.0</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>90.7 ± 4.5</td>
<td>87.5 ± 5.1</td>
<td>85.6 ± 5.6</td>
<td>85.8 ± 5.1</td>
<td>85.3 ± 6.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LLSA</td>
<td>HP</td>
<td>0.75 ± 1.1</td>
<td>0.78 ± 1.1</td>
<td>1.00 ± 0.8</td>
<td>2.64 ± 3.2</td>
<td>1.50 ± 1.8</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>0.15 ± 0.6</td>
<td>0.27 ± 0.6</td>
<td>1.60 ± 2.3</td>
<td>2.61 ± 2.4</td>
<td>2.75 ± 2.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LLCL</td>
<td>HP</td>
<td>0.00 ± 0.5</td>
<td>0.00 ± 0.0</td>
<td>0.00 ± 0.0</td>
<td>0.00 ± 0.0</td>
<td>0.00 ± 0.0</td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td>0.00 ± 0.5</td>
<td>0.00 ± 0.0</td>
<td>0.00 ± 0.0</td>
<td>0.00 ± 0.0</td>
<td>0.00 ± 0.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EV</td>
<td>HP</td>
<td></td>
<td>3.53 ± 3.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CON</td>
<td></td>
<td>4.16 ± 3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SaO₂: arterial oxygen saturation, LLSA: Lake Louise Self Questionnaire, LLCL: Lake Louise Clinical Score, EV: Lake Louise Score Evaluation, Ar: at arrival to an altitude > 3,000 m, 6 h: after 6 hours of arrival to an altitude > 3,000 m (idem for 12 h: 12 hours, 1 d: 1 day, 2 d: 2 days, 3 d: 3 days). (NS) no significant differences between groups.

Results and Discussion
16 expeditions to an altitude of 4,340 ± 364 m took part in the present study. 8 participants in each group presented AMS symptoms (RR=1.00; CI of 95% 0.48 to 2.08). SaO₂, LLSA, LLCLS and EV showed no difference between groups at altitude (p>0.05; NS) (See Table 1). LLS and SaO₂ were found to be inversely correlated. None of the observed correlations had a predictive power. However, as participants completed more hypoxic training sessions (HP group), the average SaO₂ maintained was higher (See figure 1).
Figure 1. SaO₂ evolution throughout training program sessions in both groups.

Figure 2. AMS clinical assessment in both groups after proposed training programme.

This single blind placebo-controlled study showed that a training program consisting of 4-12 sessions at a simulated altitude of 5,000 m is not effective as a preventive strategy against AMS. A previous study used a different acclimatisation training programme (60 min cycling (at 60% VO₂ max) 3 times a week for 3 weeks at 2,500, 3,000 m and 3,500 m) [3]. The main objective of this study was to evaluate the efficacy of the programme to ascend rapidly to an altitude of 4,459 m and authors concluded that their effects on performance during ascent and ventilatory acclimatisation strategy could not be demonstrated. In a 26-male population, double-blind placebo study by Wille et al [4] the intervention was based on 7 exposures of 1 h to 4,500 m in normobaric hypoxia, followed by longer exposures to evaluate the incidence and severity of the
AMS (8 h at 5,300 m before and after cessation of 1 h protocol). The result was that AMS incidence appeared to show no difference between groups, but the severity of the symptoms was reduced.

However, the hypoxic training programme in the present study appeared to be effective at increasing the SaO2 as the number of sessions increased (see Figure 1), even though it did not statistically reduce the AMS incidence.

In summary, this hypoxic training programme provided no benefit in preventing AMS, but SaO2 appeared to be higher as the hypoxic training sessions increased within HP group.

References
Alterations in behavioural thermoregulation after 10 days of simulated high altitude and confinement

Shawnda A. Morrison1*, Urša Ciuha2,3, Daniela Zavec-Pavlinic2, Igor B. Mekjavič1
1Dept of Automation, Biocybernetics and Robotics, Jozef Stefan Institute, Ljubljana, Slovenia
2Biomed d.o.o., Stari Trg 4, Ljubljana, Slovenia
3Jozef Stefan International Postgraduate School, Ljubljana, Slovenia
*corresponding author: shawnda.morrison@ijs.si

Introduction
Acute hypoxia-induced alterations in cutaneous peripheral blood flow can alter the threshold for sensation of cutaneous thermal inputs. However, it is not known whether these changes will persist over chronic exposure to simulated high-altitude, or whether one’s behavioural thermoregulation will ultimately affect their thermal comfort zone.

Methods
Sixteen active, healthy men (age: 25 ± 3 y, height: 1.79 ± 0.55 m, weight: 74 ± 8 kg, VO2peak: 41 ± 5 mL·kg⁻¹·min⁻¹) were accommodated on a dedicated floor of the Slovenian Olympic Sport Centre (at altitude: 940 m). Participants were confined to one floor for 10-d in which all activities (eating, drinking, hygiene, exercise, sleep) were conducted at a simulated high-altitude of 4000 m (FIO₂=0.14). In random order, eight were assigned an exercise intervention of: 2 x 60 min cycle exercise/ d (intensity: heart rate at 50% of their hypoxia-specific peak power output (EX)); the remainder did not complete any daily exercise (CON). Behavioural thermoregulation was assessed after acute, 24-h exposure to hypoxia (Day 2), and again on ‘Day 10’ by manipulating the water temperature circulating through a water-perfused suit. First, cool water (27°C) circulated for 5 min, after which participants could determine the direction of water temperature change (either hotter or colder) at will for the next 60 min. Weighted mean skin temperature (Tsk, 6 sites), skin-surface temperature gradients (2 sites: forearm-fingertip, calf-toe) and frequency of volitional temperature change were recorded.

Results and Discussion
There were no significant differences by group or hypoxia exposure for (pooled group results): baseline mean Tsk (Day 2: 32.9±0.70 v Day 10: 33.0±0.8°C), after 5-min in the suit (33.1±0.7 v 33.1±0.8°C), or the time-to-peak Tsk (50±11 v 47±17 min). However, the EX group maintained higher end mean Tsk on the acute v chronic hypoxia exposure (Day 2: 35±1.1 v Day 10: 34.3±0.5°C; p=0.049). This effect was not observed in the control group (35.1±0.9 v 34.7±1.5°C; p=0.214). The number of volitional temperature changes were not different (pooled data Day 2: 20±8 v Day 10: 19± 7 clicks; p=0.435), nor the breadth of the thermal comfort zone, which remained stable between acute v chronic exposures (Day2: 7.2±4.2 v Day 10: 10.2±7.5°C), irrespective of group.

Conclusions
Exposure to hypoxia may slightly attenuate the behavioural regulation of skin temperature. At this simulated level of hypoxia (4000 m), the differences would not necessarily be life threatening, however, if this effect is exacerbated at higher altitudes, it would mean that individuals could be at higher risk of hypothermia, since they would not be attempting to maintain higher skin temperatures through traditional behavioural mechanisms.
Haematological responses over 18 years in an elite climber - Follow up study.

Gaizka Mejuto1*, Julio Calleja-González1,2, Josean Lekue2, José Ignacio Emparanza3, Nicolás Terrados4

1 Laboratory of analysis of Sport Performance, Sport and Physical Education Department, Faculty of Sport Sciences, University of the Basque Country, Spain.
2 Sport Performance Center, Culture Department, Basque Government, Spain.
3 Epidemiology Unit. Donostia Hospital. CASPE-CIBERESP, San Sebastian, Spain.
4 Regional Unit of Sport Medicine- Avilés City-Council Foundation and Functional Biology Dept, University of Oviedo, Spain.
*corresponding author: gaizka.mejuto@ehu.es

Introduction

Extreme altitude climbing is considered one of the most challenging and physiologically stressing sport disciplines. Summiting the highest peaks on Earth “by fair means” (no bottled O2) can be achieved by only a few top level athletes. To the best of our knowledge, there are no follow up studies of these individuals and their responses to such demanding expeditions.

Methodology

This is a retrospective case study of a highly trained elite climber (22–41 yr, 187.0 ± 0.1 cm, 72.7 ± 1.0 kg, 70.8 ± 4.4 ml·kg⁻¹·min⁻¹). He was the 4th climber in alpine history to summit the 14 highest peaks without supplementary O2 and is the holder of several other records. Blood samples were collected in a sea level laboratory 7 ± 2 d before expedition (BEX) and 9 ± 5 d after expedition (AEX), over 18 yr of expeditions. During this study period, participant reached all the peaks over 8.000 m on Earth (2 of them twice). The rest of altitude exposures for BE and AE data were at least 7,100 m. Blood was analysed for red blood cells (RBC), haematocrit (Hct) and haemoglobin concentration ([Hb]). All test procedures were approved by Fadura-Getxo Sport Performance Center (Basque Government) Ethical Committee.

Results

All variables increased an average of 16.3% AEX compared to BEX during the period of study. BEX vs. AEX (Hct: BEX 41.9 ± 1.9 vs. AEX 49.2 ± 3.7%; RBC: BEX 4.62 ± 0.27 vs. AEX 5.40 ± 0.48 ·10¹²/L; [Hb]: BEX 14.6 ± 0.6 vs. AEX 16.8 ± 1.5 gm/dL) (p<0.01). A negative correlation (p<0.01) between AEX and the same variables over the time during 18 yr was also observed (RBC: r²=0.662; Hct: r²=0.487; [Hb]: r²=0.557).

Conclusion

Exposures to extreme altitudes (>7,000 m) lead to an increase in RBC, Hct and [Hb] in the present case. Interestingly, this haematological response to extreme hypobaric hypoxia is attenuated with repeat exposures over the years.
Effects of voluntary control of breathing on cerebral blood flow and ventilatory mechanics during passive heating

Yuta Hoshi1, Yasushi Honda3, Bun Tsuji1, Yosuke Sasaki1, Sakatoshi Ida3, Narihiko Kondo2, Takeshi Nishiyasu3*

1 Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan
2 Faculty of Human Development, Kobe University, Japan
3 Institute of Health and Sports Science, University of Tsukuba, Japan
*corresponding author: nisiyasu@taiiku.tsukuba.ac.jp

Introduction
During passive heating of resting humans, ventilation changes little as core temperature rises until the temperature reaches about 38°C. Above this threshold, ventilation increases linearly as core temperature rises [1, 2]. This hyperthermic hyperventilation causes a decrease in arterial CO2 pressure (PaCO2), resulting in reduced cerebral blood flow [3, 4]. Although hyperthermic hyperventilation occurs spontaneously, it is uncertain whether humans can voluntarily suppress the hyperventilation during passive heating, and if so, the reductions in PaCO2 and cerebral blood flow are attenuated by the suppression. In addition, we previously reported that hyperthermic hyperventilation at rest is attributable to increases in respiratory frequency and tidal volume [5], though ventilatory mechanics during hyperthermic hyperventilation and further during voluntary control of breathing are not yet understood. Therefore, the purpose of this study was to investigate (1) whether humans can voluntarily suppress hyperthermic hyperventilation at rest and (2) the effects of the voluntary control on end-tidal CO2 pressure (PETCO2) as an index of PaCO2, middle cerebral artery mean blood velocity (MCAVmean) as an index of cerebral blood flow and ventilatory mechanics.

Methods
Six healthy male students participated in this study. This study was performed according to the Declaration of Helsinki. Written, informed consent was obtained from all subjects. Subjects were passively heated using hot-water immersion (41°C) and a water-perfused suit until esophageal temperature (Tes) reached 39°C or the subjects could no longer tolerate the heating. Throughout the gradual increase in Tes from normothermia to hyperthermia up to 39°C, subjects breathed normally (normal breathing trial) or tried to control minute ventilation (via respiratory frequency timed with a metronome and target tidal volume values displayed on a monitor) to their levels of 10 min of heating (controlled breathing trial). During the experiment, Tes, skin temperatures, respiratory parameters, MCAVmean, expiratory reserved volume and work of breathing were measured.

Results and Discussion
To estimate the relationships between core temperature and ventilatory and cerebrovascular responses, minute ventilation (VE), PETCO2 and MCAVmean were plotted against Tes. Consistent with previous studies, a Tes threshold for increases in VE was observed at 38.0 ± 0.3°C in normal breathing, and VE increased linearly with rising Tes above the threshold, whereas controlled breathing attenuated the increased VE (VE at Tes 38.7°C: 27.0 ± 7.5 vs. 12.5 ± 1.7 L/min, P < 0.05). PETCO2 and MCAVmean in normal breathing decreased with rising Tes above the Tes threshold for hyperventilation, whereas controlled breathing attenuated the reductions in PETCO2 and MCAVmean (PETCO2 at Tes 38.7°C: 24.2 ± 5.4 vs. 39.0 ± 2.6 mmHg; MCAVmean at Tes 38.7°C: 43.8 ± 4.4 vs. 61.1 ± 7.6 cm/s, P < 0.05, respectively). These results indicate that humans can voluntarily suppress
hyperthermic hyperventilation during passive heating, and this suppression could benefit smaller changes in $\text{PaCO}_2$ and cerebral blood flow.

The result of ventilatory mechanics will be discussed at the conference.

References
Mild hypoxia and complex cognition

Stephen Legg¹*, Stephen Hill², Andrew Gilbey³, Zachary J. Schlader⁴, Aaron Raman⁴, Toby Mündel⁴

¹School of Management, Massey University, New Zealand
²School of Psychology, Massey University, New Zealand
³School of Aviation, Massey University, New Zealand
⁴School of Sport and Exercise, Massey University, New Zealand

*corresponding author: s.j.legg@massey.ac.nz

Introduction

Mild hypoxia, equivalent to a cabin altitude of 2438 m (8000 ft) and typically experienced by passengers and crew of pressurised commercial aircraft, does not generally affect tasks that involve well-learned cognitive, vigilance or perceptual-motor performance; but learning, novel and complex cognitive tasks that include multiple demands may be impaired [1,2]. The purpose of this study was to evaluate whether complex cognition, as assessed by multiple memory and reasoning, was impaired during mild hypoxia.

Methods

Using a single-blind, cross-over design in standard normobaric conditions (21 ± 1 °C, 756 ± 6 mm Hg), 25 male students (24 ± 4 y) breathed normoxic (FiO₂ = 0.206) or hypoxic air (FiO₂ = 0.143, equivalent to 2438m) for 2 h and performed at baseline, 30 and 90 minutes: a) a multiple memory task that assessed sentence judgement error, working memory span and prospective memory, and b) a complex logical reasoning task that assessed accuracy, response time and a reasoning quality index for easy (non-conflict valid), difficult (non-conflict invalid), fairly difficult (conflict valid) and very difficult (conflict invalid) syllogisms. Data were assessed using repeated-measures ANOVA.

Results and Discussion

Compared with normoxic air, hypoxia reduced SpO₂ from 97 ± 1% to 91 ± 2% with heart rate and P₂CO₂ similar between conditions. Interaction analyses showed that working memory performance (change from baseline) was poorer for hypoxia than normoxia at 90 minutes but not at 30 minutes (p=0.03), and that performance on difficult (conflict) reasoning syllogisms, but not easier (non-conflict) syllogisms, was poorer for mild hypoxia than normoxia after 90 minutes but not after 30 minutes (p=0.06).

In conclusion, mild hypoxia can impair working memory and may impair complex logical reasoning that involves more difficult conflicts. In an industry such as aviation, these findings indicate that in certain circumstances (e.g. unexpected mechanical failures; loss of situational awareness; dealing with novel complex flight issues) even mild hypoxia may affect pilots’ ability to resolve unexpected problems.

References

Basic research for development of stress assessment technology

Emiko Minakuchi¹*, Eriko Ohnishi², Miwa Motomura¹, Takayasu Kawaguchi¹
¹ Graduate School of Comprehensive Human Sciences, Faculty of Medicine, University of Tsukuba
² Bio-Laboratory, Foundation for Advancement of International Science
*corresponding author: em.tsukuba@gmail.com

Introduction
In recent years, depression and other stress-related illnesses have increased[1], and this mental stress has been considered a risk factor of illnesses[2, 3]. Mental stress is induced by various disturbing physical or emotional factors ("stressors"). The effects of the stressors on the body constitute the stress response, which may be measured by behavioural, biochemical, and genetic modifications. Although several studies have measured stress using biomarkers such as salivary cortisol and salivary alpha-amylase [4, 5], these studies are expensive and require special expertise technique. Thus quantitative assessment of mental stress in a low-cost and non-invasive manner to obtain rapid results is regarded as an important issue.

Finger plethysmography (FPG) has been recognized as a simple, non-invasive and well-known method for monitoring peripheral circulation [6, 7]. FPG detects volumetric fluctuations in blood flow in the fingertip resulting from changes in intra-arterial pressure through changes in the optical absorbance of haemoglobin. In order to quantify nonlinear signals such as FPG, nonlinear time series analysis is commonly used. Chaos analysis is one of nonlinear time series analysis, and an important mathematical model of complex systems science. Tsuda and colleagues [8] constructed the chaos attractor from fingertip capillary vessels, and reported that shape and size of chaos attractor visualizes chaos statements, and reflects the age and health condition of individuals. Furthermore, peripheral blood flow reflects autonomic nervous system activity [9-12], which is commonly known as one mental stress indicator.

However, there are few studies to measure mental stress from both autonomic nerve system activity and peripheral chaos attractor on FPG. The purpose of the present study was to develop a system to measure in detail and analyse dynamics of FPG, in order to quantitatively evaluate mental stress.

Methods
Forty healthy adults (9 men, 31 women) participated in the study. Mean ages were 26.3±10.4 years in men and 22.7±2.5 years in women. The present study was approved by the research ethics committee of the Graduate School of Human Sciences, University of Tsukuba on September 2, 2010 (certification no. 22-179). Participation was voluntary and all participants provided written informed consent. This study was carried out using a before-and-after study design. The experimental protocol is shown in Figure 1.

Figure 1. Design of the study protocol. We used Stroop colour-word conflict test as Stress test.

At first, the participants sat down on a chair for 10 min ("Rest 1” period). Then, the participants performed the computerised version of Stroop

colour-word conflict test (CWT) for 10 min as a mental stress test (“Stress test” period). The words in colour were presented upon a computer screen, and the participants were asked to select the correct colour of the word quickly. It induced a state of mental stress in the participants because the written colour sometimes corresponded to the colour of the word (e.g., “RED” in red ink) and sometimes did not (e.g., “RED” in blue ink). At the end, participants rested and calmed down for 10 min (“Rest 2” period). During the experiment, as shown in Figure 2, finger pulse wave data were recorded continuously throughout these three periods (sampling rates: 1 KHz).

Figure 2. FPG-detecting device

Indicative of peripheral circulation dynamics, we reconstructed the colourful attractors from the experimental data by adopting the method of Takens [13]. Indicative of autonomic nervous system activity, high frequency (HF, 0.15-0.4Hz) and low frequency (LF, 0.04-0.15Hz) components were calculated from FPG by fast Fourier transform analysis. In general, LF/HF is an index of sympathetic nerve activity and HF is an index of parasympathetic nervous activity. Subjective reactions were also examined by the brief-form Profile of Mood States (POMS).

Results and Discussion
As shown in Figure 3, the attractor size reduced during the Stress test remarkably, and it returned to an original size in Rest 2. We could not observe the exact shape of attractor, but depth determined by colours seemed apparently shallow. The results indicated that mental stress decreased peripheral dynamics, in other words, chaos was going to the null state.

Figure 3. Representative changes of chaotic attractor reconstructed by data of FPG

As shown in Table 1, the Confusion scale of POMS was increased (p<0.05) after the Stress test. The results indicate that the CWT in the present study was definitely effective as a stress-induce test. As for the autonomic nervous system activity, HF decreased (p<0.001) and LF/HF increased (p<0.01) significantly during the Stress test. These results indicated that mental stress activates
sympathetic nerve activity as expected. It is commonly known that psychological and physical strain increases sympathetic nerve activity. Our results illustrate that, FPG successfully measured the responses of the autonomic nervous system activity to stress stimulus.

**Table 1.** Mean values of high frequency (HF), ratio of low frequency and high frequency (LF/HF) and score of Confusion during three periods.

<table>
<thead>
<tr>
<th>Period</th>
<th>HF</th>
<th>LF/HF</th>
<th>Confusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest 1</td>
<td>5.96±0.72</td>
<td>1.04±0.15</td>
<td>52.13±10.30</td>
</tr>
<tr>
<td>Stress test</td>
<td>5.27±0.68&lt;sub&gt;ab&lt;/sub&gt;</td>
<td>1.14±0.16&lt;sub&gt;ab&lt;/sub&gt;</td>
<td>n.d.</td>
</tr>
<tr>
<td>Rest 2</td>
<td>5.81±0.60</td>
<td>1.09±0.13</td>
<td>56.23±10.54&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: Values represent mean ± SD (n=40); n.d., No data.

<sup>a</sup> – Significantly different to Rest 1 value (p<0.05)

<sup>b</sup> – Significantly different to Rest 2 value (p<0.05) (Wilcoxon signed-ranks test)

**Conclusions**

Our results demonstrate that indices of both autonomic nervous system activity and peripheral dynamics can be extracted from FPG, and those indices acutely vary with physiological and emotional changes in response to mental stress. The results confirm that FPG are a useful index to evaluate the autonomic modulations and mental stress. However, to determine exact chaotic state is difficult because of its dependence on several physical and mental conditions, so we need more experiments to investigate dynamics in human body from other aspects.

**Acknowledgements**

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**References**


EXERCISE AND BODY TEMPERATURE

A guide to the conduct of severe human studies on human subjects

Ralph F. Goldman
Comfort Technology, Inc.
Corresponding author: ralph@ralphgoldman.com

The stress imposed by: 1) the weight of loads carried by troops during military operations; 2) the climate during operations in Arctic, Desert or Jungle environments; or 3) associated with the protective clothing worn in such environments; or 4) against fragmentation, chemical or biological weapons; can be excessive physiologically, or physically, and/or psychologically. Further complicating the conduct of experiments under such conditions is the ingrained belief of many successful military leaders that, under their inspired leadership, their troops can do almost anything. Early in my research for the Army I learned that unless the troops were actually dropping in their tracks, the Generals often felt that any difficulty in completing missions simply indicated that the troops required more training. How can research on volunteer subjects be realistic and safely carried out under such circumstances?

A) Do no harm!
Recalling the inhumane studies carried out during the 20th century on prisoners: e.g., 1) Manchurian War captives forced to hold their hands, or feet, in the cold to determine the time for fingers or feet, w/ or w/o hand/footwear, to freeze - as a function of the “cooling power” of the environment, measured by a “Kanto-Kai” (a form of kata-thermometer”); or, 2) of Nazi prison camp inmates immersed in near freezing cold water to determine the efficacy of various re-warming techniques that might be applied to revive Luftwaffe pilots downed in the icy North Atlantic during WW-II.

How can one ensure against becoming involved in conducting extremely dangerous studies on human volunteers?

My solution involved three points:

1) I would be willing to be a subject myself; and I usually was. One of my first, extended studies of human tolerance to heat stress, was at rest under increasingly: a) hot-dry; or b) hot-humid, and c) windy conditions (> 600 subject exposures, 10 at a time over a two month period. It became clear that three, different, types of tolerance limits were reached; 1) in ~50% of the subjects, the preset “safe” tolerance limit of 180 beats/minute heart rate was reached; 2) in ~40% of the exposures, the preset tolerance limit of 103.5 °F deep body temperature was reached; 3) in ~10% of the exposures, hyperventilation and wash-out of blood pCO2 levels to the point of clinical signs led to removal of the subjects from the climatic chambers. Each morning, during the 30 minutes the subjects were being fitted out with deep body and skin temperature probes, and baseline temperatures and heart rates at rest in a comfortable environment were being measured, I would enter the climate chamber, wearing the same shorts and sandals as the subjects, and measure the air temperature, humidity and wind speed to make sure the conditions I had specified for that day were met, and endurable for at least 20 minutes. One day, toward the end of a series at 100% humidity, a 120 °F, 20 mph wind condition was scheduled; shortly after I entered the chamber my skin sensors reached the acute pain threshold (≥ 113 °F); I immediately canceled that day’s study.
2) Any of my co-investigators, or technicians, who might be involved in such a study would also be a subject in the pilot study if they might be in a position to encourage a subject to continue for a while longer, or “just until the next measurement could be completed”. In one study, involving walking through increasing depths of snow at a fixed pace, a co-investigator – an unusually fit civilian with a tendency to push himself and others to their limits – after serving as a subject during the preliminary trials at the knee deep snow depth, had such severe leg cramps that evening, that he did not suggest in any way that a subject who was ready to stop for the day should try to continue.

3) My final criterion (in fact, one I ultimately resigned from my Army position rather than violate) was I would let my children serve as subjects in any test I ran.

B) Know your subjects

Despite the ringing declaration of the 16th U.S. President, that “all men are created equal”, nothing could be further from the truth. As shown in Figure 1 below,
hour after the girls had started. When I asked one of my Sergeants how things were going, he replied that the girls were beating the previous male troop’s times; indeed, they finished in record time. I had sent my best technicians in to the University to measure these girls’ VO2max before this trial, but to insure “double blind” testing, had not asked about the results. Chats during the cookout after the last girl finished, provided the answer. That year’s Olympics had added Women’s Crew to its events; the Boston University Crew team won. These had all been recruited by my BU student to be the subjects for this study. Without exception, their measured individual VO2max values exceeded those of my military subjects; and predictions based on the girls’ body and load weights, and VO2max values agreed nicely with their measured times to complete the course.

C) Insofar as possible, homogenise your subjects.

Do not be a “Universal Subject” user. Do not mix men and women, fit and unfit, acclimatized and un-acclimatized subjects, etc. Indeed, to the extent possible, select 8 to 10 subjects of approx. the same age, sex and somatotype - and then “homogenize them” by conditioning and acclimatizing them for ~7 days insofar as possible to the conditions under which they will be tested, only without the clothing, loads, state of hydration, etc. which are being studied. This offers a major advantage in that you, and or your technicians, will get to “know” your subjects and their responses to stress. I remember two subjects very well; the first, as long as he was volubly complaining, could go on for quite a bit longer, but the minute his complaints stopped he was close to his tolerance limit. In contrast, the second would march without comment for a long time, but the minute he made a sound he was close to his limit of endurance.

D) Use an “adequate forcing function” for your study.

This “engineering” concept can be explained simply. If, for example, you want to study and compare the performance of Cadillac and Volkswagen automobiles, you can learn little or nothing by driving them both at 25 mph on a level, smoothly paved roadway; this is an “inadequate” forcing function; you will learn little about differences between the two makes of car. On the other hand, if you drive both cars off a 20 foot cliff – junk is junk; such an “excessive” forcing function also reveals little about differences between the two cars. However, using a study design which involved driving both cars at 45 mph around an icy, twisting course, a statistical analysis should not be needed to compare their performance.

E) Always model & predict the outcome of any trial.

The goal of a research study, whether in the area of Military Ergonomics or any other field, usually is to be able to understand changes in a given variable - and possibly to develop tools to predict the effect(s) of, and the factor(s) producing, such change. Unless one starts with some form of prediction model, based on the factors that one thinks should be involved, and assigning varying degrees to each factor, it is often difficult - if not impossible – to understand the results, and to decide on the next study required to include additional factors.

F) Why a minimum of 8 subjects?

Scientists accept the 5% level of probability of one outcome or event as significant; i.e., there is
only 1 chance out of 20 that it will occur. This has become the accepted gate for publication of results in the scientific literature. How does this 5% level translate to 8 Ss? Each time one flips a coin, the probability of getting a head or a tail is 50% (1/2); this first toss is then considered as the “one degree of freedom”. However, what are the odds of a second toss producing the same result; i.e., if the first toss was “heads”, what are the chances of the 2nd toss being heads? The odds of matching the first, “free”, toss are ½ or 50%. The odds of a 3rd toss matching the first two tosses are, again, 50% so the odds of 3 in a row are 33%; of a 4th toss matching are 16.5%; of a 5th toss are 8.25%; of a 6th toss are 1/6, or 4.125%. Thus one needs a minimum of 6 subjects to reach the 5% criteria. However using 8 subjects, even if 1 of them has a different response, the 5% criterion can be reached. In recent years, the American Psychological Association has argued they should not have to meet this level for publication; since each individual’s psyche is different, and impossible to homogenize, they are probably correct.
Effect of combinations of passive and active warming on muscle temperature and sprint performance

Steve H. Faulkner1*, Richard A. Ferguson2, Simon G. Hodder1, Maarten Hupperets3, George Havenith1
1 Environmental Ergonomics Research Centre, Loughborough Design School Loughborough University, Leicestershire LE11 3TU, UK.
2 School of Sport, Exercise and Health Sciences, Loughborough University, Leicestershire, LE11 3TU, UK.
3 ait Sport Research Lab, adidas AG, 91074 Herzogenaurach, Germany
*corresponding author: s.h.faulkner@lboro.ac.uk

Introduction
Muscle temperature (Tm) has a significant effect on muscle function, force and power production [1], hence the adoption of warm up procedures before power based events. In the majority of sprint or power based events there are periods of maximal activity interspersed with periods of low or no activity, during which Tm may decline, adversely affecting subsequent performance. We have previously shown that Tm will decline during 30 minutes of inactivity following the completion of a warm up, and that the use of passive external heating between warm up completion and sprint cycling performance reduces Tm decline and improves peak power output [2]. The aim of the present study was to follow on from our first Tm study and determine whether, apart from using the electrical heating between warm up and event, there is an additional benefit of using the electrical heating during warm up completion on muscle temperature and subsequent measures of sprint cycling performance. The secondary goal was to look at the efficacy of a redesigned heating system covering a larger area of muscle than in [2].

Methods
Following familiarisation with the test protocol, on three separate occasions, 10 male cyclists (age 23.5 ± 3.4 years, height 1.80 ± 0.04 m, body mass 73.7 ± 0.7 kg; mean ± S.D.) completed a standardised 15-minute intermittent sprint based warm up on a cycle ergometer in standard cycle shorts, followed by 30 minutes of passive recovery before completing a 30-second maximal sprint test. Warm up was completed either with (HH) or without (SH) additional external electrical heating. During the passive recovery all participants donned a tracksuit top, with the specially designed trousers incorporating electrical heaters used in both SH and HH conditions. The control group wore a standard tracksuit ensemble throughout recovery (CONT). Muscle temperature was measured at 2-minute intervals throughout the recovery period at a depth of 2 cm in the vastus lateralis using an indwelling Tm probe. Mean, relative and absolute peak power output were determined during the 30 second maximal sprint test. All procedures were first approved by the Loughborough University Ethical Advisory Committee.

Results
Tm declined exponentially during CONT but did not fit the exponential model for either SH or HH. ΔTm was reduced in HH vs CONT from minute 20 of the recovery (p<0.05) and minute 28 for SH vs CONT (p<0.05). Mean power (4%) and both relative (11%) and absolute (11%) peak power output were improved in SH (p<0.05) and HH (p<0.05) compared to CONT. There was no additional benefit of HH on Tm or power output compared to SH.

Conclusion
These data confirm our previous results and show that the use of external passive heating will reduce the decline in Tm during rest, and improve mean, relative and peak power output. The
additional finding of an increased mean power is possibly attributable to the additional area of heating coverage compared to [2]. It is recommended that athletes involved in intermittent sprint activities consider the use of passive heating during rest to maintain $T_m$ and improve performance.

References
No circadian changes in heat storage and muscle temperature during intermittent high intensity exercise

Geoffrey L. Hartley, Stephen S. Cheung*
Department of Kinesiology, Brock University, St. Catharines, Canada
*corresponding author: scheung@brocku.ca

Introduction
Changes in heat loss mechanisms observed at rest precipitates fluctuations in core temperature of approximately 1°C throughout a circadian cycle [1], and it remains debated if this disparity in core temperature results in a modified thermoregulatory response to exercise at different times of the day. Furthermore, circadian change in skin and muscle blood flow during recovery may alter the rate of post-exercise heat loss [2]. The purpose of the present study was to investigate possible differences in whole body heat storage and muscle temperature during intermittent high intensity exercise and post-exercise recovery at 0700 and 1700 h.

Methods
Fifteen recreationally active participants performed two 6-minute exercise intervals at 85% \( \dot{V}O_{2\text{peak}} \) (226.8 ± 33.9 W) interspersed with six minute 20 W active recovery periods, followed by 60 minutes of passive recovery at 0700 and 1700 h. Heat storage, determined from partitional calorimetry, rectal and skin temperature was measured continuously throughout the 90-minute trial. Muscle temperature was measured at baseline, following exercise and at 0, 30 and 60 minutes of passive recovery, using a thermocouple inserted 3 cm below the skin-surface of the vastus lateralis. Data were analysed using two-way (time of day x elapsed trial time) repeated measures ANOVAs.

Results and Discussion
Despite a significant difference in baseline core temperature (0700h = 36.96±0.33°C; 1700h = 37.28±0.31°C; \( p=0.003 \)), the rate of heat storage was similar during intermittent exercise and passive recovery at 0700 and 1700 h (0700h = 246.68±79.76 W·m⁻²; 1700h = 241.60±79.71 W·m⁻²; \( p=0.565 \)). This resulted in a similar change in core temperature (0700h = 0.67±0.21°C; 1700h = 0.55±0.26°C; \( p=0.264 \)) and absolute skin temperature (0700h = 33.12±1.64°C; 1700h = 32.98±3.49°C; \( p=0.224 \)) throughout exercise and passive recovery periods. The changes in muscle temperature throughout exercise and recovery were not statistically different between the 0700 and 1700 h trials (0700h = 35.35±1.77°C; 1700h = 35.96±1.40°C; \( p=0.062 \)). These results indicate that, despite differences in circadian thermoregulation at rest, exercise at 0700 and 1700 h does not elicit any differences in exercise or post-exercise recovery heat loss or differences in muscle temperature.

References
Sweating responses to passive calves stretch during activation of muscle metaboreflex in forearm in humans

Tatsuro Amano¹, Masashi Ichinose², Mikio Miwa¹, Yoshimitsu Inoue³, Takeshi Nishiyasu⁴, Narihiko Kondo¹*

¹ Laboratory for Applied Human Physiology, Graduate School of Human Development and Environment, Kobe University, Kobe, Japan
² School of Business Administration, Meiji University, Tokyo, Japan
³ Laboratory for Human Performance Research, Osaka International University, Osaka, Japan
⁴ Institute of Health and Sports Science, University of Tsukuba, Tsukuba, Japan

*corresponding author: kondo@kobe-u.ac.jp

Introduction

Non-thermal factors such as central command, muscle metaboreflex, muscle mechanoreflex, and mental stress, as well as thermal factors (core and skin temperatures) contribute to the sweating response during dynamic exercise [1]. Previous studies indicate that the muscle metaboreflex and mechanoreflex, which are afferent inputs from peripheral working muscles, can independently induce sweating [2, 3]. Although these two reflexes may be activated simultaneously during dynamic exercise, it is unclear how the sweating response is integrally controlled by both afferent inputs.

The integrated effects of the two afferent inputs on cardiovascular responses have been evaluated. For example, calf muscle stretch stimulates muscle mechanoreceptor increased heart rate (HR) and blood pressure during post-isometric calf exercise occlusion (activation of muscle metaboreflex) in humans [4], indicating that the muscle mechanoreflex has an additional effect on these responses. In addition, although it has been reported that the levels of muscle metaboreflex activation related to exercise intensity affect the sweating response [2], the additional effect of the muscle mechanoreflex on cardiovascular responses is independent of the level of muscle metaboreflex activation [4]. Thus, passive stretch and post-isometric exercise occlusion are two means of examining the effects of integrated activation of the muscle metabo- and mechanoreflexes on sweating response (SR). In addition, the integrated control of the SR caused by both reflexes would not be influenced by the level of muscle metaboreflex activation.

The present study was performed to investigate the sweating response caused by activating the muscle mechanoreflex during different levels of activating the muscle metaboreflex.

Methods

Figure 1 illustrates the experimental setting and the protocol used. After a 50-minute rest in an environmental chamber (ambient temperature, 35°C; relative humidity, 50%) in the semi-supine position, 16 young and healthy subjects (14 males and two females; age, 21.7 ± 0.6 years; height, 169.6 ± 2.0 cm; body mass, 63.5 ± 2.6 kg) performed isometric handgrip (IH) exercise for 1 minute at 35% and 50% maximum voluntary contraction intensity with the exercising arm occluded (250 mmHg). The occlusion was sustained for 3 min after stopping the IH exercise to selectively activate the muscle metaboreflex. Feet were passively dorsiflexed to a predetermined angle for 30 s at the second minute of the occlusion period to activate the muscle mechanoreflex. During the resting period between the two IH trials, passive stretch alone was conducted for 30 s to evaluate the responses caused by activating the muscle mechanoreflex. The subjects did not report any pain sensation during the stretch, and respiratory frequency was controlled at 15 cycles/minute throughout the experiment using an auditory signal. All variables were averaged every 10 s. Responses to passive stretch for HR, mean arterial blood pressure (MAP), and mean SR on the
forehead, chest, and forearms were obtained from the peak values during the stretch. The responses to post-exercise occlusion were obtained from the pre-stretch values. Paired and unpaired t-tests were used for statistical analyses. In all analyses, p<0.05 was taken to indicate statistical significance. This study was approved by the Human Subjects Committee of the Graduate School of Human Development and Environment, Kobe University, Japan, and that conformed to the standards set by the latest revision of the Declaration of Helsinki.

Results and Discussion
Passive calf stretch alone significantly increased MAP and mean SR but not HR compared to pre-stretch values (p<0.05, Fig. 2A), indicating that the blood pressure increase during passive stretch was due to activation of the muscle mechanoreflex [4]. Therefore, the increased mean SR during the stretch in the present study was likely caused by the muscle mechanoreflex.

During the forearm occlusion period, MAP and SR remained above resting levels at both exercise intensities due to activation of the muscle metaboreflex (p<0.05, Fig. 2B, E). Passive stretch during this period produced further increases in these parameters at both exercise intensities (p<0.05, Fig. 2C, F). The increased SR and MAP during passive stretch under occlusion conditions (Fig. 2C, F) were not significantly different from the sum of the values of passive stretch alone or occlusion at both exercise intensities (p>0.05; Fig. 2D, G).

These results indicate that activation of the muscle mechanoreflex in the calves has an additional effect on SR and MAP during activation of the forearm muscle metaboreflex. In addition, as we hypothesized, this additional influence of muscle mechanoreflex on the responses was independent of the levels of muscle metaboreflex activation.
Figure 2. Changes in heart rate (HR), mean blood pressure (MAP), and mean sweating rate (SR) induced by a passive calf stretch alone (A), by post-exercise forearm occlusion at 35% maximum voluntary contraction (MVC) (B) and 50% MVC (E), by stretch during forearm occlusion at 35% MVC (C) and 50% MVC (F), and the sum of the calf stretch and occlusion values at 35% MVC (D) and 50% MVC (G). #Significantly different from pre-stretch (A) or pre-exercise values (B, C, E, and F), p<0.05. *Significantly different between conditions, p<0.05.

References
Sunscreen use reduces sweat evaporation but not production

James R. House, Mickey Breed

Extreme Environment Laboratory, Department of Sports and Exercise Science, University of Portsmouth, Portsmouth, United Kingdom.

*corresponding author: jim.house@port.ac.uk

Introduction

The purpose of this study was to determine if two different sunscreen types influence thermoregulatory responses to exercise in the heat. Athletes commonly use an alcohol based sunscreen (AS), whereas military personnel (UK) are issued with an oil-based sunscreen (OS). We hypothesised that sunscreen use whilst exercising in the heat would: reduce sweat production, increase sweat dripping from the skin, which would increase the rise of rectal and skin temperatures. We also hypothesised that OS would increase sweat dripping from the skin, more than AS, compromising thermoregulation further.

Methods

Following ethical approval, 8 male and 4 female healthy volunteers were recruited. Participants stepped using a 22.5 cm step for 60 min on three separate occasions in 40 °C (20% relative humidity) air, twice with sunscreen (AS and OS) and once without (CON), in a balanced order. The participants’ clothed, naked and clothing masses were recorded immediately before and after the exercise period to an accuracy of 5 g. Rectal temperature was recorded every minute, heart rate every five minutes, subjective responses and infrared thermograms (front and rear) taken every 15 min to measure skin temperature. Expired-air samples (Douglas Bag) were taken after 20 and 40 min of exercise. Sunscreen was applied at the recommended dosage (20 g.m⁻²), 30 g to 40 g per participant. Participants wore loose fitting sports shorts but no T-shirt (females wore a sports bra), cotton wrist sweatbands, cotton hand towels tucked over shorts around waist, cotton socks and training shoes. Data were analysed using ANOVA.

Results

Both mean (SD) oxygen uptake and sweat production were similar between conditions [CON 1.26 (0.30) L.min⁻¹; AS 1.23 (0.29) L.min⁻¹; OS 1.20 (0.32) L.min⁻¹] (p=0.422) and [CON 0.85 (0.21) L; AS 0.85 (0.23) L; OS 0.86 (0.21) L] (p=0.939) respectively. Mean (SD) sweat evaporation was less in OS [0.67 (0.13) kg] compared to both CON [0.72 (0.15) kg] and AS [0.70 (0.14) kg] (p<0.05), but similar between CON and AS (p=0.602). Sweat mass absorbed by clothing was less in CON [0.08 (0.07) kg compared to both AS [0.102 (0.08) kg] and OS [0.14 (0.1) kg] (p<0.05). There were no differences in the values or rates of change of heart rate or rectal, mean skin or mean body temperatures.

Discussion and Conclusions

Sunscreen use did not reduce sweat production, but did reduce evaporation, presumably because of an increased sweat run-off from the skin as evidenced by the increase in clothing mass post-test in the two sunscreen conditions. The differences however, were small (30 g to 50 g in 1 hour) and did not influence heat strain. Visual evidence indicated that sweat run-off in the OS condition resulted in considerable wash-off of the cream from the skin. It was not possible to determine whether this wash-off occurred in the clear fluid AS condition, nor whether any of the protective ingredients of the sunscreens were washed off. Athletes and military personnel, when able to thermoregulate, should continue to use sunscreen when required without fear of underperforming due to a compromise in thermoregulation. The preservation of protection following prolonged sweating should be investigated.
The role of increased body temperature in the changes seen in lung function during and after exercise

Pippa Band1, Martin Barwood2*, Dan Roiz Da Sa3, Michael Tipton2
1 HMS Nelson, HM Naval Base Portsmouth, Portsmouth, UK
2 Extreme Environments Laboratory (EEL), Dept. Sport and Exercise Science, University of Portsmouth, Portsmouth, UK
3 Environmental Medicine Unit, Institute of Naval Medicine, Gosport, UK
*corresponding author: martin.barwood@port.ac.uk

Introduction
The capacity to increase ventilation is ultimately limited by resistance to airflow in the bronchial tree. This limit to gas-flow rates can be characterised by measuring the flow-volume curve. The received wisdom is that exercise improves the flow-volume relationship because increased circulating levels of catecholamines result in bronchodilatation. We tested the hypothesis that some of the improvement seen with exercise is due to temperature per se.

Method
The study employed a within-participant repeated measures cross-over design with each participant acting as their own control. Nine participants (mean [SD]: age 22 [3] years; height 177.7 [8.3] cm; mass 80.2 [19.1] kg) completed three conditions in a balanced order at the same time of day, these were: exercise (EXERC; 30 minutes), immersion in 40 °C water to passively raise T̄rec (IMM40; 30 minutes) and immersion in 35 °C water (IMM35; 30 minutes) to act as a thermoneutral control condition for hydrostatic effects. T̄rec and skin temperature at 4 sites were recorded every 30 seconds, while a forced vital capacity (FVC) manoeuvre was performed at the start of the test and every 10 minutes of each exposure. Participants exited the water bath in the IMM40 and IMM35 conditions and provided their FVC measure whilst in a standardised seated position similar to that adopted on the bicycle during the EXERC condition. Participants briefly rested (1-minute) in the EXERC condition prior to providing their respiratory measure. The following mean [SD] data were calculated at rest and every 10 minutes of each exposure: T̄rec, forced expiratory volume over 1 second [FEV1], FEV1/FVC, 25, 50 and 75 % maximal expiratory flow during FVC (MEF25, MEF50 & MEF25). Data were compared within participant, between conditions using ANOVA to an alpha level of 0.05.

Results
Between conditions T̄rec, FEV1, and FEV1/FVC (p<0.05) were greater in the IMM40 and EXERC conditions compared to the IMM35 condition. The T̄rec response peaked, on average, after 30 minutes in the EXERC and IMM40 conditions and were 38.0 (0.3), 38.2 (0.2) respectively compared to 37.2 (0.2) °C in the IMM35 condition (p<0.05). At the corresponding time point the FEV1 was 4.5 (0.6), 4.6 (0.3), and 4.4 (0.6) L respectively. Interaction effects were evident for MEF50 and MEF25 (p<0.05), being higher in IMM40 and EXERC conditions in contrast to the IMM35. These data are indicative of dilation of the small airways in response to raised deep body temperature.

Conclusion
We accept the hypothesis that temperature, independent of exercise, causes an improvement in flow-volume characteristics and may therefore explain, in part, the alteration seen with exercise.

In memoriam: Dr Mark (“Buster”) Harries
Effects of hyperventilation-induced hypocapnia on respiratory and metabolic responses and performance during high-intensity intermittent exercise

Shun Hashimoto¹, Bun Tsuji², Naoto Fujii², Akira Sugihara¹, Takeshi Nishiyasu³*
¹ Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan
² JSPS Fellow, Japan
³ Institute of Health and Sports Science, University of Tsukuba, Japan
*corresponding author: nisiyasu@taiiku.tsukuba.ac.jp

Introduction
An aerobic capacity has been thought to be related to short-term high-intensity exercise performance. To stimulate anaerobic metabolism and enhance short-term high-intensity exercise performance, intermittent exercise is used in training fields and there is experimental evidence indicating that intermittent training would improve anaerobic capacity [3].

We recently found that, during short-term high-intensity exercise, a decrease in arterial carbon dioxide pressure (hypocapnia) induced by voluntary hyperventilation before exercise did not change performance, whereas it decreased oxygen uptake, suggesting an increase in anaerobic metabolism (unpublished data). However, it is uncertain whether the same is true during intermittent exercise. Therefore, the purpose of this study was to examine the effects of hyperventilation-induced hypocapnia on respiratory and metabolic responses and performance during high-intensity intermittent exercise.

Methods
Eleven (8 male, 3 female) college-age track and field athletes volunteered for this study. Written consent was obtained and the study was performed according to the Declaration of Helsinki. Participants performed high-intensity intermittent exercise, which consisted of 30-s constant workload and 30-s maximal pedaling exercises with 5-min rest. Workload was body mass * 0.1 kp, and cadence was kept at 70 rpm during constant workload pedaling exercise. During the experiment, the subjects breathed normally (Control trial) or performed voluntary hyperventilation before each exercise to reduce end-tidal CO₂ pressure to about 20 mm Hg (Hypocapnia trial). Respiratory parameters, power output, blood lactate concentration and ratings of perceived exertion (RPE) were measured.

Results and Discussion
Maximal, minimum and average power outputs during maximal pedaling exercise were not significantly different between two trials (all p>0.05). Oxygen uptake during both constant workload and maximal pedaling exercises was significantly lower in Hypocapnia than in Control trial (p<0.05). Minute ventilation during maximal pedaling exercise was significantly lower at 5-15 s of exercise in Hypocapnia than in Control trial (p<0.05).

Given that exercise efficiency did not change between two conditions, it is possible that the total amount of energy supplied during exercise was similar between the conditions, and anaerobic metabolism was increased to compensate for a decrease in oxygen uptake in Hypocapnia trial. The decreased ventilation observed in this study, a decreased blood flow in active muscle [1] and a delayed activity of pyruvate dehydrogenase [2] may all contribute to the decrease in oxygen uptake caused by hypocapnia in this study.
Conclusion
Our results indicate that, during high-intensity intermittent exercise, voluntary hyperventilation-induced hypocapnia before exercise can increase anaerobic metabolism without change in exercise performance.

References
Influence of environmental temperature on running-performance in men's marathon

Yoko Kajiwara¹*, Masami Hirashita², Saburo Yokokura³, Shinichiro Ono⁴
¹Bunkyo University, Saitama, Japan. ²Kanazawa Gakuin University, Ishikawa, Japan. ³Meisei University, Tokyo, Japan. ⁴Showa University, Tokyo, Japan.
*Corresponding author: kajiwara@koshigaya.bunkyo.ac.jp

Introduction
Since the Los Angeles Olympic Games in 1984, major competitions such as the Olympics and World Championships tend to be held in hot environments during the summer. Outdoor sporting activities including athletic competitions held in hot environments during the summer, particularly the marathon as an endurance and road event, are largely influenced by weather conditions such as the temperature, humidity, and radiant heat. In the event of an excessive rise in the core body temperature, the physical load increases, and performance levels drop (Costill, 1970; Costill, 1972) [3, 4]. The weather conditions are an important factor for athletes to display their best performances by maintaining optimal conditions and the collection of such information is indispensable for their competition strategies. The wet bulb globe temperature (WBGT) index is widely used in athletic and industrial settings.

The American College of Sports Medicine (1975 and 1984) proposed a preventive measure against heat-related illnesses in distance runners based on the WBGT as a thermal index of hot environments. In line with this guideline, the IAAF (International Association of Athletics Federations) issued the “Medical Manual for Athletic and Road Racing Competition - A Practical Guide” (1998) [1, 2].

Although significant attention has been focused on the evaluation of environmental conditions based on the WBGT as a thermal index, the data have barely been reported in detail in marathons at the Olympics or World Championships. As previously mentioned, the collection of information on weather conditions affecting athletes' performance and conditioning is significant for their competition strategies. However, such information is insufficiently provided during races and reported after competition, with the exception of the past four IAAF World Athletics Championships; thus, the environmental conditions marathons were held in and whether the effects varied among marathon runners depending on their running-performance have not yet been investigated. Therefore, this study aimed to obtain basic strategic data regarding the performance and conditioning in marathon runners by analysing the weather conditions and runners' achievements by rank at the past four IAAF World Athletics Championships.

Methods
The subject of the study was the past four IAAF World Athletics Championships (2005 Helsinki, 2007 Osaka, 2009 Berlin and 2011 Daegu). The subjects were athletes who competed in the men's marathon achievements. The data were collected from the formally published list of participants and formal results. The % difference between the race time at the past four IAAF World Athletics Championships and personal best (% off personal best) was calculated as: [(finish time - personal best)/personal best] × 100. Environmental temperature measurement was performed at the site of each except for 2005 Helsinki. In 2005 Helsinki, the WBGT was estimated based on the Dry-bulb temperatures and Relative humidity. The running speed per minute (m/min) was calculated by measuring split times at intervals of 5 km: the start to 5; 5 to 10; 10 to 15; 15 to 20; 20 to 25; 25 to 30; 30 to 35; 35 to 40; and 40 to the finish (2.195 km). Fluctuations in the running speed were calculated, considering the speed when running the first 5 km (the start to 5 km) as 100. The
measured data were analysed in comparison between 4 - 7 groups of athletes classified according to their ranks.

For statistics, the SPSS statistical package program (Version 20.0 for Windows) was used. For the comparative analysis of the % off personal best, the first and second half times, and their indices by rank, a one-way ANOVA was performed. In the case that a significant difference was shown between the groups, Fisher’s least significant difference was applied. The significance level was set at p<0.05.

Results and Discussion
The mean WBGT in 2007 Osaka was the highest of the four IAAF World Athletics Championships (2007 Osaka: 27.5 ± 1.4 > 2011 Daegu: 23.6 ±1.0 > 2009 Berlin: 20.9 ± 2.0 > 2005 Helsinki: 18.6 ± 0.0 °C, p<0.01).

According to the risk chart of the IAAF, the level of environmental conditions during the 2007 Osaka race was "high".

Figure 1 shows the mean first and second half times, and the mean % off personal best record. In 2007 Osaka, the mean first and second half time, the mean finish time were significantly slower, and the mean % off personal best record was significantly higher, compared to those in the three other championships.

Figure 2 shows linear regression equations of the % off personal best record on the WBGT, coefficient of determination, and significance probability in the regression analysis of variance. Regarding all runners, the risk rate was lower than 5% and the validity of the regression equation has been established. Regression equations of the medallists suggested higher correlations, compared to other runners.

Table 1 shows the % off personal best record by rank. The overall mean and standard deviation for the % off personal best records were 5.5 ± 3.6 in 2005 Helsinki (n=50), 10.2 ± 4.0 in 2007 Osaka (n=50), 3.8 ± 2.6 in 2009 Berlin (n=50) and 5.8 ± 3.8 in 2011 Daegu (n=50). The % off personal best record for men's marathon in 2007 Osaka was significantly higher than that in 2005 Helsinki, in 2009 Berlin and 2011 Daegu (p<0.01). No significant differences in the % off personal best records in past four IAAF World Athletics Championships were observed between the groups ranked top
10, 11 to 20th place, but comparison between these and other groups (ranked 21 to 30, 31 to 40 and 41 to 50th place) revealed significantly higher values in the latter. The high-ranked groups had world-class personal best records and a low % off personal best. Under the condition of high WBGT, such as in World Championships 2007 Osaka, first-class runners change their running speed according to the environmental condition (Table 2).

Table 1. Percent off personal best record by rank.

<table>
<thead>
<tr>
<th>11-20th</th>
<th>Medalist</th>
<th>Prizewinner</th>
<th>Top 10</th>
<th>21-30th</th>
<th>31-40th</th>
<th>41-50th</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005 Helsinki</td>
<td>21-30th</td>
<td>31-40th</td>
<td>5.5 ± 3.6</td>
<td>0.5 ± 1.4</td>
<td>3.1 ± 1.8</td>
<td>2.3 ± 1.9</td>
</tr>
<tr>
<td>2007 Osaka</td>
<td>21-30th</td>
<td>31-40th</td>
<td>10.2 ± 4.0</td>
<td>6.8 ± 1.2</td>
<td>6.9 ± 3.0</td>
<td>7.0 ± 2.3</td>
</tr>
<tr>
<td>2009 Berlin</td>
<td>21-30th</td>
<td>31-40th</td>
<td>3.8 ± 2.6</td>
<td>1.7 ± 0.7</td>
<td>2.9 ± 1.4</td>
<td>2.1 ± 1.5</td>
</tr>
<tr>
<td>2011 Daegu</td>
<td>21-30th</td>
<td>31-40th</td>
<td>5.8 ± 3.8</td>
<td>3.4 ± 1.1</td>
<td>2.9 ± 1.3</td>
<td>3.2 ± 1.2</td>
</tr>
</tbody>
</table>

Value are mean ± SD. Significantly different at the 0.05 level. 2005 Helsinki, Helsinki,2007 Osaka,Osaka,2009 Berlin, Berlin,2011 Daegu, Daegu.

Table 2. Running speed (m/min) by rank in 2005 Helsinki and 2007 Osaka.

<table>
<thead>
<tr>
<th>2005 Helsinki</th>
<th>Medalist</th>
<th>Top 10</th>
<th>21-30th</th>
<th>41-50th</th>
</tr>
</thead>
<tbody>
<tr>
<td>5km</td>
<td>33.2 ± 1.5</td>
<td>325.3 ± 1.5</td>
<td>325.5 ± 0.9</td>
<td>323.8 ± 3.0</td>
</tr>
<tr>
<td>10km</td>
<td>33.2 ± 1.0</td>
<td>325.3 ± 1.0</td>
<td>321.7 ± 3.0</td>
<td>324.3 ± 6.8</td>
</tr>
<tr>
<td>15km</td>
<td>328.1 ± 0.2</td>
<td>325.2 ± 0.2</td>
<td>323.1 ± 2.1</td>
<td>318.4 ± 6.8</td>
</tr>
<tr>
<td>20km</td>
<td>322.0 ± 0.2</td>
<td>325.2 ± 0.2</td>
<td>321.7 ± 1.5</td>
<td>309.5 ± 9.5</td>
</tr>
<tr>
<td>25km</td>
<td>316.9 ± 0.1</td>
<td>325.2 ± 0.2</td>
<td>321.7 ± 1.5</td>
<td>309.5 ± 7.6</td>
</tr>
<tr>
<td>30km</td>
<td>311.3 ± 0.6</td>
<td>324.7 ± 3.0</td>
<td>316.1 ± 8.7</td>
<td>286.6 ± 8.4</td>
</tr>
<tr>
<td>35km</td>
<td>311.5 ± 6.2</td>
<td>311.5 ± 6.2</td>
<td>302.2 ± 8.3</td>
<td>274.1 ± 14.5</td>
</tr>
<tr>
<td>40km</td>
<td>315.0 ± 4.1</td>
<td>315.0 ± 4.1</td>
<td>302.2 ± 8.3</td>
<td>274.1 ± 14.5</td>
</tr>
<tr>
<td>Finish</td>
<td>303.2 ± 0.7</td>
<td>291.0 ± 13.9</td>
<td>270.6 ± 25.3</td>
<td>261.0 ± 21.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2007 Osaka</th>
<th>Medalist</th>
<th>Top 10</th>
<th>21-30th</th>
<th>41-50th</th>
</tr>
</thead>
<tbody>
<tr>
<td>5km</td>
<td>300.9 ± 0.0</td>
<td>300.9 ± 0.0</td>
<td>300.7 ± 0.4</td>
<td>300.2 ± 1.4</td>
</tr>
<tr>
<td>10km</td>
<td>307.6 ± 0.2</td>
<td>307.6 ± 0.2</td>
<td>306.7 ± 3.5</td>
<td>306.8 ± 3.1</td>
</tr>
<tr>
<td>15km</td>
<td>316.3 ± 0.5</td>
<td>316.3 ± 0.5</td>
<td>312.1 ± 5.3</td>
<td>307.6 ± 6.9</td>
</tr>
<tr>
<td>20km</td>
<td>306.3 ± 0.5</td>
<td>306.3 ± 0.5</td>
<td>308.9 ± 3.2</td>
<td>304.5 ± 6.3</td>
</tr>
<tr>
<td>25km</td>
<td>308.9 ± 0.2</td>
<td>308.9 ± 0.2</td>
<td>307.0 ± 4.0</td>
<td>297.0 ± 11.0</td>
</tr>
<tr>
<td>30km</td>
<td>316.9 ± 1.0</td>
<td>316.9 ± 1.0</td>
<td>311.7 ± 6.5</td>
<td>290.0 ± 11.0</td>
</tr>
<tr>
<td>35km</td>
<td>311.3 ± 0.6</td>
<td>314.7 ± 3.0</td>
<td>316.1 ± 8.7</td>
<td>286.6 ± 8.4</td>
</tr>
<tr>
<td>40km</td>
<td>301.8 ± 5.9</td>
<td>301.8 ± 5.9</td>
<td>296.4 ± 9.1</td>
<td>264.8 ± 16.9</td>
</tr>
<tr>
<td>Finish</td>
<td>301.8 ± 5.9</td>
<td>296.4 ± 9.1</td>
<td>264.8 ± 16.9</td>
<td>256.4 ± 13.7</td>
</tr>
</tbody>
</table>

Value are mean ± SD. Significantly different at the 0.05 level. The running speed per minute (m/min) was calculated by measuring split times.

Figure 3. Fluctuations in the running speed when running the first 5 km (the start to 5 km) as 100.
According to a study on marathon running performance based on the WBGT conducted by Ely and colleagues (2007) [7], the rate of decline in the results in a hot environment equivalent to that at the 2009 Berlin and Daegu tends to be 2 to 3%, and is similar in top finishers.

The results of this study support this finding: the rates of decline in the results were 5 to 6%, and shown to be smaller in higher performance runners. On the other hand, Kajiwara and colleagues (2001) conducted a study involving 45 female marathon runners at the Sydney Olympic Games in 2000 (WBGT: 21.5°C), and reported that the rate of decline was 3 to 4%, showing smaller values in higher-performance runners [6].

Comparing with the rate reported by Ely and colleagues, this was 2 % lower; although such a difference may be beyond the error threshold, various factors such as the weather conditions, course, scale and significance of the competition, presence/absence of a pace-maker, mixed-gender marathon, and performance levels of runners may be associated with marathon performance. Figure 3 indicates that the top 10, including the medallists and prizewinner (4 to 8th place) runners-up, had the ability to maintain faster speeds, compared to runners ranked 11 to 50th place.

Conclusions
This study aimed to obtain basic strategic data regarding performance and conditioning in marathon runners by analysing the weather conditions and runners’ % off personal best records by rank at the past three World Athletics Championships in 2005 Helsinki, 2007 Osaka, 2009 Berlin and 2011 Daegu. From the results, the following findings were obtained: In 2007 Osaka, the % off personal best record for marathon was higher than those for the other races. There is around 10% slowing of marathon performance in hot environments, but the top 10 finishers have a higher personal best record and achieve times closer to their personal best record in these conditions.

Conditioning and countermeasures to heat stress are essential for winning summer competitions such as the Olympics and World Athletics Championships, and the results of this study may be informative for athletes and coaches to plan their strategies. Based on the study results, the finish time of winners (including medallists) in future long-distance races under varying environmental conditions can be estimated.

The results are considered useful for developing effective strategies, including an estimated running pace in a race. The relationship between temperature conditions and performance is an interesting issue and should be continuously investigated.

References
**ACUTE HEAT STRESS AND ADAPTATION**

Heat production per unit mass, not relative exercise intensity, determines the core temperature response during exercise in compensable conditions

*Matthew N. Cramer*, **Ollie Jay**

1. Corresponding author: mcram028@uottawa.ca

**Introduction**

Under compensable conditions, the core temperature response to exercise has been associated with the percentage of peak oxygen uptake (%VO₂peak) [1]; however, differences in heat production (W), body mass (kg), and body surface area (m²) are likely to modify these responses [2]. We hypothesized that heat production per unit mass (W/kg) will determine the change in core temperature, independently of %VO₂peak.

**Methods**

Nine male subjects, six of high body mass (HI: 89.1±6.3 kg; 2.09±0.10 m²) and three of low body mass (LO: 67.2±5.7 kg; 1.83±0.10 m²), cycled for 60 min at 500 W, 6.5 and 9.0 W/kg in 25°C, 45% relative humidity (RH), and 9.0 W/kg in 35°C, 30% RH. Heat production was estimated via indirect calorimetry. Rectal (Tre) and mean skin (Tsk; 8-pt, ISO) temperatures, as well as local sweat rates on the forearm and upper back, were recorded continuously.

**Results and Discussion**

The change in Tre (ΔTre) was significantly lower in HI at 500 W (HI: 0.51±0.06°C; LO: 0.96±0.10°C; p=0.004) despite similar %VO₂peak between groups (HI: 45±3%; LO: 47±1%; p=0.573). Although %VO₂peak was greater in HI at 6.5 W/kg (HI: 50±7%; LO: 42±1%; p=0.096) and 9.0 W/kg (HI: 67±5%; LO: 57±4%, p=0.021) no differences in ΔTre were observed between groups at 6.5 W/kg (HI: 0.72±0.12°C; LO: 0.81±0.11°C; p=0.603), 9.0 W/kg in 25°C (HI: 0.93±0.10°C; LO: 1.18±0.22°C; p=0.252), or at 9.0 W/kg in 35°C (HI: 1.19±0.24°C; LO: 1.22±0.11°C; p=0.840). Similar Tsk were observed between groups in all conditions (p>0.05). Greater mean LSR was found in HI under all conditions, and may be explained by differences in body surface area-to-mass ratio (HI: 235±7 cm²/kg; LO: 273±9 cm²/kg; p<0.001) leading to different rates of heat production per unit surface area (p<0.05) at the same W/kg.

In summary, these results indicate that the assessment of core temperature responses between independent groups should be performed by prescribing exercise intensities that elicit similar rates of heat production per unit mass, irrespective of %VO₂peak. Moreover, mean LSR may be determined by heat production per unit surface area within a given environment.

**References**


Sex differences in effective and ineffective sweating rates during exercise in hot, humid conditions

Yoshimitsu Inoue1*, Tomoko Ichinose-Kuwahara1, Ayaka Tanaka1, Erika Tanaka1, Hiroyuki Ueda2, Tatsuro Amano3, Yutaka Tochihara4, Narihiko Kondo3

1 Laboratory for Human Performance Research, Osaka International University, Japan
2 Osaka Shin-Ai College, Japan, 3 Kobe University, Japan, 4 Kyusyu University, Japan
*corresponding author: inoueyes@oiu.jp

Introduction

There are sex- and menstrual cycle-related differences in the heat loss effector function [1-5]. During passive heating, we have found that heat loss in females, compared with males, depends more on cutaneous vasodilation than on sweating and that the lower sweating rate (SR) in women is attributable to a lower sweat output per gland (SGO) and not to a lower number of activated sweat glands [1]. We have also found that the SR and SGO are lower in untrained female than in untrained male subjects and that this sex difference becomes pronounced with increasing exercise intensity and was observed more markedly in trained subjects compared with untrained subjects [4]. Similar results were found in the acetylcholine-induced SR and SGO among physically trained and untrained male and female subjects [5]. This lower sweating capacity in females might result in greater heat storage and a shorter tolerance during exercise in hot environments, which is dependent on heat dissipation mediated by the evaporation of sweat. Females who originally have less body fluid than males may prevent unnecessary body fluid loss via ineffective sweating and may efficiently regulate temperature by minimal sweating (like tropical residents) [6]. However, there are few reports demonstrating that the sweating efficiency of females is superior to that of males.

Therefore, in the present study, we hypothesized that females have a superior sweating efficiency because they exhibit less-ineffective sweating (dripping of sweat) compared with males. To test this hypothesis, time-dependent changes in the total sweating rate, ineffective sweating rate, effective sweating rate, and sweating efficiency were compared between female and male subjects during exercise in a hot, humid environment.

Methods

Healthy, young, physically trained female (n = 6) and male (n = 7) subjects volunteered to participate in this study. They had participated in endurance sports (e.g., long- or middle-distance running) for longer than 6 years. Each subject wore the same clothes (sports bra, short pants, and shorts) and performed two sweating tests by exercise on a separate day: 1) 50%VO2max cycling exercise and 2) 100-W cycling exercise. Experimental protocols were performed in a random order at the same time of day for each subject and were spaced 3 to 5 days apart. We targeted physically trained females in whom there were no remarkable effects of the menstrual cycle on heat loss responses [2, 3], but the sweating tests were not conducted during the menstrual period in female subjects. Experiments were conducted between early November and late December in Japan. The institutional committee for human investigation approved the experimental protocols.

The subject maintained a sitting position on a chair for at least 30 min while the measurement devices were applied in air conditions of 25°C and 50%RH. The subject then entered the environmental chamber, which was maintained at 30°C and 80%RH, and began the sweating test. In the test, after baseline measurements were taken for 5 min, the subject performed the cycling exercise at a work level of 50%VO2max or 100 W for 60 min while maintaining a pedaling frequency of 55 rpm. During the sweating test, the rectal (Tre) and skin (chest, upper arm, and
thigh) temperatures were measured continuously. The mean skin temperature ($T_{sk} = 0.43T_{chest} + 0.25T_{arm} + 0.32T_{thigh}$) and mean body temperature ($T_{b} = 0.8T_{re} + 0.2T_{sk}$) were calculated. The heart rate (HR) was also measured continuously.

The total sweating rate ($SR_{total}$) and ineffective sweating rate ($SR_{ineffective}$) during exercise were recorded at sampling rates of 6 Hz, and data were stored in a personal computer by accurate continuance weight scale devices. In brief, two accurate weight scales that could measure changes in body mass ($SR_{total}$) and $SR_{ineffective}$ in succession were used. Based on the recorded data, we calculated the $SR_{total}$, effective sweating rate ($SR_{effective} = SR_{total} - SR_{ineffective}$), and sweating efficiency ($= SR_{effective} / SR_{total} \times 100$). All data are reported as means ± SEM. Statistical significance was set at a value of $p<0.05$.

**Results**

Female subjects had significantly lower height and surface area and higher percent body fat than did male subjects. Mass tended to be lower in female than in male subjects ($p = 0.06$). However, there was no significant difference in terms of age, surface area/mass, or VO$_2$max (57.0 ± 1.0 vs. 52.8 ± 2.2 ml/kg/min for female and male, respectively) between the two sexes.

**50%VO$_2$max exercise:** There was no significant difference in absolute exercise intensity (102 ± 3 vs. 107 ± 7 W) between the two sexes. No significant difference was observed in baseline $T_{re}$ or $T_{re}$ at the end of the exercise between the two sexes (38.45 ± 0.10°C vs. 38.30°C ± 0.13°C). As a result, the change in $T_{re}$ from baseline ($\Delta T_{re}$) was not significantly different between female and male subjects. Similarly, baseline $T_{sk}$ and $T_{sk}$ at the end of the exercise, baseline $T_{b}$ and $T_{b}$ at the end of the exercise (37.88 ± 0.10°C vs. 37.79 ± 0.13°C), and $\Delta T_{b}$ were not significantly different between female and male subjects. Although $\Delta HR$ tended to be greater in female than in male subjects ($p = 0.06$), baseline HR and HR at the end of the exercise (158 ± 1 vs. 158 ± 5 beats/min) were not significantly different between the two sexes.

As shown in Fig. 1, the $SR_{total}$ increased approximately equally until 30 min in both female and male subjects. Subsequently, whereas it continued increasing until the end of the exercise in male subjects, it did not change in female subjects. Therefore, the total sweating rate after 47 min was significantly lower in female than in male subjects. The $SR_{ineffective}$ was negligible during exercise in the female subjects, whereas it had begun to increase after 30 min in the male subjects. Therefore, the $SR_{ineffective}$ after 40 min was significantly smaller in the female than in the male subjects. In both sexes, the $SR_{effective}$ increased approximately equally until 30 min and then hardly changed until end of the exercise. Consequently, the sweating efficiency of female subjects was significantly higher than that of male subjects after 38 min (97 ± 1% vs. 69 ± 9% at end of the exercise).

**100-W exercise:** Although baseline $T_{re}$ was not different between female and male subjects, $T_{re}$ after 15 min was significantly higher in female than in male subjects (38.49 ± 0.08°C vs. 38.12 ± 0.12°C at the end of the exercise). However, $\Delta T_{re}$ was not significantly different between female and male subjects. Baseline $T_{sk}$ and $T_{sk}$ at the end of the exercise, baseline $T_{b}$ and $T_{b}$ at the end of the exercise, and $\Delta T_{b}$ were not significantly different between female and male subjects. Although baseline HR was not different between female and male subjects, the HR after 5 min tended to be higher in female than in male subjects (159 ± 4 vs. 150 ± 7 beats/min at the end of the exercise). Overall, the sweating responses during the 100-W exercise were similar to the responses in the 50%VO$_2$max exercise. The $SR_{total}$ after 36 min was significantly lower in female than in male subjects (5.8 ± 0.1 vs. 8.6 ± 1.0 g/m²/min at the end of the exercise). The $SR_{ineffective}$ after 38 min was significantly smaller in the female than in the male subjects (0.3 ± 0.1 vs. 2.7 ± 0.9 g/m²/min at
the end of the exercise. In both sexes, the \( SR_{\text{effective}} \) increased approximately equally until 30 min and then hardly changed until the end of the exercise (5.5 ± 0.1 vs. 6.1 ± 0.4 g/m²/min at the end of the exercise). Consequently, the sweating efficiency of female subjects was significantly higher than that of male subjects after 38 min (96% ± 4% vs. 72% ± 8% at the end of the exercise).

**Figure 1.** The time courses of total sweating rate (\( SR_{\text{total}} \)), ineffective sweating rate (\( SR_{\text{ineffective}} \)), effective sweating rate (\( SR_{\text{effective}} \)), and sweating efficiency during a cycling exercise at 50% VO\(_2\)max of female and male subjects under a hot, humid environment. Values are means ± SEM. *Significantly different between female and male subjects, \( p < 0.05 \).

**Discussion**

The novel findings of the present study using 50%VO\(_2\)max and 100-W cycling exercises in a hot, humid environment are as follows. First, the \( SR_{\text{total}} \) was significantly lower in female than in male subjects. Second, this lower \( SR_{\text{total}} \) in female subjects was caused by a lower \( SR_{\text{ineffective}} \) compared with male subjects. Finally, these findings suggested that females have better sweating efficiency (\( = \frac{SR_{\text{effective}}}{SR_{\text{total}} \times 100} \)) than do males.

In the present study, we were able to select subjects without significant sex differences in body weight and VO\(_2\)max (ml/min and ml/kg/min). As a result, we were able to set the approximately same absolute exercise intensity in both groups, even at the 50%VO\(_2\)max cycling exercise, as with the 100 W. Therefore, it is suggested that the heat production of both groups during the 50%VO\(_2\)max exercise was approximately the same, although it was not measured. Moreover, the results with respect to \( T_{\text{rel}}, T_{\text{sk}}, \) and \( T_{\text{b}} \) without sex differences in this study suggest that thermal input and heat storage of female and male subjects were approximately the same during both exercise conditions. Therefore, the group difference in the sweating response found in the present study likely reflects sex differences, because we conducted experiments with both sexes with similar heat production and thermal input, which affect the sweating response, both directly and indirectly, of female and male subjects under both exercise conditions.

The \( SR_{\text{total}} \) of female subjects was significantly lower than that of male subjects during the latter part of both types of exercise. These results support those of Avellini et al. [7] which compared the
SR\text{total} between female and male subjects who have same relative and absolute VO\text{2max}, in a hot, humidity environment (36°C, 75%RH). We reported that females show poorer sweat gland function than do males [1, 4, 5]. In other words, compared with males, the glands in females are smaller and/or female sweat glands have a lower cholinergic sensitivity. Moreover, this sex difference becomes pronounced during profuse sweating and has been observed more markedly in trained than untrained subjects [4, 5]. In the present study, the SR\text{total} of male subjects continued increasing to 9 to 10 g/m\text{2}/min at the end of both types of exercise. Meanwhile, the SR\text{total} of female subjects maintained a steady state at 5 to 6 g/m\text{2}/min after 30 min, regardless of the increase in core body temperature. This steady state was also observed even in a female subject in whom the T_{ea} at the end of the exercise reached 38.70°C. Taken together, these and previous results suggest that the sex differences in the SR\text{total} increase when profuse sweating is demanded under further hyperthermia.

Under the conditions of the present study, the SR\text{effective} calculated from the difference between the SR\text{total} and SR\text{ineffective} was approximately the same in female and male subjects in both exercises. Therefore, in the present study, the sweating efficiency (= SR\text{effective} / SR\text{total} \times 100) of female subjects was superior to that of male subjects in a hot, humid environment. In other words, although the female subjects had a lower SR\text{total} than that of male subjects, their SR\text{effective} was equal to that in male subjects because female subjects had a lower dripping SR\text{ineffective}, which is useless for regulation of body temperature. During profuse sweating and/or in a hot, humid environment, hidromeiosis—in which the sweating rate gradually decreases with time—is observed [8]. The mechanism of hidromeiosis is unclear, but it is considered that reducing the dripping SR\text{ineffective}, which does not contribute to heat dissipation, will prevent unnecessary loss of body fluid. Based on this concept, it is speculated that females may try to control body fluid loss by reducing excessive sweat that drips from the body in a hot, humid environment. From the viewpoint of body fluid conservation, because the body fluid content of females is less than that of males, the difference in heat loss response between the two sexes, as a SR\text{ineffective}, is explicable.

Conclusions
The total sweating rate and ineffective sweating rate were significantly lower in female than in male subjects. In contrast, female subjects showed the same effective sweating rate as that of male subjects. These results suggest that females have a better sweating efficiency than do males.

Acknowledgments
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References
Assessing the effects of relative humidity during low-intensity exercise in a hot environment through partitional calorimetry

Nicole E. Moyen1*, Carolyn L.V. Ellis1, Anthony B. Ciccone1, Taylor S. Thurston1, Kristen C. Cochrane1, Toby Mündel2, Lee E. Brown1, Jared W. Coburn1, Daniel A. Judelson1

1 Department of Kinesiology, California State University, Fullerton, California, USA
2 School of Sport and Exercise, Massey University, Palmerston North, New Zealand
*corresponding author: Nicole E. Moyen; nemoyen@csu.fullerton.edu

Introduction

Exercise and high ambient temperatures exacerbate cardiorespiratory and thermoregulatory strain, requiring heat dissipation to maintain thermal equilibrium. At high ambient temperatures, relative humidity (RH) might also affect physiological function and performance. The most relevant study [1] isolating the effects of RH on physiological function during exercise (time to exhaustion at 70% \( \dot{V}O_2 \text{max} \)) found increased RH decreased exercise duration; however, no differences existed among trials at fatigue in core temperature, skin blood flow, heart rate, and substrate utilization. As military personnel, some athletes, and day laborers sometimes exercise for prolonged periods in hot humid climates, investigating the independent effects of RH at low exercise intensities over longer durations also merits attention. Therefore, the purpose of this study was to use partitional calorimetry to express the effects of RH on thermoregulation during low intensity exercise in the heat.

Methods

Thirteen healthy, non-heat acclimated male recreational exercisers (age = 23 ± 2 y, mass = 83.1 ± 13.3 kg, height = 179.9 ± 5.9 cm, \( \dot{V}O_2 \text{max} = 55.6 ± 7.3 \) m\( \cdot \)kg\(^{-1}\)\cdot\)min\(^{-1}\), body fat = 12.6 ± 4.4\%) walked for 90 min at 35% \( \dot{V}O_2 \text{max} \) (calculated from a baseline treadmill \( \dot{V}O_2 \text{max} \) test) in 35 °C, completing trials at 40% RH (40RH), 55% RH (55RH), 70% RH (70RH), and 85% RH (85RH). Rectal temperature (\( T_{re} \)), skin temperatures, and environmental conditions were measured every 5 min, while pulmonary ventilation, absolute oxygen consumption, and respiratory exchange ratio were obtained every 25 min throughout trials. From these data the following variables were derived [2-5]: heat storage (\( S \)), metabolic heat production (\( H \)), convective heat exchange (\( C \)), radiative heat exchange (\( R \)), evaporative heat loss (\( E \)), evaporative respiratory heat exchange (\( E_{res} \)), convective respiratory heat exchange (\( E_{res} \)), maximum evaporative capacity of the environment (\( E_{max} \)), required rate of evaporative cooling (\( E_{req} \)), and Heat Strain Index (HSI) values. Due to subjects’ minimal contact with thermally conductive objects, conduction was deemed negligible. Air velocity was assumed to be 0.2 m\( \cdot \)s\(^{-1}\) due to airflow created by leg movement in still air [6]. Additionally, subjects drank 2 ml\( \cdot \)kg\(^{-1}\) body mass of water (~25 °C) every 15 min, which ensured hypohydration never exceeded 2% body mass loss in any trial and therefore isolated the effects of RH from changes in hydration status. Separate 4 (RH) by X (time) repeated measures ANOVAs assessed how RH affected each variable, where X represented how frequently a variable was assessed per trial; Tukey’s HSD examined pairwise comparisons for statistically significant ANOVAs. An alpha of \( p \leq 0.05 \) defined significance. All values reported are mean ± SD.

Results

Average ambient temperature remained constant across all trials (mean = 35.0 ± 0.2 °C; \( p = 0.469 \)), while average RH significantly differed among trials (40RH = 41 ± 1%, 55RH = 55 ± 1%, 70RH = 70 ± 1%, and 85RH = 84 ± 1%; \( p < 0.0005 \)).
All trial by time interactions reported below are statistically significant (p<0.0005), unless otherwise specified. $E_{\text{max}}$ decreased ~30-40 W·m⁻² with each 15% RH increase between trials; E similarly diminished by equal amounts (~30-40 W·m⁻²) as RH increased. All trials differed at each time point for $E_{\text{res}}$, incrementally decreasing as RH increased.

No differences existed between 40RH and 55RH in $S$, $T_{\text{re}}$, $H$, $C_{\text{res}}$, $C$, and $R$. Analysing $S$ in 30 min intervals revealed that no differences existed among trials for the first 30 min, and only $S$ in 85RH was greater than all trials from 30-90 min (p=0.039). Total $S$ (≤ 90 min) in 85RH was greater than 70RH, and both exceeded 40RH and 55RH. After 40 min, $T_{\text{re}}$ in 85RH significantly exceeded 70RH, and both surpassed 40RH and 55RH. $H$ in 85RH was greater than 40RH and 55RH after 30 min and greater than 70RH after 60 min. Additionally, $H$ in 70RH exceeded 40RH and 55RH after 30 and 60 min, respectively. $C_{\text{res}}$ data exactly mirrored all $H$ responses. $C$ and $R$ in 85RH exceeded all other trials, but $C$ and $R$ in 70RH were only greater than 40RH and 55RH at 90 min (both p=0.002). A main effect of trial existed for HSI, where 40RH = 55RH < 70RH < 85RH, and all values exceeded 1.0 (40RH = 1.1 ± 0.2; 55RH = 1.5 ± 0.2; 70RH = 2.1 ± 0.2; 85RH = 3.3 ± 0.6).

Discussion and Conclusion

Increasing RH incrementally decreased $E_{\text{max}}$, which consequently reduced E and $E_{\text{res}}$. Decreases in evaporative heat loss conceivably increased $S$, however, equal $S$ among trials during the first 30 min implies RH’s influence on $S$ was initially negligible. The higher total $S$ in 70RH and 85RH likely led to the higher $T_{\text{re}}$ elicited in those trials (especially since $S$ and $T_{\text{re}}$ in 85RH both exceeded 70RH), which plausibly triggered the Q₁₀ effect and increased $H$. Greater $S$ and $H$ in the higher RH trials presumably prompted the higher $C$ in attempt to dissipate more heat via non-evaporative pathways; the consistently positive $C$ values after 10 min (indicating heat dissipation) support this notion. Yet consistently negative $R$ values (indicating heat absorption) largely counteracted $C$ and limited non-evaporative heat loss to 5-10 W·m⁻², indicating increased convection only minimally offset the decreased $E$ with increasing RH. Similarly, increased $C_{\text{res}}$ plausibly resulted in attempt to maintain total respiratory heat loss as $E_{\text{res}}$ decreased with increasing RH.

As variables not directly influenced by the environment ($S$, $T_{\text{re}}$, $H$, $C$, and $C_{\text{res}}$) matched between 40RH and 55RH but significantly changed during the 70RH and 85RH trials, a RH threshold for sufficient evaporative heat loss plausibly exists. In this study, the threshold presumably occurred between 55-70% RH, as significant differences manifested among trials within this range (i.e., increased $S$, $T_{\text{re}}$, $H$, $C$, and $C_{\text{re}}$). Unexpectedly, HSI values exceeding 1.00 defined all environments as uncompensable [3]. Altogether, these data indicate the RH threshold for sufficient evaporative heat loss may not necessarily lie at the point where heat stress becomes uncompensable; instead, the RH threshold exists where decreases in $E_{\text{max}}$ cause $T_{\text{re}}$ to surpass the “set point” that triggers other compensatory responses (in this case, ~37.7 ± 0.3 °C). Literature supports this concept of a $T_{\text{re}}$ threshold, as hormone concentrations [7], muscle and skin sympathetic nerve activity [8], and oxygen consumption [9] increase exponentially after $T_{\text{re}}$ exceeds ~37.5- 38.5 °C. Determining all factors mediating this RH threshold requires further research as ambient temperature, exercise intensity, and exercise duration likely influence this threshold.

References

Cutaneous warm thresholds at rest and thermoregulatory responses during whole body warming: Comparisons between tropical and temperate indigenes

Joo-Young Lee¹,²,³*, Ilham Bakri², Titis Wijayanto², Yutaka Tochihara²
¹ Seoul National University, Seoul, Korea
² Kyushu University, Fukuoka, Japan
³ Institute of Human Ecology, Seoul National University, Seoul, Korea
*corresponding author: leex3140@snu.ac.kr

Introduction
It is widely believed that acclimatisation to a different climate is a reversible response [1]. For instance, it has been observed that heat deacclimatisation in thermal effector systems occurs in tropical indigenes who reside in temperate climates for several years. But, just as all physiological systems do not adapt at the same rate [2], adaptations do not decay at the same rate. Thermal inputs through the skin trigger feed forward temperature regulation, which leads behavioural temperature regulation. Recently, Lee and colleagues [3] reported that no heat deacclimatisation was found in cutaneous warm and cool perceptions for tropical indigenes who reside in temperate climates for up to 5 years. However, it is still unclear whether, for those tropical indigenes, heat adaptive properties in thermal effector responses to heat (e.g., sweating) can be maintained such durations in temperate climates. In addition, it is unclear whether heat deacclimatisation affects relationships between cutaneous thermal perception and thermal effector responses. Therefore, the purpose of the present study was to investigate whether (i) heat deacclimatisation, for the tropical indigenes (~5 year stay in temperate climates), occurs earlier in thermal effector responses than in cutaneous thermal perception; and (ii) to examine the relationship between cutaneous warm thresholds for perceptions at rest and thermoregulatory responses during body warming. It was hypothesised that:

1. For tropical indigenes who stayed less than 5 years in temperate climates, heat deacclimisation in thresholds for sudomotor and vasomotor responses would precede those for cutaneous warm perceptions.

2. An individual who is less sensitive to cutaneous warmth would express reduced feelings of skin wettedness, heat, discomfort and humidity in a hot environment.

Methods
Thirteen university male students, born and raised in tropical countries, participated in this study (tropical group, TRP). Tropical indigenes had lived in Fukuoka, Japan for 28 ± 20 months (range: 5 – 61 months). As a control group (temperate group, TEM), 10 Japanese male students and 1 Chinese male student participated. All temperate indigenes were born and raised in Japan or China, which are characterised by temperate climates. The height, body mass, body surface area (BSA), and body fat (%BF) ranged from 156.6 to 185.5 cm, 49.6 to 127.8 kg, 1.49 to 2.49 m², and 10.3 to 43.9%, respectively [Tropical group: 31 ± 6 y in age, 174.3 ± 7.3 cm in height, 74.2 ± 19.9 kg in body mass, 1.88 ± 0.24 m² in BSA, and 24.6 ± 9.0 %BF; Temperate group: 22 ± 2 y, 170.2 ± 9.9 cm, 63.8 ± 14.4 kg, 1.74 ± 0.21 m², and 19.7 ± 7.8 %]. There were no significant differences between the tropical and temperate groups in the above anthropometric items, except for age (p < 0.001).

Experiment 1: Cutaneous warm thresholds
Cutaneous warm body temperature thresholds were measured at 12 regions (forehead, cheek, back of neck, chest, abdomen, upper back, upper arm, forearm, palm, thigh, calf, and foot) using a thermal stimulator controlled by a Peltier element and a push-button switch (Intercross-200,
Intercross Co., Japan). Each subject wore shorts alone. The climatic chamber was maintained at an air temperature of 28°C and a relative humidity (RH) of 50% so that the participants did not feel any thermal discomfort when lying in a supine position on a portable net bed. The speed of the warming (+) of the probe was set at 0.1°C per second. The cutaneous warm threshold was defined as the skin temperature when subjects perceived the initial warmth on each body region. The cutaneous warm thresholds on the 12 body regions were area-weighted averaged. The techniques used to take the measurements were previously described by Lee et al. [3].

**Experiment 2: Whole body warming**

Subjects wore only shorts during the 2nd experiment on a different day. One hour prior to the experiment, subjects drank 200 mL of water. After body mass measurement, subjects entered the chamber controlled at 28°C $T_a$ and 50% RH, and rested on a stool for at least 40 min for stabilisation. Thereafter, all measurements were started from the 15-min baseline. The $T_a$ and RH in the climatic chamber were then increased gradually to 38°C and 70% RH during the first 10 min and maintained at the $T_a$ and RH.

Rectal temperature ($T_{re}$) was measured using a thermistor inserted 13 cm beyond the anal sphincter. Skin temperature was measured using thermistors at 15 regions (forehead, cheek, chest, abdomen, upper back, upper arm, forearm, hand, palm, finger (dorsal), finger (bottom), thigh, calf, foot and toe). Mean skin temperature ($T_{sk}$) was estimated from a modified Hardy and DuBois’ equation (1938). Local sweat rate ($\dot{m}_{sw}$) on the forehead, back, forearm and thigh was measured continuously using a ventilating capsule method hygrometer (ATMO CHART SS-100II, KANDS, Japan). Skin blood flow (SkBF) on the forehead and forearm was measured using laser Doppler flowmetry (FLO-C1, OMEGA WAVE, Japan). Blood pressure was measured at the upper arm using an automated sphygmomanometer (STBP-780B, COLIN, Japan). Mean arterial blood pressure (MAP) was calculated from systolic blood pressure (SBP) and diastolic blood pressure (DBP) [MAP = DBP + (SBP – DBP)/3]. Total body mass loss during the experiment was estimated from the body mass difference between before the protocol and immediately after, using a calibrated scale (ID2, Mettler-Toledo, Germany). Independent t-tests were conducted to test differences between TRP and TEM at the same time point. Significant differences were established at $p<0.05$. All data were presented as mean values and standard deviation (SD).

**Results**

**Comparisons between tropical and temperate indigenes**

The tropical indigenes were, on average, 3.3 and 3.5°C less sensitive to warm and hot sensations, respectively, than the temperate indigenes ($p < 0.05$, Table 1). $T_{re}$ and $T_{sk}$ at the end of exposure tended to be higher in the tropical indigenes than in the temperate indigenes ($p<0.1$), while changes in $T_{re}$ and $T_{sk}$ during heat stress did not show significant differences between groups. Total sweat rate was lower in the temperate indigenes compared to the tropical indigenes, but sweat onset time for four body regions showed no differences between the two groups. No group differences were found in HR or MAP either. Interestingly, subjective responses, such as perceived skin wettedness, thermal sensation, thermal comfort, and humidity sensation during heat stress, showed marked differences between the tropical and temperate indigenes ($p<0.05$, Table 1).
Table 1. Cutaneous thermal sensation thresholds and thermoregulatory responses: Comparisons between tropical and temperate indigenes

<table>
<thead>
<tr>
<th>Experiment 1</th>
<th>TROPICAL</th>
<th>TEMPERATE</th>
<th>P - VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm threshold (°C)</td>
<td>40.7 ± 2.0</td>
<td>37.7 ± 0.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Warm-noticeable increase (°C)</td>
<td>5.8 ± 1.9</td>
<td>2.5 ± 0.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hot threshold (°C)</td>
<td>43.8 ± 2.4</td>
<td>40.5 ± 1.6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Hot-noticeable increase (°C)</td>
<td>8.9 ± 2.3</td>
<td>5.4 ± 1.5</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 2</th>
<th>TROPICAL</th>
<th>TEMPERATE</th>
<th>P - VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{re}$ at 5-10th min (°C)</td>
<td>37.3 ± 0.4</td>
<td>36.9 ± 0.5</td>
<td>0.096</td>
</tr>
<tr>
<td>$T_{re}$ at 70-75th min (°C)</td>
<td>37.2 ± 0.3</td>
<td>37.0 ± 0.3</td>
<td>0.067</td>
</tr>
<tr>
<td>$\Delta T_{re}$ (°C)</td>
<td>0.01 ± 0.14</td>
<td>0.10 ± 0.30</td>
<td>0.455</td>
</tr>
<tr>
<td>$\bar{T}_{sk}$ at 5-10th min (°C)</td>
<td>33.1 ± 0.5</td>
<td>33.2 ± 0.5</td>
<td>0.744</td>
</tr>
<tr>
<td>$\bar{T}_{sk}$ at 70-75th min (°C)</td>
<td>36.2 ± 0.3</td>
<td>35.9 ± 0.4</td>
<td>0.091</td>
</tr>
<tr>
<td>$\Delta \bar{T}_{sk}$ (°C)</td>
<td>3.04 ± 0.44</td>
<td>2.70 ± 0.30</td>
<td>0.047</td>
</tr>
<tr>
<td>$\Delta (\bar{T}<em>{re} - \bar{T}</em>{sk})(°C)$</td>
<td>-3.03 ± 0.39</td>
<td>-2.66 ± 0.40</td>
<td>0.040</td>
</tr>
<tr>
<td>Total sweat rate (g·hr⁻¹)</td>
<td>64.1 ± 19.2</td>
<td>44.2 ± 12.5</td>
<td>0.008</td>
</tr>
<tr>
<td>Sweat onset time on the forehead (min)</td>
<td>39.5 ± 1.6</td>
<td>40.2 ± 6.9</td>
<td>0.757</td>
</tr>
<tr>
<td>Sweat onset time on the forearm (min)</td>
<td>43.8 ± 3.1</td>
<td>42.3 ± 2.4</td>
<td>0.236</td>
</tr>
<tr>
<td>Sweat onset time on the back (min)</td>
<td>45.3 ± 7.9</td>
<td>43.7 ± 7.5</td>
<td>0.624</td>
</tr>
<tr>
<td>Sweat onset time on the chest (min)</td>
<td>45.5 ± 4.2</td>
<td>44.2 ± 5.1</td>
<td>0.549</td>
</tr>
<tr>
<td>Skin blood flow on the forehead</td>
<td>127 ± 18</td>
<td>156 ± 55</td>
<td>0.092</td>
</tr>
<tr>
<td>Skin blood flow on the forearm</td>
<td>259 ± 72</td>
<td>276 ± 121</td>
<td>0.687</td>
</tr>
<tr>
<td>Heart rate at 70-75th min (bpm)</td>
<td>86 ± 9</td>
<td>86 ± 17</td>
<td>0.999</td>
</tr>
<tr>
<td>Mean arterial pressure (mm Hg)</td>
<td>88 ± 10</td>
<td>87 ± 6</td>
<td>0.724</td>
</tr>
<tr>
<td>Perceived skin wettedness at 70th min (%)</td>
<td>45 ± 34</td>
<td>79 ± 29</td>
<td>0.015</td>
</tr>
<tr>
<td>Thirst sensation at 70th min</td>
<td>1.2 ± 0.6</td>
<td>2.0 ± 0.6</td>
<td>0.050</td>
</tr>
<tr>
<td>Thermal sensation at 70th min</td>
<td>2.7 ± 0.5</td>
<td>3.5 ± 0.7</td>
<td>0.050</td>
</tr>
<tr>
<td>Thermal comfort at 70th min</td>
<td>-1.1 ± 1.1</td>
<td>-2.3 ± 1.0</td>
<td>0.015</td>
</tr>
<tr>
<td>Humidity sensation at 70th min</td>
<td>1.5 ± 0.9</td>
<td>2.5 ± 0.5</td>
<td>0.002</td>
</tr>
</tbody>
</table>

*Published in Lee et al. [3]

Relationships between cutaneous warm thresholds and thermoregulatory parameters
We did not find any significant relationships between cutaneous warm sensation threshold and $T_{re}$, $\bar{T}_{sk}$ or sweat onset time. However, total sweat rate was related to the threshold for sensation of cutaneous warming, which indicates that an individual who is less sensitive to warmth on the skin sweats more. On the other hand, subjective responses (perceived skin wettedness, thermal sensation, thermal comfort, and humidity sensation) at the end of exposure during the whole body warming showed significant relationships with their cutaneous warm threshold at rest ($p < 0.05$).
Conclusions

Two hypotheses were tested in this study. We found that the tropical indigenes in the present study maintained heat adaptive properties in their cutaneous warm perceptions despite a long duration of living outside of the tropics, whereas it seemed that their body temperature, sudomotor and vasomotor responses were transitioning to heat deaclimatisation. Cutaneous warm thresholds at rest was negatively related to perceived skin wettedness, thermal sensation, thermal comfort and humidity sensation during body warming, which indicates that an individual who is less sensitive to cutaneous warmth expressed reduced feelings of skin wettedness, heat, discomfort and humidity in a hot and humid environment. These results indicate that a direct relationship exists between cutaneous thermal input and thermal sensation/comfort. Furthermore, it is likely that the strong relationship above is maintained while heat deaclimatisation in body temperature, sudomotor and vasomotor responses are in transition.

References

Effects of duration of stay in Japan on sweating responses to hot water leg immersion in tropical Asian males

Titis Wijayanto1,2*, Sayo Toramota1, Hitoshi Wakabayashi3, Yutaka Tochihara1
1 Faculty of Design, Kyushu University, Fukuoka, Japan
2 Research Fellow of the Japan Society for the Promotion of Science, Japan
3 Faculty of Engineering, Chiba Institute of Technology, Narashino, Japan
*corresponding author: titis09@gsd.design.kyushu-u.ac.jp

Introduction
In our previous report, the tropical natives from Malaysia appeared to have smaller increases of rectal temperature during hot-water leg immersion, lower local sweat rate with a longer sweating onset time during heat exposure compared with the Japanese [1]. Those aforementioned thermoregulatory responses in the acclimatised subjects from a tropical area have been suggested to be the result of long-term heat acclimatisation on physiological functions, and indicate a superior heat tolerance in people from tropical areas [2, 3]. However, heat tolerance gained from long-term heat acclimatization was reported to decay after residing in a cooler area for some period [4, 5]. Lee et al. [5] demonstrated that the sweat onset time was shorter and the sweat volume was greater in Malaysians with longer duration of stay in Japan (for 2 to 72 months), indicating decay in the heat acclimatisation in tropical natives gradually after residing in temperate area.

The present study investigated the thermoregulatory responses to hot-water leg immersion in the tropical group who were born and raised in the tropics but moved to live in a temperate area. This study particularly clarified whether the tropical group loses their heat tolerance during passive heat exposure through residence in a temperate country.

Methods
Twelve male students from South East Asian countries (Tropical group, TR: 5 Indonesians, 4 Vietnamese, one Thais, one Filipinos, and one Malaysians) have resided in Fukuoka, Japan for 24.5±5.0 months (range: 4 to 47 months) prior to the experiment, and twelve Japanese male students who were born and raised in Japan (Japanese group, JP) participated in this study. Based on the length of stay in Japan, TR group was divided into 2 groups, TR-S (n=5) for those who had stayed in Japan for 4 to 12 months, and TR-L (n=7) with 23 to 47 months residence. There are no significant differences in the morphological characteristics between TR-S and TR-L as shown in Table 1. The purpose of the study and the procedures were explained to the subjects before they provided consent. All experimental protocols were approved by the Institutional Review Board of Kyushu University.

Table 1. Morphological characteristics (mean ± SE) of tropical Asian groups (TR-S, TR-L, TR) and Japanese group (JP)

<table>
<thead>
<tr>
<th></th>
<th>TR-S n=5</th>
<th>TR-L n=7</th>
<th>TR n=12</th>
<th>JP n=12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.4±1.9</td>
<td>27.3±1.6</td>
<td>25.6±1.3</td>
<td>24.1±0.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.5±2.4</td>
<td>173.0±2.2</td>
<td>173.1±1.5</td>
<td>169.9±1.6</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>63.4±1.9</td>
<td>63.6±2.0</td>
<td>63.6±1.3</td>
<td>59.7±2.5</td>
</tr>
<tr>
<td>BSA (m2)</td>
<td>1.80±0.03</td>
<td>1.77±0.04</td>
<td>1.78±0.02</td>
<td>1.72±0.04</td>
</tr>
</tbody>
</table>

Subjects from both groups sat on a chair in a climatic chamber set at an air temperature of 28°C and 50% relative humidity (RH) for at least 40 min then immersed their feet and calves in a hot-
water bath maintained at 42°C. A trial consisted of 10-min stabilisation and then 60-min leg immersion in a sitting position. To minimise the circadian rhythm effect on the physiological responses, the experiment session was started from 13:00 (h:min) after subjects having 2 hours initial rest in supine position in a chamber maintained at an air temperature of 28°C and 50% RH. The same experimental protocol was applied to both the TR and JP subjects. The experiment was performed in winter for both TR and JP groups.

Local sweat rate ($m_{sw}$) on the forehead (FH), upper back (UB), and forearm (FA) were measured continuously using a ventilating capsule method hydrometer. Sweating onset time (OT) was determined as the time until a prompt increase of $m_{sw}$ after the commencement of leg immersion. Total body sweat rate ($M_{sw}$) was calculated from nude body weight measured before and after leg immersion using a calibrated scale and was corrected for insensible body weight loss and then divided by total leg immersion time (60 min) and BSA.

Data and figures are presented as mean ± standard error (SE). $p<0.05$ was considered significant with $p<0.10$ indicating a tendency toward a difference.

Results and Discussion

$M_{sw}$ during 60 minutes of leg immersion showed a tendency to be lower in TR than in JP (71.05 ± 4.93 g/m²/h and 88.33 ± 6.99 g/m²/h; $p=0.06$). $m_{sw}$ on the forehead during 60 minutes of leg immersion tended to be lower in the TR than in the JP group ($p=0.07$, Figure 1). Meanwhile, $m_{sw}$ on the forearm and upper back during 60 minutes of leg immersion showed no differences between the TR and the JP group ($p>0.05$). Sweating OT on the upper back after the start of leg immersion was longer in the TR group than in the JP group ($p=0.04$), whereas there were no differences between the two groups in OT for the forehead ($p=0.16$) or for the forearm ($p=0.42$).

![Figure 1. Local sweat rate during 10 minutes of stabilisation and 60 minutes of leg immersion in the tropical (TR) and Japanese (JP) groups. (A) Forehead; (B) Upper back; (C) Forearm. † $p<0.10$ between TR and JP.](image-url)

There were no statistical differences in $m_{sw}$ on the FH, UB, and FA between TR-S and TR-L. The $m_{sw}$ on the FH tend to be lower in TR-S and TR-L groups than in JP group ($p=0.07$). The $M_{sw}$ during 60 minutes of leg immersion was on average less in TR-S group (63.1 ± 8.10 g/m²/h) than in TR-L group (79.0 ± 6.1 g/m²/h). However, there was no significant difference in $M_{sw}$ between the TR-S and TR-L groups ($p=0.31$). $M_{sw}$ tended to be lower in the TR-S than in the JP group ($p=0.06$), whereas there was no significant difference between the TR-L and the JP groups ($p=0.23$).

OT for the forehead and upper back was significantly longer in the TR-S than the TR-L group ($p<0.01$ for the forehead and $p=0.03$ for the upper back), whereas OT for the forearm tended to be
longer in TR-S than in TR-L (p=0.07). The TR-S group had a significantly longer OT on the forehead and upper back compared with the JP group (p=0.01 for the forehead and p<0.001 for the upper back), whereas there were no differences for the comparison between the TR-L and JP groups. OT on the forehead (r = −0.73, p<0.01; Figure 2) and upper back (r = −0.66, p=0.02; Figure 2) were negatively correlated with duration of stay in Japan, and they decreased as the duration of stay in Japan increased (from 4 to 47 months). Prolonged residence in temperate areas by tropical natives modified the sweating mechanism in the direction typical for temperate natives, characterized by an earlier onset of sweating [4, 5].

![Graphs showing relationship between duration of stay in Japan and sweating onset time](image)

**Figure 2.** Relationship between duration of stay in Japan and sweating onset time. (A) Forehead; (B) Upper back; and (C) Forearm.

For the $\dot{M}_{sw}$, significant relationships were found between duration of stay in Japan and the $\dot{M}_{sw}$ (r = 0.59, p<0.05; Figure 3). These findings corroborate the study of Saat et al. [4] and Lee et al. [5], who reported changes in sweating reaction as the duration of stay in Japan increased.

![Graph showing relationship between duration of stay in Japan and total sweat rate](image)

**Figure 3.** Relationship between duration of stay in Japan and total sweat rate after 60 min of leg immersion.

**Conclusions**

From the findings of the present study, the sweating responses to passive heat exposure of tropical natives who were born and raised in the tropics but had stayed in Japan for up to 47 months decayed during their prolonged stay in this temperate area, signifying a time-dependent characteristic. The decay in sweating response after having stayed in temperate area seen in the present study indicates that heat acclimatisation in tropical natives reflects physiological adjustments to environmental condition rather than genetic factors.
References


The effect of surface condensation on mine shelter occupant heat stress

Mark A. Hepokoski\textsuperscript{1*}, Mark D. Klein\textsuperscript{1}, Allen R. Curran\textsuperscript{1}

\textsuperscript{1}ThermoAnalytics, Inc., Calumet, MI, USA
*corresponding author: Mark.Hepokoski@ThermoAnalytics.com

Introduction

Underground mine refuge shelters are designed to provide breathable air and sustenance for miners in the event of a mining accident. Once inside the shelter, the greatest risk to the miners’ safety is the prolonged exposure to high temperature and humidity levels. To assess this risk, a thermal model was developed to predict the temperature and humidity within the shelter resulting from metabolic heating; evaporation due to sweat and respiration; moisture and heat from the air cleaning equipment; and heat transfer (conduction, convection, radiation, condensation) with the shelter walls. The miners’ predicted body core temperature was used to evaluate the potential for heat stress related injury [1].

Methods

A thermal model of an inflatable tent-style refuge chamber was created containing 26 occupants, each modelled as a separate instance of a segmental thermoregulation model. A human thermoregulation model was used not only to simulate the interaction of each human with the shelter environment, but also to provide an assessment of the magnitude of heat stress incurred [2]. The sensible heat transfer from each human was explicitly modelled by accounting for radiation to the surrounding surfaces (including to the other humans), natural convection to the air, and conduction to the mine shelter floor.

Shell element geometry was used to represent both the humans and the shelter itself (Figure 1). The surrounding mine seam was also represented with a geometric mesh, although not shown in Figure 1. The shelter was modelled as 0.5-mm thick polyurethane; a nominal contact resistance of 0.01 m\textdegree K/W was assumed between the humans and shelter floor, and between the shelter bottom and mine floor. The humans were subjected to the shelter environment for four days, with each human starting from its ideal thermo-neutral state.

![Figure 1. Shell-element geometric representation of a mine shelter with human occupants](image)

The shelter and surrounding mine seam were initialized to the ambient temperature of the mine (18 °C). In addition to the heat generated by the occupants, heat from the CO\textsubscript{2} scrubber was imposed on the air inside of the tent.

Given the small size of the shelter and the number of (sweating and respiring) humans, a moisture model was developed to keep track of the changing humidity of the air by calculating the transient...
moisture storage rate, $\dot{m}_{\text{stored}}$. The moisture storage rate was determined by performing a mass balance at each time interval during the simulation (Equation 1).

Mass Balance:

$$\dot{m}_{\text{stored}} = \sum_{i} \left( \dot{m}_{\text{sweat},i} + \dot{m}_{\text{respiration},i} + \dot{m}_{\text{scrubber},i} \right) - \omega \cdot \dot{m}_{\text{air, exiting}} - \sum_{j} \dot{m}_{\text{condensation}} \quad (1)$$

The moisture entering the shelter environment was calculated from the sum of the mass flow rates due to the evaporated sweat, $\dot{m}_{\text{sweat}}$, and respiration, $\dot{m}_{\text{respiration}}$, from each human, and the latent heat output from the air scrubber (per person), $\dot{m}_{\text{scrubber}}$. The exit moisture mass transfer rate was evaluated from the product of the humidity ratio of the air within the tent and the mass of the dry air leaving the tent, $\omega \cdot \dot{m}_{\text{air, exiting}}$.

Shelter air temperature is calculated by accounting for convective heat transfer with all surfaces in the shelter. Relative humidity, $\phi$, is calculated from the air temperature and the moisture storage rate and then is subsequently used to determine whether evaporation or condensation was occurring.

A simple condensation model was developed to approximate the thermal effect of condensation on the surfaces within the mine shelter (Equation 2).

Condensation Model:

$$\dot{m}_{\text{condensation}} = (\phi \cdot P_{\text{sat, air}} - P_{\text{sat, surface}}) \cdot h \cdot LR \cdot A_{\text{surface}} \quad (2)$$

The condensation rate, $\dot{m}_{\text{condensation}}$, is evaluated from the vapour pressure difference between the air, $P_{\text{air}}$, and the surfaces, $P_{\text{sat, surface}}$; the product of the local convection coefficient $h$ and Lewis Ratio $LR$; and the surface area $A_{\text{surface}}$ exposed to the condensing vapour (Equation 2). When this potential difference is positive, the surface dew point temperature is reached, and condensation will occur.

For the scenario being modelled, evaporation from the shelter surfaces did not need to be considered. This was due to the shelter’s completely dry initial condition as well as the combination of high humidity and rising air temperature that occurred during the simulation.
Results

Transient heat rates and temperatures were predicted for the shelter and its occupants. The surface (shelter, clothing and skin) temperatures are shown in Figure 2.

![Surface temperatures within the mine shelter.](image)

Figure 2. Surface temperatures within the mine shelter.

The air temperature and relative humidity within the shelter quickly rise in the first few hours, exceeding 30 °C and 95%, respectively, at the end of the first 12-hour period (Figure 3). The air subsequently remains nearly saturated by the ongoing influence of the humans and the CO₂ scrubber, which further impacts the humans' evaporation rates and thus their survivability.

![Temperature and relative humidity inside the mine shelter (initial temperature = 18 C).](image)

Figure 3. Temperature and relative humidity inside the mine shelter (initial temperature = 18 C).

Air temperature is affected both by the increasing surface temperatures as well as by condensation occurring on the mine shelter structure’s surfaces, which include the support beams, walls and floor. Neglecting condensation for the set of conditions modelled would result in an error of approximately 7 °C in the predicted air temperature by the end of the simulation (Figure 4).

![Effect of condensation modelling on tent interior air temperature](image)

Figure 4. Effect of condensation modelling on tent interior air temperature.
More importantly, in the absence of a condensation model, the assessment of the shelter's viability in terms of thermal burden can be overestimated. In other words, it can appear that the human core temperature is maintained below acceptable limits; however, when condensation is considered, it becomes apparent that the thermal environment is not safe for human occupation (Figure 5).

![Figure 5. Comparison of mine shelter safety in terms of core temperature including differences obtained between simulations performed with and without a condensation model](image)

**Conclusion**

When assessing the thermal burden of an enclosed and poorly ventilated room with human occupants, it is important that a proper humidity model is developed to track the moisture in the air. A simple technique has been presented for tracking the moisture storage rate in the air (due to sweat evaporation, respiration and in this simulation a CO₂ scrubber) along with a model accounting for latent heat transfer. The importance of modelling condensation is demonstrated from a human safety perspective.

**References**

Thermoregulatory responses to hot water leg immersion of tropical Asian and Japanese males in summer and winter

Titit Wijayanto¹,²*, Sayo Toramoto¹, Yasuhiko Maeda¹, Hitoshi Wakabayashi³, Yutaka Tochihara⁴

¹Faculty of Design, Kyushu University, Fukuoka, Japan
²Research Fellow of the Japan Society for the Promotion of Science, Japan
³Faculty of Engineering, Chiba Institute of Technology, Narashino, Japan
*corresponding author: titis09@gsd.design.kyushu-u.ac.jp

Introduction

Earlier reports indicate that people living in temperate areas that have four different seasons, such as Japan, clearly show seasonal variations in thermoregulatory responses to identical heat [1, 2] and cold stress [3]. During heat stress, residents of temperate areas were reported to sweat less [1, 2, 4] and incur greater increases of core temperature [1, 5] in winter compared to those in summer. Meanwhile, tropical indigenes, born and raised in the tropics, are reported to have their heat tolerance decayed after moving to a temperate area. Lee et al.[6] demonstrated that the sweat onset time was shorter and the sweat volume induced by achetylcholine was greater in Malaysians with longer duration of stay in Japan for 2 to 72 months, indicating loss of heat tolerance in tropical subjects. It is believed that heat tolerance gradually disappears because it was not maintained by repeated heat exposure.

In our previous study, we reported that tropical natives from Southeast Asia showed decay of acclimatisation in their sweating responses to heat after they moved and resided in Japan between 4 to 47 months [7]. Lee et al. [6] suggested that prolonged residence in temperate areas by tropical natives modified the sweating mechanism in the direction typical for temperate natives. It was considered that decay of heat acclimatisation in tropical natives occurred because it was not maintained by repeated heat exposure [8]. However, it should be considered that after moving to a temperate area with four different seasons, tropical natives must be experiencing seasonal changes in their daily life. From the aforementioned, the purpose of the present study was to investigate seasonal variation effects on thermoregulatory responses to hot-water leg immersion in tropical Asians residing in Japan. We hypothesized that after residing in a temperate area, Japan, the tropical natives might show seasonal variation in physiological responses to heat.

Methods

After approval of the experimental protocol that conforms to the principles of Helsinki Declaration from the Institutional Review Board of Kyushu University, twelve male students from South East Asian countries (Tropical group, TR: 5 Indonesians, 4 Vietnamese, one Thais, one Filipinos, and one Malaysians) who had been residing in Fukuoka, Japan for 22.5 ± 5.0 months (range 4 to 47 months) before the experiment, and ten Japanese male students (Japanese group (JP)) were enrolled in the study. The TR subjects were born and raised in the tropical countries, defined as countries with hot and humid weather and with two seasons (dry and rainy). Subjects' morphological characteristics are shown in Table 1.
Table 1. Subjects’ morphological characteristics (mean ± SE) in summer (SM) and winter (WN)

<table>
<thead>
<tr>
<th></th>
<th>Tropical (TR), n=12</th>
<th>Japanese (JP), n=10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>Winter (WN)</td>
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<tr>
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<td>Winter (WN)</td>
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<tr>
<td>Age (years)</td>
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<td>Height (cm)</td>
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<td>Body mass (kg)</td>
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<td>BSA (cm²)</td>
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<td>1.78±0.02</td>
</tr>
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</table>

The experiments were carried out on the end of July - August (Summer, SM) and January - early February (Winter, WN). Subjects from both groups sat on a chair in a climatic chamber set at an air temperature of 28°C and 50% relative humidity (RH) for at least 40 min then immersed their feet and calves in hot water maintained at 42°C. A trial consisted of 10-min stabilisation and 60-min leg immersion in a sitting position. To minimize the circadian rhythm effect on the physiological responses, the experiment session was started from 13:00 (h:min) after subjects having 2 hours initial rest in supine position in a chamber maintained at an air temperature of 28°C and 50% RH.

We measured rectal temperature ($T_{re}$), mean skin temperatures ($T_{sk}$) from 10 body sites (forehead, upper back, chest, abdomen, upper arm, forearm, hand, thigh, calf, and foot), and total sweat rate ($M_{sw}$) determined from the change of body mass measured before and after leg immersion. Statistical analyses were conducted using repeated-measures ANOVA and Student’s paired t-tests, with a Bonferroni correction where appropriate. Data are presented as the mean ± SE with significance established at $p<0.05$.

Results and Discussion

There were no significant differences in the morphological characteristics between SM and WN in both groups (Table 1).

Both TR and JP showed higher initial $T_{re}$ in SM compared with those in WN ($p<0.05$; Fig 1). In comparison between TR and JP, TR showed higher initial $T_{re}$ in both SM and WN than JP ($p<0.05$). Initial $T_{sk}$ was higher in SM than in WN for both TR and JP groups. No significant differences were observed in $T_{sk}$ after 60 min of leg immersion in any seasons for both TR and JP group.

Higher pre-exposure core temperature will increase the convective heat dissipation as the core-to-skin temperature gradient increases and suppresses the increase of core temperature [9, 10]. According to the law of initial value, the higher the initial value of a physiological process, the smaller the response to function-raising is. Therefore, both groups suppressed the increase of $T_{re}$ during leg immersion more in SM than in WN ($p<0.05$; Table 2).
Figure 1. Rectal temperature ($T_{re}$) and mean skin temperature ($T_{sk}$) of tropical (TR) and Japanese (JP) groups during 10 min of stabilization and 60 min of leg immersion in summer (SM) and winter (WN). a $p<0.05$ between TR(SM) and TR(WN); b $p<0.05$ between JP(SM) and JP(WN); c $p<0.05$ between TR and JP in summer; d $p<0.05$ between TR and JP in winter.

As shown in Table 2, there were seasonal variations in $\Delta T_{re}$ and $\Delta T_{sk}$ for both groups. $\Delta T_{re}$ and $\Delta T_{sk}$ were significantly smaller in SM than in WN for both groups ($p<0.05$). There were significantly smaller $\Delta T_{re}$ in all seasons for TR group compared to the JP group ($p<0.05$), illustrating that the TR group had superior heat tolerance which might be induced by long residence in a tropical climate.

Table 2. Change in rectal temperature, total sweat rate and sweat sensitivity

<table>
<thead>
<tr>
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<th>Tropical (TR), n=12</th>
<th>Japanese (JP), n=10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Summer (SM)</td>
<td>Winter (WN)</td>
</tr>
<tr>
<td>$\Delta T_{re}$ ($^\circ$C)</td>
<td>0.26±0.04$^{a,b}$</td>
<td>0.53±0.05$^b$</td>
</tr>
<tr>
<td>$\Delta T_{sk}$</td>
<td>0.83±0.11$^a$</td>
<td>1.76±0.05</td>
</tr>
<tr>
<td>$M_{sw}$ (g m$^{-2}$ h$^{-1}$)</td>
<td>82.98±5.23</td>
<td>71.74±4.97$^b$</td>
</tr>
<tr>
<td>Sweat sensitivity (g m$^{-2}$ h$^{-1}$ °C$^{-1}$)</td>
<td>451.5±104.50$^a$</td>
<td>153.40±20.23</td>
</tr>
</tbody>
</table>

$\Delta T_{re}$ change in rectal temperature; $M_{sw}$ total sweat rate

There were no significant differences between $M_{sw}$ after 60 min of leg immersion in SM and WN for both TR and JP groups ($p>0.05$). There were no significant differences in $M_{sw}$ between groups in SM, but there was a significantly lower $M_{sw}$ for TR group than that for JP group in WN ($p=0.04$). Sweat sensitivity that was defined as total sweat rate ($M_{sw}$) per changes in $T_{re}$ ($\Delta T_{re}$) was greater in SM than in WN for both TR group ($p<0.05$) and JP group ($p<0.10$). However, although the TR group on average had nearly double the sweat sensitivity in SM than JP group, no significant difference was found ($p=0.13$, Table 2).

Ihzuka et al. [5] suggested that heat tolerance was improved in summer by repeated exposure to heat and the heat-acclimatised individuals showed superior heat tolerance during summer. We considered that the subjects in TR group experienced heat exposure before migrating to temperate area. During their stay in a temperate area, these subjects experienced the same exposure during summer, which enabled them to reacclimatise to heat exposure. Therefore, body
temperature regulation for heat dissipation can reach the same level as during their stay in their origin. This might explain the reason the TR group could maintain smaller $\Delta T_{re}$ and greater sweat sensitivity during heat stress through residence in temperate area.

Conclusions
After having resided for between 4 and 47 months in a temperate area such as Japan, subjects in the TR group showed seasonal variations in their body temperatures ($T_{re}$ and $\bar{T}_{sk}$) before exposure and in their thermoregulatory responses during hot-water leg immersion ($\Delta T_{re}$, $\Delta T_{sk}$ and sweat sensitivity). Heat tolerance of subjects in both groups was improved in summer by repeated exposure to heat during summer and it might be the reason why TR group could have superior heat tolerance through residence in temperate area.

References
NOVEL STRESS CONDITIONING IN HEALTH AND PERFORMANCE

Novel stress conditioning for health and performance

James D. Cotter
University of Otago, Dunedin, New Zealand
* corresponding author: jim.cotter@otago.ac.nz

Summary
Many forms of stress can acutely impair yet also chronically improve the structures and functions which underpin human health and physical performance; depending on the severity, pattern and frequency of exposure to such stress, and the individual’s status. For example, oxidative stress and heat stress can each degrade cellular proteins, and also promote production of new proteins to improve health and movement capabilities. This symposium is intended to highlight the rationale and possibilities in using novel approaches (i.e., targeted stressors) to promote health and improve human capability, or help prevent illness or disease.

Exercise is a complex stressor, and its many forms of strain drive adaptation
An under-appreciated feature of exercise training for health or fitness outcomes is that it contains several powerful stressors which are important and useful (see Figure 1). Each stressor can induce one or more forms of strain, e.g., heat stress causes higher tissue temperatures, and more dehydration and glycogen utilisation. In turn, strain causes fatigue. Thus, people are often advised by institutions and commercial interests that these ‘adverse’ acute effects of exercise-, environmental- and/or nutritional-stressors should be attenuated (through the use of avid rehydration, energy drinks, multivitamins, appropriate clothing, etc). This may facilitate exercise or work performance (e.g., in sporting competition or occupational activity), but the purpose of training/conditioning is to adapt. Adaptation is driven by strain - not stress per se - and of several types. So, useful adaptations are suppressed by behaviours aimed at reducing strain.

![Figure 1. Schematic illustration of the multi-factorial nature of adaptation. The key point is that strain – not stress per se – drives adaptation, and many forms of strain can mediate these adaptations. See text for details.](image)

Mechanical tension is well recognised as driving adaptation in many tissues, including the vasculature. Hypoxia also drives useful adaptations for endurance performance and possibly health [1], but less certain is the role of different mechanisms in ergogenic outcomes or the net
balance between desirable and harmful health-related outcomes. High tissue temperatures have anabolic and stress-protective effects in skeletal and cardiac muscle [2], and increase blood volume even in well trained athletes – an effect closely related to the increased exercise capacity [3]. Similarly, exercise training with low energy substrate stores can improve metabolic adaptations in muscle, but performance outcomes remain unclear [4]. Finally, oxidative stress has important roles in muscle adaptations [5]. Separate stressors can – to some extent - also drive the same functional adaptations, through shared and separate pathways.

So why not just exercise to optimise health and performance?
It might be reasoned that novel conditioning strategies are unwarranted because exercise contains all of these stressors, is so readily achieved, and is able to be periodised to optimise the various strain stimuli for adaptation. That is fair. However, one benefit in having such discussion is in appreciating this elegant complexity of exercise in conditioning. Furthermore, not everyone can exercise, whereas stressors such as heat or hypoxia (ischaemia) can be applied to anyone, at whole-body or localised levels. Finally, exercise can be used in conjunction with nutritional and environmental stressors to further improve fitness. Historically this has mostly been limited to hypoxia – i.e., ‘altitude training’ – although the principal applies to all stressors that drive useful forms or magnitudes of strain.

Acknowledgements
These ideas reflect discussions over many years with valued colleagues and students; notably, Samuel Lucas, John Hawley, Jørn Helge, Nancy Rehrer, Philip Ainslie and Kate Thomas. Thank you also to other panel members, who have so willingly contributed to this mini-symposium: Michael Tipton, Damian Bailey and Martin Barwood.

References
Heat stress as cardiovascular conditioning

Kate N. Thomas1,2*, André M. van Rij1, Samuel J.E. Lucas2,3, James D. Cotter2
1 Department of Surgical Sciences, University of Otago, Dunedin, New Zealand
2 School of Physical Education, University of Otago, Dunedin, New Zealand
3 Department of Physiology, University of Otago, Dunedin, New Zealand
*corresponding author: kate.thomas@otago.ac.nz

Introduction
Exercise is a highly effective means of preventing and treating Cardiovascular Disease (CVD) via a range of effects, and has numerous other physiological and psychological benefits. For population groups with a compromised ability to exercise, an alternative form of “stress conditioning” that retains important strain-inducing features of exercise would be useful. Heat is an important component stressor of exercise; it alone can drive improvements within cardiac and skeletal muscle, the vasculature, plasma volume expansion, and transcription of heat shock proteins. However, the thermal profiles of exercise versus passive heat stress need direct comparison (within the same individuals). Therefore, the aim of this study was to compare the cardiovascular strain induced by a single bout of traditionally recommended exercise, to that induced by a single bout of passive heating, in healthy adults.

Methods
Ten healthy, recreationally-active participants (8 male, 2 female; age: 27 ± 5 y; height 181 ± 8 cm; body mass 81 ± 8 kg) completed one session of exercise (30 min at 65-75% predicted heart rate maximum) and one passive heat session (30 min immersed up to the waist in water at 42°C) in a randomised order, at least three days apart. Heart rate (HR), blood pressure (BP), stroke volume (SV), cardiac output (Q), core temperature (oesophageal, Tc), muscle temperature (medial gastrocnemius at 2 cm depth, Tm) and skin temperature (thigh, calf, chest and back) were measured before, during (where practicable) and after the stress intervention.

Results and Discussion
While HR increased during the bath (by 38 ± 10 beats·min⁻¹) and exercise (by 87 ± 10 beats·min⁻¹), the increase was ~2 fold greater in exercise (p < 0.001; 95%CI: 40 to 57 beats·min⁻¹). In contrast, Tc increased approximately twice as much during the bath than the exercise (+1.3 ± 0.4°C from baseline vs. +0.6 ± 0.4°C, p < 0.001; CI: 0.3 to 1.0°C), and Tm also rose more in the bath (measured within 5 min of exercise cessation; +5.0 ± 1.0°C vs. +3.9 ± 1.0°C, p = 0.01; CI: 0.2 to 2.1°C).

Similarly, the heat impulse was ~3 fold larger during the bath for Tc (19.0 ± 5.8 vs. 6.0 ± 9.4 °C·min⁻¹, p = 0.002), and 1.5 fold larger for Tm (44.1 ± 2.8 vs. 30.4 ± 8.9 °C·min⁻¹, p = 0.002). Since the temperature of the heart and skeletal muscle can mediate physiological adaptations [1, 2], these data indicate that the passive heat stimulus holds potential to induce a level of adaptation to improve cardiovascular health.

The bath trial caused a larger post-stress hypotension than did exercise (-8 ± 8 vs. 0 ± 12 mm Hg); although not reliably so, due likely to the large variability in the post-exercise responses (p = 0.16; CI: -4 to 19 mm Hg). As hypotension appears necessary for stimulating post-exercise-induced expansion of plasma volume [3], heat stress may be a useful stimulus to induce this beneficial cardiovascular adaptation. Importantly, Convertino et al. [4] demonstrated that 40% of the exercise-induced plasma volume expansion could be accounted for by thermal effects alone. Therefore, if the passive heat-induced hypotension was translated into increased plasma volume, this form of conditioning may provide advantages of greater body fluid for thermoregulatory control, as well as larger intra-vascular volume for increased stroke volume and lower heart rates.
Conclusions
Heat, a component stressor of exercise, has potential to be used as a stand-alone stressor, at least as a way to induce transitory hypotension and increased core and muscle temperature. Future research should address its application to groups of people whom for whatever reason, are unable to exercise, as well as on other measures of cardiovascular health; for example, arterial function, and exercise capacity.

References
The acute cardiovascular and thermoregulatory effects of hot yoga

Ashley P. Akerman1*, Samuel J.E. Lucas1,2, Susie Ferkins1, James D. Cotter1
1 School of Physical Education, University of Otago, Dunedin, New Zealand
2 Department of Physiology, University of Otago, Dunedin, New Zealand
*corresponding author: Ashley.akerman@otago.ac.nz

Introduction
A plethora of evidence supports the notion that repeated heat stress provides sufficient physiological stimulus for adaptation in the heart [1,2], vasculature [3], blood [4], skeletal musculature [5], and thermoregulatory capacity [6]. The heat acclimated phenotype also affords secondary tolerance to combat novel acute stressors (cross-tolerance); primarily due to reprogramming of gene expression and post-translational modifications within shared pathways [7].

The combination of exercise and heat stress can potentially provide the most severe cardiovascular challenge (apart from haemorrhage) to humans. Although moderate- to high-intensity exercise has traditionally been shown to perturb cardiovascular function, a low metabolically challenging exercise, albeit utilising a large muscle mass, may provide an effective physiological stimulus for adaptation in untrained subjects [8]; furthermore this form of stress could be inherently useful in populations unable to tolerate high intensity exercise (e.g., coronary heart disease and peripheral vascular disease patients). Although recent data indicates that Hot Yoga can benefit psychological parameters [9], there is little exploration of the physiological stimulus or adaptation afforded by such exercise. Therefore, the current study investigated the cardiovascular, thermoregulatory, and perceptual responses during and for 24-h following a single bout of Hot Yoga.

Methods
A controlled-trial, crossover design was used for this ethically approved study. Subjects were recruited from a healthy, recreationally active student population (4 male, 4 female; mean ± SD; age, 21 ± 2 years; height, 173 ± 9 cm; mass, 73.9 ± 9.6 kg). Subjects acted as their own time controls ~1 week prior to/after the experimental trial. Time of day, diet, and activity patterns were standardised between trials, and trial order was assigned randomly and counter-balanced. During the experimental trial, subjects participated in a 90-minute session of yoga in a heated environmental chamber (40°C, 70% rh) dressed in shorts and a t-shirt, without the aid of fan-cooling. Heart rate (HR), blood pressure (BP), core temperature (rectal, Tre), weighted (6 sites) skin temperature (Tsk), perceptual scales (exertion, thermal sensation, and perceived temperature), and blood parameters (haematocrit, Hct; and haemoglobin, Hb) were measured before, during (where appropriate) and after (recovery) each trial. Changes in body mass were adjusted for fluid consumption and urine output, being indicative of sweat loss.

Results
During the 90 minutes of Hot Yoga, Tre was elevated and reached a peak value >1.5°C higher than control (mean difference ± SD; 1.62 ± 0.26°C; 95% CI: 1.48 – 1.76°C). The largest elevation in Tre during the experimental trial was observed at the 60th minute (38.83 ± 0.49 vs. 37.26 ± 0.30°C; Hot Yoga vs. time control, respectively; p=0.01). During the trial, 6 of 8 subjects’ Tre increased above 39°C, and 3 subjects exceeded 39.5°C, and 1 subject reached 40°C. Skin temperature rose over the duration of the protocol (~5.5°C increase in peak skin temperature) that approached significance (p=0.09). Perceptions of exertion, sensation, and body temperature rose linearly across the first 60 minutes, with the largest difference between experimental and control groups in the 60th minute
[exertion (17 ± 4), perceived temperature (12 ± 1), and thermal sensation (4 ± 1)]. Thereafter, all perceptions slowly declined for the remainder of the session. Surprisingly, plasma volume changes indicated no significant difference between trials (all \( p > 0.75 \)), and thus no haemoconcentration across the 90-minute Hot Yoga session, or rebound hypervolaemia.

The acute bout of Hot Yoga produced a significantly higher HR (\( p = 0.001 \)) over the 90-minute session compared to control, reaching a peak value of 143 ± 13 beats·min\(^{-1}\) (difference vs. time control: 71 ± 18 beats·min\(^{-1}\); CI: 58 - 84 beats·min\(^{-1}\)) and remaining elevated after 1 hour of recovery. The highest recorded HR coincided with a concomitant rise in systolic blood pressure, peaking at 145 mm Hg (difference vs. time control: 17 ± 13 mm Hg; CI: 25 – 8 mm Hg; \( p = 0.008 \)). In the subsequent 20 hours following the trial, diastolic blood pressure remained lower than that of control (Table 1; \( p = 0.06 \)), whereas HR remained elevated following the stress (Table 1; \( p = 0.06 \)).

Table 1. Mean ± standard deviation, and 95% confidence intervals highlighting the difference in blood pressure recovery measures, in the Hot Yoga vs. Time Control trial

<table>
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<tr>
<th>Recovery (hours)</th>
<th>Systolic BP (mm Hg)</th>
<th>Diastolic BP (mm Hg)</th>
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<td>5 ± 18</td>
<td>7 ± 15</td>
</tr>
<tr>
<td></td>
<td>-1 to 25</td>
<td>-18 to 18</td>
<td>-32 to 11</td>
<td>-11 to 21</td>
<td>-6 to 21</td>
</tr>
<tr>
<td>20</td>
<td>6 ± 16</td>
<td>-1 ± 13</td>
<td>-9 ± 9</td>
<td>2 ± 13</td>
<td>7 ± 10</td>
</tr>
<tr>
<td></td>
<td>-8 to 21</td>
<td>-12 to 10</td>
<td>-17 to -1</td>
<td>-10 to 13</td>
<td>-1 to 16</td>
</tr>
</tbody>
</table>

Discussion

Whilst the current low intensity, low metabolically challenging exercise is not likely to independently perturb cardiovascular function, the impact of added high thermal stress is a probable factor driving the increase in HR, blood pressure, core and skin temperature. Heat stress per se challenges thermoregulatory homeostasis by decreasing the core-to-skin gradient for heat loss, prompting a redistribution of blood flow to the periphery to potentially aid in evaporative heat loss at the skin surface. Protocols utilising high thermal stress, and the concomitant rise in peripheral blood flow with repeated heat exposure per se, have indicated that the consequential shear stress and hyperaemia stimulate vascular adaptation; particularly related to the endothelium and nitric oxide mediated vasodilation [3]. Although our 24-hour recovery data provided little insight (no hypotension or rebound plasma volume expansion) into the potential role for acute cardiovascular adaptation, we are continuing to investigate the cardiovascular recovery profile following hot yoga.
Increases in cardiac contractility, and systolic parameters are frequently reported during heat stress [1]. With the high thermal strain induced in the present experimental trial, and subsequent dehydration (evidenced by an increase in urine specific gravity, and decrease in body mass), it is possible that dehydration *per se* may have affected cardiovascular dynamics [10]. Whilst this is known to occur after an acute bout of passive heat stress, and heat stress and exercise, little is known about the changes in cardiac structure and function following a prolonged protocol of heat exposure in humans. Although pioneering work has highlighted areas of adaptation in short-term heat acclimation and long-term heat acclimation in untrained rats [1], these findings are yet to be transferred to a human population.

**Conclusion**

Collectively our findings illustrate that the high thermal demand and physical strain induced by participation in this form of combined exercise and heat stress could induce physiological adaptations similar to those of higher intensity exercise. The stress placed on the thermoregulatory system, and concomitant changes in physiological function could therefore lead to beneficial adaptation in the heart, vasculature, and for fluid regulation. Our further research aims to examine this possibility.

**References**

THERMOREGULATION: BLOOD FLOW AND AGEING

Circadian rhythm in thermoregulatory responses to passive heat stress: Effects of aging

Siyeon Kim¹, Hyung-Seok Jeon², Joon-Hee Park², Jae-Young Kim³, Joo-Young Lee¹,²*
¹Department of Clothing and Textiles, Seoul National University, Seoul, Korea
²Institute of Human Ecology, Seoul National University, Korea
³College of Medicine, Han Yang University, Seoul, Korea
*corresponding author: leex3140@snu.ac.kr

Introduction
It is known that a circadian rhythm in internal body temperature at rest exists. It is also well-agreed that sudomotor and vasomotor responses during passive heat stress follows the same circadian pattern as internal body temperature. Interestingly, while the sensitivity of vasodilation to passive heat stress [1] and body temperature thresholds for the onset of sweating illustrate a circadian rhythm [2], the slope of sweat rate to internal body temperature appear not to change over the 24-h day [2,3].

Circadian rhythm in body temperature varies with age, with older adults exhibiting a deterioration in circadian rhythm [4]. This may be attributable to the body clock, the effector pathways or irregulations in lifestyle. The appearance of reproducible and stable circadian rhythms of high amplitude and with a characteristic phasing with respect to other biological processes and the external environment, is believed to guarantee an optimal functioning of the biological system, with maximum efficiency and performance [4]. However, there are few reports exploring the effects of aging on circadian rhythms in thermoregulatory responses during passive heat stress in comparison to the responses of young adults. The majority of deaths in Korea resulting from heat waves (instances where the temperature remains above 35°C) occur among older people, thus investigating the diurnal rhythm in temperature regulations to passive heat stress of the elderly is important.

Therefore, the purpose of the present study was to investigate the effects of aging on thermoregulatory responses to passive heat stress according to circadian rhythms. The present study hypothesized the following: 1) aging reduces the amplitudes of circadian rhythm in body temperature during passive heat stress, 2) circadian rhythms in sudomotor responses are not found for the elderly group, and 3) the onset of sudomotor responses to passive heat stress in the aged group is delayed when compared to the responses of a young group.

Methods
Subjects and experimental conditions
Nine young male subjects (19.9 ± 1.4 yrs; all owl types - approx. 1~2am sleep and 8~9am getting up) and eight older male participants (71.3 ± 3.6 yrs; all early bird types- approx. 10~11pm sleep and 5~6am getting up) volunteered for this study. Written consent was obtained and the study was approved by the Institutional Review Board of Seoul National University (IRB No.1209/001-002). The experiments were performed at four different times of day [0600 h (morning), 1200 h (noon), 1800 h (evening), and 2400 h (night)], and each experiment was conducted on a different day. The four experiments were performed in random order to avoid the effect of familiarisation and at least 2 days elapsed between experiments in order to return to a normal sleep-awake cycle. Subjects did not perform heavy exercise within 24 h of the experiments, and were prohibited from taking food for 3 h before each session.
**Measurements and procedures**

All experiments were conducted in a climatic chamber at an air temperature of 28.0 ± 0.3°C and relative humidity (RH) of 39 ± 2%. Subjects were dressed only in shorts and equipped with sensors and probes to measure: rectal temperature ($T_{re}$ at 16 cm depth; 1 s interval) and 11 skin temperatures ($T_{sk}$ on the forehead, chest, abdomen, back, upper arm, forearm, hand, finger, thigh, calf, and foot; 1 s). Measures of: local sweat rate (SR on the forehead and forearm; a ventilated capsule covered 1 cm$^2$ of skin area; 1 s); blood pressure (BP; 10 min); heart rate (HR; 5 s) were also obtained. Subjects then rested for at least 30 min seated on a stool prior to having their legs immersed in a hot water bath. After measuring all parameters to establish the initial baseline for 10 min, subjects immersed their lower legs in the water bath maintained at 42.4 ± 0.3°C for 60 min. The same experimental protocol was followed at each session.

**Calculations and data analysis**

The mean skin temperature ($T_{sk}$) was calculated using a modified Hardy and DuBois equation. Total sweat rate (TSR) of the whole body was determined by measuring the difference in body weight before and after the experiment, while total local sweat rate on the forehead and forearm was determined by the sum of local sweat rate from the onset of sweating up to the end of the experiment on each site (Integral values above zero). In case that no sweat appeared during the entire heat stress, sweat‐onset time was appointed as 60 min. $T_{re}$ thresholds for the onset of sweating for each experiment were determined using the same criteria as previous studies [1,2].

Data were averaged from the first 9 min (initial baseline, REST) and the last 3 min of the leg immersion (LAST). Group differences according to circadian rhythms (two groups × 4 phases) were analyzed by ANOVA with repeated measures and a post hoc test (SPSS v.20.0). The significance was set at $p<0.05$.

**Results**

**Circadian variations at rest and during passive heat stress**

For the young and elderly groups, both $T_{re}$ at rest and during heat stress showed its lowest temperature in the morning ($p<0.05$), but there are no significant differences among $T_{re}$ recorded at noon and in the evening (Fig. 1, Table 1). During the passive heat stress, the increase in $T_{re}$ ($\Delta T_{re}$) for the young group was greatest in the morning and lowest at night ($p<0.05$), while the elderly group showed the greatest and lowest $\Delta T_{re}$ in the morning and evening, respectively. Age difference in $T_{re}$ was only significant at night. $T_{sk}$ at rest and during passive heating showed no differences between four phases. As for age differences, the elderly group showed lower $T_{sk}$ at rest, but greater increases in $T_{sk}$ during heat stress than the young group ($p<0.05$). There were no significant differences among four phases in MAP and HR at rest and during passive heat stress for both groups, while the elderly group showed significantly lower HR than the young group.
Leg immersion (42°C) showed significantly greater sweating in the evening and night than in the morning for the young group, representing an approximately four times greater sweat rate in the forehead than in the forearm for all four phases (Fig. 2A). However, there were no differences in TSR and local sweat rate by four phases for the elderly group. The elderly group showed smaller sweat rate, in particular in the evening and at night, compared to the young group (p<0.05). Several aged male participants showed no sweat on the forehead or forearm during the entire heat stress (Table 1).

**Table 1.** Thermoregulatory responses at rest and during passive heat stress for the young group

<table>
<thead>
<tr>
<th>State</th>
<th>Parameters</th>
<th>Young group (°C)</th>
<th>Elderly group (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0600</td>
<td>1200</td>
<td>1800</td>
</tr>
<tr>
<td>REST</td>
<td>T_{re}</td>
<td>36.7±0.2</td>
<td>37.3±0.2</td>
</tr>
<tr>
<td></td>
<td>T_{sk}</td>
<td>32.8±0.3</td>
<td>32.9±0.5</td>
</tr>
<tr>
<td></td>
<td>T_{forehead}</td>
<td>32.7±3.0</td>
<td>34.6±0.7</td>
</tr>
<tr>
<td></td>
<td>MAP</td>
<td>87±6</td>
<td>85±7</td>
</tr>
<tr>
<td></td>
<td>HR</td>
<td>78±12</td>
<td>86±12</td>
</tr>
<tr>
<td>Heat stress</td>
<td>T_{re}^{last}</td>
<td>37.4±0.2</td>
<td>37.5±0.2</td>
</tr>
<tr>
<td></td>
<td>ΔT_{re}</td>
<td>0.36±0.23</td>
<td>0.20±0.19</td>
</tr>
<tr>
<td></td>
<td>ΔT_{sk}</td>
<td>0.4±0.6</td>
<td>0.2±0.9</td>
</tr>
<tr>
<td></td>
<td>ΔT_{forehead}</td>
<td>2.1±2.5</td>
<td>0.6±0.6</td>
</tr>
<tr>
<td></td>
<td>MAP_{sk, LAST}</td>
<td>85±7</td>
<td>87±6</td>
</tr>
<tr>
<td></td>
<td>HR_{LAST}</td>
<td>90±8</td>
<td>92±6</td>
</tr>
<tr>
<td></td>
<td>Forehead Sweat</td>
<td>45±57</td>
<td>43±55</td>
</tr>
<tr>
<td></td>
<td>Forearm Sweat</td>
<td>9±6</td>
<td>11±4</td>
</tr>
<tr>
<td></td>
<td>No sweat</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Forehead(person)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Forearm (person)</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* different to 0600 (p<0.05); * different to the young group (p<0.05).

**Onset time and T_{re} thresholds for sweating on the forehead and forearm**

At both forehead and forearm, sweating was initiated earlier at night than morning (p<0.05; Fig. 2B, 2C), but the elderly group showed no differences between four phases.
Figure 2. Total body mass loss (A), onset time for local sweating on the forehead (B) and on the forearm (C) during passive heat stress.

$T_{re}$ thresholds for sweating (at both forehead and forearm) were both significantly lower in morning than other three phases for the young group. For the elderly, however, there was no difference in $T_{re}$ thresholds for sweating between morning and night (Table 2). The age differences in $T_{re}$ thresholds were remarkable at night ($p<0.05$).

Table 2. $T_{re}$ thresholds for the onset of sweating of the young and elderly groups

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Body region</th>
<th>0600 MORNING</th>
<th>1200 NOON</th>
<th>1800 EVENING</th>
<th>2400 NIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>Forehead</td>
<td>36.79 ± 0.20</td>
<td>37.24 ± 0.18$^*$</td>
<td>37.35 ± 0.20$^*$</td>
<td>37.45 ± 0.29$^*$</td>
</tr>
<tr>
<td>Young</td>
<td>Forearm</td>
<td>36.78 ± 0.19</td>
<td>37.24 ± 0.18$^*$</td>
<td>37.35 ± 0.19$^*$</td>
<td>37.44 ± 0.29$^*$</td>
</tr>
<tr>
<td>Elderly</td>
<td>Forehead</td>
<td>36.70 ± 0.36</td>
<td>37.10 ± 0.26$^*$</td>
<td>37.31 ± 0.28$^*$</td>
<td>36.94 ± 0.25$^*$</td>
</tr>
<tr>
<td>Elderly</td>
<td>Forearm</td>
<td>36.75 ± 0.44</td>
<td>37.15 ± 0.26$^*$</td>
<td>37.34 ± 0.22$^*$</td>
<td>37.00 ± 0.19$^*$</td>
</tr>
</tbody>
</table>

$^*$ different to 0600 ($p<0.05$); $^a$ different to the young group ($p<0.05$).

Conclusions

The present study found the following: 1) the amplitudes of circadian rhythm in body temperature showed no age differences, but the zenith in $T_{re}$ went forward (evening) when compared to the young group (night), 2) circadian rhythms in sweat rate and onset of sweating during passive heat stress were not found for the elderly group, while the young group represented delayed and smaller sweating in the morning than at night, and 3) the onset of sudomotor responses in the aged group was delayed when compared to the responses of a young group.

References

Age-related changes to cardiac systolic and diastolic function during whole-body passive heat stress

Rebekah A.I. Lucas¹, Satyam Sarma¹, Zachary J. Schlader¹, James Pearson¹,², Craig G. Crandall¹*

¹Institute for Exercise and Environmental Medicine, Texas Health Presbyterian Hospital, Dallas, TX and Department of Internal Medicine, University of Texas Southwestern Medical Centre, Dallas, TX, USA. ²School of Health Sciences, Cardiff Metropolitan University, Cardiff, Wales.

*corresponding author: CraigCrandall@TexasHealth.org

Introduction
Older men (~70 y) have attenuated increases in cardiac output and stroke volume to whole-body passive heat stress relative to younger men [1]. An age-related attenuation in left ventricular systolic function and/or decreases in diastolic function during hyperthermia may contribute to these responses. However, the effect of aging on hyperthermia-induced changes in cardiac function is unknown. This study tested the hypothesis that heat-induced changes in left ventricular systolic and diastolic function would be altered in older adults when compared to young adults.

Methods
Eight older (O: 71 ±5 y) and eight younger (Y: 29 ±5 y) adults, matched for physical activity and body mass index (O: 24.6 ±2.6 vs. Y: 25.1 ±3.3 kg·m⁻², p>0.05), underwent whole-body passive heat stress. Mean arterial pressure (MAP, Finometer), cardiac output, stroke volume (Innocor rebreathing system) and echocardiographic indices of diastolic and systolic function were performed following a normothermic supine period, and again following an increase in internal temperature of ~1.0°C via passive heat stress.

Results
Hyperthermia decreased MAP and augmented cardiac output to a similar (p>0.05) extent in both groups, though stroke volume decreased (p<0.05) in the younger but not the older adults. Aging did not alter the magnitude of heat stress-induced changes in systolic or diastolic function (see Table). However, older adults were unable to augment late diastolic ventricular filling [i.e., E/A ratio, A/(A+E) ratio] to the same extent during hyperthermia, relative to the young (p<0.05).
Table 1. Haemodynamic and echocardiographic indices in older (71 ± 5 y) and younger (29±5 y) participants under normothermic and hyperthermic conditions.

<table>
<thead>
<tr>
<th></th>
<th>Younger Normothermic</th>
<th>Younger Hyperthermic</th>
<th>Older Normothermic</th>
<th>Older Hyperthermic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Haemodynamic Measures</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAP (mm Hg)</td>
<td>83 ±7</td>
<td>69 ±7 ‡</td>
<td>90 ±10 #</td>
<td>74 ±7 ‡</td>
</tr>
<tr>
<td>Cardiac output (L·min⁻¹)</td>
<td>6.2 ±1.2</td>
<td>8.1 ±1.0 ‡</td>
<td>3.9 ±1.1 #</td>
<td>5.4 ±1.5 ‡</td>
</tr>
<tr>
<td>Stroke Volume (mL)</td>
<td>101 ±26</td>
<td>87 ±17 ‡</td>
<td>60 ±17 #</td>
<td>60 ±17 #</td>
</tr>
<tr>
<td><strong>Index of systolic function</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral S’ (cm·s⁻¹)</td>
<td>9.6 ±1.5</td>
<td>13.7 ±2.6 ‡</td>
<td>8.3 ±1.0 #</td>
<td>10.7 ±2.4 ‡</td>
</tr>
<tr>
<td><strong>Indices of diastolic function</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lateral E’ (cm·s⁻¹)</td>
<td>15.4 ±3.3</td>
<td>15.2 ±3.8</td>
<td>8.7 ±2.3 #</td>
<td>9.6 ±2.7 #</td>
</tr>
<tr>
<td>E (cm·s⁻¹)</td>
<td>89 ±20</td>
<td>83 ±13</td>
<td>69 ±12 #</td>
<td>74 ±9 #</td>
</tr>
<tr>
<td>IVRT (ms)</td>
<td>65 ±12</td>
<td>46 ±7‡</td>
<td>102 ±14 #</td>
<td>72 ±13 #‡</td>
</tr>
<tr>
<td><strong>Indices of late diastolic ventricular filling (i.e., atrial contribution)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (cm·s⁻¹)</td>
<td>41 ±5</td>
<td>75 ±14 ‡</td>
<td>71 ±11 #</td>
<td>84 ±17#‡</td>
</tr>
<tr>
<td>E/A Ratio</td>
<td>2.25 ±0.80</td>
<td>1.11 ±0.08 ‡</td>
<td>1.00 ±0.30 #</td>
<td>0.91 ±0.14</td>
</tr>
<tr>
<td>[A/A+E]*100 (%)</td>
<td>32.1 ±6.3</td>
<td>47.4 ±1.9 ‡</td>
<td>50.9 ±7.5 #</td>
<td>52.7 ±3.8 #</td>
</tr>
</tbody>
</table>

S’, Systolic annular tissue velocity; E’, Early diastolic annular tissue velocity; A’, Late diastolic annular tissue velocity; IVRT, Isovolumetric relaxation time; [A/A+E], Atrial contribution to diastolic filling; # Significantly different from younger group, p<0.05; ‡ Significantly different from normothermic baseline, p<0.05.

Conclusions
These data indicate that heat stress-induced changes in indices of systolic and diastolic function are generally unaffected by aging, the exception being the atrial contribution to diastolic filling being attenuated in the elderly.

Reference
Skin rewarming following a cold challenge – the role of skin blood flow

Clare Eglin*, James R. House, Martha Davey, Michael Tipton
Extreme Environments Laboratory, Department of Sport and Exercise Science, University of Portsmouth, Portsmouth, UK.
*Corresponding author: clare.eglin@port.ac.uk

Introduction
Individuals with non-freezing cold injury (NFCI) can suffer from long-term cold sensitivity. This is often assessed by a 2-min cold challenge of the injured limb and subsequent rewarming period, with colder starting skin temperatures (Tsk) and slower rates of rewarming indicating more severe cold sensitivity. The presumption in such a cold sensitivity test (CST) is that it measures the vasomotor response to a cold challenge; we tested the null hypothesis that this is not the case.

Methods
In air at 30°C, six non-cold injured participants, undertook two CSTs. The control (CON) CST involved 12 min of gentle exercise prior to immersing a foot (protected by a thin plastic bag) into 15°C water for 2 min followed by 15 min of spontaneous rewarming. The occlusion (OCC) CST was the same except that blood flow to the foot was occluded during the rewarming period. These were compared to CSTs from six NFCI patients with cold sensitivity (CS) and a non-perfused model of a human digit (NPDM). Skin blood flow (SkBF) and Tsk were measured on the Great toe pads using laser Doppler flowmetry and infra red thermography respectively.

Results and Discussion
Before immersion, Great toe SkBF was similar in CON (313 ±117 Laser Doppler Units [LDU]) and OCC conditions (196±58 LDU) and was higher than in CS (59±52 LDU; p=0.002). After immersion, SkBF in CON returned to 104% of the pre-immersion value and was higher (p<0.01) than both OCC and CS throughout the rewarming period.

Great toe Tsk before immersion was lower in the SC group (p=0.001) compared to the other conditions (Figure). During rewarming skin/surface temperature were similar in OCC, CS and NPDM and lower than CON (p<0.05).

In conclusion, SkBF does contribute to the skin rewarming profile during a CST as a faster rate of rewarming was observed in CON compared to either OCC or NPDM, therefore the null hypothesis was rejected. The lower Tsk in individuals with cold sensitivity may be due to a reduced basal SkBF.
Functions of the endothelial dilation and the reflex from skeletal muscle in badminton players are different between dominant and non-dominant arms

Rei Tahara¹, Kazuhito Watanabe¹, Masashi Ichinose², Masashi Suita³, Seiji Maeda³, Takeshi Nishiyasu³*

¹ Graduate School of Comprehensive Human Sciences, University of Tsukuba, Japan
² School of Business Administration, Meiji University, Japan
³ Institute of Health and Sport Sciences, University of Tsukuba, Japan

*corresponding author: nisiyasu@tailku.tsukuba.ac.jp

Introduction
In badminton, a player’s dominant arm is frequently used to swing the racket. Accordingly, badminton players’ muscle mass and strength of the dominant arm are known to be greater than those of the non-dominant arm. In addition, blood flow to muscles of the dominant arm is markedly increased compared to the non-dominant arm in the sport. Therefore, cardiovascular regulatory mechanisms assumed to contribute to increase blood flow to active muscle, such as the endothelial dilation and the muscle metaboreflex, might be modulated in the players’ dominant arm. The purpose of this study was to test the hypothesis that functions of the endothelial dilation and the muscle metaboreflex are different between dominant and non-dominant arms of badminton players.

Methods
Twelve badminton competitive players (6 male and 6 female) participated in this study. This study was performed according to the Declaration of Helsinki. Written, informed consent was obtained from all subjects. Using high-resolution ultrasound, we examined endothelium-dependent flow-mediated dilation (FMD) in the brachial artery following an increase in shear stress induced by 5-min forearm ischemia in dominant and non-dominant, respectively. In addition, 4-min post-exercise muscle ischemia (PEMI) following 1-min isometric handgrip exercise at 50% of maximal voluntary contraction (MVC) was conducted in both arms respectively to determine the function of muscle metaboreflex.

Results and Discussion
Although shear rate area under the curve (SR-AUC), which is an index of the stress to the vessel wall, was not different between the two arms (2108 ± 292 vs. 2285 ± 360 s⁻¹·s, dominant arm vs. non-dominant arm, p>0.05), FMD and FMD/SR-AUC in dominant arm were larger than non-dominant arm (FMD: 5.8 ± 0.7 vs. 3.8 ± 0.7 %, FMD/SR-AUC: 0.0031 ± 0.0005 vs. 0.0022 ± 0.0006 %s⁻¹·s, dominant arm vs. non-dominant arm, p<0.05). These results indicate that function of endothelial dilation as well as the vasodilatory responsiveness to given shear stress are greater in the dominant arm than the non-dominant arm. During PEMI, arterial pressure and total peripheral resistance were increased from rest, but there was no difference between trials. In contrast, significant tachycardia occurred during PEMI only if the exercise was performed in non-dominant arm (52 ± 1.3 to 55 ± 1.9 beats/min, from rest to PEMI, p<0.05). This result indicates that, if exercise were performed at the same relative intensity, the muscle metaboreflex-mediated cardiac sympathetic activation would be greater in the non-dominant arm than the dominant arm.

Conclusion
Our results demonstrate that functions of the endothelial dilation and the muscle metaboreflex are different between dominant and non-dominant arms of badminton players. Therefore, chronic localised training in dominant arm might modulate the functions of the endothelial dilation and the muscle metaboreflex.
Displacement plethysmographs for measuring limb segment blood flow (forearm, hand, calf, foot) with independent control over local skin temperature: A project for an older tool

Joanne N. Caldwell, David J.R. Hoyle, Nigel A.S. Taylor*
Centre for Human and Applied Physiology, University of Wollongong, Wollongong, Australia
*corresponding author: Nigel_Taylor@uow.edu.au

Introduction
Measuring cutaneous blood flow is an essential building block for understanding thermoeffector responses to changes in central and peripheral tissue temperatures. Under thermoneutral conditions, skin blood flow modifications are the primary pathway for heat exchange. Outside this zone, flow changes provide information pertaining to the thermoregulatory control mechanisms that modulate vasomotor tone. Whilst there are numerous methods available for measuring regional blood flow in humans, the most common method for evaluating the cutaneous flow is via venous-occlusion plethysmography, which has been used for over a century (an older tool), with strain-gauge plethysmographs being most commonly used today.

Unfortunately, with these devices, it is often very difficult to investigate the impact of changes in local skin temperature on segmental blood flow. Since this is a research interest of the current investigators (see accompanying communication), a method was required that would allow for the independent manipulation, and the subsequent clamping of core, mean skin and local skin temperatures. With water immersion able to elicit rapid tissue temperature changes, it was decided that water-filled plethysmographs would serve this objective. Herein is described the construction of four displacement plethysmographs (forearm, hand, calf, foot), along with the validation of one of these devices (forearm) against a strain-gauge plethysmograph.

Methods
Each of the four plethysmographs was constructed using the same basic design (Figure 1). The main body (aluminium shell) was divided into two independent, water-filled compartments: internal and external chambers. Water in the former chamber was used to change local skin temperature and, through its displacement, to quantify changes in limb segment blood flow. The latter chamber had a water volume approximately ten times that of the inner chamber. This water was continuously circulated through water baths, with its temperature being tightly regulated. Due to the water volume difference between these compartments, the water temperature of the inner chamber could be changed relatively quickly (< 10 min) to elicit local skin temperature changes.

The inner chamber was defined by its rigid aluminium (outer) wall and a tightly fitting (inner) latex sleeve, glove or sock that covered the limb segment in question, which itself was housed within the plethysmograph. These latex membranes were made within the laboratory using plaster moulds. A rigid flange (Figure 1A) secured each membrane to the main chamber, rendered this compartment water tight. Protruding from the internal chamber were two aluminium pipes (Figure 2); one was the measurement arm (housing a glass expansion adapter with two-hole rubber stopper, glass pipette and pressure transducer), and the other was for filling the inner chamber with water and for calibration. The latter pipe remained closed during testing, whilst the former, also closed to the atmosphere, provided a trapped air space into which water could be displaced following venous occlusion. Changes in this displaced water volume were detected using a differential pressure transducer. Digital outputs from the transducer were displayed and
collected onto a computer. It was assumed that, within resting states, changes in these segmental blood flows were due solely to variations in the cutaneous vascular flow.

**Figure 1.** Three-dimensional diagrams (not to scale) showing the internal and external chambers of four, water-filled plethysmographs (forearm (A), hand (B), calf (C), foot (D)).

Having completed this construction, it was necessary to evaluate the precision with which blood flow could be measured, in comparison with a commercially available technique (mercury-in-silastic strain-gauge) under conditions of relevance to future experimental applications. Therefore, male \((n=4)\) and female \((n=4)\) subjects completed two separate trials, with limb segment (forearm) blood flow measured using two plethysmographic techniques: **Trial 1**: strain-gauge plethysmograph; **Trial 2**: water-filled plethysmograph. Within each trial, skin blood flow was measured with the local skin being at two different temperatures (mid-dorsal forearm): firstly thermoneutral \((31.6^\circ C \pm 0.4)\) and then heated \((37.4^\circ C \pm 0.5)\).

**Results and Discussion**

When averaged across the entire trial, there were no significant differences in core temperature between the two trials (**Trial 1**: \(36.9^\circ C\); **Trial 2**: \(37.0^\circ C\); \(p>0.05\)). Similarly, there were no differences in either mean skin temperature (**Trial 1**: \(31.6^\circ C\); **Trial 2**: \(31.1^\circ C\); \(p>0.05\)) or mean arterial pressure (**Trial 1**: \(88.3\) mm Hg; **Trial 2**: \(88.1\) mm Hg; \(p>0.05\)) between these trials. This outcome was important, since it was essential that cutaneous blood flow was not influenced by thermoregulatory or cardiovascular reflexes.
During the thermoneutral phase of each trial, cutaneous blood flow was 1.96 mL·100 mL⁻¹·min⁻¹ (Trial 1) and 1.47 mL·100 mL⁻¹·min⁻¹ (Trial 2; p>0.05). Local heating within each trial elicited significantly higher blood flows (p<0.05), but these did not differ significantly between techniques (Trail 1: 5.53 mL·100 mL⁻¹·min⁻¹; Trial 2: 5.06 mL·100 mL⁻¹·min⁻¹; p>0.05). These results indicate that the water-filled plethysmograph provided a valid method for measuring forearm blood flow.

Conclusion
This validation was an important outcome, since not only did it allow for a thermoneutral comparison, but it permitted a validation when local skin temperature was elevated. In a subsequent communication to this society, we report changes in blood flow from four limb segments measured using these plethysmographs, with core and mean temperatures modified and clamped, and then when local skin temperatures were elevated and reduced during this thermal clamping. Moreover, inter-segmental comparisons of these vascular responses can now be made across identical thermal states, and this work has provided the foundation upon which several subsequent experiments are currently being developed.
The effects of the different morning bathing methods on salivary melatonin responses and subjective evaluation

Soomin Lee1*, Hiroko Fujimura2, Yoshihiro Shimomura3, Tetsuo Katsuura2

1 Centre for Environment, Health and Field Sciences, Chiba University, Japan
2 Urban Research Institute, Tokyo Gas Co., Ltd., Japan
3 Graduate School of Engineering, Chiba University, Japan
*corresponding author: yisoomin@chiba-u.jp

Introduction
Bathing in Japan has become accustomed from ancient times as means of body cleaning and relaxation. The effects of evening bathing on human physiological functions including salivary melatonin response and subjective evaluation has been previously studied, and responses well established. On the other hand, taking a bath in the morning has increased prevalence in the modern society in Japan during recent years, however the effects of the morning bathing on human sleep quality and physiological functions have not yet been revealed. From this current condition, we intended to verify the effects of the different morning bathing methods on human sleep quality at night and daytime responses. Therefore, we measured the salivary melatonin concentration and subjective evaluation following morning bathing, including: showering, mist sauna bathing, and no bathing as a control.

Methods
Ten male healthy young adults participated in this study. The first night, each subject entered a laboratory at 19:00 and went to bed at 24:00. On the second day, he got up at 07:00, and took a bath (showering, mist sauna bathing, or no bathing) between 07:10 - 07:20. Every hour, the subject conducted an alpha attenuation test (AAT), a Stroop colour-word test, and a mental arithmetic task from 09:00 to 17:00. We measured rectal temperature (Tre), skin temperature (Tsk), heart rate (HR), blood pressure (BP), and subjective evaluation throughout the experiment. We obtained saliva from each subject to measure salivary melatonin concentration at 22:30, 23:00, 23:30, and 24:00 of the second day. On the third day, the subject got up at 07:00 and finished at 07:30. Subjects’ completed each bathing condition during three separate visits, with the order of bathing conditions counterbalanced among the subjects. Informed consent for participation in the study, approved by the bioethics committee of the Graduate School of Engineering, Chiba University, was obtained from all subjects. To examine the effects of the bathing methods, a two-way repeated measures ANOVA (bathing method factor and time factor) was conducted.

Results and Discussion
We found that the salivary melatonin concentration after morning showering was significantly lower than those after no bathing at 23:00, 23:30, and 0:00 respectively. In addition, HR after the mist sauna bathing was significantly lower than after no bathing at 11:00 on the second day. Tsk at 9:00 and 15:00 after mist sauna bathing was higher than after showering on the second day. Further, "good feeling" on the subjective evaluation after mist sauna was significantly higher than those after no bathing at 7:20. In addition, "fatigue" after mist sauna bathing was significantly lower than those after showering during the task period at 14:00.

These results suggested that the burden after the mist sauna bathing was lower than after other bathing methods for the cardiovascular system. Furthermore, our findings indicate that the morning mist sauna bathing method produced higher good feeling and prevented fatigue.
compared to other bathing methods. Meanwhile, we estimated that the morning showering decreased sleeping quality compared to other bathing methods based on salivary melatonin concentration.
THE SKIN'S ROLES IN TEMPERATURE REGULATION

Thermal perceptions: Stable versus fluctuating skin temperatures during exercise in the heat

Sarah Davey¹, Martin Barwood², Michael Tipton²*
¹Environmental Ergonomics Research Centre, Loughborough University, Loughborough, UK
²Department of Sport & Exercise Science, Portsmouth University, UK
*corresponding author: Michael.tipton@port.ac.uk

Introduction
This study tested the hypothesis that intermittent cooling in air-perfused garments will not only maintain thermal balance, but due to cyclical activations of cutaneous thermoreceptors, also enhance thermal perceptions.

Method
Ten physically active males completed four conditions in which they exercised at a moderate intensity (~30% VO₂max) in a hot environment (~34.0°C, 50% RH) for 72 minutes, followed by a 33-minute period of rest. They wore an air-perfused vest (APV) throughout. The four conditions differed in respect to the profile of ambient air that was perfused through the APV: continuous perfusion (CC); intermittent perfusion in 6-minute ON/OFF periods (IConoff); a steady increase and decrease in flow rate in equal increments (ICramp); and an initial step-increase in the flow rate (340 L·min⁻¹) followed by an incremental decrease to 0 L·min⁻¹ (ICtriang). Cooling profiles IConoff, ICramp, ICTriang were designed to have a total flow of air during each condition (17,841 L) that was exactly half of that ventilated during CC. Whole body and torso thermal comfort (TC, TTC), whole body and torso temperature sensation (TS, TTS), whole body and torso skin temperature (sk, sktorso), local relative humidity (RHtorso) and rectal temperature (Tre) were measured. The study was approved by the University of Portsmouth Biosciences Ethics Committee.

Results and Discussion
There were no significant differences in Tre (mean = 37.99°C), Tsk (mean = 35.86°C), Tktorso (mean = 35.91°C), between the cooling profiles. There was a significant difference between the intermittent cooling profiles in the rate of change in Tktorso, with ICTriang experiencing the greatest change (-0.30 [±0.08]°C·min⁻¹). There was no difference in the rate of change in whole body Tsk. There were no differences between the cooling profiles in the thermal perceptions, except for TTS which was perceived to be cooler in CC and ICramp than in IConoff and ICTriang. A level of adaptation may have occurred in CC, as TC and TTS tended to become less favourable over time (p = 0.081).

Conclusion
To improve the efficacy of an APV (or other ventilated cooling systems), when used in conditions similar to this study, it is recommended that an intermittent cooling profile should be adopted.
The duration-dependant effect of skin temperature on self-paced cycling exercise

Koen Levels¹,²*, Jos de Koning¹,³, Carl Foster¹,³, Hein A.M. Daanen¹,²

¹ MOVE Research Institute Amsterdam, Faculty of Human Movement Sciences, VU University, Amsterdam, The Netherlands
² TNO Behavioural and Societal Sciences, Soesterberg, The Netherlands
³ University of Wisconsin-La Crosse, La Crosse, USA
*corresponding author: k.levels@vu.nl

Introduction

Skin temperature has been suggested as a relevant physiological signal for the anticipatory and feedback control of work rate during self-paced exercise [1, 2]. However, a sudden extreme skin temperature elevation did not affect pacing during a 7.5-km cycling time trial [3]. Possible explanations for the discrepancy in these results are the duration of the self-paced exercise and the length of the skin temperature manipulations. To investigate whether the duration of the manipulation in skin temperature, or the duration of the time trial is more relevant for the influence of an elevated skin temperature on pacing pattern and performance during aerobic exercise, we investigated the effect of two different lengths of radiative heat exposure on pacing pattern during a 15-km cycling time trial. Together with results from our previous study [3], in which an identical intervention was applied during a cycling time trial of 7.5 km, conclusions can be drawn about the relative importance of time trial duration and the duration of the manipulation.

Methods

Nineteen well-trained male cyclists completed three 15-km cycling time trials in 18°C and 50% relative humidity with (H-SHORT and H-LONG) or without (CON) radiative heat stress. The heat stress was applied by a panel consisting of 22 infrared heaters that was quickly positioned in front of the cycle ergometer after 1.5 km. The panel was quickly removed at 6.0 km (H-SHORT) or 10.5 km (H-LONG) resulting in 4.5 or 9.0 km of heat stress, respectively. This intervention was identical to the heat stress intervention in a previous study in our lab [3]. During the time trials, power output (PO), skin (Tsk) and rectal (Tre) temperature, heart rate (HR), RPE, VO₂, VCO₂, thermal sensation, and thermal discomfort were measured. The significance of effects of experimental condition on the dependent variables over time was determined using two-way ANOVA for repeated measurements, with two within subject factors (experimental condition and distance completed). One-way ANOVAs were used to determine the significance of effects of experimental conditions on time to completion and values at the finish. Post-hoc analyses used Bonferroni correction to adjust for multiple comparisons.

Results

The radiative heat exposure resulted in 1100 W·m⁻² radiation on the frontal side of the cyclists leading to higher Tsk during the time trial for H-SHORT (35.0 ± 0.6 °C) and H-LONG (35.3 ± 0.5 °C) than for CON (32.5 ± 1.0 °C; F=155, ρmain effect<0.001), whereas Tre remained similar (F=0.603, ρmain effect=0.55). During the second half of the time trial, Tsk was higher for H-LONG than for H-SHORT (p<0.05) resulting in a higher final Tsk for H-LONG (35.6 ± 0.5 °C) than for H-SHORT (35.3 ± 0.6 °C; p=0.011). Time to completion of the time trials was longer in H-SHORT (1352 ± 65 s) and H-LONG (1357 ± 80 s) than in CON (1326 ± 49 s; F=5.42, ρmain effect=0.009). In line with the longer time to completion, PO was lower for H-SHORT (273 ± 8 W) and H-LONG (271 ± 9 W) than for CON (287 ± 7 W; F=5.45, ρmain effect=0.02), but no difference in pacing pattern was observed (F=0.944, ρmain effect=0.55; Figure 1). No differences in any performance measures were found between H-SHORT
and H-LONG. HR was lower in H-SHORT (172 ± 11 b·min⁻¹; p<0.001) and H-LONG (171 ± 11 b·min⁻¹; p<0.001) than in CON (177 ± 9 b·min⁻¹). No differences were found between the trials in RPE, VO₂, and VCO₂, whereas thermal sensation (p<0.001) and thermal discomfort (p=0.03) were higher for H-LONG than for H-SHORT during km 6.0-10.5.

![Figure 1](image_url) **Figure 1.** Pacing pattern during the 15-km cycling time trial. Grey bars indicate the appliance of radiative heat stress during H-SHORT (upper bar) and H-LONG (lower bar). * Significant difference between CON and H-SHORT (p<0.05). † Significant difference between CON and H-SHORT (p<0.05). # Significant main effect between conditions (p=0.02).

**Discussion**

This study shows that a sudden radiative heat exposure substantially increases skin temperature, prolongs time to completion, and reduces mean power output during a 15-km cycling time trial. Interestingly, pacing pattern (expressed as the development of power output over the distance of the trial) was similar. This indicates that the difference in time to completion is caused by a lower power output that is maintained from the start until the end of the time trial. Apparently, the knowledge of the upcoming thermal challenge influences the anticipatory selection of power output, which has been documented before [4]. Importantly, we found decreased performance in both H-SHORT and H-LONG, indicating that in a 15-km time trial, the length of heat exposure (and the resulting elevated skin temperature) is relatively unimportant for pacing and performance, as were the associated differences in thermal sensation and thermal discomfort appear to be relatively irrelevant.

Since we observed no differences in pacing and performance after a similar intervention during a 7.5 km cycling time trial [3], the length of the time trial, rather than the length of the manipulation appears to be relevant for the self-selected work rate during aerobic cycling exercise. Since there appears to be a dose-response relationship between the duration of self-paced exercise and the
effect of a manipulation on pacing and performance, the duration of exercise should always be taken into account when analyzing the effect of skin temperature manipulations on exercise performance. We speculate that this relationship exists not only for skin temperature, but for all physiological and environmental signals that have an effect on exercise performance.

Conclusion
A sudden radiative heat exposure during a 15-km cycling time trial decreases power output during the time trial and prolongs time to completion. The duration of the radiative heat stress does not modulate this effect. Since radiative heat exposure did not affect performance during a 7.5-km cycling time trial, the length of the time trial, rather than the length of the manipulation appears to be relevant for the self-selected work rate during aerobic cycling exercise.

References
The role of decreasing contact temperatures in the perception of wetness on the skin

Davide Filingeri1*, Bernard Redortier2, Simon Hodder1, George Havenith4
1 Environmental Ergonomics Research Centre, Loughborough University, Loughborough, UK
2 Thermal Sciences Laboratory, Oxylane Research, Villeneuve d’Ascq, France
*corresponding author: D.Filingeri@Lboro.ac.uk

Introduction
Previous studies have indicated that the perception of wetness on the skin results from the integration of the somatosensory sub-modalities of touch and temperature [1]. However, how these inputs interact to evoke this synthetic perception is still unclear [2].

Methods
In this study, the role played by peripheral cold afferents and thermal sensations in evoking the perception of wetness was examined when six different cold-dry stimuli (-2, -5, -7, -10, -15, -20°C less than the individual’s skin temperature) were applied in a balanced order on the bare and dry forearm of 9 female participants (27.3 ± 8.8 years) resting in an environmental chamber (20°C; 50% relative humidity). Participants were informed only about the body region subjected to the stimulation. No information was provided on the type and magnitude of the stimulation, to limit any expectation effects. Skin temperature, skin conductance, thermal sensation and wetness perception were recorded before, during and after the application of each cold stimulus (30 s) and during the following re-warming phase. Data were analysed using a repeated measures ANOVA, Friedman test and multiple regressions.

Results and Discussion
Each cold-dry stimulus produced significantly different decreases in the skin temperature (p<0.05), varying in a range between -0.8°C ± 0.8 to -12.3°C ± 2.7, corresponding to a cooling rate of 0.02 to 0.41°C/s. Stimuli produced statistically significant differences (p<0.05) in thermal sensation, with colder stimuli producing colder thermal sensations. Data related to wetness perception showed that overall, in 19 out of 54 scores (35.2%), a cold-dry stimulus was perceived as wet. For this reason, we proceeded with the analysis of individual data which showed the existence of two sub-groups within the whole sample tested in this experiment. 5 out of 9 participants (responders) perceived skin wetness as result of cold stimuli producing a cooling rate ranging from 0.14 to 0.41°C/s, whereas 4 out of 9 participants (non-responders) did not perceive skin wetness at all. Regression analyses were performed between the variation in skin temperature from baseline, thermal sensation and wetness perception values recorded from the responders sub-group. All the relationships were found to be statistically significant (p<0.01), showing the skin cooling and the evoked thermal sensations to drive the perception of wetness in this sub-group.

Conclusions
These findings showed that skin cooling and thermal sensations can contribute significantly in the perception of skin wetness but other somatosensory sub-modalities, particularly touch and vision, are potentially essential to characterize this multi-sensory experience.

References
Exploring the interactions of core, mean skin and local skin temperatures on the cutaneous blood flow of the forearm, hand, calf and foot: Three-dimensional perspectives

Joanne N. Caldwell, Mayumi Matsuda-Nakamura, Hugh H.K. Fullagar, Nigel A.S. Taylor*
Centre for Human and Applied Physiology, University of Wollongong, Wollongong, Australia
*corresponding author: Nigel_Taylor@uow.edu.au

Introduction
Cutaneous blood flow manipulation supports body temperature regulation. Whilst deep tissue temperature has the greatest influence on this flow, local skin temperature influences flow independently of the sympathetic nervous system. Furthermore, the neural control of cutaneous blood vessels differs between acral and non-acral skin, with the former also containing arteriovenous anastomoses. These interactions are well known and have previously been explored. However, the interactions of core and local skin temperatures on cutaneous blood flow have not been studied in mildly hypothermic and hyperthermic individuals over a range of local skin temperatures, and certainly not within both the acral and non-acral skin regions. This was the primary focus of this study.

Methods
Eight males completed trials in each of three thermal states (hypothermia (oesophageal temperature 35°C), thermoneutral (37°C) and hyperthermia (39°C)). Each state was achieved using water immersion, and was clamped (water-perfusion suit) during the experimental phase, with subjects remaining supine. Cutaneous blood flow was measured from four sites (forearm, hand, calf, foot: see companion communication) using venous-occlusion plethysmography. Five local skin temperatures were applied to each site during this thermal clamping: 5°, 15°, 25°, 33° and 40°C.

Results and Discussion
Three thermal states were achieved: 36.1° (±0.4), 37.0° (±0.3) and 38.5°C (±0.3). Positive correlations were found between local skin temperature and cutaneous blood flow across each state (p<0.05). Blood flow was lowest in the foot (0.59 mL·100 mL⁻¹·min⁻¹ (±0.16)) during whole-body hypothermia with strong local cooling (5°C), reflecting a very powerful constrictor tone. Conversely, blood flow was largest in the hand (20.08 mL·100 mL⁻¹·min⁻¹ (±1.90)) during whole-body hyperthermia with strong local heating (40°C). This was significantly higher than the corresponding forearm, calf and foot blood flows (p<0.05). During this presentation, these thermal interactions will be summarised using three-dimensional surfaces for each of the four sites investigated.

Conclusion
The current study not only provided the first three-dimensional description of the interactions of core, mean skin and local skin temperatures on cutaneous blood flow, but it provided direct comparisons between acral and non-acral skin regions. The hand and the foot showed the greatest changes in local blood flow during heating, and these are believed to result from the presence of arteriovenous anastomoses within these regions.
Different physiological responses but similar thermal perceptions for males with various body fatness during cold air exposure

Damien Fournet1,2*, Katy Griggs1, Bernard Redortier2, George Havenith1
1 Environmental Ergonomics Research Centre, Loughborough University, Loughborough, UK
2 Thermal Sciences Laboratory, Oxylane Research, Villeneuve d’Ascq, France
*corresponding author: D.Fournet@lboro.ac.uk

Introduction
There is no consensus regarding the potential effect of body fatness on subjective responses to cold at rest [1,2]. Most studies have examined overall sensation and comfort with no attention to regional values or the influence of exercise on thermal perception. The present study aimed at exploring overall and regional perceptual responses of males, varying in body fat content (%BF) in association with their physiological responses, specifically regional skin temperatures (Tsk).

Methods
Twenty healthy and semi-nude males sat for 60 minutes on a stool with limited motion. The resting phase was followed by a 30-min exercising phase at 100W on a cycle ergometer. Both phases were performed in a 10°C, 50% RH climatic chamber. Three distinct categories of body fat percentage (%BF), but similar fitness level, were arbitrarily created (Low Fat (LF): 5-10%, Medium Fat (MF): 10-15% and High Fat (HF): 15+) with a total range varying from 7 to 40 %BF. Skinfold thickness was assessed at 24 locations. Regional Tsk and mean Tsk were measured by infrared thermography at different stages of the protocol [3] together with oxygen uptake (\(\dot{V}_O_2\)) by the Douglas bag method. Rectal temperature (Tre), finger tip blood flow (Laser Doppler flowmetry) and heart rate were monitored throughout the whole protocol. Thermal sensation (TS) and comfort (TC) were evaluated for the whole-body (overall) and 11 different body regions (local).

Results and Discussion
Physiological responses differed between the three body fat groups. Mean Tsk was significantly colder for HF compared to MF, and in turn LF (Figure 1). Dynamics of Tre were different between the groups (p<0.05), especially with a drop of 0.4°C at rest for LF on one hand and the larger rise of Tre during exercise for HF on the other (Figure 1). Heat dissipation was favoured for LF with a higher risk of hypothermia in the case of prolonged exposure at rest and it was specifically more impeded for HF whilst metabolic heat production was increased. \(\dot{V}_O_2\) did not differ between groups at all stages (p=0.55).
Regional Tsk was significantly different between the groups as observed by population-averaged body maps of absolute Tsk. However, normalised maps revealed consistent patterns in the Tsk distribution. Between subjects, %BF and local skinfold thickness were negatively correlated with mean Tsk and regional Tsk (from r = -0.50 to r = -0.93, p<0.05) in line with LeBlanc [4]. Within subjects, local skinfold thickness did not however explain the variability of regional Tsk over the body.
Overall perceptual responses were similar between body fat groups. There was no relationship between overall TS, TC and %BF. Dynamics of overall TS and TC tracked dynamics of mean Tₜₙ at rest but not during exercise. Overall perceptual votes always followed the worst local thermal votes during passive cooling, in agreement with others [5]. This was however not true at the end of exercise.

Local thermal votes (TS and TC) were similar between groups and there was also no correlation with local Tₜₙ between subjects. The only exception was found for the hand TS, perceived significantly warmer for HF compared to MF and LF (p<0.05) but only at the end of exercise. This could be associated with the early rise observed in cutaneous blood flow for HF followed by a rise in hand Tₜₙ, significantly larger and sooner for HF during exercise. Extremities have been shown to be a specific region for heat loss in overweight individuals [6].

Conclusions
Despite different physiological responses (mean Tₜₙ, local Tₜₙ, Tₑₑ), participants with higher body fat had similar perceptual responses than their leaner counterparts.

Interestingly, there were clear consistencies between groups for Tₜₙ patterns and this may in part contribute to the similar thermal votes.

Skinfold thickness explained between subjects but not within subject differences in Tₜₙ.

The study also confirms the contribution of body fatness in heat dissipation during passive body cooling (seated rest) and exercise-induced mild hyperthermia (cycle ergometry).
References
Performance and thermoregulatory consequences of wearing compression tights in a hot environment with a radiant heat load

Martin Barwood1*, Jo Corbett1, John Feeney1, Paul Hannaford1, Dan Henderson1, Ian Jones1, Jade Kirke1

1 Extreme Environments Laboratory (EEL), Dept. Sport and Exercise Science, University of Portsmouth, Portsmouth, U.K
*corresponding author: martin.barwood@port.ac.uk

Introduction
The study aimed to establish the thermal and performance effects of wearing a lower-body, dark-coloured graduated compression garment (GCG; COMPRESSION) in a hot environment (35.2 (0.1)°C) with a representative radiant heat load (~800 W.m⁻²; 90° angle) in contrast to CONTROL and SHAM conditions with the latter included to establish any placebo effect. The SHAM treatment was a compression garment 1-size larger than recommended by the manufacturer.

Methods
The study was granted ethical approval. Eight participants (mean [SD]); age 21 [2] years; height 1.77 [0.06] m; mass 72.8 [7.1] kg; surface area, 1.89 [0.10] m² completed three treadmill runs at a fixed speed (10 to 12 km.h⁻¹; fixed within participant) for 15-minutes followed by a self-paced 5 km running time trial (TT). Pressure exerted by the garments in the COMPRESSION and SHAM conditions was measured prior to each test. Performance (completion time) and pacing (split time), thermal responses (aural [Tₐₐ], skin [Tₘₖₚₖₚₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖₖ₆

Results
Both garments exerted graduated pressure at the calf (COMPRESSION: 20 (3) mm Hg, SHAM: 17 (4) mm Hg) and thigh (COMPRESSION: 11 (2) mm Hg, SHAM: 10 (2) mm Hg). The COMPRESSION condition exerted a significantly greater average pressure under the COMPRESSION garment (p = .024; mean (SD): SHAM: 13 (2), COMPRESSION: 16 (2) mmHg. Performance in COMPRESSION was not different to either SHAM or CONTROL at any stage (p>0.05); mean (SD) completion time: 26.08 (4.08), 26.05 (3.27), 25.18 (3.15) minutes, respectively. Using the mean differences between trials and SD within trial, a further 33 and 71 participants would need to be tested (Minitab, power of .80, alpha .05) in order to see statistically significant differences between the CONTROL and SHAM and CONTROL and COMPRESSION conditions respectively. Performances showed a coefficient of variation of 4.3 (3.4) %. At the end of the 5 km TT, RPE was not different; 19 (1) across conditions. In general, thermal and perceptual responses were not different although the radiant heat load increased site-specific skin temperature (quadricep) in the garment conditions. At the end of the TT the change in Tₐₐ was 1.95 (1.28) °C, 3.67 (1.40) °C and 3.60 (1.46) °C in the CONTROL, SHAM and COMPRESSION conditions, respectively.

Conclusion
GCG did not enhance performance in a hot environment with a representative radiant heat load. The SHAM treatment did not induce any placebo effect on performance. Thermal data suggest that dark coloured compression garments, which may absorb more radiant heat, have the potential to increase local skin temperature.
Individual ability to discriminate between wetness and dryness during short contacts with a warm surface

Davide Filingeri1*, Bernard Redortier2, Simon Hodder1, George Havenith1
1 Environmental Ergonomics Research Centre, Loughborough University, Loughborough, UK
2 Thermal Sciences Laboratory, Oxylane Research, Villeneuve d’Ascq, France
*corresponding author: D.Filingeri@Lboro.ac.uk

Introduction
The interaction between thermal and touch sensing seems to be largely acknowledged as the principal responsible of the perception of skin wetness [1]. However, it is still unclear which sensory input is essential or sufficient to generate this perception [2].

Methods
In this study, the role played by thermal afferents and thermal sensations in contributing to the perception of wetness was investigated when 4 different warm stimuli (+4 and +8°C above individual skin temperature) varying in terms of wetness level (using a dry or a wet fabric) were applied in a balanced order on the bare and dry upper and lower back of 8 participants (20.9 ± 1.6 years) resting in an environmental chamber (22°C; 50% relative humidity). Participants were informed only about the body region subjected to the stimulation. No information was provided on the type and magnitude of the stimulation, to limit any expectation effects. Skin temperature, skin conductance, thermal sensation and wetness perception were recorded before and after the application of each stimulus (10 s). Data were analysed using a repeated measures ANOVA and Friedman test.

Results and Discussion
The relative increase in skin temperature resulting from the application of the stimuli was found to be not significantly different (p>0.05) between upper (+0.96 ± 0.1°C) and lower back (+0.75 ± 0.1°C). Resting local skin temperature was always increased by the application of the stimuli. Warmer stimuli produced statistically significant greater (p<0.05) thermal sensations with no differences between warm-dry and warm wet. No statistically significant differences (p>0.05) were found between wetness perception scores resulting from the application of the different stimuli to both skin sites. The threshold we set (point “–2 slightly wet” of the wetness perception scale) to identify a clearly perceived wetness was never reached during none of the four stimulations, neither for the upper nor the lower back. Average variations in votes (post stimulation – resting wetness perception) were calculated for each stimulus and then compared. No statistically significant differences (p>0.05) were found between the average variations in votes resulting from each stimulus for both skin sites. Participants did not discriminate between warm-dry and warm-wet stimuli and no perception of wetness was reported at all during any of the experimental conditions.

Conclusions
These findings indicate that thermal sensations can significantly alter the perception of skin wetness and that the co-activity of other sensory modalities varies in importance according to multiple factors.

References
Performance and thermoregulatory consequences of cutaneous L-Menthol application during self-paced exercise in hot conditions


Extreme Environments Laboratory (EEL), Department of Sport and Exercise Science, University of Portsmouth, Portsmouth, UK
*corresponding author: martin.barwood@port.ac.uk

Introduction

L-menthol stimulates cutaneous thermoreceptors and induces cool sensations thereby improving thermal comfort. However, the application of L-Menthol has been linked to heat storage responses by inducing vasoconstriction and delaying sweating. Consequently, it is possible that L-Menthol could lead to a conflict in behavioural and thermoregulatory drives during self-paced exercise; i.e. improving comfort but leading to an increased rate of rise in core temperature. The present study tested this hypothesis.

Methods

Ethical approval was granted for the study. Six untrained male participants (age 21 [1] years; height 1.80 [0.07] m; mass 78.9 [6.9] kg; surface area 1.98 [0.13] m²) undertook three separate trials in hot (34°C; 55% RH) conditions where their standardised clothing (shorts, socks, t-shirt and running shoes) was sprayed (CONTROL-SPRAY [97% water, 3% surfactants] or MENTHOL-SPRAY [97% water, 2.8% surfactants, 0.2% L-Menthol] or not sprayed (CONTROL) after a fixed velocity running period (15-minutes; fixed within participant at 10 or 12 km·h⁻¹), which induced thermal discomfort, before completing a 5 km treadmill time trial (TT). Measures included: Thermal perception (sensation TS; comfort TC on a 20 cm visual analogue scale), thermal responses (aural temperature [Tₐu], skin temperature [Tₖₚ] to calculate mean body temperature [Tₘb]), perceived exertion (RPE), heart rate, pacing and performance. Data were compared using ANOVA and t-tests and to an alpha level of 0.05.

Results

The volume of spray applied to the body in the CONTROL-SPRAY (102.5 [1.1] mL) and MENTHOL SPRAY conditions was similar (100.3 [1.0] mL). At the end of the fixed intensity exercise period (i.e., immediately before participants were sprayed) the TS and TC averaged 15.5 (1.4) cm and 9.8 (3.0) across conditions which corresponded to the descriptors warm to hot and just uncomfortable. During the TT, MENTHOL-SPRAY induced significant improvements (feeling cooler and more comfortable) in TS (up to 3 km of TT) and TC (up to 1 km) with Tₐu showing a tendency to be higher than CONTROL-SPRAY (+0.20 [0.29]°C) and CONTROL condition (0.30 [0.34]°C); although this was not significant. The rate of rise in Tₐu was linear and not different between conditions. Tₐu was still rising uncompensably between the 4th and 5th kilometre of the TT (p<0.05). The other variables were unchanged. TT completion time and pace were not different: CONTROL 27.92 [1.65], CONTROL-SPRAY 28.10 [1.12], MENTHOL-SPRAY 27.53 [2.85] minutes.

Conclusions

Spraying L-MENTHOL on athletic clothing prior to exercise in the heat culminated in improved thermal perception but not altered performance. This did not result in a faster rate of rise in deep body temperature.
Global and local thermal comfort in aircraft

Marius Janta¹ *, Veit Senner¹, Klaus Bengler¹, Markus Nöscher², Iris Nöske²
¹ Technische Universität München, Chair of Ergonomics / Specialty Division Sport Equipment and Materials
² Fraunhofer Institute for Building Physics IBP
* corresponding author: janta@lfe.mw.tum.de

Introduction
Global thermal comfort of humans has been researched extensively. Several thermo-physiological models, perception models and simulations have been developed to design thermally-ergonomic workplaces [1-4]. Yet, few data are available in regard to body-part-specific thermosensitivity, which plays an important role in thermal comfort. It therefore seemed necessary to gain more insight into this issue.

The purpose of the present study was to determine segmental and whole-body thermal discomfort for people seated in aircraft, because both aspects of discomfort distinguish one’s overall thermal perception.

Methods
At the Fraunhofer Institute of Building Physics, an eight-hour flight was simulated in a low pressure chamber. Fourteen subjects were tested in the cockpit, wherein their local and global thermal perceptions were asked using the seven-point ASHRAE scale [5] via a Comfort Questionnaire (CQ). Local thermal perceptions were recorded for the head, back, arms, legs, and feet. The local skin temperatures and relative humidity were measured with thermocouples and humidity sensors (MSR12 data logger) at the head, arms, hands, back and chest, from which mean skin temperature and mean humidity were calculated.

In the cockpit, subjects were exposed to a predefined temperature condition of 24°C for 45 minutes. Afterwards the subjects had the opportunity for three five-minute time frames to adjust their personal climate with four ventilation outlets: shoulder, chest, feet and overhead, each of which was flow and temperature controlled and individually adjustable. Additionally, a seat heating and ventilation mat was integrated in the seat and an air scarf system between back- and heat-rest provided additional local adjustments. The relative humidity of cockpit air was controlled at a mean value of 6% (SD= 1%) at the cockpit inlets. The whole procedure lasted 100 minutes. A detailed schedule of the experiment is shown in Table 1.

Table 1: Time schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Cabin</th>
<th>Cockpit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minutes minimum</td>
<td></td>
</tr>
<tr>
<td>Conditioning</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comfort Questionnaire (CQ)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant setting (24°C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indiv. Setting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indiv. Setting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure</td>
<td></td>
<td></td>
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<tr>
<td>Indiv. Setting</td>
<td></td>
<td></td>
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<tr>
<td>Exposure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indiv. Setting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Results
Figure 1 shows the mean skin temperature of the 14 subjects during the cockpit testing; the shaded region depicts minimum and maximum values measured among all subjects over each point in time.

On average, the mean skin temperature was 31.0 °C (SD 0.5); during the constant setting it was 30.7 °C (SD 0.2) and during individual settings it was 31.2°C (SD± 0.4). Applying a t-test with a significance level of α=0.05, a significant difference in mean skin temperature was evident for conditioned and individual settings \((p<0.01)\). Over time, temperature varied; temperature oscillation can be observed in the transition phase from constant to individual settings, caused by outlet usage.

The mean relative humidity on the skin was37% (SD 8). During constant settings, the mean humidity on the skin was 37%(SD 8), and during individual settings it was 37% SD 8 \((z \ p<0.01)\). Over time, humidity on the skin was constant. Again the shaded region shows the range of minimum and maximum values.

Subjects perceived the environment to be slightly cool during set cockpit conditions of 24°C (Figure 3). When subjects could adjust the temperature and flow conditions, the overall thermal perception increased to a neutral level, which was a significant improvement (Wilcoxon signed-rank test: \(p<0.01\)). Thus, a difference in mean skin temperatures of 0.5 °C and relative humidity of 1% was associated with more neutral perceptions.
The following tables show local temperatures and humidities at different body segments in the constant and individual setting of the experiment.

**Table 2: Mean local temperature**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Constant Setting</th>
<th>Individual setting</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>32.7 (± 1.4)</td>
<td>32.7 (± 1.6)</td>
<td>0.29</td>
</tr>
<tr>
<td>Back</td>
<td>34.4 (± 1.7)</td>
<td>34.7 (± 1.7)</td>
<td>0.00*</td>
</tr>
<tr>
<td>Head</td>
<td>32.2 (± 0.2)</td>
<td>32.8 (± 0.6)</td>
<td>0.00*</td>
</tr>
<tr>
<td>Arm, left</td>
<td>31.3 (± 0.7)</td>
<td>31.03 (± 1.0)</td>
<td>0.00*</td>
</tr>
<tr>
<td>Arm, right</td>
<td>31.3 (± 1.6)</td>
<td>31.28 (± 1.8)</td>
<td>0.64</td>
</tr>
<tr>
<td>Hands</td>
<td>29.2 (± 0.2)</td>
<td>29.74 (± 0.6)</td>
<td>0.00*</td>
</tr>
</tbody>
</table>

**Table 3: Mean local relative humidity**

<table>
<thead>
<tr>
<th>Mean</th>
<th>Constant Setting</th>
<th>Individual setting</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>45.0 (± 23.1)</td>
<td>41.76 (± 22.4)</td>
<td>0.00*</td>
</tr>
<tr>
<td>Back</td>
<td>31.90 (± 20.0)</td>
<td>23.76 (± 10.6)</td>
<td>0.00*</td>
</tr>
<tr>
<td>Head</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Arm, left</td>
<td>57.2 (± 19.0)</td>
<td>60.1 (± 22.5)</td>
<td>0.00*</td>
</tr>
<tr>
<td>Arm, right</td>
<td>47.3 (± 15.2)</td>
<td>46.95 (± 16.3)</td>
<td>0.45</td>
</tr>
<tr>
<td>Hands</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

As expected due to humans’ thermo physiological heat transfer during rest, extremities generally showed lower temperatures than core regions. Local temperatures between constant and individual settings showed significant differences at the back, head, left arm and hands. Relative humidity differed among locality (although absolute humidity would be more relevant for heat transfer and likely would lead to less local changes). Among settings, significant differences were shown at the chest, the back and the left arm.

**Table 4: Local comfort perception in cockpit between constant and individual settings**

<table>
<thead>
<tr>
<th>Body Part</th>
<th>Constant setting</th>
<th>Individual setting</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>Slightly cold</td>
<td>Neutral</td>
<td>0.01*</td>
</tr>
<tr>
<td>Arms</td>
<td>Slightly cold</td>
<td>Neutral</td>
<td>0.14</td>
</tr>
<tr>
<td>Legs</td>
<td>Neutral</td>
<td>Neutral</td>
<td>0.14</td>
</tr>
<tr>
<td>Feet</td>
<td>Slightly cold</td>
<td>Neutral</td>
<td>0.01*</td>
</tr>
<tr>
<td>Back</td>
<td>Neutral</td>
<td>Slightly warm</td>
<td>0.29</td>
</tr>
</tbody>
</table>

The subjective evaluation of local thermal perception also showed differences between the body segments. At 24°C, subjects felt slightly cold at their head, arms, and feet, but neutral on the legs and back, maybe caused by seating insulation. Perception at the head and feet was significantly different (p=0.01). A change towards a dominant neutral perception was evident between the settings.
Conclusion
This study examined differences in local and global thermal comfort in aircraft conditions. It was shown that differences appear in local and global thermal perception and therefore need to be more addressed in comfort modelling.

It was also shown that thermal comfort perception could include more than temperature perception, since big differences in humidity appear that are likely to be perceptible by humans, but not consequently regarded in comfort assessment. Here, huge differences in local humidity should be further considered but, based on absolute values. Additionally, subjects are able to precisely discriminate perceptually between localities. They further perceive even small temperature changes which seem to influence the overall comfort perception. Because vehicles are mainly heated via convective principles it is essential to additionally investigate radiation and conduction and their relationship to comfort perception separately and also their interaction.

In conclusion, it seems to be necessary to realise efficient thermal management in vehicles by using both local and decentralised systems.

References
ACUTE COLD STRESS

The effects of combined arterial de-oxygenation and systemic cooling on the rate of muscular fatigue development

Alex Lloyd1, George Havenith1, Simon Hodder1
1Environmental Ergonomics Research Centre, Loughborough University, Loughborough, UK
*corresponding author: A.Lloyd@Lboro.ac.uk

Introduction
Cooling and fatigue are known to have similar effects on muscle performance and physiology [1]. Studies have shown a significantly increased rate of fatigue development during both low, and high intensity work [2, 3]. Numerous researchers have also reported that acute hypoxemia exaggerates the rate of fatigue development, centrally [4, 5, 6, 7] and peripherally [7, 8, 9, 10, 11, 12]. While abundant research exists on cold and hypoxic stressors separately, the interactive effects of combined exposure on the rate of muscle fatigue development remains unexamined. We hypothesised that relative to baseline performance levels, independent exposure to arterial de-oxygenation and systemic cooling will induce a significant increase on post exercise fatigue, compared to values observed during thermoneutral normoxia. During combined hypoxic-cold exposure, we expected a significant synergistic interaction on post exercise fatigue, with peripheral blood flow reductions during cold accentuating the fatiguing effect of low arterial oxygenation.

Methods
Eight physically active, non smoking men were exposed for 1-hour 10-minutes to four conditions in a balanced order. The conditions were control/ normoxic thermoneutrality (N), hypoxic thermoneutrality (H), normoxic cold (C) and hypoxic cold (HC). Thermoneutral conditions were 22°C ambient temperature (T_{am}) and cold conditions were 5°C. Hypoxic exposures were 0.13 fraction of inspired oxygen (FiO\_2). After a 15-minute rest period, participants carried out dynamic forearm exercises at 15% maximal voluntary contraction (MVC) for eight consecutive, 5-minute work bouts, each separated by a 1-minute 50-second rest period. Electromyography and MVC force (Kgf) was used to quantify the rate of fatigue development in the forearm. To test post exposure data for significance, two-way (2 x 2) repeated measures ANOVA was used. A Wilks Lambda Multivariate Analysis of Variance (MANOVA) was also conducted on three fatigue related markers in a combined dependent variable. Multiple regression and Pearson correlations tested for significant relationships with skin temperature (T_{sk}), laser Doppler Flowmetry (LDF) and Peripheral Oxygen Saturation (SpO\_2).

Results and Discussion
The results indicate that when compared to exercise in thermoneutral or normoxic conditions, both cold and hypoxia induce significant (p <0.01) increases on indicators of muscle fatigue. Also, the level of fatigue is increased when the stressors are combined, however there is no interactive effect between these stressors. The effect of cold and hypoxia combined is additive. A key dependant variable used to define fatigue in this study – the fatigue index (FI) [3] - showed that when expressed as a percentage of the control condition (FI_{bN}), hypoxia and cold independently increased fatigue by 24 ± 7% and 39 ± 9% respectively. When hypoxia and cold were combined, FI reflected a summative value equal to 62 ± 11%. Furthermore, when physiological markers were combined using multiple regression, the results showed that over 50% of the variance in fatigue was accounted for by varied SpO\_2 and T_{sk} (p <0.01, adjusted r\^2 = -0.52).
Conclusions
Altitude is a multi-stressor environment, in which both cold and hypoxia dramatically reduce muscular endurance, thus increasing the risk of overuse injuries or musculoskeletal disorders [13]. When these stressors are combined the level of fatigue is increased further and the effects appear additive, not showing an interaction during low intensity, repetitive exercise.

References
Effects of cooling on ankle muscle maximum performances, gait ground reaction forces and electromyography (EMG)

Amitava Halder¹,²*, Chuansi Gao², Michael Miller¹, Ingvar Holmér²
¹ Division of Physiotherapy, Department of Health Science, Faculty of Medicine, Lund University, Sweden
² Division of Ergonomics and Aerosol Technology, Department of Design Sciences, Faculty of Engineering, Lund University, Sweden
*corresponding author: Amitava.Halder@design.lth.se

Introduction
Temperature is considered as a significant determinant of skeletal muscle function and performance [1, 2]. There is evidence that, there is an optimal temperature range where the best performance of muscle occurs. [3]. Controversial evidence is found in the literature which has examined the effects of decreased muscle temperature on muscle contractile properties. There have been several reports that muscular contraction force and rate of force development were impaired at low muscle temperature [4,5].

Since 1868, a lot of studies have focused on the muscle function and performance influenced by temperature [6]. Some investigations have dealt with the role of local temperature on skeletal muscle performance, yet its effects on neuromuscular function and performance through gait still remain unexamined. The purpose of this study was to assess the effects of cooling on the muscle performance through maximum force, muscle electrical activities during low dynamic and static contraction and ground reaction force during gait. Since no studies have investigated the relationship between the ankle muscle strength, ground reaction force during gait and EMG before and after cooling. It was hypothesized that, cooling and fatigue on muscle characteristics, maximal force and required force during gait would be reduced also affect the electrical activities of specific muscles of the lower extremities such as tibialis anterior (TA) and gastrocnemius medialis (GM).

Methods
The experimental study was carried out through within subject design. All volunteer participants signed the informed consent form. Sixteen healthy university students participated in the study, 8 males and 8 females, mean ± SD: age, 27.0 ± 2.9 years; body mass, 66.3±9.8 kg; height, 169.5±7.8 cm. The study (project no. 100026) was approved by the regional ethical review board in Lund (EPN), and performed in according to declaration of Helsinki for research involving human subjects. Two experimental stations were designed for the experiment with one in a ‘room temperature environment’ where a walkway with a force plate was placed while the other experimental station was in a ‘cold climate chamber’ with a chair and water container. A physical examination bed was also placed inside the climatic chamber to allow the individual to be supine during the dynamometer measurement.

Figure 1. Hand held dynamometer was used to measure plantar flexion strength against foot resistant.

The subjects were instrumented by attaching EMG electrodes to the skin of muscle belly by shaving or abrading to minimize the electrical impedance, followed by the isometric resisted tests through using a hand held dynamometer while lying on the supine on the examination bed in cold
climate chamber and then walking over the ground reaction force plate while EMG data were obtained. Before immersion the subjects was fully prepared by wearing necessary clothes. The local cooling was induced by immersing both lower legs up to knee for 20 min in the cold water (10°C) in a climate chamber with air temperature being kept at 9.5°C. Electromyographic (Megawin’ ME6000-T16 Mega Electronics, Kuopio, Finland) activities and strengths of the ankle dorsi and plantar flexors maximum isometric forces were measured in tibialis anterior and gastrocnemius medialis muscles by using surface electrodes and ‘Lafayette Hand Dynamometer’ (model: LA-01163 IN, US). Ground reaction forces during gait were measured with force plate (Kistler 9281B Switzerland) while the subjects were walking on the walkway.

Results and Discussion
There was a significantly reduced isometric maximum force in TA muscle (p<.001) after cooling. The mean EMG amplitude of GM muscle was significantly increased after cooling (p<.003). There were no significant changes in ground reaction forces and required coefficient of friction (RCOF) in gait trials after cooling. RCOF is the ratio of Fy over Fz and is used to assess slip risk. If available coefficient of friction is smaller than RCOF, a slip will occur. The main findings showed that the cooling decreased maximum force of the TA but not the GM muscle. The study also showed that cooling increased the EMG amplitude significantly of the GM but not the TA during the maximum voluntary contractions and gait trials. These results partly support initial hypothesis that maximum lower leg muscle force decreases through ankle maximal voluntary contractions. (see Table 1 & 2).

Table 1. The means and standard deviations of the three MVC trials as well as the mean EMG amplitude during the three MVC trials, and median EMG (normalized) during three gait trials are given for the TA and GM muscles before and immediately after cooling (n=16).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Dorsi Flexion (TA) Pre Cooling Mean ± SD</th>
<th>Post Cooling Mean ± SD</th>
<th>Sig. ‘P’ value</th>
<th>Planter Flexion (GM) Pre Cooling Mean ± SD</th>
<th>Post Cooling Mean ± SD</th>
<th>Sig. ‘P’ value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVC Mean (Kg)</td>
<td>23.8±2.7</td>
<td>21.3±2.7</td>
<td>&lt;.001</td>
<td>30.6±4.5</td>
<td>29.7±3.0</td>
<td>.221</td>
</tr>
</tbody>
</table>

**EMG (MVC)**

<table>
<thead>
<tr>
<th>Tibialis Anterior</th>
<th>Gastrocnemius Medialis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD</td>
<td>Sig. P value</td>
</tr>
<tr>
<td></td>
<td>‘t’ Test</td>
</tr>
<tr>
<td></td>
<td>‘t’ Test</td>
</tr>
<tr>
<td>EMG (MVC) Mean (µV)</td>
<td>446.4±218.2</td>
</tr>
</tbody>
</table>

**EMG during Gait trials (normalized values in %)**

| Gait trial EMG | 11.3±5.3 | 13.1±7.3 | .158 | .077 | 13.6±10.3 | 19.8±11.9 | <.001 | .004 |

*Non-parametric ‘Wilcoxon Signed-Rank’ Test for EMG data.
Table 2. Vertical and longitudinal Ground Reaction forces (normalized by body weight) during heel strike and toe-off in relation to dorsi-flexion and plantar flexion respectively before and after cooling (n=16).

<table>
<thead>
<tr>
<th>Ground Reaction Forces (GRF)</th>
<th>Heel Strike (HS) Phase</th>
<th>Toe-Off (TO) Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre Cooling</td>
<td>Post Cooling</td>
</tr>
<tr>
<td>Forces (normalized)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Vertical (Fz)</td>
<td>.14±.11</td>
<td>.17±.10</td>
</tr>
<tr>
<td>Peak Longitudinal (Fy)</td>
<td>-.21±.05</td>
<td>-.21±.06</td>
</tr>
<tr>
<td>Required Coefficient of Friction (RCOF)*</td>
<td>.26±.04</td>
<td>.25±.05</td>
</tr>
</tbody>
</table>

*RCOF during heel strike phase was included in the analysis.

A significant decrease in MVC strength was observed from pre to post cooling for dorsi-flexion (DF) only, whereas, EMG amplitude for plantar flexion (PF) in GM muscle significantly increased. This might be induced by muscular fatigability as it was proved that fatigued muscular EMG during isometric contraction increased the amplitude [7]. One possible reason for the discrepancy of GM MVC not being affected might be that due to, GM being a much larger muscle than the TA, the drop in temperature of this large muscle was less affected by the cooling method of this study. Furthermore, it has been reported that EMG amplitude of the fatigue and cooled working muscles increased amplitude on isometric and sub-maximal exercise is due to recruiting more fibres to produce the same force [7,8].

The analysis of ground reaction force showed no significant alterations on peak vertical and longitudinal ground reaction forces. However, a small decrease can be seen in vertical force during the heel strike and toe-off phases and also some decrease in the longitudinal anterior-posterior force during the heel strike phase. Eils et al. [9] and Stål et al. [10] showed that an anaesthetic effect on feet by following ice water immersion and reported that gait changed on a force plate, such that the timing of first (HS) and second peak (TO) was modified by delaying and braking and acceleration forces were also reduced. As this study also used cold water, the cutaneous sensation might have reduced [11].

The results of this study concerning the cooling effects were consistent with the hypothesis in matter of muscular performance except ground reaction forces. These non significant changes of ground reaction forces after cooling might be explained by the task of walking on a level and dry vinyl surface not being demanding enough. Gait speed could be an another determination, subjects were asked to walk only a few steps on a 7.5 m walkway, so the speed required to complete a trial was low might not affected the ground reaction forces. Sport and work performance may decline due to local cooling in cold environments where subject may not produce their maximum force. Ground reaction forces may be affected by the cooling during high velocity human movement. It would be interesting to examine sports surfaces where athletes produce force for momentum for example, jumping surfaces to evaluate the performance. It is still not clear how about cooling influence muscle fatigue; further studies are needed to compare fatigue muscle characteristics of repetitive movements with muscle characteristics after cooling.
Conclusions
In conclusion, the present study showed that neuromuscular performances were partly altered after cooling. Maximum strength loss occurred in dorsi-flexion (TA). Fatigued, over-exerted power loss observed in plantar flexion (GM) though cooling did not make a significant contribution to normal gait ground reaction forces on a dry and level surface. These may indicate that 20 min cooling in cold water at 10°C can influence our maximum muscle performance, but the cooling may not be severe enough to impact our daily sub maximal activities.

Acknowledgement: The study was financed by AFA Insurance, Sweden.

References
Cold exposure reduces double poling performance

Øystein N. Wiggen1*, Cecilie T. Heidelberg2, Silje H. Waagaard2, Mariann Sandsund1, Hilde Færevik1, Randi E. Reinertsen1

1 SINTEF Technology and Society, Department of Health Research, NO-7465 Trondheim, Norway
2 Norwegian University of Science and Technology, Department of Biology, NO-7491 Trondheim, Norway
*corresponding author: oystein.wiggen@sintef.no

Introduction
Cross-country skiing is a popular and commonly practiced outdoor activity in Northern Europe. The environmental conditions during winter can frequently expose cross-country skiers to ambient temperatures below -10°C and a significant cold stress. Cross-country skiing is therefore one of the endurance sports in which athletes are most often predisposed to cooling due to extreme cold. Subnormal muscle temperature reduces performance and increases the relative strain on the muscles and may cause fatigue earlier than normal muscle temperature [1].

According to Basset and Howley [2] endurance performance can be determined by three main components, namely; maximal oxygen consumption (VO2max), running velocity or oxygen consumption (VO2) at lactate threshold and running economy. The effect of cold on these components has somewhat contradictory results, in that some studies have found no effect of cold [3, 4], while other have shown a detrimental effect in the cold [5-7].

One of the key components of success in modern cross-country skiing is upper body power [8, 9]. A frequently employed technique in modern cross-country skiing is double poling. This technique places high loads on the upper body, and is typically used during high-speed stages on relatively flat terrain. In addition to the upper body, the torso and leg musculature have also been shown to significantly contribute during double poling [10, 11].

The aim of this study was to investigate the effect of low ambient temperature on double poling performance in well-trained male cross-country skiers. We hypothesised that a low ambient temperature would result in reduced double poling endurance performance.

Methods
Thirteen highly-trained male cross-country skiers participated in the study. The participants had been informed of the aims of the study and had given their written consent. The study was performed according to the Helsinki Declaration and was approved by the Regional Research Ethics Committee in Medicine, Central Norway. Participants’ physical characteristics were (mean ± SD): age 23 ± 2 years, height 180 ± 5 cm, body mass 76.5 ± 4.7 kg, body fat 9.8 ± 2.0%, peak oxygen uptake while double poling (VO2peakDP) 4.70 ± 0.50 (L·min⁻¹), peak power output (POpeak) 142 ± 32 W.

To avoid any order effects, the main tests were performed in random order under a low (-14.5 ± 0.7°C) and a moderate (5.6 ± 0.3°C) ambient temperature (later referred to as -15°C and 6°C, respectively) with a wind velocity of 4 m·s⁻¹. Core temperature was measured as rectal temperature and skin temperatures were measured with thermistors (YSI 400, Yellow Springs Instruments, ± 0.15°C). Mean skin temperature was calculated as the mean value of twelve measured skin sites [12].

During the experimental tests a double poling ergometer (ThoraxTrainer, Holbæk, Denmark) was used. After a 30 minute rest period in a preparation-room (23 ± 2°C) to stabilize body temperature, the participants entered the climatic chamber and performed a 10-minute warm-up
at a load of 50-60 W. After the warm-up the participants mounted the ergometer and performed a five-minute submaximal double poling economy test at a power output of 70 W (hereafter termed test 1). Double poling economy was calculated by dividing oxygen uptake ($\text{VO}_2$) by the power output [13, 14]. After a three-minute break, they performed a 20-minute maximal double poling test (hereafter termed 20-minute test). In this test the participants chose their individual pace with focus on maximal performance and they were encouraged by the test leader to perform at their best. After the test the participants had eight minutes to recover before another five-minute submaximal double poling economy test at 70 W (hereafter termed test 2). Statistical analyses were conducted using two-tailed paired-samples t-tests and ANOVA. Effect sizes, Cohen’s $d$ and partial eta squared (ANOVA) were determined for post hoc comparisons. Effect sizes of 0.2, 0.5, and >0.8 were calculated to represent small, medium and large differences, respectively [15]. Data were accepted as statistically significant at $p < 0.05$.

**Results**

**Skin and core temperature**

Rectal temperature did not differ between conditions (Figure 1), but mean skin temperature were significantly lower at -15°C than at 6°C ($p < 0.001$, partial eta squared = 0.99)

![Image](image1.png)

*Figure 1.* Rectal (A) and mean skin (B) temperatures. Data are mean and standard deviation. #, indicates a significant difference throughout the exposure between 6°C and -15°C.

**Double poling economy**

From test 1 to test 2 at 6°C there was a $7.9 \pm 5.3\%$ ($p < 0.001$, $d = 0.69$) reduction in double poling economy. The same was observed at -15°C, where economy was reduced by $10.7 \pm 5.4\%$ ($p < 0.001$, $d = 0.91$). The change in double poling economy was $3.7\%$ ($p = 0.003$, $d = 0.82$) greater in the cold.

**Double poling endurance performance**

The 20-minute test in the cold led to a $2.9 \pm 3.0\%$ ($p = 0.007$, $d = 0.32$) shorter distance covered and a $5 \pm 5.2\%$ ($p = 0.01$, $d = 0.31$) decrease in power output (Figure 2).
Figure 2. Distance and power output in the 20-minute maximal double poling test. Data are mean and standard deviation. 

Discussion

The main finding of this study was a reduced double poling economy and overall performance in the cold, which is in line with previous studies [5, 16, 17]. These studies have suggested that alterations in mechanical efficiency or economy [17-19] can partially explain reduced performance in the cold. However, the mechanisms underlying the change in double poling economy are not known, but it has been suggested that during exercise at suboptimal muscle temperatures, more and also faster muscle fibres might be recruited, and that this change in motor-unit recruitment can partially explain the decrements in double poling economy [18]. In addition, muscle cooling can lead to reduced oxidative enzyme activity, nerve and muscle excitability, and nerve conduction [1].

Cross-country skiers have high aerobic capacity and a low percentage of body fat. Their high aerobic capacity enables them to produce large amounts of heat to efficiently maintain thermal balance [20], but their low percentage of body fat makes them vulnerable to heat loss and thus to cooling. The double poling technique involves the whole body, and a dominant proportion of the active muscles are located in the arms and torso. The large surface-to-volume ratio of the arms makes them more susceptible to cooling compared to the legs [21]. Even though the temperature effect on double poling performance might be small (Cohen’s d around 0.3), it is definitely present and should not be neglected as a limiting factor when striving for optimal performance. Cold environments, high movement velocities, light insulation in cross-country race suits, body type, and physical characteristics of the skiers, call attention to how cold can affect modern cross-country skiing performance and the important role of optimal clothing and insulation.

Conclusion

In conclusion, this study demonstrated that double poling performance was reduced at -15°C compared to 6°C in male cross-country skiers. In spite of high work intensities and increased rectal temperature, a significant reduction in skin temperatures was shown in the cold, which might indicate a superficial cooling of the working muscles.

References


Muscular, cardiorespiratory and thermal strain of mast and pole workers

Juha Oksa¹ *, Sanna Hosio¹, Tero Mäkinen¹, Harri Lindholm¹, Hannu Rintamäki¹ 2, Sirkka Rissanen¹, Jari Latvala¹, Kimmo Vaara³, Panu Oksa¹

¹ Finnish Institute of Occupational Health
² University of Oulu
³ Medical Center Health House
*corresponding author: juha.oksa@ttl.fi

Introduction
Mast and pole work is defined as erecting and pulling down masts and poles, putting up and taking down antennas, installing and transposing air traffic guiding lights, installing pipes and cables and carrying out their maintenance. The work contains several features that can induce significant muscular, cardiorespiratory and thermal strain such as climbing onto high masts (with tools, up to 140 m), working on an uneven and soft terrain (e.g. snow coverage, woodland and marshland), exposure to harsh weather conditions (especially winter) and use of protective gear. Since physical strain during mast and pole work is not known, this study evaluated the level of muscular, cardiorespiratory and thermal strain of mast and pole workers with special emphasis on winter.

Methods
Fourteen voluntary and healthy male mast and pole workers participated in the study. We measured their muscular strain using electromyography (EMG, ME6000, Mega Electronics Ltd, Finland), expressed as percentage in relation to maximal EMG activity (%MEMG). We indirectly estimated VO₂ from HR (Polar Sport tester, Polar Electro Ltd, Finland) measured during work (using individual VO₂-HR relationship measured in the laboratory) and expressed it as percentage of maximum VO₂ (%VO₂max). To quantify thermal strain skin and deep body temperatures were measured using temperature sensors (NTC DC95, type 2252 Ohm, Digi-Key, USA) and telemetric pill (Jonah™ Temperature capsule, Respironics Inc, USA) and receiver VitalSense, Respironics Inc, USA), respectively.

Results and Discussion
We found the highest average muscular strain in the wrist flexor (24±2%MEMG) and extensor (21±1%MEMG) muscles, exceeding the recommendation of 14%MEMG. Average cardiorespiratory strain was 48±3% VO₂max. Nearly half (40%) of the subjects exceeded the recommended 50% VO₂max. Winter condition increased both muscular and cardiovascular strain on average by 4 and 2 %, respectively. Deep body temperature varied between 36.8 and 38.0°C and mean skin temperature between 28.6 and 33.4°C indicating possible occasional superficial cooling. Cooling was most pronounced in extremities during winter. Lowest single temperatures in middle finger, hand and big toe varied between 6.4 and 18.5, 9.4 and 24.9 and 15.4 and 24.6°C, respectively.

Conclusion
In conclusion, this field study shows that workers may be at risk for local and/or systemic muscular and cardiorespiratory overloading (the winter enhancing this effect slightly) and thus for excessive fatigue, reduced work efficiency and increased risk for musculoskeletal symptoms. Generally, thermal strain remained at a tolerable level.
Use of a fall-arrest system in the cold

Sirkka Rissanen¹*, Hannu Rintamäki², Ville Hyvärinen¹

¹Finnish Institute of Occupational Health, Oulu, Finland
²University of Oulu, Department of Biomedicine, Oulu, Finland

*corresponding author: sirkka.rissanen@ttl.fi

Introduction
While working at heights such as masts, constructions or scaffoldings workers need to wear a fall-arrest harness (FA). A full-body harness consists of a supporting blade on the back side, an integrated well-padded belt and shoulder and leg straps. The harness may compress the clothing layers on the torso area and in the groin and hence decrease thermal insulation and impair the ventilation properties of the clothing. Furthermore, additional weight may increase the physiological strain. The purpose of this study was to evaluate the effects of a full-body FA on human thermal responses and thermal insulation of the clothing during an exposure to cold and windy conditions.

Methods
Six young non-cold-acclimated male participants volunteered for this study. The volunteers were wearing winter protective clothing. The full-body FA, weighing 2.2 kg, was used. The trials were performed while using the FA or without it (Con). The trial consisted of pre-exposure at -15°C (volunteers were standing for 15 min) (PRE), followed by walking on a treadmill at a velocity of 3.3 km/h and with 15° angle for 20 min (WALK), and standing/leaning against the harness for 15 min (POST). WALK and POST were performed at -15°C with wind velocity of 3 m/s. Skin temperature, heat flux from the skin, heart rate and relative humidity between clothing layers were measured.

Results
Results are based on the preliminary data. When using FA mean skin temperature was 0.2, 0.4 and 0.3°C higher during PRE, WALK and POST, respectively, in comparison with Con. Torso skin temperature was 0.7, 1.0 and 1.2°C higher (p<0.05) with FA during PRE, WALK and POST, respectively compared with Con. During PRE total thermal insulation of the clothing (Icl) was 0.368 and 0.397 m²K/W for Con and FA, respectively. Icl decreased by 49% during WALK and by 36-42% during POST in both ensembles. Relative humidity between clothing layers on the front side (calm side) was 92 and 69% (NS) for Con and FA, respectively during POST. Corresponding values on the back side (wind side) were 58 and 80% (p<0.01).

Conclusions
Preliminary results show that the full-body harness provides increased thermal protection during a short-term exposure to cold and windy conditions. Microclimate humidity was greater under the supporting blade but total thermal insulation of the clothing was not decreased by the harness.

This study was carried out as part of the project “Harsh Weather Testing Network”, which was financially supported by the European Union, Interreg IV Nord (www.harshnet.eu).
Effect of repeated forearm tissue cooling on non-shivering thermogenesis in hypothermic skeletal muscle in human

Hitoshi Wakabayashi1*, Takayuki Nishimura2, Titis Wijayanto2, Shigeki Watanuki2, Yutaka Tochihara2
1 Faculty of Engineering, Chiba Institute of Technology, Narashino, Japan
2 Faculty of Design, Kyushu University, Fukuoka, Japan
*corresponding author: wakabayashi.hitoshi@it-chiba.ac.jp

Introduction
This study aimed to investigate the effect of repeated local forearm tissue cooling on the metabolism in hypothermic skeletal muscle. It is hypothesised that repeated decrease of muscle temperature increases the oxygen consumption in hypothermic skeletal muscle.

Methods
Eight healthy males participated in this study. Their right forearm tissues were locally cooled to 25°C by cooling pads attached to the skin. This local cooling was repeated eight times on separate days. To evaluate adaptation in non-shivering thermogenesis in skeletal muscle, a local cooling test was conducted before and after the repeated cooling period. Changes in muscle haemodynamics (changes in oxy- and deoxy-haemoglobin content) during 25-second isometric handgrip (10% maximal voluntary construction) was measured by Near-infrared spectroscopy at every 2°C reduction in the forearm tissue temperature. The arterial blood flow was occluded for 15 seconds by upper-arm cuff inflation during the isometric handgrip. The oxygen consumption in the flexor digitorum muscle was evaluated by a slope of the oxy- and deoxy-haemoglobin difference during the arterial occlusion [1].

Results and Discussion
In both test experiments, skeletal muscle oxygen consumption decreased significantly depending on the muscle temperature reduction (p<0.05); specifically, the oxygen consumption in hypothermic skeletal muscle tended to be higher at the post-local cooling test than pre-test for each tissue temperature level. This result indicated that repeated local tissue hypothermia and hypothermia-induced hypoxia might facilitate non-shivering thermogenesis in the skeletal muscle. This increased oxidative metabolism may be due to an increase in the mitochondrial density similar to that of the adaptive response in skeletal muscle to hypoxic training [2]; and/or an increase of muscle oxidative capacity via mitochondrial uncoupling, as shown in isolated human skeletal muscle biopsies taken after mild cold exposure [3].

Conclusions
In summary, non-shivering thermogenesis in hypothermic skeletal muscle was facilitated after repeated local tissue cooling.

References
Sex differences on susceptibility to hand or foot cold injury after alpine skiing

Shawnda A. Morrison1*, Adam C. McDonnell1,3, Urša Ciuha2,3, Daniela Zavec-Pavlinič2, TadejDebevec1, Igor B. Mekjavič1

1Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute, Jamova 39, SI-1000, Ljubljana, SLOVENIA
2Biomed d.o.o., Stari Trg 4, Ljubljana, SLOVENIA
3Jozef Stefan International Postgraduate School, Jamova 39, SI-1000, Ljubljana, SLOVENIA
*corresponding author: shawnda.morrison@ijs.si

Introduction
Exercise in cold, high-altitude environments can increase the likelihood of suffering freezing or non-freezing cold injuries. However, very few data exist which compare digit temperatures between male and female athletes in field-based scenarios.

Methods
Fifty-five experienced alpine skiers (male: n=29, age: 30±13 yr, height: 1.81±0.6 m, mass: 79±9 kg; female: n=26, age: 27±7 yr, height: 1.67±0.4 m, mass: 60±7 kg) completed this field study at the Nassfeld Pass Ski Resort, situated on the Austrian-Italian border (bottom station: 610 m, top station: 2 020 m, total vertical rise: 1 410 m). Skiers were required to ski continuously ~3h in the morning (AM: 9h00-12h00) and afternoon (PM: 13h00-16h00) on alpine slopes rated predominantly “difficult”. All skiers had approximately 1-h rest for lunch (~12h00). Hand and foot digit temperatures were assessed on Day 1, Day 2 and Day 4 via infrared thermographs taken immediately before AM ski session and immediately after PM session. Skiers wore standardised gloves during the ski sessions, and removed them only for lunch and when requested by a researcher after returning to the mobile lab at the base of the mountain. Hand temperatures were analysed via 2-way RM ANOVA (time x day) with one between-subjects factor (sex). Foot temperatures were analysed with independent t-test (Day 4).

Results and Discussion
Foot digit temperatures were significantly colder by ~6.7°C immediately after alpine skiing (AM: 27.1±2.4 v PM: 21.4±6.3°C; p<0.000) irrespective of sex (p=0.672). Minimum mean toe temperatures < 15°C were reported in N= 8/26 females and 2/29 males, respectively. Hand digit results were complicated due to a 3-way interaction between time x day x sex (p=0.001), such that females had colder hands than men by ~3°C (CI: -4.09 to -1.70; p<0.0001) at any given time point. Day1 had the warmest skin temperatures post-ski compared to Day2 and Day4, by 5.2 and 4.7°C, respectively (p=0.0001). On Day2, women had highly variable mean finger temperatures post-ski (AM: 25.5±5.0 v PM: 23.5±7.4°C; p=0.08), but were consistently warmer after Day4 (AM: 24.3±3.5 v PM: 27.9±4.0°C; p<0.000). Discrepancies in post-ski data could have been due to variable weather conditions or ski intensities across testing days.

Conclusions
Whether these slight differences in post-skiing hand digit temperatures in females represent a clinically significant difference in terms of one’s predisposition to future cold injury appears unlikely. Foot data reveal significant decreases in toe temperatures after alpine skiing, dropping below 10°C in some individuals, which could represent a predisposition to suffering freezing or non-freezing cold injuries in those persons exhibiting coldest toe temperatures.
Sex differences in thermal strain induced by a typical hiking scenario in a cool environment

Damien Fournet¹,²*, Katy Griggs¹, Bernard Redortier², George Havenith¹
¹ Environmental Ergonomics Research Centre, Loughborough University, Loughborough, UK
² Thermal Sciences Laboratory, Oxylane Research, Villeneuve d’Ascq, France
* corresponding author: D.Fournet@lboro.ac.uk

Introduction
Most research investigating hill walking has focused on the mechanisms of accidental hypothermia with protocols involving males exposed to prolonged wet and windy environments [1]. No attention has been paid to discomfort associated with the different phases of recreational hiking in non-adverse conditions. The present study was designed to evaluate overall and local thermal strain during a typical hiking scenario and to highlight potential differences between males and females. This knowledge can be of practical importance for improved clothing requirements.

Methods
Eight males and eight females, physically active, took part in a laboratory-based 110-min simulated hike at a fixed relative intensity in a 15°C environment. The protocol was split into four main stages, a 5-min standing rest (PRE), a 60-min ascent (no wind) at 55% \( \dot{VO}_2_{max} \) (CLIMB), a 15-min seated rest exposed to 2.8 m.s\(^{-1}\) frontal wind (SUMMIT) and a 30-min descent (no wind) at 20% \( \dot{VO}_2_{max} \) (DOWN). Treadmill gradient (up and down) was set at 15% and all participants wore standardised clothing (T-shirt, fleece top, trousers) and a backpack adjusted to 10% of body mass. At the different stages, nude whole-body skin temperature \( (T_{sk}) \) was recorded by infrared thermography in order to obtain mean \( T_{sk} \), regional \( T_{sk} \) as well as population-averaged maps of whole-body \( T_{sk} \) distribution [2]. Rectal temperature \( (T_{re}) \) and heart rate \( (HR) \) were recorded throughout the whole protocol. Gross sweat loss \( (GSL) \) was calculated from pre- and post-weight measurement. Thermal sensation, wetness sensation and thermal comfort were also evaluated for the whole-body and for 11 body regions.

Results and Discussion
Sex differences were mainly observed for thermoregulatory responses and to a much lesser extent for perceptual responses. Specifically, females exhibited a significantly higher \( T_{re} \) and lower mean \( T_{sk} \) (on average 0.3°C and 0.6°C respectively) over the protocol (Figure 1). Four of the females were at the luteal phase of the menstrual cycle and the other four at the follicular phase. At SUMMIT, \( T_{re} \) dropped continuously for both groups, with a more pronounced drop in the females \((p<0.05)\) whereas the increase in mean \( T_{sk} \) was more important during DOWN for females compared to males \((p<0.05)\).

Regional \( T_{sk} \) displayed significant sex differences specifically located in the lower limbs and arms, being 2°C colder for females on average \((p<0.01)\). These sex differences were less pronounced than during another experiment in the cold with unclothed female and male runners [2]. HR was 20 bpm lower for females during CLIMB \((p<0.05)\) but similar at SUMMIT and DOWN \((p=0.91)\). Overall thermal sensation was colder for females at PRE \( (cold vs slightly cool) \) and overall thermal comfort was worse at SUMMIT \( (uncomfortable vs slightly uncomfortable) \) compared to males \((p<0.05)\). The last sex difference was at a regional level with males perceiving their face as wetter than females \( (wet vs dry) \) at CLIMB \((p<0.05)\).

Similarities between sexes were observed for all other parameters. GSL was similar between groups \((p=0.36)\). Overall thermal and wetness sensation reached similar levels at CLIMB \( (warm \)
and wet), SUMMIT (*slightly cool and moist*) and DOWN (*slightly warm and moist*) for all participants with no sex differences.

The body maps of Tsk of males and females showed for the first time the regional variations in Tsk after a clothed-exercise bout showing the contribution of active muscles during hiking as well as the discrete importance of the backpack pressure onto the skin.

![Figure 1](image-url)

**Figure 1.** Evolution of rectal temperature (Trc, °C) and mean skin temperature (Tsk, °C) for 8 females and 8 males with load carriage (10% body mass) during a simulated hike in a 15°C environment. *significantly different from males (p<0.05)

Over the protocol, correlation analyses indicated that face Tsk was a good indicator of local face sensation and it was also positively correlated with overall thermal sensation (from r = -0.65 to r = -0.85, p<0.05).

**Conclusions**

Our evaluation emphasizes that perceptual responses of males and females were relatively similar during hiking at a fixed relative intensity despite sex-differences in thermoregulatory responses. The exceptions in terms of perception were mainly found during the resting phases.

The limited overall and regional sex differences are not of practical importance for clothing design. Overall data yet indicate the need for a good adaptability of the clothing ensemble when facing various climates and exercise demands.

**References**


Finger cold induced vasodilation at different four phases of a circadian rhythm

Siyeon Kim\(^1\), Hyung-Seok Jeon\(^2\), Joon-Hee Park\(^2\), Hyo-Hyun Lee\(^2\), Ju-Hee Park\(^2\), Joo-Young Lee\(^1,2,*\)

\(^1\)Department of Clothing and Textiles, Seoul National University, Seoul, Korea
\(^2\)Institute of Human Ecology, Seoul National University, Korea
*corresponding author: leex3140@snu.ac.kr

Introduction
The cold-induced vasodilation (CIVD) phenomenon was first identified by Lewis in 1930 [1], yet the underlying mechanisms of CIVD are still unclear and debated to this day [2-4]. CIVD is a complex response that is initiated by the dilation of arterio-venous anastomoses (AVAs), which are mediated by local and/or central pathways. Flouris and colleagues [5] recently reported that the CIVD response in a finger was greater when body temperature was increased. It is reported that the enhancement of the CIVD response following exercise is most likely due to the elevation in core temperature [6]. A circadian rhythm in core temperature at rest has long been recognised. It is also well-agreed that sudomotor and vasomotor responses during passive heat stress follows the same circadian pattern. While most research has been conducted in terms of thermoregulatory responses to heating, it is still unclear if there is a circadian rhythm in cutaneous vascular activity to local cooling. Furthermore, relationships between CIVD responses and body temperatures according to circadian variations are yet to be examined. The purpose of this study was to explore the CIVD responses of the finger in relation to rectal temperatures according to circadian rhythm. We hypothesized that finger CIVD responses would be less dynamic in morning than other phases, which would be attributable to a lower internal body temperature in the morning.

Methods
Subjects and four experimental conditions
Sedentary male students (n=9; 19.9 ± 1.4 yrs, 174.9±5.0 cm, 64.0±14.0 kg) participated. All subjects were informed of the purpose of the study and signed consent forms prior to participation. The experiments were performed at four different times of day [0700 h (Morning), 1300 h (Daytime), 1900 h (Evening), and 0100 h (Night)]. The four experiments were performed in random order to avoid the effect of familiarisation. Subjects were non-smokers and did not perform heavy exercise within 24 h of the experiments, and were prohibited from ingesting food from 3 h before each session.

CIVD test
Subjects wore only shorts and short sleeved t-shirts. A climatic chamber was maintained at an air temperature of 28°C with 40% RH. Subjects were equipped with sensors and probes for monitoring body temperature and blood pressure in the chamber. An experimental trial consisted of a 10-min rest followed by a 30-min finger cold-water immersion and a 20-min recovery in a seated posture. Subjects maintained their arms on a desk at heart level during the whole trial of 60 min. At the 10\(^{th}\) min of the trial, subjects were asked to immerse the left middle finger up to the level of the middle phalanx in cold water. Cold-water immersion was maintained for 30 min. The remaining fingers were supported comfortably on the insulated platform of the water bath. The water temperature was maintained at 3.8±0.4°C and was mechanically stirred. During the whole trial of 60 min, skin temperatures (\(T_{sk}\)) were recorded every 5 s on the following left-sided body regions (except for the forehead): the forehead, chest, abdomen, upper back, upper arm, forearm, hand, middle finger tip (palmar side), thigh, calf and foot using a data logger (LT-8A, Gram Ltd,
Mean skin temperature \( (T_{sk}) \) was estimated from a modified Hardy & DuBois’ equation: 
\[ T_{sk} = 0.077T_{\text{forehead}} + 0.35(T_{\text{chest}} + T_{\text{abdomen}} + T_{\text{upper back}})/3 + 0.14(T_{\text{upper arm}} + T_{\text{forearm}})/2 + 0.05T_{\text{hand}} + 0.19T_{\text{thigh}} + 0.13T_{\text{calf}} + 0.07T_{\text{foot}} \]
Rectal temperature \( (T_{re}) \) was monitored at a depth of 16 cm from the anal sphincter every 5 s using the data logger. Heart rate (HR) was recorded every 5 s (Polar, Finland). Blood pressure (BP) was measured at the right upper arm using an automated sphygmomanometer (Meditec, Korea). BP was measured three times every 10 min, and the average value was used. Mean arterial blood pressure (MAP) was calculated from systolic blood pressure (SBP) and diastolic blood pressure (DBP) \[ \text{MAP} = \frac{\text{DBP} + (\text{SBP} – \text{DBP})}{3} \]. Finger pain sensation was recorded every 5 min using a categorical scale with seven cardinal numbers from 0 to 6 with four verbal descriptors [0 (no pain), 1 – 2 (slightly painful), 3 - 4 (painful), 5 – 6 (very painful)]. CIVD parameters (maximum/ minimum/mean finger temperatures, onset time, amplitude and peak time) are shown in Figure 1. AREA under the curve was calculated for each subject, with 4°C set as the baseline. Resistance Index for Frostbite (RIF) was calculated from \( T_{\text{mean}}, t_{\text{onset}}, \) and \( T_{\text{min}} \) according to the formula of Yoshimura and Iida [7]. Differences between the 4 phases were tested by repeated measures ANOVA and Post hoc test.

Results and Discussion
Figure 2 shows the averages of rectal and finger temperature from nine subjects over his four phases. There was a circadian rhythm in \( T_{re} \), with the lowest value in the Morning and the highest in the Evening \( (p<0.05, \text{Table 1}) \). At rest, peripheral temperatures showed no differences over the four phases. During cold immersion, there were also no differences in both MAP and HR among four phases. For CIVD parameters, \( T_{\text{min}}, T_{\text{max}}, T_{\text{mean}}, \) Amplitude, onset time of CIVD \( (t_{\text{onset}}) \), frequency of waves, RIF, and pain sensation showed no differences according to circadian rhythms (Table 2). However, during recovery, finger temperature was lower in the Morning \( (16.4±4.6°C) \) than at Night \( (21.6±5.9°C) \) \( (p<0.05 \text{ by Post hoc test, Table 1}) \), and AREA during recovery was significantly smaller in the Morning \( (462±87°C\cdot\text{min}) \) than at Night \( (526±35°C\cdot\text{min}) \) \( (p<0.05, \text{Table 2}) \).
Figure 2. Rectal, mean skin and finger temperatures during the finger cold immersion for 30 min followed by 20-min recovery (the averages of 9 male students).

Table 1. Thermoregulatory and subjective responses at rest and during passive heat stress

<table>
<thead>
<tr>
<th>State</th>
<th>Parameters</th>
<th>Morning</th>
<th>Daytime</th>
<th>Evening</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rest</td>
<td>T&lt;sub&gt;re&lt;/sub&gt; (°C)</td>
<td>36.7±0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>37.0±0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.2±0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>37.0±0.3&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;sk&lt;/sub&gt; (°C)</td>
<td>32.4±0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.0±0.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>33.4±0.3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>33.1±0.6&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;chest&lt;/sub&gt; (°C)</td>
<td>31.6±1.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.1±0.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>33.2±1.0&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>32.7±1.0&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;hand&lt;/sub&gt; (°C)</td>
<td>32.0±1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>31.9±1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>31.5±1.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>32.1±1.7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;foot&lt;/sub&gt; (°C)</td>
<td>30.6±2.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.9±1.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>29.9±1.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>31.0±1.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>MAP (mmHg)</td>
<td>84±9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>81±6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>82±6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83±7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>HR (bpm)</td>
<td>73±13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77±9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77±11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>73±9&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cold immersion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Last 5 min of cold immersion)</td>
<td>T&lt;sub&gt;re&lt;/sub&gt; (°C)</td>
<td>36.7±0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>37.2±0.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>37.3±0.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>37.0±0.3&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;sk&lt;/sub&gt; (°C)</td>
<td>32.4±0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.0±0.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>33.3±0.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>33.1±0.7&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>T&lt;sub&gt;hand&lt;/sub&gt; (°C)</td>
<td>30.2±2.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.8±1.4&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>31.3±1.9&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>32.1±1.2&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>MAP (mmHg)</td>
<td>85±8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>84±9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>84±7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>86±7&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>HR (bpm)</td>
<td>72±13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77±9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>76±11&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72±10&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Finger pain sensation</td>
<td>2.3±1.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.0±1.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.6±0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.0±1.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Recovery (3min)</td>
<td>T&lt;sub&gt;finger&lt;/sub&gt; (°C)</td>
<td>16.4±4.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.2±5.0&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>19.5±5.0&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>21.6±5.9&lt;sup&gt;bc&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Data are expressed as mean±SD; <sup>a,b,ab,c</sup> different group between four phases by post hoc test (p<0.05).

There was no significant relationship between T<sub>re</sub> and CIVD parameters except T<sub>min</sub>. Figure 3 shows the relationships between T<sub>re</sub> and T<sub>min</sub> during finger cold immersion in four phases. Overall, there was a negative relationship (r= -0.188, p<0.05). However, each phase is related to T<sub>re</sub> in different ways, and only Morning showed a significant negative relationship between T<sub>min</sub> and T<sub>re</sub>, which is in contrast to previous studies [5, 6] reporting a more pronounced CIVD response at higher body temperature.
Table 2. CIVD parameters during finger cold-water immersion over a day

<table>
<thead>
<tr>
<th>CIVD parameters</th>
<th>Morning</th>
<th>Daytime</th>
<th>Evening</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum finger temperature (T_{min}), °C</td>
<td>5.8±1.5</td>
<td>5.9±1.4</td>
<td>5.4±1.5</td>
<td>6.3±2.0</td>
</tr>
<tr>
<td>First maximum temperature (T_{max}), °C</td>
<td>10.4±2.7</td>
<td>10.6±2.9</td>
<td>12.4±3.4</td>
<td>11.9±3.7</td>
</tr>
<tr>
<td>Maximum temperature during immersion (T_{max-immersion}), °C</td>
<td>11.1±3.3</td>
<td>10.8±3.2</td>
<td>13.2±4.2</td>
<td>12.7±3.7</td>
</tr>
<tr>
<td>Mean finger skin temperature (T_{mean}), °C</td>
<td>8.8±2.4</td>
<td>8.4±1.7</td>
<td>9.6±3.2</td>
<td>10.1±2.5†</td>
</tr>
<tr>
<td>Amplitude (T_{max} - T_{min}), °C</td>
<td>4.6±3.0</td>
<td>5.0±2.7</td>
<td>6.8±2.8</td>
<td>5.6±2.4</td>
</tr>
<tr>
<td>Onset time (t_{onset}), min</td>
<td>5.7±1.6</td>
<td>5.9±1.8</td>
<td>5.2±1.0</td>
<td>4.9±1.2</td>
</tr>
<tr>
<td>Peak time (t_{peak}), min</td>
<td>6.3±2.8</td>
<td>8.2±4.7</td>
<td>7.8±6.3</td>
<td>8.1±3.3</td>
</tr>
<tr>
<td>Frequency of waves (Frequency), times</td>
<td>1.7±1.2</td>
<td>1.6±1.1</td>
<td>2.0±1.1</td>
<td>2.4±0.9</td>
</tr>
<tr>
<td>AREA (baseline of 4°C for 30-min immersion), °C · min</td>
<td>151±58</td>
<td>141±48</td>
<td>159±81</td>
<td>179±72</td>
</tr>
<tr>
<td>AREA (baseline of 4°C for recovery), °C · min</td>
<td>462±87</td>
<td>514±43</td>
<td>490±79</td>
<td>526±35*</td>
</tr>
<tr>
<td>Cooling rate of the finger (ΔT_{min} / t_{onset}), °C · min⁻¹</td>
<td>5.0±1.5</td>
<td>5.5±2.0</td>
<td>5.6±1.4</td>
<td>6.0±1.5</td>
</tr>
<tr>
<td>RIF</td>
<td>8.4±0.7</td>
<td>8.3±0.9</td>
<td>8.8±0.7</td>
<td>8.9±0.3</td>
</tr>
</tbody>
</table>

Data are expressed as mean±SD; *different from Morning (p<0.05). † tended to be different from Daytime (p <0.10).

Figure 3. Relations between rectal temperature (T_{re}) and minimum finger temperature (T_{min}) during cold immersion.

Conclusions

We confirmed that circadian variation exists in body temperature, but CIVD responses during finger cold-water immersion showed no significant differences between the four phases; however, several CIVD responses tended to be more pronounced in the Evening and at Night compared to the Morning. However, a unique finding in the present study was that finger skin temperature during recovery was lower and heat loss from the finger during recovery was significantly greater in the Morning than at Night. That is, the recovery of finger temperature to a comfortable level after finger cold-water immersion was delayed in morning. In addition, our findings did not support the hypothesis that the CIVD response of the finger is greater when the body temperature increased.

References

THERMAL TESTING STANDARDS AND METHODOLOGY

Thermal environments for people with physical disabilities

Ken Parsons1*, Lynda Webb2
1 Loughborough Design School, Loughborough University, UK
2 School of Civil and Building Engineering, Loughborough University, UK
*corresponding author: K.C.Parsons@lboro.ac.uk

Introduction
People with physical disabilities can be affected by heat and cold in ways which differ from people without disabilities. This can be because of the nature of the disability, the influence of technological aids such as wheelchairs and the effects that some medication may have on thermal sensitivity, physiological response and both physiological and behavioural thermoregulation.

The series of studies presented in this paper investigated how people with a range of physical disabilities respond to thermal environments. The application of these data will be to provide an understanding of the thermal requirements of people with physical disabilities and to contrast those with requirements usually assumed for people without disabilities. This will allow an evaluation of traditional methods of environmental design and assessment for diverse population.

Methods
Two questionnaire surveys were carried out (391 people with physical disabilities and 38 carers) and 531 subject trials in an environmental chamber over a range of temperatures from 29 °C to 18.5 °C. The physical disabilities of people who provided responses included; multiple sclerosis, stroke, rheumatoid arthritis, osteo-arthritis, spina bifida, polio, paraplegia, muscular dystrophy, spinal injury, cerebral palsy, Friedrich’s ataxia, blindness, paralysis, heart condition, encephalitis, Guillain-Barré syndrome, missing limbs and metal in legs.

Results and Discussion
Of the people who acquired their disability after they were 18 years of age 53% wanted their environment to be warmer than before being disabled, 13% cooler and 33% the same as before they were disabled. 43% felt they wore more clothing than before being disabled, 11% less clothing, and 46% about the same. 29 of the 38 carers thought that people with physical disabilities had different temperature needs, generally people wanted to be warmer. In the laboratory experiments, it was found that some groups were comfortable in what would be predicted for people without physical disabilities to be ‘slightly warm to warm’, ‘slightly warm’ and ‘neutral’ environments. No group preferred the predicted ‘slightly cool to cool’ environment although there are individual differences.

Conclusions
A main finding was the individual differences in response even within categories of disability. It is particularly important to consider individual factors and characteristics. The threat of thermal environments is important and this is related to the adaptive opportunity for people with disabilities to move away from heat or cold, adjust clothing etc. Current methods for assessing thermal environments provide good description of average responses but are not adequate to consider individual requirements.
Occupational thermal stress and the Universal Thermal Climate Index UTCI

*Peter Bröde*¹, *Dusan Fiala*², *Bernhard Kampmann*³*

¹ Leibniz Research Centre for Working Environment and Human Factors (IfADo), Dortmund, Germany
² ErgonSim – Comfort Energy Efficiency, Stuttgart, Germany
³ Department of Safety Engineering, Bergische Universität Wuppertal, Germany

*corresponding author: kampmann@uni-wuppertal.de*

Introduction
The Universal Thermal Climate Index (UTCI) was developed to assess the outdoor thermal environment, and was funded by the EU COST Action 730 [1]. It is based on the dynamic physiological human response to cold, heat and moderate climatic conditions as simulated by the advanced multi-node Fiala-model of thermoregulation [2], which was coupled with a clothing model [3] considering the clothing behaviour of an urban population. As shown by Figure 1, UTCI summarises the interaction of ambient temperature, wind, humidity and radiation fluxes as an equivalent temperature. The operational procedure [4] was completed using an assessment scale categorising the index values in terms of thermal stress, and by simplified algorithms for calculating UTCI values without the need to run the complex simulation models.

The assessment of cold and heat stress by UTCI was shown to agree well with experimental data [5,6] and with international standards concerned with the ergonomics of the thermal environment [5,7]. But in its current stage, UTCI does not consider the characteristics of special protective clothing, and its applicability to occupational thermal stress is limited by the moderate activity level (metabolic rate of 135 W/m²) and the maximum exposure time of two hours, which were assumed for the simulation runs.

However, the high level of detail devoted to the modelling of the physiological and clothing systems allows for expanding UTCI to wider conditions of activity level and clothing, which need to be taken into account when assessing occupational settings. This paper aims at demonstrating this with respect to varying exposure times and activity levels for the UTCI reference climatic conditions, as defined in Figure 1.

Methods
We calculated additive correction terms for UTCI considering activity ranging from a resting level with metabolic rate of heat production of 1.1 met (1 met = 58.15 W/m²), to a very high level (ISO 8996 [8], Table A.2) of 4.9 met, and exposure duration covering an 8-hour shift length in 30-min steps. Simulations were performed with the UTCI-Fiala model [2] using the adaptive UTCI-clothing model [3].

Air temperatures varied from -50°C to +50°C in 1 K steps for UTCI reference climatic conditions as shown in Figure 1, which were defined by calm air, mean radiant temperature equalling air temperature, and 50% relative humidity (but vapour pressure not exceeding 2 kPa).

For the 9,696 combinations of air temperature, activity level and exposure time, UTCI computations were performed with the model output obtained after the actually simulated exposure times replacing the 2-hour values in the original calculations [4]. By subtracting UTCI for the reference conditions (equalling air temperature by definition [4]) from these calculated values, we obtained additive correction terms depending on UTCI, activity level and exposure time.
Results and Discussion

The correction terms are illustrated by Figure 2 for UTCI values categorised according to Bröde et al. [4] into cold stress, no thermal stress and heat stress conditions, respectively. As expected, they were close to zero for the UTCI reference condition with respect to climate, activity level and exposure duration, as presented in Figure 2 at the intersection of the vertical and horizontal reference lines.

Furthermore, the correction terms indicated that compared to UTCI reference conditions, thermal stress decreased with shorter exposure times and increased with longer times, and that high activity increased heat stress, whereas low activity increased cold stress. The effect size was moderated by the stress category, with greater effects of activity and exposure time in the cold compared to moderate or warm climates.

Simulating high activity levels with highly-insulating clothing at low temperatures turned cold stress to heat stress conditions, as shown in Figure 2A. This phenomenon concurs with field observations and laboratory studies [9], but is not covered by current ergonomic standards for the assessment of cold and heat stress.

For application purposes, such correction terms will be used in a two-step approach to calculate UTCI not only related to parameters of the thermal environment, but also to activity level and exposure time. First, as shown in Figure 1, UTCI values are calculated by the usual operational procedure from air temperature, humidity, wind and radiation [4]. Then, the correction terms depending on activity level, exposure time and UTCI are determined, e.g. by a look-up table or regression approach as for UTCI calculation, and are added to the UTCI values computed for reference activity and reference exposure time in the first step.
Figure 2. Additive terms correcting UTCI with respect to activity level and exposure time for UTCI values between -50 °C and +50 °C representing cold stress (A), no thermal stress (B) and heat stress (C) conditions, respectively. Third order polynomial trend lines for exposure time are added. The vertical line indicates the UTCI reference exposure time of 2 hours.
Although the UTCI reference climatic conditions considered here cover only a small portion of all relevant thermal environments [4], the correction terms obtained in this study might be representative for other climates with UTCI values between -50°C and +50°C as well, because identical index values should represent equal thermal strain [1]. Of course, this conjecture requires verification by further studies.

Conclusions
These results open the perspective to a comprehensive assessment of occupational thermal stress and strain by UTCI. However, as the climatic conditions in this study comprised less than 0.1% of the relevant combinations of temperature, wind, humidity and radiation [4], and because the effects of work clothes were not considered, further extensive simulation studies are still needed to achieve this goal.

References
Assessment of heat stress at various outdoor spaces in the city (an example from Warsaw)

Krys Błażejczyk1*, Katarzyna Lindner-Cendrowska2, Anna Błażejczyk3

1 Institute of Geography and Spatial Organization, Polish Academy of Sciences, Warsaw, Poland
2 Faculty of Geography and Regional Studies, University of Warsaw, Poland
3 Bioklimatologia. Laboratory of Bioclimatology and Environmental Ergonomics, Warsaw, Poland
*corresponding author: k.blaz@twarda.pan.pl

Introduction
Contemporary bioclimatic research is based on studying direct relationships between the atmosphere and the human organism. So called “bio thermal conditions” illustrate physiological responses in man to atmospheric stimuli in order to equilibrate heat balance of an organism and to keep the body core temperature within a narrow range around 37°C [4, 9]. In contrast the temperature of skin can vary widely, depending on ambient conditions. The indices that are based on human heat balance are called “rational” [3, 6]. Such modelling of the human heat balance goes back 70 years.

In the past two decades multi-node models of human thermoregulation have been developed. The newest Universal Thermal Climate Index (UTCI) is derived from Fiala multi-node model which simulates heat transfer inside the body and at its surface. UTCI is defined as the air temperature (Ta) of the reference condition causing the same model response (in sweat production, shivering, skin wettedness and skin blood flow as well as in rectal, mean skin and face temperatures) as the actual conditions [3, 7]. The offset, i.e., the deviation of UTCI from air temperature depends on the actual values of air and mean radiant temperature (Tmrt), wind speed (va) and water vapour pressure (vp). This may be written in mathematical terms as:

\[ UTCI = f(Ta; Tmrt; va; vp) = Ta + \text{Offset} (Ta; Tmrt; va; vp) \]

Figure 1. Spatial distribution of UTCI in Warsaw on a sunny, hot and humid day;
Sites of field research: 1 – Lazienki Royal Park, 2 – Old Town
Source: Blazejczyk [1]
The aim of the paper is to discuss the applicability of UTCI in research of heat stress assessment at various outdoor spaces, typical for daily life-style of the citizens of Warsaw. Warsaw is a city with an area of about 500 km² and with great differentiation of land use. About 243 km² is a built-up area (residential and industrial). Forests cover about 13% of city and 85 km² is used as meadows and fields [2]. The general spatial overview of UTCI in Warsaw is presented at figure 1 [1].

Methods
In the Fiala model the human organism is separated into two interacting systems of thermoregulation: [1] the controlling active system, and [2] the controlled passive system. The passive system is a multi-segmental, multi-layered representation of the human body with information of anatomic and physiological body properties. Body elements are subdivided into 12 spatial sectors and into 187 individual tissue nodes. The active system of the model predicts thermoregulatory reactions of the central nervous system: changes of cutaneous blood flow, shivering thermo genesis, and sweat excretion [5, 7]. The UTCI values are categorized in terms of thermal stress (Table 1).

<table>
<thead>
<tr>
<th>UTCI (°C) range</th>
<th>Stress Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>above +46.0</td>
<td>4 extreme heat stress</td>
</tr>
<tr>
<td>+38.1 to +46.0</td>
<td>3 very strong heat stress</td>
</tr>
<tr>
<td>+32.1 to +38.0</td>
<td>2 strong heat stress</td>
</tr>
<tr>
<td>+26.1 to +32.0</td>
<td>1 moderate heat stress</td>
</tr>
<tr>
<td>+9.1 to +26.0</td>
<td>0 no thermal stress</td>
</tr>
<tr>
<td>0.1 to 9.0</td>
<td>-1 slight cold stress</td>
</tr>
<tr>
<td>-13.0 to 0.0</td>
<td>-2 moderate cold stress</td>
</tr>
<tr>
<td>-27.0 to -12.9</td>
<td>-3 strong cold stress</td>
</tr>
<tr>
<td>-40.0 to -26.9</td>
<td>-4 very strong cold stress</td>
</tr>
<tr>
<td>below -40.0</td>
<td>-5 extreme cold stress</td>
</tr>
</tbody>
</table>

To present possible heat stress at various local, outdoors environments GIS methods were used [1, 8]. Firstly, we have defined variation of essential meteorological parameters: solar radiation, wind speed as well as air temperature and humidity. In the second step simulated meteorological variables were applied for the calculation of UTCI for every type of urban space. The following meteorological scenarios were used: cloudy, and sunny (solar radiation of 200 and 1000 W·m⁻², respectively), air temperature from 10 to 35°C, relative humidity of air 35 and 80% and wind speed 2 and 8 m·s⁻¹.

To validate simulated UTCI values we have calculated several physiological variables based on meteorological data gathered during a special measuring campaign carried out in July 2010 in two outdoor spaces in Warsaw, frequently visited by the citizens and tourists (The Old Town and Lazienki Royal Park).

Results
Depending on weather conditions deviations of UTCI from air temperature (dUTCI) ranged from -11.5°C to +35.5°C. The biggest negative deviations are noted on water banks and in forests, however the biggest positive deviations are observed at downtown and industrial zones. In the forests positive UTCI deviations are observed during cold days. However, negative dUTCI occur in hot days with low wind speed. Slight positive deviations of UTCI occur at ground transportation.
belts and at built-up areas. At air temperature of 35°C (reported by airport meteorological station) the highest dUTCI, up to 27-35°C, are noted in downtown and industrial areas (Fig. 2).

![Figure 2. Deviations of UTCI (dUTCI) in selected types of urban spaces, at various air temperature (ta); weather conditions: sunny, humid, windy](image)

Table 2 presents UTCI values calculated for four weather scenarios (defined for airport meteorological station): sunny and cloudy with small and great humidity and weak wind as well as with air temperature of 25 and 30°C. The data show how heat stress can differ depending on outdoor space. For hot, dry, calm and sunny weather UTCI varied from about 22°C (no thermal stress) inside forests to 35-36°C (strong heat stress) in downtown and industrial areas. During cloudy, hot weather UTCI ranged from 18°C (no thermal stress) at river banks to 31°C (moderate heat stress) at industrial areas. During very hot and humid weather UTCI was significantly higher reaching 50-52°C (extreme heat stress) inside industrial areas. Only in the forests can we experience UTCI of 25-31°C.

<table>
<thead>
<tr>
<th>Types of outdoor space</th>
<th>UTCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>airport meteorological station</td>
<td>29.3</td>
</tr>
<tr>
<td>downtown</td>
<td>34.6</td>
</tr>
<tr>
<td>no-dense settlement</td>
<td>26.0</td>
</tr>
<tr>
<td>industrial areas</td>
<td>35.9</td>
</tr>
<tr>
<td>parks</td>
<td>31.5</td>
</tr>
<tr>
<td>ground transportation belts</td>
<td>32.2</td>
</tr>
<tr>
<td>water banks</td>
<td>25.9</td>
</tr>
<tr>
<td>fields and wetlands</td>
<td>29.3</td>
</tr>
<tr>
<td>meadows</td>
<td>28.2</td>
</tr>
<tr>
<td>forests</td>
<td>22.3</td>
</tr>
</tbody>
</table>

When comparing simulated and observed meteorological data we can see satisfied concordance. Both simulated and observed UTCI values show tendency of milder heat stress in the park than in the Old Town. Similar relations are also seen at average thermal sensations reported by visitors of Royal Park (n=98) and the Old Town (n=115). Stronger biothermal conditions in the city centre than in park are also indicated by different physiological variables calculated with the use of Fiala and PHS models. Significantly stronger conditions were reported by PHS model (hotter thermal sensations and greater sweating rate) in comparison to Fiala model (Table 3).
Table 3. Simulated and observed meteorological variables as well modelled physiological indicators at two urban spaces in Warsaw: Lazienki Royal Park and Old Town

<table>
<thead>
<tr>
<th>Site</th>
<th>Type of data</th>
<th>ta (°C)</th>
<th>Tmrt (°C)</th>
<th>RH (%)</th>
<th>UTCI (°C)</th>
<th>Sensation (°C)</th>
<th>Tskin (°C)</th>
<th>Tre (°C)</th>
<th>Sweating (g/h)</th>
<th>Wettedness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Royal Park</td>
<td>simulated</td>
<td>28.0</td>
<td>45.1</td>
<td>35</td>
<td>31.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>observed</td>
<td>27.8</td>
<td>46.7</td>
<td>34</td>
<td>32.7</td>
<td>1.4</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Fiala</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.2</td>
<td>33.9</td>
<td>37.5</td>
<td>185</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>PHS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.4</td>
<td>35.0</td>
<td>37.6</td>
<td>510</td>
<td>-</td>
</tr>
<tr>
<td>Old Town</td>
<td>simulated</td>
<td>31.2</td>
<td>47.8</td>
<td>31</td>
<td>34.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>observed</td>
<td>28.7</td>
<td>46.0</td>
<td>29</td>
<td>33.2</td>
<td>1.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Fiala</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.3</td>
<td>34.1</td>
<td>37.5</td>
<td>199</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>PHS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.5</td>
<td>35.0</td>
<td>37.6</td>
<td>500</td>
<td>-</td>
</tr>
</tbody>
</table>

Conclusions
In the past various biothermal indices derived from the human heat balance were used to present sensible climate in different urban spaces [2]. Till now UTCI has been applied few times to present spatial differentiation of bioclimatic conditions [1, 8]. We showed that both UTCI and other biothermal indices indicated similar types of outdoor spaces as favourable or stressful for humans. However, the greatest advantage of UTCI is providing the most realistic, actual physiological responses of an organism. GIS tools are satisfactorily precise and can be used in assessing spatial distribution of heat stress.

References
Thermal environment evaluation in commercial kitchens

Angela Simone, Bjarne W. Olesen*
ICIEE-BYG, Technical University of Denmark, Kgs. Lyngby, Denmark
*corresponding author: bwo@byg.dtu.dk

Introduction
Today there are no specific regulations or even parameters to guarantee that the thermal conditions in commercial kitchens are either comfortable or cost-effective; general evaluation criteria for thermal comfort may be inadequate and unsuitable for practical application. Thermal conditions of the working environment in commercial kitchens are primarily driven by radiant heat which directly impacts the employees. Moreover, appliances, size and arrangement of the kitchen zones, number of employees, variable environmental conditions during business hours, etc., complicate further an evaluation of the indoor thermal environment in kitchens. Based on standardised methods, a procedure for collecting data for the physical environment and subjective reactions in commercial kitchens is presented in this paper. The thermal strain on the occupants was not measured. On a few subjects the heart rate was measured as an indicator of the metabolic rate during a working day. This procedure has been used in a larger study of the indoor environment in more than 100 commercial kitchens. The procedure and main results are presented in this paper.

Evaluation of the thermal environment in commercial kitchens
For many years the international Standard Organisation (ISO) and ASHRAE have been developing standards for the indoor thermal environment. ASHRAE has mainly developed standards for moderate thermal environments (ASHRAE-55 [1]) while ISO standards cover the range from cold stress to comfort to heat stress (ISO EN 7730 [2], ISO EN 7933 [3], ISO EN 11079 [4]).

As the commercial kitchen environment presents different conditions than those studied earlier, a measuring procedure was established focusing in particular on the processes characterising the kitchen space. For example, employees facing high-energy appliances, such as an under-fired char broiler, ovens, steamers, deep-fat fryers, or to bursts of very humid hot air, are subject to higher radiant conditions than employees working on a preparation line with their backs a few feet from the appliances.

Methods
Data collection includes several types of measurement: external air temperature and humidity, HVAC-system (heating, ventilation and air conditioning) performance (supply, make-up, and transfer air temperature and relative humidity), indoor (thermal) environment, physiological and subjective evaluation. The intention was to collect data for the physical environment (physical parameters) and personal factors such as clothing and activity, to be able to calculate existing indices for evaluation of thermal comfort and/or heat stress.

Therefore, three different kitchen zones (cooking, food preparation, and dish-washing) were measured; these being considered to have different thermal conditions in the commercial kitchen. Loggers were installed for one week (1st walk in) to record kitchen operative and air temperatures (t₀ and t₄) and relative humidity (RH) in time interval of 15 minutes. Other recording devices were used for more detailed spot measurements (2nd walk in) of thermal parameters (air temperatures, humidity, air velocity, and radiant temperatures) close to the working position of the employees and at different heights during the peak operating hours of one working day (breakfast, lunch, and/or dinner time).
**Instrumentation**

Air temperatures, air velocities, globe temperatures and plane radiant temperatures were measured in three heights (0.1, 1.1 and 1.7m above floor). These measurements, together with relative humidity (accuracy ±2.5%), were stored in small data loggers.

The air temperature ($t_a$), plane radiant temperature ($t_{ir}$) and operative temperature (globe, $t_o$) (sensors were built according to the results of Simone et al. (2007) [5] obtained by experimental laboratory work and described in ISO 7726 [6]. Both temperature sensors have an accuracy of ±0.3°C in the range of 10°C to 40°C. An omnidirectional anemometer was used for measuring air velocity. It can measure across a range from 0.005 to 5 m/s, with an accuracy of 0.02 m/s ±1% of readings. All physical parameters of the investigated environment were recorded with a maximum frequency of one second.

**Evaluation of clothing and metabolism**

The thermal resistance and evaporative resistance of clothing can be estimated by ISO 9920/2006 [7]. In particular, during the spot measurements, researchers estimated the level of workers’ clothing insulation as the sum of the individual values of various garments as listed in Table B.2 of the ISO9920/2006 [7].

The metabolic rate can be estimated by ISO 8996/2004 [8], taking into account the type of work. The activity level in a kitchen changes a lot during a working day, so it is recommended to estimate a time-weighted average during the previous hour. During the measuring time in the commercial kitchens, the employees’ activity level was estimated by “observation” and by “analyses” with the assessed employee heart rate of one or more individuals within each kitchen, together with their age, weight and sex.

**Subjective response (questionnaires)**

During the field studies the subjects were asked to fill in two questionnaires (based on ISO 10551/2001 [9]); one on long-term general effects and one on occupants’ immediate reactions, used to evaluate thermal and working conditions, to support physical data monitoring and to analyse the relationship between the physical parameters of the environment and subjective aspects of the occupants’ perception of thermal comfort in the kitchen environment. To minimise disturbance for the employees, the few questions related to the instant environment perception were verbally asked and recorded electronically by the investigator. An exception was needed for the evaluation of the thermal sensation collected by using the 7-points thermal sensation scale (Figure 1). In fact, the employee at his working station was asked to look at the scale and indicate his/her thermal perception was at that instant. The employee was asked to use it as a continuous scale.

![Figure 1. Seven points Thermal Sensation scale](image)

Several other questions, dealing with the working conditions and environment in general, including some facts about the person (like: age, weight, etc.), were reported in the long term questionnaire which consists of eight parts: Background characteristic, Personal comfort, Personal control, Work conditions, Work area satisfaction, Health characteristic, Environment sensitivity, and Occupants’ clothing.
Results
Several results of this study of 100 kitchens are presented here.

In the study of thermal environment in commercial kitchens, one-week measurements at three locations were measured in all kitchens, in both summer and winter. Spot measurements of thermal parameters at three heights and at three locations, together with subjective evaluations, were performed in 39 kitchens during the summer monitoring phase and in 35 kitchens during winter, totaling 373 respondents.

It was not possible to find a temperature where everyone was satisfied. However in 5 K range of operative temperature, the lowest level of dissatisfaction was about 11% at an operative temperature around 20-25 °C. The dissatisfaction increases progressively on both sides of this range.

To investigate the relation between the thermal sensation votes (TSV) in the Kitchen and the percentage of dissatisfied employees (PD), the TSV values were grouped in ranges. In this way, having a critical number of subjects in each range, % of dissatisfied can be estimated. Figure 2 shows a strongly polynomial relation ($R^2=0.98$) between TSV and the % dissatisfied, reported as equation 1.

$$PD(\%) = 5.102 \cdot f(TSV)^2 - 40.247 \cdot f(TSV) + 84.124 \quad R^2 = 0.98 \quad (1)$$

The polynomial relation TSV-PD (Figure 2) shows similarities with the PMV-PPD (Predicted Mean Vote-Predicted Percentage Dissatisfied) curve (Fanger, 1970 [11]) with the same minimum at 5% for TSV=0. The increase in %-dissatisfied with increasing TSV is however much lower than the PMV-PPD relation.

In a significant number of measuring positions, the thermal conditions (mean radiant temperature) were out of the range for using the PMV-index and resulted in PMV-values outside the range $\pm$ 3.

Conclusions
A recommendation for measuring locations and type of sensors to use, and a method and a procedure for evaluating the indoor thermal environment in commercial kitchens was established and used in 100 commercial kitchens.
Especially due to the high thermal radiation from the appliances in the cooking zone the measured conditions were in many cases outside the range of the PMV-index (ISO EN 7730).

From the measurements a first estimation of a thermal comfort range for commercial kitchens workspace was given as the interval of operative temperature of 20-25 °C (68-77 °F) corresponding to 11% of dissatisfied employees. Besides, a strong quadratic relation was estimated between the TSV and percentage dissatisfied.

Acknowledgement

This project was sponsored by ASHRAE RP1469 “Thermal Comfort in Commercial Kitchens” and by the International Centre for Indoor Environment and Energy at DTU.

References

4. ISO EN Standard 11079-2007: Ergonomics of the thermal environment -- Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects.
Validation of ASTM F2732 and comparison with ISO 11079 with respect to temperature ratings for cold weather protective clothing

Li-Yen Lin¹, Chuansi Gao²*, Amitava Halder², Kalev Kuklane², Ingvar Holmér²

¹ Department of Testing and Certification, Taiwan Textile Research Institute (TTRI), 6 Chengtian Road, Tucheng District, New Taipei, 23674, Taiwan
² Thermal Environment Laboratory, Division of Ergonomics and Aerosol Technology, Department of Design Sciences, Faculty of Engineering, Lund University, Lund 221 00, Sweden

*corresponding author: Chuansi.Gao@design.lth.se

Introduction
ASTM standard F2732 determines temperature ratings (lowest environmental temperature for comfort) for cold weather protective clothing according to measured clothing insulation and human heat balance models to estimate the thermal comfort for 2 and 4 MET activities in cold environments. ISO 11079 serves the same purpose but expresses cold stress in terms of required clothing insulation (IREQ) for a given cold climate condition and work rate, or duration limited exposure (DLE) when clothing thermal insulation is known. As both standards are based on heat balance equations, it would be of interest to compare them. The IREQ equations are open and it is possible to determine temperature ratings and therefore to compare results from F2732. The objective of this study was to validate the prediction of temperature ratings using human subjects, and to compare the two standards.

Methods
The cold protective clothing ensemble including cold weather outer garments and base ensemble 1 (ASTM F2732) was used in the study. The thermal insulation was measured on the thermal manikin Tore with 17 individually controlled (heating and measuring) zones. The intrinsic insulation (Iₜ₀) of the base ensemble 1 was 0.82 clo, and the intrinsic insulation (Iₜ₀) of the cold weather ensemble was 1.89 clo. The standardized total insulation (Iₜ) of the cold weather ensemble was 2.26 clo, based on which two temperature ratings (3.4 and –30.6 °C) were obtained according to the two regression equations for 2 and 4 MET of activities respectively in ASTM F2732.

These two air temperatures were then used for experimental validations on human subjects while wearing the same cold weather protective clothing. Nine young and healthy male subjects participated. Their age, height, body weight, and body mass index (BMI) were 24.1±2.6 (mean ± SD) years, 1.81±0.05 m, 74.5±6.6 kg, and 22.8±1.5 kg/m². They had previous experience of living in a cold climate (e.g. in Sweden) for more than one year, did not have any history of cold injury, cold related sensitivity or asthma. Written information about the study was given to the subjects before they came to the laboratory. The first time when they visited the laboratory, they were given more detailed information about the tests and related equipment, sensors, etc. A written informed consent was signed by each subject before the tests, which were conducted during winter season (Nov/Dec 2012). A pre-test for each participant with the same clothing was performed to determine their individual relationships between walking speed and metabolic rate (2 and 4 MET). Thereafter, their individual walking speeds were used in the two test conditions with each test lasted for 90 minutes in the climatic chamber. Air velocity was kept the same (0.4 m/s) as in the clothing insulation measurements on the thermal manikin.

Skin temperatures and body core temperature (rectal) were recorded each 15 seconds. Mean skin temperature (Tₜₙ) was calculated according to 8-point equation below.
$T_{sk} = 0.07 (T_{forehead} + T_{upperarm} + T_{forearm}) + 0.175 (T_{chest} + T_{scapula}) + 0.05 T_{hand} + 0.19 T_{thigh} + 0.20 T_{calf}$

Results and Discussion
The calculated temperature ratings for 2 and 4 MET activity according to the standard ISO 11079 were 0.3 and -31.0 °C when the intrinsic insulation of the cold weather ensemble ($I_c$) was 1.89 clo. These temperature ratings were similar to the ratings by ASTM standard F2732. For 2 MET activity, the temperature rating by ASTM F2732 was 3 °C higher.

The mean rectal temperatures in the two cold environments with two work intensities corresponding to 2 and 4 MET were relatively stable throughout 90 min exposure although it was slightly higher in the cold at -30.6 °C and 4 MET activity. However, the mean skin temperature in the cold at -30.6 °C was about 5 °C lower than that in the cold at 3.4 °C, and it was continuously dropping in the test period.

Conclusions
Both ASTM standard F2732 and international standard ISO 11079 predict similar temperature ratings. For 2 MET activity, the temperature rating by ASTM F2732 is 3 °C higher.

When the intrinsic thermal insulation of the cold weather protective clothing is 1.89 clo, the predicted temperature rating for 2 MET activity seems valid according to test subjects’ thermophysiological responses. For 4 MET activity, however, the whole body responses are on the cold side. The results indicate that the predicted temperature rating for 4 MET activity is too low for thermal comfort, and may put users at risk for a longer work shift.

References
On the utility of cardiorespiratory surrogates of whole-body energy expenditure

Sean R. Notley, Hugh H.K. Fullagar, Benjamin J. Haberley, Daniel S. Lee, Mayumi Matsuda-Nakamura, Gregory E. Peoples, Nigel A.S. Taylor*
Centre for Human and Applied Physiology, University of Wollongong, Wollongong, Australia
*corresponding author: Nigel_Taylor@uow.edu.au

Introduction
Due to environmental and scenario constraints, direct measures of the metabolic demands of work can be difficult or impossible. Fortunately, cardiorespiratory variables respond in a predictable fashion with work rate, and can serve as surrogate indices for approximating energy expenditure (e.g. heart rate and minute ventilation). However, a failure to fully explore the utility of these indices during field-based work is a major limitation within the literature. Thus, this investigation was aimed at evaluating the transferability of predictive equations developed in the laboratory to a series of fire-fighting simulations conducted in the field.

Methods
Prediction equations using heart rate and minute ventilation were derived using 15 subjects, during lower-body, load-carriage exercise in the laboratory. These equations were then used to predict the metabolic demand of three fire-fighting simulations (70-mm hose drag, hazmat incident, bushfire hose drag) performed by 48 firefighters (male and female); 16 per simulation. During each simulation, respiratory gas exchange and cardiorespiratory variables were measured, and these data were compared with predictions of metabolic demand, leading to the derivation of mean residual prediction errors for oxygen consumption during the performance of these work simulations.

Results and Discussion
Heart rate predictions over-estimated oxygen consumption during each simulation (mean prediction error: 0.71 ±0.12 L·min⁻¹; p<0.05). These artefacts were caused by the participation of the heart in homeostatic processes beyond oxygen delivery. Since the metabolic demand of these tasks often exceeded Owles point, then minute ventilation predictions derived using data obtained beyond this point also over-estimated metabolic demand (mean prediction error: 0.59 ±0.11 L·min⁻¹; p<0.05). These results indicate that generalised predictions of metabolic rate have little utility under these circumstances, and confirm the need for an individual calibration curve for each worker to be evaluated, thereby strengthening the predictive precision of these indices.

Conclusion
This investigation evaluated the transferability of cardiorespiratory predictive equations developed in the laboratory to a series of occupational tasks. It appears that satisfactory predictive precision can only be achieved by utilising predictive equations derived from individual regression slopes that are specific to the worker under investigation, and that have been generated using data that are most closely reflective of the task in question, and the intensity at which that task was performed. A failure to satisfy any one of these criteria adversely affects the predictive precision of these surrogate indices.
The production of sweat as measured by galvanic skin conductance, epidermal hydration and regional sweat rate

Nicola Gerrett1,2*, Katy Griggs1,3, George Havenith1
1 Environmental Ergonomics Research Centre, Loughborough University, UK
2 Institute of Sport and Exercise Science, University of Worcester, UK
3 School of Sport, Exercise and Health Sciences, Loughborough University, UK
*corresponding author: n.gerrett@worc.ac.uk

Introduction
Galvanic skin conductance (GSC) increases prior to sweat reaching the skin surface [1], indicating pre-secretory sweat gland activity. Sweat travels through the duct and penetrates the stratum corneum (SC) causing epidermal hydration (HYD). Boucsein [2] claimed that SC hydrates first before sweat is released onto the skin surface. GSC is influenced by sweat within the glands, HYD and sweat on the skin surface [3]. The aim of this experiment is to determine the extent to which these contribute to the value of GSC.

Methods
Eight males (183 ± 4 cm, 80.1 ± 9.6 kg, 26 ± 4 y, 54.9 ± 3.5 mL·kg⁻¹·min⁻¹) volunteered in a protocol that aimed to slowly increase sweat production. Regional sweat rate (RSR) using absorbent pad technique [4], HYD (Moisture Meter) and change in GSC (ΔGSC) (biopac) were measured at the scalp, chest, arm and thigh. Participants were exposed to 10 minutes rest in a neutral room (23.4 ± 0.5°C, 50.0 ± 4.7% RH), followed by 60 minutes of heat exposure (30.1 ± 1.0°C, 30.0 ± 4.7% RH). Heat exposure comprised of 10 minutes rest and 50 minutes incremental exercise (30, 50 and 70% VO₂max) on a treadmill.

Results
Increases in ΔGSC (0.49 ± 0.54 to 1.12 ± 0.97 µS, p<0.05) and HYD (4.11 ± 4.8 to 9.9 ± 10.8 AU) occurred with heat exposure, prior to an increase in RSR at all locations. A ceiling effect was observed in HYD, after which ΔGSC and RSR significantly increased (p<0.05). Significant correlations were observed between ΔGSC and RSR (r²>0.80, p<0.05) during heat exposure but interestingly areas of high RSR did not correspond with the highest ΔGSC or HYD.

Discussion
Conflicting Boucsein’s claim, it was found that during epidermal hydration, sweat is released slowly onto the skin surface, indicating that the epidermis does not have to be maximally hydrated for the appearance of surface sweat. However, the epidermis appears to have a maximal hydration level, after which RSR markedly increase. Upon maximal hydration, ΔGSC is predominately influenced by surface sweat. Gerrett (unpublished data) found that only the sweat that is in direct contact with the electrode influences ΔGSC.

References
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Design of a layered heat flux sensor to replicate human skin surface temperature response

Mike Waggoner, Richard Burke

1 Measurement Technology Northwest, Seattle, WA
*corresponding author: mikew@mtnw-usa.com

Introduction
There are a number of test devices currently in use to evaluate the thermal performance of personal protective gear, and the fabric used in personal protective gear. Bench top systems include thermal protection performance (TPP), radiant protection performance (RPP), , and stored energy testers (SET). Full ensemble capabilities also exist at facilities throughout the world, in which an instrumented manikin with 122 (or more) sensors is exposed to flash fire conditions. Each of these systems attempts to simulate the conditions of a real-world hazard situation. The RPP simulates a radiant exposure to a garment, while an ISO 13506 full manikin flame test allows a complete garment to be evaluated during a simulated flash fire event.

These test methods all rely on some form of sensor to measure the heat flux through a test specimen and a predictive algorithm to interpret the sensor measurement into performance metrics of test specimens and/or burn prediction. The type of sensor used, burn algorithm, and potential error sources are described for each sensor in the table below.

Table 1. A listing of test devices, the types of sensors used in each test, and the limitations of each sensor [1,2,3,4]

<table>
<thead>
<tr>
<th>Test Standard</th>
<th>Sensor Type</th>
<th>Algorithm</th>
<th>Potential Error Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPP - ISO 17942</td>
<td>Copper Calorimeter</td>
<td>Stoll Curve</td>
<td>Sensor not temperature controlled, deviation from human skin temperature rise</td>
</tr>
<tr>
<td>RPP - ASTM F1939</td>
<td>Copper Calorimeter</td>
<td>Stoll Curve</td>
<td>Sensor not temperature controlled, deviation from human skin temperature rise</td>
</tr>
<tr>
<td>ASTM F1930/ISO 13506</td>
<td>Epoxy</td>
<td>Layered Skin Burn Model</td>
<td>Sensor not temperature controlled, Sensor not durable</td>
</tr>
<tr>
<td>ASTM F1930/ISO 13506</td>
<td>Copper Calorimeter</td>
<td>Layered Skin Burn Model</td>
<td>Sensor not temperature controlled, housing of calorimeter may increase in temperature during tests distorting reading, initial temperature not controlled, deviation from human skin temperature rise</td>
</tr>
<tr>
<td>ASTM F1930/ISO 13506</td>
<td>Alberta Skin Simulant</td>
<td>Layered Skin Burn Model</td>
<td>Sensor not temperature controlled, initial temperature not controlled</td>
</tr>
</tbody>
</table>

This mini-paper summarises a 2 part study in which the effect of sensor temperature is demonstrated, and in which the design and function of an actively cooled skin simulant heat flux sensor are detailed.
Method – Effect of heat flux sensor temperature

In order to demonstrate the effects of sensor temperature on resulting heat flux during a garment test, an experiment was performed. An experimental apparatus was created with a quartz lamp, shutter, and a Schmidt-Boelter heat flux sensor; this apparatus is shown in figure 1. The quartz lamp was dimmed to provide 10 kW/m² of heat flux to the surface of the Schmidt-Boelter calorimeter. After the lamp was dimmed and verified to be operating at a constant output, the shutter was dropped in place. Samples were held taut to the front of the Schmidt-Boelter gauge using clamps, and heat flux was applied by removing the shutter. Two experimental runs were performed; one with the cooling water controlling sensor temperature at 30 °C, and the other at 40 °C.

Results and Discussion – Effect of heat flux sensor temperature

The results of the test demonstrated a 10% difference in heat flux that increased in difference as the test continued. During a longer test the difference will grow. Sensors with higher than human skin temperature may under predict burns, and cooler sensors may over predict burns. Although it is possible to create a model that takes sensor temperature into account, it is difficult to determine the difference between the measured heat transfer and the heat transfer that would occur if the sensor truly replicated human skin temperatures.
Methods – Design and testing of a skin simulant heat flux sensor

The copper disc serves as a durable face for the sensor, and also helps to ensure a large enough measurement area for the test; it is painted with high emissivity paint to replicate human skin. The composite disc serves as a thermal capacitor between the water reservoir and the copper disc; there is relief to provide clearance for the thermocouple. The water reservoir serves as a known boundary condition for the rear of the composite disc, and is maintained at a constant temperature through the use of high flow water. The three layer construction is analogous to the model used in ISO 13506 and ASTM F1930 for burn modeling if the copper disc is seen as the epidermis/dermis, the composite layer as the subcutaneous region, and the water reservoir as core temperature [1,3]. In order to measure heat flux, the behaviour of the sensor is modeled using a discrete layered model. The model used divides the heat flux sensor into 100 layers, and the modeled temperature distribution is used to calculate heat flux through the sensor.

The sensor was exposed to various heat flux levels using the test apparatus shown in figure 1. Temperature was logged and heat flux was calculated using the discrete layered model.

Results and Discussion – Design and testing of a skin simulant heat flux sensor

![Diagram of the layered construction of skin simulant heat flux sensor](image)

**Figure 3.** Image showing the layered construction of skin simulant heat flux sensor.

![Graph showing skin model surface and sensor temperatures](image)

**Figure 4.** A chart showing that the sensor tracks the temperature of a human skin model’s surface temperature within 4 degrees during heating, and within 8 degrees while cooling. The skin model meets the specifications of ASTM F1930 and ISO 13506.
Figure 5. A chart showing sensor response to square wave heat flux input.

Figure 4 shows that the sensor responds similarly to human skin, on both heating and cooling. Additional experimentation varying the thickness and material of each property should result in a sensor that tracks human skin more closely. Figure 5 shows that the sensor responds accurately to square wave heat flux input. Additional experimentation using non-square wave exposure will be performed in the future.

Conclusions
The effect of sensor temperature on heat flux readings has been demonstrated. A sensor technology has been developed and tested which provides realistic skin response characteristics and real-time measurement of heat flux over a wide range of intensities. The physical size of the sensor is compatible with existing bench-top and full-manikin ensemble systems. The temperature controlled feature of the sensor may allow testing of scenarios which include exertion and core temperature rise before a thermal exposure.

References
Improved procedure for estimating time-dependent changes in local sweat rates by measuring local sweat volumes by using absorbing pads

Hiroyuki Ueda1*, Yoshimitsu Inoue2
1 Osaka Shin-ai College, Japan
2 Osaka International University, Japan
*corresponding author: ueda@osaka-shinai.ac.jp

Introduction
Previous studies on regional sweat rates have typically used ventilated capsules that cover a skin area of less than 10 cm². Generally, 1 capsule is used per body part in these studies. Although the small samples of sweat collected using the capsule method provide useful information about human sweating responses, these data are a vague representation of the sweat rates of the entire body and of different areas of the body. Data on the sweat accumulated from an extensive skin area is useful for designing clothes with transpiration efficiency. Recently, studies have used elaborately fabricated absorbents to collect sweat over the entire body for the short duration of moderate-intensity exercise [1]. We have devised an easier procedure that uses commercially available absorbent pads to collect regional sweat produced at various body sites during light-to-moderate physical activity [2]. However, these methods using absorbents for collecting sweat provided no information about the time-dependent changes in sweat rates. The aim of this study was to establish a procedure to estimate the time-dependent changes in sweat rates from local sweat volumes collected using absorbent pads based on the local sweat rate measured using the capsule method.

Methods
Study 1: The sweat data gathered by 3 series of studies on prepubertal boys and men and women of all ages were comprehensively reanalyzed. In these studies, local sweat rates (msw: mg/cm²/min) at 4 or 5 body sites were measured continuously by using the capsule method in a leg immersion test in which the subjects (n = 48) immersed their legs to into a 42°C stirred water bath for 40 min in a chamber maintained at 30°C and 45%RH, a constant intensity exercise test in which the subjects (n = 20) performed 3 different cycling exercises at 35, 50, and 65%VO₂max for 30 min in a seated position at 28°C and 40%RH on separate days, and an incremental exercise test in which the subjects (n = 32) performed a continuous graded cycling exercise in the semi-supine position at 35, 50, and 65%VO₂max for 20 min each without rest between intensity changes at 30°C and 45%RH. The minute percentage sweat rate (%msw) was calculated by dividing the local sweat rate by the sum of the sweat rate throughout the experiment according to the body site. To examine the difference in msw and %msw among body sites, data were analyzed using repeated-measures ANOVA with the factors of body site, time, and the interaction of these terms. In addition, the coefficients of variation were calculated as an indicator of the degree of regional difference in msw and %msw. They were derived from msw and %msw at 4 or 5 body sites on a minute-by-minute basis, and then the means of them were calculated every 10 min during the experiments.

Study 2: The time-dependent changes in sweat rate at various body sites were estimated from local sweat volume collected using absorbent pads in an exercise experiment. Six men volunteered for the experiment as subjects. The local sweat volumes of 21 body sites were collected using the absorbent pads during a bicycle exercise at 60%VO₂max for 40 min in a chamber at 25°C and 50% RH. The local sweat volume was calculated using the mass gain of the pads at each body site. The local sweat rate on the back of the subject was collaterally measured during the exercise by using
the capsule method, and the time-dependent changes in sweat rates at 21 body sites were estimated on the basis of %msw of the back. Rectal temperature and the chest, back, and forearm skin temperatures were measured continuously, and the mean body temperature was calculated using these values.

Results and Discussion
Figure 1 shows the changes of 10-min averages of msw and %msw of a typical case. The msw increased over time (p<0.05) and displayed large variation among the body sites (p<0.05) regardless of age, sex, and training. The interaction of time and body sites (p<0.05) indicated regional differences in the sweat rates. The sweat rates increased in the following order: lower limbs < upper limbs and trunk < forehead. Further, the regional differences were observed to vary according to age, sex, and training. Conversely, %msw significantly increased over time (p<0.05), although the effects of body site and the interaction of body site and time were not significant in most cases. Even if the interaction was significant, a significant simple main effect of body site was not observed. When regional differences in msw and in %msw were compared in terms of their coefficients of variation, the coefficients of %msw were obviously smaller than those of msw (Table 1). These results indicated that there were almost no regional differences in %msw. Therefore, the time-dependent changes in sweat rates at various body sites could be estimated from collected local sweat volume by using the absorbent pads based on the local sweat rate at 1 site determined by the capsule method.

Figure 1. The changes of 10-min averages of local sweat rate and %msw of young male subjects (n = 13) in a leg immersion test.
Table 1. The coefficient of variation for the absolute sweat rate and %msw [mean(SEM)].

<table>
<thead>
<tr>
<th></th>
<th>sweat rate (msw)</th>
<th>minute percentage sweat rate (%msw)</th>
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<tbody>
<tr>
<td></td>
<td>time (min)</td>
<td>1-10</td>
</tr>
<tr>
<td>Young male</td>
<td>13</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>41.7 (5.5)</td>
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<tr>
<td>Older male</td>
<td>14</td>
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<td></td>
<td></td>
<td>58.6 (7.0)</td>
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<tr>
<td>Young female</td>
<td>12</td>
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<td></td>
<td></td>
<td>29.8 (3.7)</td>
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<tr>
<td>Older female</td>
<td>9</td>
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<td></td>
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<td>46.2 (10.1)</td>
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</table>

** p < 0.01  * p < 0.05 Significantly different to corresponding sweat rate value

Constant intensity exercise test

<table>
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<tr>
<th></th>
<th>sweat rate (msw)</th>
<th>minute percentage sweat rate (%msw)</th>
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<tr>
<td></td>
<td>time (min)</td>
<td>1-10</td>
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<tr>
<td>Prepubertal boy</td>
<td>6</td>
<td>24.8 (5.5)</td>
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<tr>
<td>Young male</td>
<td>9</td>
<td>26.7 (3.4)</td>
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<tr>
<td>Older male</td>
<td>5</td>
<td>28.0 (3.4)</td>
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<tr>
<td>50% VO2max</td>
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<td>Prepubertal boy</td>
<td>6</td>
<td>40.7 (4.8)</td>
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<tr>
<td>Young male</td>
<td>9</td>
<td>41.8 (7.2)</td>
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<tr>
<td>Older male</td>
<td>5</td>
<td>51.2 (4.2)</td>
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<tr>
<td>65% VO2max</td>
<td></td>
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<tr>
<td>Prepubertal boy</td>
<td>4</td>
<td>48.5 (8.1)</td>
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<td></td>
<td></td>
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<tr>
<td>Young male</td>
<td>9</td>
<td>43.7 (9.2)</td>
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<tr>
<td>Older male</td>
<td>5</td>
<td>60.1 (10.2)</td>
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</table>

Incremental exercise test

<table>
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<tr>
<th></th>
<th>sweat rate (msw)</th>
<th>minute percentage sweat rate (%msw)</th>
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<tr>
<td></td>
<td>time (min)</td>
<td>1-10</td>
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<td></td>
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<tr>
<td>Trained male</td>
<td>5</td>
<td>43.1 (6.8)</td>
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<tr>
<td>Untrained male</td>
<td>8</td>
<td>60.4 (7.4)</td>
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<tr>
<td>Trained female</td>
<td>10</td>
<td>38.4 (4.2)</td>
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<tr>
<td>Untrained female</td>
<td>9</td>
<td>39.8 (3.6)</td>
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</table>

** p < 0.01  * p < 0.05 Significantly different to corresponding sweat rate value

Figure 2 shows the procedure for estimating the local sweat volumes of 21 body sites collected using the absorbent pads during bicycle exercise. Local sweat volumes for the trunk were large compared with those for the limbs. The volumes showed a symmetrical pattern, and those for the middle of trunk were large compared with those for both sides. The volumes for the flank were smaller than those for the front or back of the trunk. The volumes for the thighs and legs were smaller than those for the upper arm, and those for the front of the legs and thighs were larger than those for the back of these areas. These results denoted the similar tendencies of the regional differences in sweat rate relative to those observed in previous reports. To estimate the time-dependent changes in sweat rates for various body sites, msw measured on the back by using the capsule method was first converted to %msw. Then, the time-dependent changes in local sweat rates could be estimated by multiplying the local sweat volume multiplied by %msw. Further speculation could be made by noting that the time-dependent changes in sweat rates corresponded with the time course of mean body temperature. If we sketchily predict a rise in body temperature from some condition, such as exercise and ambient condition, the aforementioned predictive procedure could convey information about the local sweat rate without stressful experiments.

In particular, we suggest that the estimated sweat rates could be effective in designing functional clothes that can modulate the mean body temperature during exercise.
Figure 2. The procedure for estimating local sweat volumes collected using the absorbent pads.

References
A survey of human thermal comfort metrics

Mark A. Hepokoski1*, Allen R. Curran1, Tony J. Schwenn1
1ThermoAnalytics, Inc., Calumet, MI, USA
*corresponding author: Mark.Hepokoski@ThermoAnalytics.com

Introduction
Thermal comfort metrics can be categorised as being either environment-based or physiology-based. Environment-based metrics correlate air temperature, surrounding surface temperatures, air velocity, clothing thermal resistances, relative humidity, etc. with thermal comfort. Physiology-based metrics require the same inputs but use a human thermoregulation model to predict body core temperature, skin temperatures and skin wettedness, which are then correlated with thermal comfort.

Methods
This poster presents a survey of the metrics used in the HVAC (Heating, Ventilation, and Air Conditioning) industry for thermal comfort predictions [1]. The following metrics are considered: Skin wettedness, Fiala’s Dynamic Thermal Sensation [2], the Berkeley Comfort Model [3], Fanger’s Predicted Mean Vote, air draft rate, Equivalent Homogenous Temperature and the discomfort caused by stratified air temperature. These metrics are calculated and compared for a transient cool-down of a vehicle passenger compartment after a hot-soak.

Results
A summary of the comfort metric predictions is presented in the table below. The comfort criteria are listed in the left-most column. Time to comfort for each metric is determined by finding the transition from an unacceptable comfort state (coloured in red) to an acceptable one (coloured in green).

<table>
<thead>
<tr>
<th>Elapsed Time (min)</th>
<th>0</th>
<th>1</th>
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<th>11</th>
<th>12</th>
<th>13</th>
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<tbody>
<tr>
<td>Wettedness &lt; 25%</td>
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<td>Fiala DTS &lt; 1</td>
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<td>Berkeley Comfort &gt; 0</td>
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<td>PMV: PPD &lt; 20%</td>
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<tr>
<td>Draft Rate: PD &lt; 20%</td>
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<tr>
<td>T&lt;sub&gt;e&lt;/sub&gt;: &lt; 30°C</td>
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Conclusions
Comprehensive thermal comfort analysis should involve multiple comfort metrics that consider all aspects of thermal comfort, including draft and wettedness. For the transient cool-down case analyzed, all of the metrics predicted comfort after 12 minutes, with the exception of the draft comfort metric, which is under the passenger’s control.

References
ISO standards in environmental ergonomics

Ken Parsons
Loughborough Design School, Loughborough University, UK.
*corresponding author: K.C.Parsons@lboro.ac.uk

Introduction
There are now twenty active and published ISO standards in the area of the thermal environment with others at a variety of stages of development and more in other areas of the physical environment. The standards are intended to represent the best available and agreed information and methods that can be used internationally to assess the impact of thermal conditions on health and comfort.

It is useful to have an international standard not only to allow the best methods to be used internationally but to ensure reliability in methods and systems as well as an ability to compare results and learn from outcomes across the world. It is also worth noting that they support the establishment of quality control and fair trading in international markets as well as stimulating national and international debate that leads to research and to the development of the subject and its practical application.

Methods
For international standards in the area of thermal environments a number of principles have become established. Underpinning all of the assessment methods is that there are six important factors, all of which have to be taken into consideration when assessing human response to thermal conditions and using the standards. These are the environmental factors: air temperature; radiant temperature; air velocity; and humidity and the personal factors: clothing and activity. It is the interaction of all six factors that determine human response and not a subset or one alone. This can be demonstrated from heat transfer analysis between the human body and the environment [3]. Another principle is that a person responds to the local conditions to which they are exposed, so the above six factors have to be quantified in terms of the exposure of the person. The interaction of the four environmental factors can be considered to be the thermal exposure and of the six factors, the thermal stress. Thermal strain is the response of the body. A thermal index is a single number that represents the integrated thermal stress and can be used to predict thermal strain. Thermal strain can be physiological strain, measured by heart rate, body temperature, sweating etc. and psychological strain including subjective response, such as ratings of discomfort or intolerance, or behavioural response such as changing clothing or moving away from the stress. The principle is that a strain is a ‘movement away’ from an optimal condition such as thermal comfort where there are preferred subjective responses as well as comfortable internal body temperatures and mean skin temperatures (e.g. usually around 37 °C and 33 °C respectively for sedentary people).

Results and Discussion
Table 1 provides current international standards for the assessment of thermal environments
Table 1. Published ISO standards for the assessment of human response to the thermal environment.

ISO 7243 (1989) (ED 2) Hot environments -- Estimation of the heat stress on working man, based on the WBGT-index (wet bulb globe temperature)


ISO 7730 (2005) (ED 3) Ergonomics of the thermal environment -- Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria


ISO 9920 (2007) (ED 2) Estimation of thermal insulation and water vapour resistance of a clothing ensemble (see also amended version 2009)

ISO 10551 (1995) (ED 1) Ergonomics of the thermal environment -- Assessment of the influence of the thermal environment using subjective judgement scales

ISO 11079 (2007) (ED 1) Ergonomics of the thermal environment -- Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects


ISO 12894 (2001) (ED 1) Ergonomics of the thermal environment -- Medical supervision of individuals exposed to extreme hot or cold environments

ISO 13731 (2001) (ED 1) Ergonomics of the thermal environment -- Vocabulary and symbols


ISO 15265 (2004) provides a risk assessment strategy which outlines stages of assessment. This has yet to be fully reconciled with the current ISO system of standards and should be considered in the future.

Climate change will lead to workers being exposed to more varied and extreme climates. Improvements in health and safety systems across the world will lead to greater protection of workers from hazards. This often involves protective clothing and equipment which in turn leads
to greatly increased heat stress. Globalisation will involve a diversity of contexts, climates, cultures and populations. The principles of human response to heat will be similar across the world but specific populations will have specific requirements for the application of standards. Two standards will provide additional support. These are ISO 12894 (2001) which provides methods for screening people to ensure only those fit for the work are exposed, and ISO 28803 (2012) which provides guidance on the application of standards for people with special requirements (defined as being outside of the scope of existing standards – not fit, young, male and healthy, for example). This is important as there are millions of so called vulnerable people in the world, including some people with disabilities, and these are the people who are mainly at risk in heat waves. Disability discrimination legislation correctly identifies that where reasonably practicable, working environments should be accessible to diverse populations. This is a challenge for future standards.

Models of human thermoregulation are now routinely used in computer aided design and analysis. There is a new project (ISO/NP 16418) to produce an ISO standard in this area. Whether this will be an ISO model or guidance on the development of models is still under debate. It was not the intention of the new standard to replace existing standards as they have been developed specifically for purpose (e.g. heat stress assessment, cold, thermal comfort etc.). A new development however has proposed a Universal Thermal Climate Index (UTCI) which is based upon a model of human thermoregulation [1,2]. This is a first step in the link between meteorological data and predicting the impact of climate on health. There is still some way to go however. Deficiencies in available data (e.g. radiation) will lead to deficiencies in predictive power of the UTCI system for predicting responses to outside work and particularly inside work where local climates may be very different from those used in the calculation. There is a need for a standard to make full use of available meteorological data and this should be pursued in the future. Current meteorological data are inadequate (e.g., in terms of radiation) and are measured in the ‘wrong’ place (i.e. not at the workplace). However, they are extensive, global and often all that is available to provide a population level assessment of health impact.

Accessibility of ISO standards will greatly affect their use and hence effectiveness in the avoidance of discomfort or casualties. This is not a scientific point but is relevant to application. The structure of the ISO standards organisation ensures that there are many countries throughout the world that adopt the standards and they are available through national standards bodies and distributed to and by contributing industries and organisations. There is some cost involved which may become prohibitive to some work organisations where there is potential for heat casualties. Mechanisms for ensuring accessibility of standards at an affordable price need to be determined to ensure that standards are used in the future.

Although human response to heat does not vary and much is known, people still die because of heat and cold and complain about discomfort. Developments in technology, new techniques and indicators of thermal strain, new types of work, climate change, globalisation and diverse populations all provide significant challenges and will require continual review of existing standards and new strategies and standards for the future.

Conclusions
A comprehensive series of ISO standards has been produced in the area of environmental ergonomics. They have been produced by international effort. It is important that they are developed with the best international knowledge and expertise available as we move forward to meet future requirements.
References

Appendix 1: Countries involved in the production of ISO standards for heat stress and the Ergonomics of the physical environment (ISO TC159 SC5)

**Participating Countries:** United Kingdom (BSI - secretariat); Belgium (NBN); Brazil (ABNT); Canada (SCC); China (SAC); Czech Republic (UNMZ); Finland (SFS); France (AFNOR); Germany (DIN); Israel (SII); Italy (UNI); Japan (JISC); Korea, Republic of (KATS); Malaysia (DSM); Netherlands (NEN); Poland (PKN); Sweden (SIS); Thailand (TISI); USA (ANSI).

**Observing Countries:** Australia (SA); Austria (ASI); Bulgaria (BDS); Cyprus (CYS); Denmark (DS); Ireland (NSAI); Kenya (KEBS); Malta (MCCA); Romania (ASRO); Russian Federation (GOST R); Slovakia (SUTN); Spain (AENOR)
CLOTHING PERFORMANCE IN THE COLD

Assessing the lower temperature limit for comfort in footwear

George Havenith1, Nicola Gerrett1,2,*, Steve H. Faulkner1,3, Yacine Ouzzahra1, Davide Filingeri2

1 Environmental Ergonomics Research Centre, Loughborough University, UK
2 Institute of Sport and Exercise Science, University of Worcester, UK
3 Sport, Exercise and Life Sciences, School of Health, The University of Northampton, UK
*corresponding author: g.havenith@lboro.ac.uk

Introduction

When selecting clothing and equipment for use in the cold, consumers often receive only limited guidance from product information provided by manufacturers. In the area of sleeping bags the introduction of standards for their climatic range assessment, though often heavily debated by manufacturers, has undoubtedly provided consumers with guidance. Currently no such standards exist for outdoor footwear. Many manufacturers of footwear do claim certain lower temperature limits, going to -40°C in some cases. No information is however provided on how this is tested and what criteria are applied. Kuklane et al. (1999) did several studies on the relation between footwear insulation and comfort range, but so far this has to our knowledge not led to the development of a standard. In the present study, following up on work by Kuklane, an attempt was made to collect physiological data that may be used in setting criteria for the lower temperature range of footwear.

Methods

Dressed in suitable winter clothing, identical socks and 7 different walking shoes (5 identical models with thermal resistance increasing stepwise in 5 steps, +2 other models) six participants (3 males, 3 females) volunteered to take part. Ethical approval was obtained for the testing. Participants were exposed to five environmental conditions; 0°C, -7°C, -14°C, -20°C and -30°C. Air velocity was 0.4 m.s⁻¹. During exposure, participants completed a rest-exercise protocol of 10 minutes walking (331 W), 10 minutes stepping (313W) and 10 minutes rest, for 120 minutes. Four skin temperatures (Grant thermistors), at the arch, medial heel, lateral foot and base of 4th metatarsal, were averaged every 5 minutes. Local thermal comfort and foot acceptability were rated every 5 minutes.

Results

A relation of mean foot $T_{sk}$ with ambient temperature (negative) and boot insulation (positive) was observed, with drops in foot temperature of more than 20°C in extreme cases. A clear pattern was observed, with the toe having the coldest $T_{sk}$ followed by the lateral foot, mid-arch and the heel having the highest $T_{sk}$. Moderate to strong correlations existed between foot thermal comfort and thermal sensation and mean foot $T_{sk}$ ($r^2>0.55$, $r^2>0.77$, respectively). Threshold for ‘uncomfortable’ and a ‘cool’ local thermal sensation occurred at a mean foot $T_{sk}$ of 23°C.

Discussion

It is well established that the extremities are at great risk of cold injuries, but this study also revealed that the lateral foot was more susceptible than the medial aspect. Protective footwear should account for the uneven foot temperature distribution with the toe having the lowest $T_{sk}$ followed by the lateral foot. Footwear should aim to protect mean foot temperature from dropping below 23°C. This limit value can be used to assess how well cold footwear protects the
foot in cold climates. A time limit and a metabolic rate definition are essential components of such an assessment however.

References
1. Kuklane, K; *Footwear for cold environments Thermal properties, performance and testing*, *Arbete och Haelsa*; 1999. 23
Clothing and skin temperatures and heat flow while wearing far infrared heating vest in the cold - a thermal manikin and test subject study

Kirsu Jussila1, *, Sirkka Rissanen1, Hannu Rintamäki1,2, Ville Hyvärinen1

1 Finnish Institute of Occupational Health, Oulu, Finland
2 University of Oulu, Department of Biomedicine, Oulu, Finland
*corresponding author: kirsu.jussila@ttl.fi

Introduction
Adequate thermal insulation of clothing is required in cold conditions for sustaining body heat balance. In extreme conditions the required thermal insulation may be so high that a multi-layered cold protective clothing is too thick, limiting the movement of the extremities and increasing physical strain by its weight and friction between the layers. Moreover, if physical activity is low, sustaining body heat balance is not possible solely by the thermal insulation of the clothing. Solutions to these problems have been searched through the development of personal heating garments (PHG).

PHG can be electrically heated garments, phase change material garments, chemical heated garments or fluid/air flow heated garments [7]. Active heating on the torso area has been shown to increase mean temperatures of fingers and toes, but without significant increase in rectal temperature [1]. It has been suggested that heating power of an electrically heated vest should be about 5-13 W depending on ambient temperature to provide thermal comfort and provided heat lost to the environment should be minimized to improve heating efficiency [8]. The critical factor in use of electrically heated garments is battery performance in the cold [5-7].

The far infrared (FIR) heating method is based on the longer wavelengths than ordinary infrared (IR) heaters. It is believed that the heating effect of FIR heaters extends to deeper inside the tissue than ordinary IR heaters.

The objective of this study was to examine the effect of a FIR heating vest on clothing and skin temperatures and heat flow in a cold environment both in calm and windy conditions.

Methods
The FIR heating vest including three heating panels, two on chest (panel surface 133.3 cm²) and one on lower back (panel surface 204.5 cm²), and it was examined with layered winter clothing. The clothing included underwear and middle layer (EN 342 [2], reference clothing B), FIR heating vest with thin padding and outermost layer (with padding). The measurements were performed according to standards EN 342 and EN ISO 15831 [2-3] using a static aluminium thermal manikin consisting of 20 segments. The surface temperature of the thermal manikin was 32.5°C (standard deviation, SD ± 0.8°C). Fourteen thermistors (thermistors NTC DC95; Digi-key Corp., Thief River Falls, MN, USA) were used to measure temperatures on different layers of the three-layered clothing and heating vest as well as the micro climate close to the surface of the thermal manikin. The thermistors were located on left and right sides of the chest and on the lower back at site of the panels. Ambient temperature was set at -10°C and wind speed was 0.3 and 4 m/s.

Measurement time was one hour without heating and three hours with heating.

Pilot measurements with two test subjects were made in the climate chamber at ambient temperature of -15°C and wind speed was 0.2 m/s. Exposure time was 45 min and the subjects were standing or having very light activity. During the tests core temperature (Jonah™ Temperature Capsule, Mini Mitter, USA), skin temperature (thermistors NTC DC95; Digi-key Corp., Thief River Falls, MN, USA) from fourteen sites and heat flux (Heat Flux Transducers Model Ha13-
18-10-P, Thermonetics Co, USA) from four sites were measured. Thermal sensations of the test subjects were asked according to standard ISO 10551 [4] every 10-15 min.

Results
According to the measurements by the thermal manikin in calm conditions (0.3 m/s), temperature right under the FIR heating panels averaged 44.3°C (SD ± 11.0°C) when heating was on and 22.0°C (SD ± 5.3°C) without heating. The effect of the heating panels on the thermal manikin surface was an average 2.4°C higher temperature than without heating. Even though the heating panels had a resistance layer to prevent heat loss to the environment, the temperature on the outside surface of the vest was on an average 9.9°C higher than without heating. When exposed to wind (4 m/s) the temperatures underneath the different clothing layers were 88-98% of the values in calm (0.3 m/s) conditions. In both calm and windy conditions thermal insulation on the jacket area increased by 3-5% when heating was applied.

The pilot tests with test subjects showed that the FIR heating vest had heating benefit on the front side of about 65 W/m². When heating was not used, the heat loss from the skin was about 75 W/m². Heating increased local skin temperatures at sites of the panels on an average 3°C; however, the use FIR vest did not increase core temperature nor did it prevent cooling of the extremities during the exposure while being inactive. Local thermal sensation in the torso was warmer at the end of the study while heating was used, but the general thermal sensation was unaffected by the FIR heating.

Conclusions
The FIR heating vest used in cold conditions turned the heat loss from skin to heat gain of the skin and increased temperatures between clothing layers and micro climate close to the skin. Nevertheless, the effects were local and were not sufficient to increase temperatures at the fingers and toes during very low physical activity in the cold.

This study was carried out as part of the project “Harsh Weather Testing Network”, which was financially supported by the European Union, Interreg Nord (www.harshnet.eu).

References
The change in total thermal insulation and temperature rating of sleeping systems due to accessory items

Andrew Hunt*, Alison Fogarty
Human Protection and Performance Division, Defence Science and Technology Organisation, Melbourne, Australia
*corresponding author: andrew.hunt@dsto.defence.gov.au

Introduction
Military operations often expose dismounted combatants to a wide range of environmental conditions for extended periods of time. To maintain thermal balance and comfort for sleeping in field conditions, a sleeping system with sufficient total thermal insulation is required to limit dry heat loss and prevent heat debt. The sleeping bag is the key component, to which accessory items can be added to provide a scalable system which the operator can adjust to meet their comfort requirements in the prevailing environmental conditions. Accessory items may include a mattress, liner bags, and outer bags for protection from wind and rain, and clothing. The aim of the present study was to evaluate the effect of accessory items on the total thermal insulation and temperature ratings of a sleeping system based with a cool weather or an extreme cold weather sleeping bag.

Methods
The total thermal insulation of the sleeping system was measured using a heated manikin dressed in long thermal underwear, socks, and a face mask, while lying supine on a 10 mm foam mattress and 12 mm wooden board raised off the floor (1 m). Tests were conducted in an environmental chamber with relative humidity between 40–80% and wind-speed set to 0.3 m s⁻¹. Ambient temperature was maintained within ±0.7°C during testing, with the ambient temperature set-point between +5°C and -18°C. Manikin skin temperature was maintained at 35.0±0.2°C throughout testing. Total thermal insulation of the sleeping system was calculated using the parallel method. The lowest ambient temperature at which thermal comfort could be achieved was estimated from the European standard and included the comfort and limit temperature ratings [1].

The sleeping system had an inner-layer, mid-layer, and an outer-layer. The primary item of the sleeping system was the sleeping bag, which formed the mid-layer. This study evaluated two sleeping bags: a Cool Weather Bag (CWB) (polyester non-absorbent fill), and an Extreme Cold Weather Bag (ECW) (water resistant duck down fill). Several combinations of accessory items were evaluated with each sleeping bag. These included two types of inner-layer, a silk liner (Slin) (100% silk), and a quilted liner (Qlin) (non-absorbent polyester wadding), and an outer-layer item, a bivi bag (BIV) (Gortex 170-200 gsm). The sleeping system with the lowest, median, and highest total thermal insulation was further evaluated with different mattress types, including a foam mattress (FOAM) (10 mm closed cell foam), two self-inflating mattresses: INF (10 mm) and STA (38 mm), and no mattress (NIL). The self-inflating mattresses (INF and STA) were allowed sufficient time to inflate, followed by air being directed into the mattress to ensure full inflation.

Results
Total Thermal Insulation
The ECW system provided greater total thermal insulation than the CWB system (Table 1). The addition of accessory items to the sleeping system increased the total thermal insulation, for both the ECW and CWB systems, however, the magnitude of the effect of the accessory items differed between the CWB and ECW sleeping bags. Each of the accessory items provided a greater increase
in total thermal insulation for the CWB when compared to the ECW for both absolute and percentage differences. The sleeping system that provided the lowest, median, and highest total thermal insulation was the CWB, CWB+Qlin+BIV, and ECW+Qlin+BIV, respectively.

<table>
<thead>
<tr>
<th>Sleeping System</th>
<th>Total Thermal Insulation (°C m²/W)</th>
<th>Difference from Sleeping Bag only (°C m²/W)</th>
<th>Difference from Sleeping Bag only (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWB</td>
<td>0.84</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>CWB+Slin</td>
<td>0.88</td>
<td>0.04</td>
<td>5</td>
</tr>
<tr>
<td>CWB+Qlin</td>
<td>0.97</td>
<td>0.13</td>
<td>15</td>
</tr>
<tr>
<td>CWB+BIV</td>
<td>0.94</td>
<td>0.10</td>
<td>12</td>
</tr>
<tr>
<td>CWB+Slin+BIV</td>
<td>0.98</td>
<td>0.14</td>
<td>17</td>
</tr>
<tr>
<td>CWB+Qlin+BIV</td>
<td>1.07</td>
<td>0.23</td>
<td>28</td>
</tr>
<tr>
<td>ECW</td>
<td>1.25</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ECW+Slin</td>
<td>1.30</td>
<td>0.04</td>
<td>3</td>
</tr>
<tr>
<td>ECW+Qlin</td>
<td>1.32</td>
<td>0.07</td>
<td>5</td>
</tr>
<tr>
<td>ECW+BIV</td>
<td>1.32</td>
<td>0.07</td>
<td>5</td>
</tr>
<tr>
<td>ECW+Slin+BIV</td>
<td>1.37</td>
<td>0.12</td>
<td>9</td>
</tr>
<tr>
<td>ECW+Qlin+BIV</td>
<td>1.40</td>
<td>0.15</td>
<td>11</td>
</tr>
</tbody>
</table>

CWB = Cool Weather Bag; ECW = Extreme Cold Weather Bag; Slin = Silk Liner; Qlin = Quilted Liner. BIV = Bivi Bag.

The total thermal insulation of the three tested sleeping systems was lowest for the NIL mattress condition, similar when using the FOAM and INF mattress types, and highest with the STA mattress (Table 2). The increase in total thermal insulation provided by the FOAM and INF mattresses, above that of the NIL mattress condition, was relatively stable across the three sleeping systems. The increase in total thermal insulation with the STA mattress, above the NIL mattress condition, was relatively stable for the least and median sleeping systems, but was much higher for the sleeping system with the highest insulation. The percentage increase in total thermal insulation was consistent across the lowest, median and highest insulating systems for all mattress types, but the percentage difference tended to be greatest with the STA mattress.

**Temperature Ratings**
The total thermal insulation of the CWB sleeping system was sufficient to maintain thermal comfort in ambient temperatures as low as +6.4°C (Comfort rating) to +1.6°C (Limit rating). The inclusion of accessory items (Qlin and BIV) with the CWB sleeping system extends this range down to -1.0°C to -7.0°C. Thermal comfort in the ECW sleeping system will be achieved in ambient temperatures as low as -6.6°C to -13.5°C, which can be extended down to -11.0°C to -18.7°C with the accessory items (Qlin and BIV). These temperature ratings were applicable when either the FOAM or INF mattress types were used.
Table 2. Total Thermal Insulation of the Sleeping Systems with Different Types of Mattress

<table>
<thead>
<tr>
<th>Sleeping System</th>
<th>Mattress Type</th>
<th>Total Thermal Insulation (°C m²/W)</th>
<th>Difference from NIL (°C m²/W)</th>
<th>Difference from NIL (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CWB</td>
<td>NIL</td>
<td>0.78</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FOAM</td>
<td>0.84</td>
<td>0.06</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>INF</td>
<td>0.85</td>
<td>0.07</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>STA</td>
<td>0.92</td>
<td>0.14</td>
<td>18</td>
</tr>
<tr>
<td>CWB+Qlin+BIV</td>
<td>NIL</td>
<td>1.01</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FOAM</td>
<td>1.07</td>
<td>0.06</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>INF</td>
<td>1.10</td>
<td>0.09</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>STA</td>
<td>1.15</td>
<td>0.14</td>
<td>13</td>
</tr>
<tr>
<td>ECW+Qlin+BIV</td>
<td>NIL</td>
<td>1.30</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FOAM</td>
<td>1.40</td>
<td>0.10</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>INF</td>
<td>1.38</td>
<td>0.08</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>STA</td>
<td>1.53</td>
<td>0.23</td>
<td>18</td>
</tr>
</tbody>
</table>

CWB = Cool Weather Bag; ECW = Extreme Cold Weather Bag; Qlin = Quilted Liner; BIV = Bivi Bag.

Conclusions
The incorporation of accessory items (such as liner bags, outer bags, and mattresses) increased the total thermal insulation provided by the sleeping systems. These findings allow the user to scale the sleeping system to ensure their individual thermal comfort requirement over a wider range of environmental conditions than using a sleeping bag alone.

The additional insulation provided by accessory bags (liner and outer) was dependent on the sleeping bag, such that the absolute increase in total thermal insulation was reduced with a sleeping bag of higher total thermal insulation. On the other hand, the mattresses effect on total thermal insulation was relatively consistent over the range of total thermal insulation evaluated in the present study. Considering the dismounted combatant is required to carry all their equipment, these findings will aid in the selection of the most appropriate items to carry.

References
Sock fabrics: Measuring friction to prevent blisters

Rebecca Van Amber¹, Raechel Laing¹*, Cheryl Wilson¹, Bronwyn Lowe¹, Brian Niven²
¹ University of Otago, Department of Applied Sciences, Dunedin, New Zealand
² University of Otago, Centre for Application of Statistics and Mathematics, Dunedin, New Zealand
*corresponding author: raechel.laing@otago.ac.nz

Abstract

A sock is a functional, basic, knitted foundation garment that covers the foot. Conditions of sock use vary, as they are worn during every day activities such as walking, as well as sport and specialised activities such as hiking, cycling and skiing. Socks are often marketed as ‘technical garments’ with emphasis on characteristics such as warmth, cushioned, anti-microbial, ventilated, ‘wickable’, ‘breathable’, impact-resistant, lightweight and durable. Sock innovation, with comfort (thermal, ergonomic) and function (protection from abrasion, keeping feet dry) as the primary foci is evident from the large number of ‘technical’ products available to consumers.

Much is known about the formation of friction blisters, however, there is little understanding of friction between sock fabrics and the skin. A number of results from several studies on properties of socks have been published, but few studies have been carefully controlled. Emphasis on sock performance has been in relation to blister formation and fibre type, although whether this narrow emphasis is justified is uncertain.

Manufacturers are able to control at least three variables in unfinished sock fabric production: fibre content, yarn type and fabric structure. The current work sought to improve a commonly used friction method, and also investigated the effects of fibre type, yarn and fabric structure on friction between sock fabrics and a synthetic skin. Applied load was the main effect on static and dynamic friction of dry fabrics; however, fabric structure, fibre and yarn were all significant factors. Fibre type had the main effect on the static friction between damp fabrics and synthetic skin, but fabric structure had the main effect on the dynamic frictional force. From the number of parameters investigated and analysed, it is clear there is not a single sock fabric which can claim to prevent friction blisters.

References

Water vapour transport through clothing during exercise and rest in the cold

Stephen S. Cheung1*, Roger E. Montgomery1, Geoffrey L. Hartley1, Michael J. Taber1
1Department of Kinesiology, Brock University, St. Catharines, Canada
*corresponding author: scheung@brocku.ca

Introduction

We aimed to better understand the vapour transport properties of clothing systems in realistic use in cold environments. We directly measured water vapour pressure at multiple sites throughout the clothing microclimate during exercise and rest cycles in the cold.

Methods

In -5°C, 13 participants performed 2 repeated cycles of 30-min treadmill walking and 30-min rest. Clothing was standardised: cotton base layer of socks, underwear, pants and long-sleeve shirt; denim jeans; steel-toed boots; fleece-lined leather gloves; knit acrylic toque; and outdoor work jacket. Heat storage was determined from partitional calorimetry, adapted from a prior model used with exercise in the heat while wearing protective clothing [1]. \( \dot{E}_{sk} \) was calculated using two methods: 1) \( \dot{E}_{\text{max}} \), from a model using skin temperature and assuming 100% saturation at the skin, and 2) \( \dot{E}_{\text{model}} \), calculated directly via temperature and humidity sensors at the upper back and upper thigh. For each site, sensors were placed: 1) above the skin, 2) above the base layer, and 3) above the outer clothing layer.

Results and Discussion

Table 1. Partitional calorimetric calculations of heat storage during work and rest phases.

<table>
<thead>
<tr>
<th>Condition</th>
<th>( M )</th>
<th>( W )</th>
<th>( \dot{R} + \dot{C} )</th>
<th>( \dot{C}<em>{\text{res}} + \dot{E}</em>{\text{res}} )</th>
<th>Evaporative heat loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work1</td>
<td>313.1 (36.6)(^{a})</td>
<td>26.7 (5.7)(^{a})</td>
<td>142.3 (4.6)</td>
<td>24.9 (2.8)(^{a})</td>
<td>64.2 (32.6)</td>
</tr>
<tr>
<td>Rest1</td>
<td>68.4 (13.4)</td>
<td>0</td>
<td>136.1 (7.4)</td>
<td>5.0 (1.0)</td>
<td>88.3 (28.2)(^{a})</td>
</tr>
<tr>
<td>Work2</td>
<td>310.0 (28.3)(^{a})</td>
<td>26.7 (5.7)(^{a})</td>
<td>127.7 (6.6)(^{b})</td>
<td>24.6 (2.1)(^{a})</td>
<td>81.5 (13.5)</td>
</tr>
<tr>
<td>Rest2</td>
<td>68.9 (12.8)</td>
<td>0</td>
<td>129.8 (8.4)(^{c})</td>
<td>5.0 (0.9)</td>
<td>88.1 (11.5)(^{a})</td>
</tr>
</tbody>
</table>

\(^{a}\) Different from Rest1 and Rest2; \(^{b}\) Different from Work1; \(^{c}\) Different from Work1 and Rest1; \(^{d}\) Different from \( \dot{E}_{\text{max}} \); \(^{e}\) Different from \( \dot{E}_{\text{model}} \).

\( \dot{E}_{\text{model}} \) presented a sinusoidal pattern that rose during exercise and decreased during rest. In contrast, \( \dot{E}_{\text{max}} \) was 30 W m\(^{-2}\) higher during the initial work bout, then largely plateaued and stabilised at 50-60 W m\(^{-2}\) higher during the subsequent rest/work/rest cycles. Thus, \( \dot{E}_{\text{max}} \) underestimated heat gain during the work bouts and overestimated heat loss during the rest periods, representing ~50% of the total heat storage. In order to understand vapour transport properties of clothing systems in realistic conditions, \( \dot{E}_{sk} \) should be calculated via direct water vapour pressures when possible.

References

EXCHANGING HEAT - HUMANS, MANIKINS AND MODELS

How far are manikins representative of the human body for sports activities?

Bernard Redortier¹*, Damien Fournet¹

¹ Thermal Sciences Laboratory, Oxylane Research, Decathlon SA, Villeneuve d'Ascq, France
*corresponding author: bernard.redortier@oxylane.com

Introduction

Thermal and sweating manikins are now widespread for assessing thermal and evaporative transfer through clothing and helping understand or predict physiological responses of humans. However their application for providing valid results for sporting contexts should be questioned.

Because manikin movements are limited to walking, internal convection and ventilation within the clothing are, in many instances, obviously less than for real activity. Even for static postures, simple observation reveals that the manikin’s rigid morphology distorts reality, mainly in the back: for a biking posture, substantial air layers are introduced between skin and clothing where a human back would bend and keep the clothing in contact; when sitting (e.g. a chairlift) or lying on a mattress, a human back conforms to the surface in contact and compresses the clothing while the manikin offers a limited area of contact with significant extra air gaps all around.

This study aims at quantifying whether manikins offer an acceptable representation of the clothing-body effects on heat transfer during sports activities.

Methods

Regional thermal resistances (leg, arm, torso front, torso back) were measured on human subjects with heat flux sensors, for three activities (running, biking, skiing) which were reproduced in a climatic chamber. The clothing ensembles were standard ones for the activity considered.

Comparison was made against the corresponding thermal resistances measured with a thermal manikin (MTNW, Newton serie, 38 zones), wearing the same clothing, and operated to mimic the human activity – as close as the manikin can do (e.g., walking, sitting on a bike).

Activity, clothing and operating conditions for human and manikin trials are reported in Table 1.

Measurement of thermal resistance on humans was undertaken on six subjects:

Sensors were thin heat flux transducers (Captec; 0.6 mm x 10 mm x 10 mm; sensitivity 3μV/(W/m²)) which also incorporates a thermocouple for measuring temperature together with heat flux. Five sensors were distributed over each body segment (20 in total for whole body) and taped directly on the skin. Skin heat flux and skin temperature were integrated over each body segment to provide regional dry heat loss Hsk (W/m²) and regional mean skin temperature Tsk (°C), out of which the regional dry thermal resistance Rc (m².K/W) were calculated as Rc = (Tsk - Tair) / Hsk. Ambient temperature was adjusted to keep the subjects slightly cool, not sweating. The test was run over 10 minutes; based on thermal resistance reaching a steady state within 3-4 minutes, and the result being computed as the average across minutes 5 to 10. Data are shown as means for six subjects, with 95% confidence intervals.
**Table 1.** Conditions tested for comparing clothing thermal resistance as measured using a manikin and humans.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Running (winter)</th>
<th>Biking (winter)</th>
<th>Skiing – Downhill phase</th>
<th>Skiing – Uphill phase in chairlift</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>Run 10 km/h (on treadmill)</td>
<td>Cycle on a run bike 60 rpm (on home trainer)</td>
<td>Walk 5 km/h on treadmill, exaggerating swinging of arms</td>
<td>Sit on a chair</td>
</tr>
<tr>
<td>Manikin</td>
<td>Walk 50 double step/min</td>
<td>Static on run bike, Biking posture</td>
<td>Walk 50 double step/min</td>
<td>Sit on a chair</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wind (for human &amp; manikin)</th>
<th>10 km/h</th>
<th>18 km/h</th>
<th>28 km/h</th>
<th>9 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clothing (for human &amp; manikin)</td>
<td>Top: Underwear + running shirt (arms tight, torso slightly loose)</td>
<td>Top: Underwear + rainproof jacket (loose)</td>
<td>Top: Underwear + fleece +ski jacket (loose fit; neck, cuffs and waist tightened)</td>
<td>Legs: Tightfit leggings</td>
</tr>
<tr>
<td></td>
<td>Legs: Tightfit leggings</td>
<td></td>
<td>Legs: Ski trousers (loose, ankles tightened)</td>
<td></td>
</tr>
</tbody>
</table>

**Results and Discussion**

Regardless of the activity, for body segments where the clothing is tight fitting, thermal resistance was similar (within 10%) for humans and manikin.

For exercising humans, on segments were the clothing was loose and allowed for internal convection or ventilation, thermal resistance measured on human was 50% ±7% lower than measured on a walking manikin.

Static postures showed significant differences in the back; thermal resistance on the human back was 50% ± 10% of measured value for a manikin for sitting in a chair, and 33% ±7% lower for the biking posture. For other regions, static posture values did not differ between human- and manikin-based testing.

**Conclusions**

Thermal manikins offer a limited representation of the clothing thermal and evaporative properties for sports activities. The discrepancy may be up to 100% and should not be ignored.

Our approach provides correction factors that can be used in the context of measuring steady state resistances on a manikin or when operating the manikin in physiological control mode. However these correction factors may depend on the geometry of the manikin, and so may be valid only for the manikin on which they have been determined.
Thermal response of swimmers: Theory and experimental observations

Muthasim Fahmy1*, Carl D. Bradford1, Zhifa F. Sun1, David F. Gerrard1, James D. Cotter2, Samuel J.E. Lucas1, Eugene H. Wissler2

1 University of Otago, Dunedin, New Zealand.
2 University of Austin, Texas, USA.
*corresponding author: muthasim.fahmy@otago.ac.nz

Introduction
Open-water endurance swimming events (1.5 – 25 km) are becoming more popular worldwide; now within the Olympics, and with an international Grand Prix series. However, knowledge is sparse about the thermal implications for swimmers undertaking such swims in the wide range of environmental and individual circumstances involved (esp., water and terrestrial thermal conditions, salt vs fresh water, and swimmers’ anthropometry, fitness and efficiencies). Swimming normally exacerbates thermal strain for immersed individuals because in cold water the additional convective and conductive heat loss outweighs the additional heat production of exercise, whereas in warm water, heat production compounds heat storage because of the small skin-to-water gradient for sensible heat loss. The absence of data is most notable for warm-water swimming, and is prescient by virtue of some tropical race venues involving swimming in Twater>30°C with high radiant heat loading. The purpose of this study was therefore, (i) to obtain experimental data on swimmers’ thermal responses to endurance swimming in thermally stressful conditions, and (ii) to use those data to validate thermoregulation modeling, and ultimately to enable prediction for different real-world situations.

Methods

Experimental Observations
Twenty four swimmers (ranging from club to national level) undertook up to 9 swims each, involving three durations (20, 60 and 120 min) and three thermal conditions (Twater = 20°C, 27°C and 32°C), following familiarisation. The warmest condition was augmented with radiant heat loading (400-800 W/m²), to simulate the highest heat loading encountered during open-water swims. All swims were undertaken in a swimming flume (StreamLiNZ®, Invercargill, NZ), following collection of baseline data and a 10-min warm up. Ethical approval for this study was granted by the University of Otago Human Ethics Committee, and each swimmer signed an informed consent of participation upon enrolment. Core temperature (rectal; Tc) was recorded for all swimmers, and four skin temperatures and oesophageal temperature were also recorded for two swimmers. Swims were separated by at least 3 days, and scheduled at the same time of day for each swimmer. All swims were performance trials, to maximise distance within the allotted time (intended to simulate ~1.5-, 5- and 10-km races). Other measurements required for modeling were additionally recorded (e.g., anthropometry, Tglobe, relative humidity).

Modeling
The model [1] represents human geometry as the set of 21 cylinders shown in Figure 1. Each cylinder is subdivided into 169 small regions centered on the nodes represented in Figure 2. Physical properties, such as density, specific heat, and thermal conductivity, vary with position. Time-dependent physiological variables, temperature, metabolic rate, and blood flow rate, also vary with position. How the physiological variables vary with position and time distinguishes this system from inanimate physical systems.
Control equations for shivering, sweating, and blood flow in muscle, skin, splanchnic organs, and adipose tissue were derived from the published results of countless studies. It is important to note that those basic physiological studies did not deal with thermoregulation, per se. For example, early studies of skin blood flow employed plethysmography to measure forearm blood flow at various core and skin temperatures, while more recent studies tend to use laser Doppler techniques.

**Results and Discussion**

**Experimental studies**

Of 170 maximal-effort swims under the varied conditions, no swimmer became profoundly hyperthermic (Tc > 40°C). However, in the coolest water, two swimmers were withdrawn because of core cooling, and a third had to stop due to severe cramps. There was no clear evidence of behavioural thermoregulation during swimming in the warmest water (i.e., pace did not slow more than in temperate water).

**Modeling**

Computed results are presented here for one of the fastest, leanest swimmers. Figure 3 shows the effects of water temperature on the computed core temperature over a 10-km swim for this athlete starting with a Tc of 36.96°C and an incident direct solar radiation flux of 800 W/m². The general trends of core temperature response are uniform over the water temperature range of 20°C to 32°C. This figure was produced using the velocity profile measured in a flume trial. In this simulation a linear relationship between swim speed and the mechanical efficiency of swimming was assumed based on the measurements reported by Toussaint et al. [2].
Swimming efficiency
Gross mechanical efficiencies reported in the literature vary widely, from approximately 0.5% to approximately 20% [2, 3]. Nonetheless, the modeled effect of swimming efficiency on the maximal rise in $T_c$ was small and linear. Specifically, $T_c$ increased only an extra 0.05°C for each 1% reduction in efficiency across this range.

Acknowledgments
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References
Comparison of measured and predicted body core temperature during a 5-km march

Alison Fogarty1*, Andrew Hunt1, Daniel Billing1, Mark Patterson1
1 Defence Science and Technology Organisation, Victoria, Australia
*corresponding author: Alison.Fogarty@dsto.defence.gov.au

Introduction
The body produces heat through several mechanisms including basal cellular metabolism and muscular activity. To ensure thermal homeostasis, heat loss must equal heat production. There are four mechanisms by which the human body can exchange heat with the environment: radiation, convection, conduction and evaporation. As air temperature rises, mean skin temperature also rises, but core temperature (Tc) remains relatively stable. If air temperature converges with (or surpasses) skin temperature, evaporation of sweat becomes the only avenue for heat loss from the body. If clothing is worn, however, heat loss through evaporation is reduced. For evaporation to be most effective sweat must evaporate from the skin’s surface [1]. If heat production exceeds heat loss, core temperature will continue to rise and a heat illness / injury may result.

Military personnel are regularly required to work for prolonged durations and at moderate-to-high intensities in hot environments, often while wearing personal protective equipment and are therefore susceptible to heat injuries. To reduce this risk, the US Army Research Institute of Environmental Medicine (USARIEM) developed a model and subsequently Military Work Tables for the US Army [2]. These tables have since been adopted by the Australian Defence Force. In more recent times the tables were adapted for the Australian Defence Force Special Forces (SF) population, such that they account for the higher aerobic fitness (on average) of this group. Soldiers with a higher aerobic capacity generally have an improved heat loss capacity and tolerance to high body core temperatures [3]. Consequently, the SF Work Tables are based on the assumption that this population will exhibit a lower elevation in Tc for a set amount of work, being at least in the lower 50% of the broader Army population. While the Military Work Tables are based upon the average soldier experiencing a 1.5°C elevation in Tc, the SF Work Tables are based upon the average soldier experiencing a 2.5°C elevation in Tc, and it is assumed that the SF population Tc response will range from 2.0°C to 2.5°C. This study was undertaken to validate the application of the SF work tables to a 5-km march assessment performed as part of the SF selection process in hot, dry conditions.

Methods
Seventy-eight male Australian soldiers undergoing the SF selection process participated in this study (26.4±3.6 y, height: 179.2±6.2 cm, body mass: 83.0±8.2 kg, body fat: 10.5±4.4 kg, muscle mass: 41.3±4.6 kg, relative maximal oxygen uptake 53.1±3.3 mL·kg⁻¹·min⁻¹). The soldiers were divided into 3 groups and completed the march on 3 separate days. All performed at best pace (without running or shuffling) a 5-km march on flat terrain carrying 40 kg. WBGT was 24°C, 24°C and 25°C during the 5-km march on tests days 1, 2 and 3 respectively. Tc was measured via a telemetric temperature pill and work rate was calculated for each individual from body mass, load carried and march speed. The individual responses were then compared to the USARIEM model [4, 5] and the Australian SF Work Tables.
Results and Discussion
The SF Work Tables sufficiently, although overall conservatively, predicted the elevation in Tc (1.47±0.50°C) during the 5-km march for this population with only one candidate (less than 5%) reaching the modelled 2.5°C elevation in Tc during the march.

The final measured mean Tc for the trial population was not significantly different from the modelled final mean Tc. The individual variation in Tc response, however, was not reflected in the model predictions; with the predicted final Tc range being 1.2°C across the trial population compared with the measured range of 2.5°C. This variation in Tc response could not be explained by body composition, work intensity or aerobic capacity (Table 1).

Table 1. Differences in individual characteristics between groups for change in Tc during a 5-km march.

<table>
<thead>
<tr>
<th>Change in Tc (°C)</th>
<th>&lt;1.5</th>
<th>&gt;1.5</th>
<th>&lt;2.0</th>
<th>&gt;2.0</th>
<th>&lt;2.5</th>
<th>≥2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of candidates</td>
<td>42</td>
<td>36</td>
<td>66</td>
<td>12</td>
<td>77</td>
<td>1</td>
</tr>
<tr>
<td>Tc at the start of the march (°C)</td>
<td>37.5</td>
<td>37.7</td>
<td>37.6</td>
<td>37.6</td>
<td>37.6</td>
<td>36.9</td>
</tr>
<tr>
<td>Tc at the end of the march (°C)</td>
<td>38.6</td>
<td>39.6</td>
<td>38.9</td>
<td>39.8</td>
<td>39.1</td>
<td>39.5</td>
</tr>
<tr>
<td>Change in Tc (°C)</td>
<td>1.1</td>
<td>1.9</td>
<td>1.3</td>
<td>2.3</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Absolute VO2max (L·min⁻¹)</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
<td>3.7</td>
</tr>
<tr>
<td>Relative VO2max (mL·kg⁻¹·min⁻¹)</td>
<td>52.6</td>
<td>53.8</td>
<td>53.1</td>
<td>53.6</td>
<td>53.2</td>
<td>50.4</td>
</tr>
<tr>
<td>Relative to lean body mass VO2max (mL·kg⁻¹·min⁻¹)</td>
<td>60.5</td>
<td>61.3</td>
<td>60.8</td>
<td>61.8</td>
<td>60.8</td>
<td>63.0</td>
</tr>
<tr>
<td>March time (min)</td>
<td>48.1</td>
<td>46.9</td>
<td>47.6</td>
<td>46.8</td>
<td>47.5</td>
<td>51.3</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>83.6</td>
<td>81.9</td>
<td>83.2</td>
<td>81.2</td>
<td>83.1</td>
<td>73.6</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>10.9</td>
<td>10.0</td>
<td>10.4</td>
<td>10.9</td>
<td>10.4</td>
<td>14.7</td>
</tr>
<tr>
<td>Lean body mass (kg)</td>
<td>72.8</td>
<td>71.8</td>
<td>72.8</td>
<td>70.2</td>
<td>72.6</td>
<td>58.9</td>
</tr>
<tr>
<td>Work rate (watts)</td>
<td>745.2</td>
<td>767.4</td>
<td>754.4</td>
<td>767.4</td>
<td>758.2</td>
<td>626.9</td>
</tr>
</tbody>
</table>

These results highlight that the SF Work Tables and associated models are an effective, although somewhat conservative, risk management tool and do not replace the need to constantly observe individuals for signs and symptoms of heat illness/injury particularly given the likely individual variation in Tc response.

References
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The dry heat loss effect of melt spun phase change material fibre garments on a thermal manikin

Maria Suong Tjønnås¹*, Hilde Færevik², Mariann Sandsund³, Randi E. Reinertsen⁴
¹SINTEF Technology and Society, Department of Health Research, Trondheim, Norway
*corresponding author: MariaSuong.Tjonnas@sintef.no

Introduction

Phase change materials (PCM) have the ability to store latent heat when they change phases, and when they are incorporated in clothing, a stabilising effect on the skin temperature can be observed [1, 4, 5]. Previously, Glaubersalt PCM packs have been found to have a cooling effect on the skin [1]. A significant disadvantage with these Glaubersalt PCM packs is the large size and the heavy weight of the packs. These features make the garments bulky which in turn affect the coverage area of the skin. As the demand for better fitted and more comfortable clothing has increased, there has been great development in the designs of thermo-regulative garments containing PCMs. The EU project Noterefiga [2] has developed a melt spun PCM fiber which allows a 10-fold amount of PCM to be incorporated in textile fibres compared to products already on the market. By virtue of being a fibre, the novel PCM fibre enables manufacturers to make better fitted and more comfortable PCM-incorporated garments. The objective of this study was to compare the initial dry heat loss effect and the duration of the dry heat loss effect of melt spun PCM fibre-incorporated garments to Glaubersalt PCM pack garments, on the basis of coverage area, the PCM mass incorporated, and latent heat of fusion.

For this study, it was hypothesized that the melt spun PCM fiber facilitates a larger initial dry heat loss effect on a thermal manikin compared to that of Glaubersalt PCM packs. Further, we hypothesized that the melt spun PCM fibre would have a shorter lasting heat loss effect on a thermal manikin compared to the Glaubersalt PCM packs.

Methods

Three clothing concepts consisting of different types of sweaters were tested in this study; a melt spun PCM fibre sweater (sweater 1) with melting temperature ($T_m$) = 28.4 °C, a reference sweater (sweater 2) without any PCM fibres, and a PCM packs sweater (sweater 3) with 8 interchangeable Glaubersalt PCM packs with $T_m = 28.0$ °C.

Sweater 1 was made of melt spun PCM fibres incorporated into the core of polyester fibres, and the sweater contained PCM Parafol 18 and PET. Sweater 2 was made of 100% polyester fibres without any PCM. Sweater 3 was made of 91% polyester and 9% cotton fibres with separate pockets containing 8 Glaubersalt PCM packs (PCM packs patent number: PCT/SE 95/01309, 9404056-5, TST Sweden AB). The main ingredients of the Glaubersalt PCM packs are salt mixtures of sodium sulphate and water (sodium sulphate decahydrate Na$_2$SO$_4$·10H$_2$O) and additives. Table 1 displays the thermo-physical properties of the PCMs used in the sweaters.
Table 1. The thermo-physical properties of the phase change material (PCM) used in the test sweaters.

<table>
<thead>
<tr>
<th>Test material</th>
<th>PCM form</th>
<th>Melting temperature (°C)</th>
<th>Latent heat of fusion (J/g)</th>
<th>Weight of PCM mass covering the back segment* (g)</th>
<th>Latent heat available for the back segment* (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweater 1</td>
<td>PCM melt spun fibre</td>
<td>28.4</td>
<td>65.8</td>
<td>34</td>
<td>2.250</td>
</tr>
<tr>
<td>Sweater 2</td>
<td>Polyester fibre</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sweater 3</td>
<td>PCM packs</td>
<td>28.0</td>
<td>158.0</td>
<td>491</td>
<td>77.891</td>
</tr>
</tbody>
</table>

* The calculations for determining the heat loss effects were done for the back segment (back segment area = 0.13 m²).

Before the tests, the clothes were kept at 15 °C in a climatic chamber overnight for solidification and temperature stabilisation.

A thermal manikin, Lady [3], with 16 individually controlled segments with a surface temperature of 34 °C, was used to assess the dry heat loss caused by the test material. The air temperature (Tₐ) of the climatic chamber was kept at the same temperature as the manikin's surface temperature to obtain isothermal conditions, in order to prevent any heat loss from the manikin to the environment. The manikin dry heat losses caused by PCM cooling, the manikin surface temperature, and the ambient temperature were recorded at 10-s intervals. As the PCM packs partially covered the torso (the back and the upper chest area) and the sweaters covered the upper body of the manikin (figure 1), the back segment was thus included in the calculations of the dry heat loss effects.

Figure 1. Left picture shows the Glaubersalt PCM pack sweater (sweater 3). Right picture shows the melt spun PCM fibre sweater (sweater 1).
Results
When comparing the duration of heat loss from the back segment of the thermal manikin between the sweater with incorporated PCM fibre, the reference sweater and the sweater with PCM packs, sweater 1, the melt spun PCM fibre sweater, had a higher initial cooling effect the first 0-4.5 min (peak heat loss of 77 W·min⁻²) compared to sweater 3, the Glaubersalt PCM packs sweater (peak heat loss of 33 W·min⁻²) (figure 2). Sweater 2, the reference sweater with no PCM, showed an initial heat loss effect of 8.5 W·min⁻², which is believed to be a residual cooling effect of the stabilising period when the sweaters were stored at 15 °C. After this peak initial heat loss at 4.5 min and throughout the test, sweater 2 showed measurements below 5 W·min⁻², which is considered baseline heat loss of the regulation system in isothermal conditions for the manikin [3]. After the first 4.5 min of the test, the measurements of sweater 1 dropped below 5 W·min⁻², and were sustained at this level throughout the test. Sweater 3 had the longest lasting cooling effect, which was still present when the test ended after 1 h.

Figure 2. Heat loss from the back segment of the thermal manikin (T_{manikin}) at 34 °C when wearing the melt spun PCM fibre sweater with T_{m} = 28.4 °C, the reference sweater with polyester fibres, and the PCM pack sweater with T_{m} = 28 °C.

Discussion
The results show that the initial dry heat loss effect and duration of the heat loss effect of different types of PCM incorporated sweaters, is dependent on the mass and the latent heat of fusion of the PCM used in the sweaters, as well as the covering area of the PCM sweaters on the manikin.

The initial heat loss
The initial heat loss on the manikin for sweater 1 (PCM fibre, T_{m} = 28.4 °C) is more than twice the heat loss effect of sweater 3 (PCM packs, T_{m} = 28 °C). This can be explained by the PCM fibres incorporated into the whole sweater, completely covering the manikin’s back segment and with a tight fit that ensures the PCM fibres to reach full contact with the manikin’s body surface. As for
sweater 3, only parts of the manikin’s back segment are covered by the PCM packs, resulting in a reduced heat loss effect at the beginning of the test. These results are comparable to previous findings of PCM and covering area [4], which showed that when the covering area is reduced the heat loss effect on the manikin is proportionally reduced.

Long term heat loss
After the first 4.5 minutes the heat loss drops below 5 W·min⁻² (baseline heat loss) for sweater 1, while sweater 3 continues to have a steady heat loss throughout the test until it was eliminated. This is explained by that the amount of PCM mass in sweater 1, which is 7% of the PCM mass of sweater 3. The results are consistent with the findings of Reinertsen et al. [5] who reported that the heat strain reduction in a PCM vest is correlated to the amount of PCM incorporated. The total calculated amount of latent heat of fusion which is available on the back segment of the PCM fibre sweater is much less than that of the sweater with PCM packs. The latent heat of fusion of sweater 1 makes up only 2.9% of the latent heat of fusion of sweater 3. As the latent heat of fusion property of the PCM determines the PCM’s ability to store heat, hence cooling of the manikin’s surface temperature, the results show that there was a vast difference between the PCM fibre sweater and the PCM pack sweater when comparing the durational time of the heat loss effect. As the PCM packs have a much higher latent heat of fusion capacity, the duration of the heat loss effect on the manikin was consequently longer than that of the PCM fibre sweater. Further work will investigate the thermo-regulating effect of melt spun PCM fibres in garments on human subjects.

Conclusions
A larger initial heat loss effect on the thermal manikin was observed of the melt spun PCM fibre than that of the PCM packs. However, this heat loss effect was brief. Although the PCM pack sweater was bulkier and covered less area of the manikin’s surface, the duration of the heat loss effect lasted much longer. This study confirmed that the duration of the cooling effect of the different types of PCM sweaters is primarily dependent on the PCM mass incorporated and the latent heat of fusion of the PCM used, and secondly, on the covering area of the PCM sweaters.

Acknowledgement
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References
Improvement of thermal and sweat management in fire fighter suits

Bianca-Michaela Woelfling*, Boris Bauer, Jan Beringer, Andreas Schmidt
Hohenstein Institute, Hohenstein, Germany
*corresponding author: b.woelfling@hohenstein.de

Introduction
Harsh thermal conditions directly affect human health, performance and comfort. The interaction between the human body and functional clothing, e.g. personal protective equipment (PPE), can be described by measurements of thermo physiological parameters. For fire fighter PPS these parameters and performance requirements are given in DIN EN 469[1]. In addition the HUPF guidelines give additional construction guidelines for such PPE’s[2-3].

Today there are over one million fire fighters in Germany [4]. Nowadays the main part of their work is no longer fire extinction but support by technical assistance and in emergency situations. In all of these cases the PPE should protect the fire fighter from interior and exterior dangers. So the usability of PPE for fire fighters depends on different aspects [5]. First of all it should protect the wearer from external influences such as fire, heat, weather and water. Also it should protect from internal dangers such as overheating which can cause - in the worst case - cardiovascular failure or heat stroke. Reasons for this are the high thermal and moisture insulating properties of the nowadays-highly engineered garments fire fighters wear. The thermal insulation is so high that only a small amount of generated body heat can be transported to the outside. Hence PPE for fire fighters has to prevent overheating of the body. Another important safety characteristic of fire fighter PPE is their comfortable and ergonomic fitting which sustain the mobility of the wearer. Furthermore PPE has to attract attention especially at night or bad weather and during operations in traffic. Last but not least, damage or decreasing functionality of the PPE has to be recognisable [5]. To ensure these requirements, PPE for fire fighters is composed of different layers: hydrophobic outer shell, moisture barrier with water vapour permeable membrane, thermo insulation and lining.

Based on these demands for fire fighter PPE we investigated within a public funded German research project the thermal and moisture management of market relevant fire fighter suits under different climate conditions and activity levels.

Methods
Five material combinations consisting of 14 construction elements, which are state of the art for fire fighter PPE, were tested with the use of a sweating guarded hot plate (Skin Model) to determine the physiological wear comfort. Both hydrophilic PES or PU (material combination MA 1, MA 3 and MA 5) and hydrophobic PTFE membranes (MA 2, MA 3) as well as different thermal insulation constructions were taken into account. The measurements with a thermal manikin and wearer trials with three male test persons (TP) under heat (18°C, 25°C) and cold (-5°C, 10°C) stress with different metabolic rates (130 W, 210 W, 160 W, 300 W) have been performed in a climate chamber. For the wearer trials the test persons were equipped with temperature and moisture sensors. All test persons evaluated the subjective comfort sensation during the test period. To determine the sweat absorbance, each piece of clothing was weighed at the beginning and the end of the wearer trial.
Results and Discussion

1 Wearer Trials
During the wearer trials the temperature and relative humidity in the microclimate above the skin, the total sweat production of the test persons and the sweat uptake of the individual garment components during the test period have been measured.

The measured temperature in the microclimate above the skin decreased at low ambient air temperatures (< 10°C) independent of the metabolic rate, while it increased at higher ambient air temperatures. Also the wearer trials showed that the relative humidity in the micro climate above the skin increases at ambient air temperatures above 10°C independent of the metabolic rate. Therefore more sweat is produced by the test persons production than the fire fighter suit is able to absorb. Additionally it was shown that the sweat production and the sweat absorption increase exponentially with increasing ambient air temperature. On average, 65% of the produced sweat was evaporated. The residual sweat was absorbed by the fire fighter garment, the station wear or the undergarment. The highest sweat absorbance was reached at 25°C by the fire fighter jacket with 87 g/h test person (TP), and the jeans with 65 g/h TP, which were worn as undergarments. Also, the amount of sweat which had been absorbed by the pieces of clothing increased with rising temperatures.

Furthermore the subjective comfort sensation of all test persons correlated with the measurements of the temperature and relative humidity in the microclimate above the skin. It could be shown that the relative humidity has a significant influence on the wearer’s comfort.

2 Skin Model Measurements
The Skin Model simulates the dry as well as the sweating human skin. It can be used to determine thermo physiological parameters of textiles which are relevant to describe comfort. Under “normal” or “stationary” conditions the moisture flux from the skin appears as water vapour (insensitive sweating). In this stationary case the water vapour resistance $R_{w\text{t}}$ can be measured. DIN EN 469 requires a water vapour resistance $R_{w\text{t}}$ (stationary conditions) between 30 and 45 m² Pa/W for Level 1 PPE and $R_{w\text{t}} \leq 30$ m² Pa/W for Level 2 PPE. Level 1 PPE is not water vapour permeable. This means that the PPE is only for temporary use. But all tested material combinations (MA1–MA5) showed a water vapour resistance beneath 30 m² Pa/W (Figure 1). Furthermore it was shown that if the membrane is orientated to the lining or skin (Figure 1, black bars) the $R_{w\text{t}}$ is lower than if it is orientated to the outer layer (Figure 1, grey bars).

If the temperature increases the wearer starts to sweat sensitively, but this sweat is still evaporating within channels of the skin pores. In the clothes' microclimate an increased water vapour pressure occurs but still no liquid sweat. The buffering capacity of water vapour (moisture regulation index $F_g$) of the tested material combinations is limited by the layer with the smallest water vapour permeability, which is the membrane. The tested material combinations show a vaporous sweat transport up to 180 g per standard man and hour (i.e., per 1.8 m²/h).
Figure 1. Water vapour resistance $R_{et}$ for five material combinations, which are state of the art for fire fighter PPE

A further temperature increase leads to liquid sweat. The measurements indicate that the buffering capacity of liquid sweat (buffering index $K_f$) is not limited by the hydrophobic outer layer. These show a poor buffering capacity of liquid sweat in the range of 0.3 - 0.4. Instead, the material combinations show much better moisture transports when the wearer is sweating heavily with buffering capacities of liquid sweat between 0.75 and 0.88. This equates to a liquid sweat transport about 490 g per standard man and hour.

In order to improve the sweat management of fire fighter suits, functional undergarments were added to the material combination. Therefore the thermophysiological and skin sensorial behaviour of different undergarments consisting of aramid, aramid/PTFE or cotton were characterised first as single layer than of the whole system (material combination - undergarment). It could be shown, that such systems have the same buffering capacity of water vapour as the material combinations. However the buffering capacity of liquid water could be improved by the combination of functional undergarment with the material combinations (Figure 2).

Figure 2. Buffering capacity of liquid sweat $K_f$ of fire fighter suit M2 in combination with different functional undergarments
By placing humidity sensors between each textile layer of the whole system the importance of the interaction between undergarment and lining for an optimum sweat management could be observed.

Conclusions
Fire Fighter PPE is generally composed of four textile layers to fulfil the requirements of DIN EN 469. Based on these requirements we investigated the thermal and moisture management of fire fighter suits. For this reason the Skin model was used and wearer trials under different climate conditions and activity levels were performed.

All tested material combinations, which are state of the art for fire fighter PPE, fit in the requirements of DIN EN 469 thus they guarantee a high protection level and with an acceptable degree of moisture transport. By combining the material combinations with functional undergarments the sweat management of fire fighter suit could be improved especially at high sweating situations.

In addition to these skin model measurements it could be shown by wearer trials that the sweat absorption is much lower than the sweat production. That means in average 65% of the produced sweat is evaporated by the PPE independent on metabolic rate and ambient air temperature. The residual sweat is absorbed by the fire fighter jacket or the undergarment.

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Adapting segmental models of human thermoregulation for use with high-resolution anatomical datasets

Allen R. Curran¹*, Eric A. Marttila¹, Mark A. Hepokoski¹
¹ThermoAnalytics, Inc., Calumet, MI, USA
*corresponding author: Allen.Curran@ThermoAnalytics.com

Introduction
Predicting the health effects of electronic devices that emit radio frequency radiation (RFR) is currently of great interest to the scientific and medical community. One established biological effect of RFR exposure is tissue heating; temperature increases of as little as 4°C above normal body temperature can have potentially devastating effects on living tissue. A finite-difference time-domain (FDTD) numerical simulation can be used to predict local tissue heating due to RFR [1]. Although much interest in RFR has been directed at consumer devices (e.g., cell phones), where the thermal effects are almost negligible, there are industrial, medical and military applications where the thermal effects become important due to the use of higher power, longer periods of exposure and/or repeated exposures [2]. Predicting tissue temperatures for longer or repeated exposures requires modelling the human thermoregulatory system in addition to modelling localised tissue heating.

This paper discusses and presents solutions to the unique challenges encountered when adapting segmental models of human thermoregulation for use with the high-resolution representations of the human body that are required to predict RFR heating.

Methods

High spatial-resolution anatomical datasets are commonly represented by volume elements (voxels) in which a tissue type, along with its thermal properties, is assigned to each voxel; the voxel dataset forms a highly accurate representation of the human body [Figure 1]. Developing a voxel model is a labour-intensive process of converting two-dimensional MRI or CT images into a three-dimensional voxel description. This involves “segmenting” or identifying the tissue type or organ for each pixel in a two-dimensional data slice; maintaining continuity in the third dimension is especially challenging. Once a voxel model is created, it often needs to be repositioned into a “realistic” pose, i.e., different from the supine position in which the images are usually taken, since RFR heating is dependent on body posture.

A typical high-resolution anatomical human model might consist of over 45 million voxels (2 mm or less on each side) and approximately 35 different tissue types. Each tissue type (e.g., fat, liver, grey matter, etc.) is identified by a unique integer ID.

Although it is relatively straightforward to create a thermal model for voxel datasets [3], the sheer size of the data presents significant challenges:

1. Each voxel, regardless of tissue type, must be mapped to a segment in the thermoregulation model. Our approach was to require that different tissue IDs be used for voxels representing skin so that the body segment could be identified, i.e., abdomen skin was assigned a different ID than neck skin. We then developed an algorithm for assigning a body segment ID to each non-skin voxel; the algorithm assigns body segment IDs by looking for nearby skin voxels.
2. The surface area of a voxel representation of the human body is significantly different than the actual body surface area due to the discrete nature of a voxel representation. Heat loss due to convection, radiation and evaporation (due to sweating) must be accounted for to accurately predict the thermal interaction of the human body with the environment. If these boundary conditions were calculated and applied using the surface area predicted by a voxel representation of the human body, significant errors would result. We minimize this error by: 1) Calculating the DuBois skin surface area from the height and mass of the voxel dataset; 2) Calculating the surface area of the faces of the skin voxels that are exposed to the environment, and 3) Scaling the exposed surface area of an individual skin voxel by the ratio of the DuBois skin surface area to the whole-body voxel skin surface area.

3. Coarser voxel descriptions, i.e., > 2 mm on each side, may contain fat and possibly muscle voxels at the surface of the voxel description. Care must be taken to ensure that environmental heat exchange only occurs at skin voxels, even if non-skin voxels are present on the surface of the model. The technique described above for scaling the exposed area of an individual skin voxel is appropriate even when fat and muscle voxels are present at the surface of the voxel description.

4. An appropriate, parallelizable solution technique must be found to solve the large set of linear equations that result from applying the bio-heat transfer equation to each voxel in the domain. We first implemented a conventional successive over-relaxation (SOR) iterative technique. Since the bio-heat transfer equation is an augmented diffusion equation, and radiation is limited to exchange with the environment, the resulting solution matrix is quite sparse and amenable to solution with a distributed computing approach. We used the Message Passing Library (MPI) to distribute the computational effort across multiple compute nodes which may be either a cluster of single core machines, or a cluster of multi-core machines, or a single multi-core machine.

We also implemented an advanced technique for solving general diffusion problems: The Algebraic Multi-Grid (AMG) method. The basic principle of multi-grid is to solve the set of equations on a coarse mesh to obtain an approximation of the solution, and then transfer the approximate solution to a fine mesh for inexpensive refinement. This concept is applied recursively, and is an efficient algorithm because a great deal of information about the solution can be extracted inexpensively from the coarser meshes. In algebraic multi-grid, the coarsening is achieved by algebraic manipulation of the matrix coefficients describing the conduction relationships between voxels in the fine mesh.

Results and Discussion
The resulting computer code, ThermoReg, was developed to aid in the study of the potential health hazards of devices that emit RFR. ThermoReg is a voxel-based, bio-heat transfer code that incorporates: 1) Physiological heat sources and thermoregulatory mechanisms (metabolic heating, sweating/evaporative cooling, respiratory cooling and blood flow with vasoconstriction/vasodilatation); 2) a clothing model; 3) environmental loads (solar heating, radiation exchange, wind convection) and 4) the application of local heating due to RFR (i.e., specific absorption rates (SARs)) as predicted by the FDTD program. The output from ThermoReg is the time history of temperature for each voxel within the human thermal model.

The transient physiological response predicted by ThermoReg was evaluated using the boundary conditions specified in the most extreme case of the Stolwijk and Hardy transient experiments [4]. This scenario begins with an hour exposure to a near-neutral environment, followed by a step change to a hot environment for 2 hours, and then returning to a final hour of exposure to neutral
conditions. Predicted weighted skin temperature showed excellent agreement with measured average skin temperature [Figure2]. The differences in core temperature between the simulation and the experimental results can be largely attributed to the variation in core temperature found within the body as well as the initial thermal state. As expected, the rectal temperature (measured by Stolwijk) exhibited a far slower response than oesophageal temperature (which is similar to the body core temperature predicted by ThermoReg) under conditions of heat stress [5].

![Figure 2. Predicted average skin temperature (red) compared to measured average skin temperature (left). Predicted body core temperature (red) compared to measured rectal temperature (right).](image)

Performance tests were executed to assess the memory usage and overall solution time using the SOR solver and the AMG solver with the 5 mm-voxel human model. The simulation consisted of a 5-minute simulation with exposure to RF heating, with thermoregulation enabled. Table 1 shows the solution times for each solution method.

<table>
<thead>
<tr>
<th>Solution Method</th>
<th>Solution Time (seconds)</th>
<th>Memory Usage</th>
<th>Ave # Iterations per Time Step</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOR</td>
<td>52</td>
<td>86 Mb</td>
<td>15.7</td>
</tr>
<tr>
<td>AMG</td>
<td>63</td>
<td>432 Mb</td>
<td>6.4</td>
</tr>
<tr>
<td>AMG (linearized solution)</td>
<td>16</td>
<td>432 Mb</td>
<td>1</td>
</tr>
</tbody>
</table>

The AMG method is slightly slower than SOR for this test model, primarily because the SOR method is able to converge quickly and typically requires only 15 iterations for each time step. The AMG method provides a faster convergence rate, however the overhead of the AMG algorithm leads to a longer overall solution time. There is potential for a faster overall solution with AMG if the equations are linearized, which is accomplished by evaluating non-linear terms using values from the previous time step.

Conclusions
A technique was developed for mapping individual voxels in a high-resolution anatomical model to the corresponding body segments in a thermoregulation model. The algorithm described for scaling the surface area of voxel-based models has also been used successfully, even for coarse voxel models that contain fat and muscle voxels at the surface of the voxel description. A conventional successive over-relaxation (SOR) thermal solver performed well due to the nature of the solution matrix that results from voxel-based models. The resulting voxel-based, bio-heat
transfer code that implements these features, ThermoReg, predicts skin and core temperatures that are in agreement with human subject measurements made in a hot environment.

References
The use of non-invasive measures to predict thermal strain: How accurate are universal models?

Sarah Davey*, Victoria Richmond, Katy Griggs, Nicola Gerrett, George Havenith
Environmental Ergonomics Research Centre, Loughborough University, Loughborough, UK
*corresponding author: G.Havenith@lboro.ac.uk

Introduction
Over the past few decades there has been an upsurge in the development of monitoring devices that estimate levels of thermal strain non-invasively. However, developing a non-invasive monitoring device that estimates body core temperature (Tc) with a certain level of accuracy that is satisfactory over multiple heat stress scenarios and a wide range of body core temperatures has been shown to be a difficult task [1]. The aim of this study was to investigate the potential of using a combination of simple non-invasive measures to estimate rectal temperature (Tre) (used as a reference for Tc) over multiple types of heat stress scenarios within a varied population.

Method
A model that estimated Tre was developed and validated using a dataset that includes 35 participants (male = 19 and female = 16) and nine different environmental conditions. Each condition involved two continuous or intermittent 40-60 minute periods of treadmill walking in the heat (25°C-40°C, 20%-85% relative humidity [RH]), separated by a 20 minute seated rest in 22°C, 50% RH. Local skin temperature (11 sites), Tre, insulated skin temperature of the lower neck (Trn), clothing microclimate temperature and RH, heart rate (HR), HR variability and breathing frequency were measured. The accuracy and practical implication of any prediction error was assessed using multiple linear regression, Bland and Altman charts and limits of agreement (LOA). The model was validated using an adapted version of the leave-out-one cross validation method. A root mean square deviation (rmsd) of 0.2°C was defined as an acceptable level of error. The study was approved by the Loughborough University Ethics Committee.

Results and Discussion
The rmsd and LOA of the model over the nine conditions was 0.25°C and ± 0.51°C, respectively. Between the nine conditions the rmsd ranged between 0.16°C to 0.31°C. A higher proportion of negative errors occurred as Tre increased and several estimates had an error of ± 1.0°C. Thirty percent of Tre's above 38.5°C were estimated less than 38.5°C.

Conclusion
These results illustrate that using a universal model to accurately estimate Tc over multiple conditions at high Tre's (i.e. >38.5°C) is not suitable, despite having a large number of predictors. Future models may require equations designed specifically for certain types of environmental conditions and/or high Tre’s.

References
The effect of air permeability characteristics of protective garments on the induced physiological strain under exercise-heat stress

Yoram Epstein1,2,*, Yuval Heled1,3, Ran Yanovich3, Yair Shapiro4, Daniel Moran4
1 Heller Institute of Medical Research, Sheba Medical Centre, Tel Hashomer, Israel
2 Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel
3 Institute of Military Physiology, IDF Medical Corps, Israel
4 Ariel University Centre of Samaria, Ariel, Israel
*corresponding author: yoram.epstein@sheba.health.gov.il

Introduction
The high values of thermal resistance \( (R_{ct}) \) and/or vapour resistance \( (R_{et}) \) of chemical protective clothing (CPC) induce a considerable thermal stress. The present study compared the physiological strain induced by CPCs and evaluates the relative importance of the fabrics’ \( R_{ct}, R_{et} \), and air permeability in determining heat strain.

Methods
Twelve young (20-30 y) healthy, heat acclimated male subject were exposed fully encapsulated for 3 h daily to an exercise–heat stress (35°C and 30% relative humidity, walking on a motor driven treadmill at a pace of 5 km/h and a 4% inclination, in a work-rest cycle of 45 min work and 15 min rest). Two bi-pack CPCs (PC1 and PC2) were tested and the results were compared with those attained by two control suits -- a standard cotton military BDU (CO1) and an impermeable material suit (CO2). Physical and thermodynamic properties of the tested garments were as follows (mean values):

<table>
<thead>
<tr>
<th>Garment</th>
<th>Weight (g/m²)</th>
<th>Air permeability (mm/s)</th>
<th>Insulation ( R_{ct} ) (m²K/W)</th>
<th>Insulation ( clo ) (units)</th>
<th>Water vapour resistance ( R_{et} ) (m²Pa/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO1</td>
<td>186.0</td>
<td>96.3</td>
<td>0.11</td>
<td>0.71</td>
<td>29</td>
</tr>
<tr>
<td>CO2</td>
<td>238.5</td>
<td>0.0</td>
<td>0.21</td>
<td>1.35</td>
<td>162</td>
</tr>
<tr>
<td>PC1</td>
<td>598.7</td>
<td>23.6</td>
<td>0.31</td>
<td>2.00</td>
<td>81</td>
</tr>
<tr>
<td>PC2</td>
<td>402.8</td>
<td>68.3</td>
<td>0.21</td>
<td>1.35</td>
<td>61</td>
</tr>
</tbody>
</table>

Results
The physiological burden imposed by the two bi-layer garments was within the boundaries set by the control conditions. Overall, PC2 induced a lower strain, which was closer to CO1, while PC1 was closer to CO2. Air permeability of the PC2 cloth was almost 3 times higher than that of PC1, enabling a better heat dissipation and consequently a lower physiological strain. Furthermore, air permeability characteristic of the fabrics, which is associated with its construction and weave, significantly correlated with the physiological strain, while the correlation with \( R_{ct}, R_{et} \), and weight was poor.

Conclusions
The results emphasize the importance of air permeability in reducing the physiological strain induced by CPCs.
Evaluation of novel body mapping garments using a sweating manikin operated at constant temperature and thermophysiological model control modes

Faming Wang\textsuperscript{1,*}, Simona del Ferraro\textsuperscript{2}, Vincenzo Molinari\textsuperscript{2}, Matthew Morrissey\textsuperscript{1}, René Rossi\textsuperscript{2}

\textsuperscript{1} Laboratory for Protection and Physiology, EMPA-Swiss Federal Laboratories for Materials Science and Technology, Lerchenfeldstrasse 5, 9014, St. Gallen, Switzerland

\textsuperscript{2} Laboratory of Physiology and Ergonomics, Department of Occupational Medicine, Italian Workers’ Compensation Authority (INAIL), Monte Porzio Catone, Rome, Italy

* corresponding author: faming.wong@gmail.com

Introduction

It is well recognised that regional sweating differences exist between genders (1,2). Since the sweat production and evaporative cooling varies across the body, the local body temperature will also vary. Traditional clothing made from the same material and the same fabric structure has a limited ability to provide sufficient comfort for local body parts. In order to improve local wear comfort and thermal comfort, special textiles with different properties may be used for different body parts. In particular, as textile and clothing technology advances, and due to a growing interest in the temperature and sweat distribution of the human body, the development of novel body mapping clothing (BMC) is possible. BMC may be developed in three ways (3,4):

1) using and placing different fabric materials on different body parts;
2) changing fabric weave/knit structures within one piece of target fabric;
3) a combination of 1 and 2.

In this study, a novel BMC kit was designed and assessed on a sweating manikin. Comparisons with commercial BMC, traditional sportswear and the novel BMC kit were made. Local heat losses and clothing microclimate conditions were investigated. In addition, physiological responses during a simulated exercise-rest cycle were studied to examine the real thermophysiological benefits of wearing BMC.

Methods

A novel ‘modular’ BMC design (5) was studied to evaluate body mapping garments. The BMC features four zippers, two of which are placed at the front and the remaining two on the back. Based on human sweat patterns and the intended conditions of use, the front and back fabric pieces can be exchanged. Four common textile materials were selected: cotton fabric with a hydrophobic surface treatment (code: CO), mesh fabric with very high air permeability (code: N), thin polyester fabric coated with PU (code: C), and ‘moisture management’ polyester fabric (code: MM). The thermal resistance of these four fabrics was 0.019, 0.006, 0.040 and 0.010 K·m\textsuperscript{-2}·W\textsuperscript{-1}, respectively. The fabric water vapour resistance was 2.87, 0.81, 14.76 and 1.81 Pa·m\textsuperscript{-2}·W\textsuperscript{-1}, respectively.

Traditional cotton (CO) and moisture management garments (MM), six body mapping garments (i.e., CN, CW, CC, MN, MW, MC) and two commercial BMC products (i.e., ADI, CRA) were assessed on a ‘Newton’ type sweating manikin operated at two modes: constant temperature (CT) mode and thermophysiological model (TM) control mode. From the constant temperature mode testing (\textit{Tmanikin}=Tr=34±0.5 °C, Ta\textsubscript{1}=34±0.5 °C, RH\textsubscript{1}=38±5%; Ta\textsubscript{2}=30±0.5 °C, RH\textsubscript{2}=47±5%; \textit{va}=0.5±0.1 m·s\textsuperscript{-1}), local heat losses and relative humidity are presented. Under the physiological model control mode (\textit{Ta}=30 °C, RH=47%, \textit{va}=0.5±0.1 m·s\textsuperscript{-1}), a 40-min exercise (4.3 Mets) and a 20-min rest (1.2

METs) period were simulated. The development of mean skin temperature and core body temperature over time is reported.

Results and Discussion
The segmental heat losses at the upper arms, chest, shoulders, stomach and back under two different environmental conditions are displayed in Figure 1.

Figure 1. Local heat losses of 10 clothing scenarios at two different ambient conditions. U Arms: upper arms; ND: nude.

It was found that commercial products ADI and CRA showed a better performance in dissipating heat than non-body mapping sportswear made from pure cotton and moisture management polyester fibres. However, when mesh fabrics were used, segmental heat losses at the chest and back in clothing CN and MN showed much higher values than ADI and CRA. In contrast, when impermeable coated fabrics or thick wool fabrics were used in sportswear CC, MC, CW and MW, local heat losses at the chest and back showed the lowest values of all 10 clothing scenarios. Thus, local heat exchanges can be adjusted by matching fabrics with different thermal and moisture transfer properties with certain body parts. Properly designed BMC can improve the local thermal conditions of the human body. For example, the impermeable fabrics or wool fabrics may be used when the wearers move from a hot condition to cooler and/or windy environment in order to prevent excessive body cooling at rest.

The development of the body core temperature (i.e., hypothalamic temperature) and the mean skin temperature over time is presented in Figure 2. For all four sportswear ADI, CO, MM and MN, there is no significant difference in both core temperature and mean skin temperature throughout the simulated one-hour tasks. It may be argued that such body mapping clothing has limited thermophysiological benefits to the wearers in the simulated conditions, but may still affect thermal comfort sensations.
Figure 2. Development of the hypothalamic (Thy) and mean skin temperatures (Tsk) over time in ADI (BMC), CO (traditional sportswear), MM (traditional sportswear) and MN (BMC).

Conclusions
Local thermal body status can be adjusted by wearing appropriate BMC. The modular BMC kit developed in this study can meet multiple wear/thermal comfort requirements in various environmental conditions. Although such BMC may have limited thermophysiological benefits for the wearers, BMC shows evident improvements in adjusting local body heat exchanges and thus, the local thermal/comfort sensations may be much improved by using BMC.

References
LIFE ON THE MOON FOR LIFE ON EARTH

Lunar habitat simulation

Igor B. Mekjavič¹, Adam C. McDonnell¹,², Michail E. Keramidas¹, Roger Kolegard³, Britta Lind³, Ola Eiken³

¹ Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute & ² Jozef Stefan International Postgraduate School, Jamova 39, SI-1000 Ljubljana, Slovenia
³ Department of Environmental Physiology, School of Technology and Health, Royal Institute of Technology, Berzelius väg 13, S-171 65 Solna, Sweden

Introduction
To minimise the preparation time for extravehicular activities (EVAs) without increasing the risk of decompression sickness, it is envisaged that future Lunar and Mars habitats will be hypobaric and hypoxic. The present study investigated the separate and combined effects of unloading/inactivity and hypoxia on the cardiovascular and musculoskeletal systems.

Methods
Healthy male subjects (n=11) participated in a repeated measures cross-over designed study, such that each subject participated in three 10-day experimental campaigns at the Olympic Sport Centre Planica (Ratece, Slovenia): normoxic bedrest (NBR), hypoxic bedrest (HBR), hypoxic ambulatory (Hamb). During the hypoxic bedrest and confinement trials, the simulated altitude of 4000 m on one entire floor of the Centre was achieved and maintained by a vacuum pressure swing adsorption system. The ascent to 4000 m was achieved over three days: day 1=3000 m, day 2=3500 m, day 3 and thereafter 4000 m. Before and immediately after each intervention, we measured subjects’ orthostatic tolerance, VO₂max, maximum heat rate, muscle strength, body composition (Dual Energy X-Ray Absorption), and haematology.

Results
The ascent profile did not induce any Altitude sickness. With the exception of the haematological variables (EPO, Hb, Hct) which were significantly increased only during the hypoxic trials, and VO₂max, which was reduced in the HBR trial, all other inactivity-induced changes in cardiovascular and musculoskeletal function were similar in the normoxia condition.

Conclusions
During such short term (10-d) studies, hypoxia does not appear to enhance the bedrest-induced alterations in the observed physiological systems.

Acknowledgements
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Cerebral haemodynamic response to graded lower body positive pressure

Blake G. Perry¹*, Aaron Raman¹, Zachary J. Schlader¹, Darryl Cochrane¹, Samuel J.E. Lucas², Toby Mündel¹

¹ School of Sport and Exercise, Massey University, Palmerston North, New Zealand
² Department of Physiology and School of Physical Education, University of Otago, New Zealand
*corresponding author: B.G.Perry@massey.ac.nz

Introduction
Lower body positive pressure (LBPP) has been used previously in the treatment of haemorrhagic shock and offsetting g-force induced fluid shifts. However the effects of LBPP on cerebral perfusion are yet to be investigated.

Methods
Fifteen healthy volunteers (mean ± SD: age, 26 ± 5 y; body mass, 79 ± 10 kg; height, 174 ± 9 cm) completed 5 minutes of 20 and 40 mm Hg LBPP, in a randomised order, with each stage separated by 5 minutes. Baseline data were acquired during the fifth minute of each baseline and averaged across that minute. Beat-to-beat MCAv (Doppler Ultrasonography, an index of cerebral blood flow), blood pressure (finger photoplethysmography) total peripheral resistance and cardiac output (Modelflow), continuous end-tidal PCO₂ and heart rate were recorded, and presented as change from the preceding baseline period.

Results and Discussion
All measures were similar between baseline periods (all p>0.30), as was end-tidal PCO₂ throughout the entire protocol (p>0.05). Mean arterial pressure (MAP) increased by 7 ± 6 (8%) and 13 ± 7 mm Hg (19%) from baseline during 20 and 40 mm Hg (p<0.01), respectively. The greater MAP increase at 40 mm Hg (p<0.01 vs. 20 mm Hg) was mediated via a greater increase in total peripheral resistance (p<0.01), with heart rate and cardiac output remaining unchanged (both p>0.40). MCAv increased from baseline by 3 ± 4 cm/s (5%) during 20 mm Hg (p<0.01), whilst no change (p>0.05) was observed during 40 mm Hg.

These results indicate a divergent response to LBPP, highlighted by the separation in the relationship between MAP and MCAvmean. LBPP-mediated increases in central venous pressure have been shown to reduce muscle sympathetic tone via increased cardiopulmonary baroreceptor loading; yet above 30 mm Hg, activation of intramuscular pressure receptors may offset this cardiopulmonary baroreceptor mediated restraint and maintain peripheral sympathetic tone [1]. Furthermore as PETCO₂ and Q̇ were unchanged, reductions in, and the subsequent restoration of, sympathetic nerve activity appears to be the most likely explanation for the modest increase in MCAvmean observed at 20 mm Hg LBPP and negligible increase in MCAvmean observed at 40 mm Hg LBPP.

Conclusion
Modest levels of LBPP elevated supine MCAv, possibly via a removal of sympathetic tone in the cerebral vasculature and an increase in perfusion pressure. Although only modest increases in MCAv were seen in these normothermic conditions, these haemodynamic responses to LBPP may be more pronounced and beneficial during a heat-induced circulatory challenge. Our current work is examining such a challenge.

References

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Effects of hypoxia, exercise and confinement on sleep architecture

Shawnda A. Morrison1,2*, Andrej Pangrc2, Igor B. Mekjadić1, Leja Dolenc-Grošelj2
1 Department of Automation, Biocybernetics and Robotics, Jozef Stefan Institute, Jamova 39, SI-1000, Ljubljana, SLOVENIA
2 Institute of Clinical Neurophysiology, Division of Neurology, University Medical Centre, Ljubljana
*corresponding author: shawnda.morrison@ijs.si

Introduction
Exposure to high altitude (hypoxia) in newcomers is associated with poorer sleep patterns, increased incidences and severity of central sleep apnea and more night awakenings. It is not known whether daily endurance exercise training would modify these responses after chronic exposure to a simulated altitude of 4000 m.

Methods
Fourteen active, healthy men (age: 25 ± 3 y, height: 1.79 ± 0.06 m, weight: 74 ± 8 kg, 41 ± 5 mL·kg⁻¹·min⁻¹) were accommodated on a dedicated floor of the Slovenian Olympic Sport Centre Planica (at altitude: 940 m). Participants were confined to one floor for 10 d in which all activities (eating, drinking, hygiene, exercise intervention, sleep) were conducted at a simulated high altitude of 4000 m (FiO₂=0.14). In random order, half of the participants were assigned an exercise intervention of: 2 x 60-min cycle exercise/ d (intensity: heart rate at 50% of their hypoxia-specific peak power output (EX)); the remainder did not complete any daily exercise (CON). Sleep architecture and respiration was assessed after acute exposure to hypoxia (Night 1; N1), and again on ‘Night 10’ (N10) using full polysomnography (PSG) setup. All participants were instructed to adhere to a standard sleep-wake cycle with lights out at 23:00 and lights on at 07:00 for the duration of the confinement study. Recordings were conducted only after they had slept in the facility for 2 nights prior to the experiment. Data were analysed using 1-way ANOVA (time) with one between-subjects factor (group: CON v EX) at a significance level of p<0.05.

Results and Discussion
Total sleep time was 5.5 ±1.1 and 5.7 ±1.1 h for N1 and N10, respectively, which was not significantly different across time (p=0.520) or between groups (p=0.570). No differences were observed for sleep latency (N1: 20.4±11.4, N10: 28.3±30.3 min; p=0.211) or sleep efficiency (N1: 70.0±14.9, N10: 70.7±19.3%; p=0.855). Total awakenings per night were lower on N10 (34±10) compared to N1 (25±13; p=0.007), irrespective of group (p=0.290). The number of stage shifts demonstrated a significant time x group interaction, such that the CON group saw larger decreases in stage shifts on N10 compared to N1 (CON: -47, EX: -10 shifts; p=0.023). Sleep architecture was altered between nights for both light (stage 2; N1: 52±11 to N10: 45±8%; p=0.07) and deep (stage 3; N1: 19±5 to N10: 24±5%; p=0.011) sleep, regardless of group (p=0.537). The amount of time spent in REM sleep also increased from N1 to N10 (up from 18±7% to 22±%; p=0.032). Unsurprisingly, the proportion of total sleep time spent at a given arterial oxygen range (SpO₂) was shifted up after chronic hypoxia exposure.

Conclusions
Chronic exposure to simulated altitude increased time spent in deeper sleep stages and REM, although total sleep time, sleep latency and efficiency were not affected by either exposure time or exercise intervention.
The Double Sensor: Applications of a non-invasive heat-flux sensor on Earth and in space

Hanns-Christian Gunga1*, Oliver Opatz1, Alexander Stahn1, Mathias Steinach1, Andreas Werner1, Frank Sattler2, Joehim Koch2

1 Charité Medical University, Center for Space Medicine Berlin, Berlin, Germany
2 Draegerwerk AG, Luebeck, Germany
*corresponding author: hanns-christian.gunga@charite.de

Introduction

Accurate measurement of the core body temperature (Tc) is fundamental to the study of human temperature regulation. Standard sites used for the placement of Tc measurement sensors have been the rectum, esophagus, nasopharynx and acoustic meatus [1,2]. Nevertheless those measurement sites exhibit limited applicability under field conditions and in rescue operations. The ideal non-invasive measurement of core temperature has to meet requirements such as i) a convenient measurement site, ii) no bias through environmental conditions, and iii) a high sensitivity of the sensor regarding time shift and absolute temperature value. Together with the Draegerwerk AG we recently developed a non-invasive Tc sensor (Double Sensor)1) aiming to meet the requirements described above [3,4]. Four investigations will be presented to demonstrate the applicability of the Double Sensor in humans: i) under physical exercise and changing environmental conditions, ii) during long-term bed-rest, iii) during long-term isolation and confinement (MARS500), and finally iv) during exercise under micro-g conditions in space (DLR Thermolab on ISS).

Methods

In the first study (study 1), 20 male subjects had rectal, nasopharyngeal, skin, Double Sensor temperatures and cardiovascular data collected continuously before, during and after the different experimental set-ups from 25-55% maximal aerobic power at 10, 25, and 40°C environmental temperatures. In the second study (study 2), the Double Sensor was tested in comparison to rectal temperatures in 7 male subjects during a long-term bed rest. In the third study (study 3), the Double Sensor was used to monitor at different time points the circadian rhythm of body core temperatures in 6 male subjects who participated in MARS500. Finally, the Double Sensor was applied in 10 astronauts during a regular VO2 ergometer testing before, several times in space on the ISS, and after spaceflight. Statistical methods were descriptive statistics as well as GLM (general linear model) and paired t-Test, with P < 0.05 considered as statistically significant. To show the correlation between the two methods we used Lin’s Concordance Correlation Coefficient (CCC).

Results

The study 1 revealed that the device under test i) differed between -0.16 to 0.1°C from the average of the rectal temperature and the Double Sensor, ii) showed increasing CCC with increasing ambient temperatures (10°C: 0.49; 25°C: 0.69; 40°C: 0.75), and iii) exhibited a faster temperature decrease at all resting periods at all ambient conditions as compared to rectal temperature. Study 2 revealed that the Double Sensor data correlated well (r=0.704) with the rectal temperature recordings. Study 3 showed that the subjects lost their circadian core temperature profiles during Mars500, and study 4 revealed that in space on the ISS, the astronauts had marked and prolonged increases during exercise in core temperature, sometimes >40°C.
Conclusions
The Double Sensor seems to be a reliable method of assessing core temperature under different environmental and clinical conditions including space.

Acknowledgements
This research was partly supported by the Draegerwerke AG and the DLR/ BMWi Projects 50WB0223, 50WB0724, and 50WB1030.

(*) Several EU and US patents applied.

References
Effects of diet-induced thermogenesis on cardiovascular responses to a lower-body negative pressure

Masami Hirashita¹*, Yoko Kajiwara², Shigeru Okada³

¹The Faculty of Sports and Health, Kanazawa Gakuin University, Japan.
²The Faculty of Education, Bunkyo University, Japan.
³The Faculty of Social Welfare, Kinjo University, Japan.
*corresponding author: masami12@camel.plala.or.jp

Introduction

Arterial pressure decreases due to reduction in venous return and cardiac output when moving to a more upright posture; this induces the baroreceptor reflex and so compensatory contraction of peripheral resistance vessels and an increase in the heart rate. This series of responses is called the orthostatic cardiovascular adjustment reflex, and is markedly affected by internal and external factors including the ambient temperatures [1], level of physical training [3], and diurnal rhythm. In humans, food intake elevates the body temperature due to diet-induced thermogenesis (DIT), increases the heart rate and skin blood flow [2], and promotes heat radiation by increasing blood flow through arterio-venous anatomoses in the hands and feet. However, this vascular dilation conflicts with the cardiovascular adjustment response to lower-body negative pressure, i.e., the contraction of peripheral resistance vessels. The effects of food intake on cardiovascular adjustment responses and changes in haemodynamics caused by an elevation of the body temperature associated with food intake, i.e., DIT, may be concurrent. In this study, the effects of food intake on cardiovascular adjustment responses to negative pressure-loading on the lower body were evaluated by comparing responses before and after food intake.

Methods

1) Thirty four healthy males were divided into 16 who were fasted for at least 12 hours before the experiment (control group), and 18 who ate a specified meal of about 800 kcal (20% proteins, 61% lipids, and 19% carbohydrates) one hour before the experiment (food-intake group). A free intake of water was allowed, but the intake of alcoholic or caffeine-containing beverages was not permitted. All subjects gave their informed consent prior to the experiments. The experiments were performed in accordance with the Declaration of Helsinki (1964) and were approved by the Local Ethical Committee of Kanazawa Gakuin University.

2) Lower-body negative pressure (LBNP): In a climatic chamber adjusted to an ambient temperature of 25 ± 0.2 °C, subjects lay supine, the body below the iliac crests was placed in a box to induce a LBNP, and the gap between the abdominal region and box was made airtight with the rubber seals and bands attached to the box. After the subjects were rested, LBNP was applied incrementally in 60 mm H₂O steps from 0 to 300 mm H₂O (Figure 1). LBNP at each level was applied for 4 minutes.

3) Measurements: After the sublingual temperature of the subjects was measured, the following items were assessed every 30 s for the last 3 min of the 4-min LBNP at each level. The mean blood pressure in a cardiac cycle was calculated as diastolic pressure plus 1/3 of pulse pressure. Heart rate was determined by auscultation of the pulse at the carotid artery or apex of the heart for 15 s. Forearm blood flow was determined by venous occlusion plethysmography using a mercury strain gauge applied at tension of 10 g to the centre of the left forearm. A pressure of 250 mm Hg was applied to a manchette (5 cm wide) positioned around the wrist to block blood flow to the fingers. Stabilisation of the needle of the recorder was confirmed, and the venous return was obstructed by applying a pressure of 40-50 mm Hg to the brachial manchette (12 cm wide) for 15
seconds; and the blood flow was calculated by the following formula from the volume change per unit time: Forearm blood flow = 2×100×Tn×V/G×(a/P), where G is Forearm girth (mm); Tn is Tangent of the increase in G due to a rise in venous blood flow; V is Chart speed (mm/min), and (a/P) is change on the chart (mm) associated with a change of 1 mm in the mercury strain gauge. Also, the forearm vascular resistance (mean air pressure divided by the forearm blood flow) was calculated as an index of the degree of contraction of the forearm resistance vessels.

Results
Before the application of LBNP, the sublingual temperature and heart rate were significantly higher in the food-intake than control group. While no difference was noted in forearm blood flow between the two groups, forearm vascular resistance was lower in the former. This means that forearm resistance vessels were dilated in the food-intake compared with the control group. No difference was noted in the systolic, diastolic, or mean blood pressure between the two groups. As the negative pressure-loading on the lower body increased, the systolic pressure tended to decrease, and diastolic pressure to increase, with no marked change in the mean blood pressure. Also, no marked difference was noted on these blood pressure changes between the food-intake and control groups. The heart rate tended to increase with LBNP in the control group but showed no clear change in the food-intake group. At a negative pressure of 300 mm H2O, the heart rate was significantly higher in the control than in the food-intake group. In both groups, forearm blood flow decreased significantly, and forearm vascular resistance increased significantly, with increases in the LBNP, and more importantly, these changes differed between the two groups. The decrease in forearm blood flow and increase in forearm vascular resistance were greater in the control group, and these differences were particularly significant at negative pressure level of 240 and 300 mm H2O (Figure 2).
Figure 2. Variations in forearm blood flow and forearm vascular resistance with changes in LBNP in the control (●) and food-intake (○) groups. * Significantly different compared with the value at 0 LBNP. ☆ Significantly different between the food-intake and control groups. The values are the means, and the bars show ranges of ±SE.

Conclusions
LBNP was applied to 34 healthy adult males either after a meal of approximately 800 kcal (n=18) or when fasted. These results of this study clearly indicate that cardiovascular adjustment responses are modified by food intake. A LBNP causes blood retention in this area, decreases in venous return and cardiac output, and lowers the blood pressure. These changes are compensated for by the contraction of peripheral resistance vessels and an increase in the heart rate via low-pressure and high-pressure pressoreceptor reflexes. However, the decreases in antebrachial blood flow and increase in antebrachial vascular resistance with elevations in the LBNP pressure were clearly smaller in the subjects after a meal than in those that fasted (Figure 2). These results indicate that feeding impacts on cardiovascular regulatory responses to mild orthostatic stress; attenuating the magnitude of cardiovascular autonomic pressure responses to LBNP.

References
CLOTHING PERFORMANCE IN THE HEAT

Physiological evaluation of wearing protective ensembles with different total heat loss values in temperate and hot/humid conditions

Aitor Coca1*, Jung-Hyun Kim1, Jeffrey Powell1, Raymond Roberge1
NIOSH/NPPTL, Pittsburgh, PA, USA
*corresponding author: esq6@cdc.gov

Introduction
According to the World Health Organization (WHO, [1]), 20 to 50% of workers are at risk of exposure to hazardous environments such as chemical and biological agents. In an effort to protect workers from hostile work environments and minimize the risk of occupational diseases, a variety of personal protective clothing and equipment (PPE) has been developed, and is now widely used in both industrial and non-industrial workplaces. PPE, such as fire-fighting ensembles, emergency medical clothing, bomb suits, etc., is designed to protect the wearer’s body from specific hazards in the workplace. While these types of PPE effectively increase wearer safety from certain hazards, the risk of heat stress also increases due to the accumulation of metabolic heat and sweat, which in turn elevates the microclimate temperature and humidity inside the ensembles. The materials used to build these ensembles have different thermal characteristics (thermal resistance and vapour permeability) depending on the level of hazard protection and PPE applications. The National Fire Protection Association (NFPA) has provided guidelines on thermal characteristics of fabric used to manufacture protective ensembles (PE) based on the Total Heat Loss (THL; W/m²) value determined by a sweating hot plate test on a sample fabric [2]. This study compared the physiological responses to exercise in two different environmental conditions while wearing two ensembles with different THL value materials. The purpose of the study was to evaluate the effect of the materials’ thermal characteristics as well as the environmental conditions on the physiological responses to wearing PE.

Methods
Seven healthy male adults participated in this study. After subjects read and signed informed consent forms approved by the National Institute for Occupational Safety and Health (NIOSH) human subjects review board, subjects performed a graded exercise test to determine their fitness level (Table 1) followed by four tests in random order. The four tests consisted of two different environmental conditions, neutral (22°C, 50% relative humidity) or hot (35°C, 65% relative humidity), and two PE with identical design but different THL values. Ensemble A was a commercially available chemical PE with a THL value of 191 W/m²; ensemble B was a prototype with a THL value of 904 W/m². Subjects donned either ensemble A or B in either neutral or hot conditions, on separate days, and performed treadmill exercise at 4.8 km/h and 3% incline for 60 min. Rectal (Tre) and skin (Tsk) temperatures, heart rate (HR), and microclimate temperature (Tmc) and humidity (RHmc) were continuously measured. Nude weight was measured before and after to calculate sweat loss (SL). The mean (SD) values at baseline, half way (30 min) and the end of exercise (60 min) are reported (Table 2 and Figures 1, 2 and 3). Statistical comparisons were carried out using repeated measures analysis of variance (ANOVA) for all the variables at alpha level of 0.05.
Table 1. Subjects’ anthropometrics and physiological characteristics.

<table>
<thead>
<tr>
<th>No</th>
<th>Age (yrs)</th>
<th>Weight (kg)</th>
<th>Height (m)</th>
<th>BMI (kg/m²)</th>
<th>VO2max (ml/kg/min)</th>
<th>HRmax (b/min)</th>
<th>Surface area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>80.3</td>
<td>1.85</td>
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<td>193</td>
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<td>2</td>
<td>20</td>
<td>90.2</td>
<td>1.83</td>
<td>26.93</td>
<td>58</td>
<td>184</td>
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<td>81.8</td>
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<td>23.14</td>
<td>53</td>
<td>193</td>
<td>2.08</td>
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<td>4</td>
<td>30</td>
<td>84.1</td>
<td>1.85</td>
<td>24.57</td>
<td>50</td>
<td>193</td>
<td>2.08</td>
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<td>5</td>
<td>21</td>
<td>74.2</td>
<td>1.85</td>
<td>21.68</td>
<td>65</td>
<td>196</td>
<td>1.97</td>
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<td>23</td>
<td>86.5</td>
<td>1.78</td>
<td>27.33</td>
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<td>190</td>
<td>2.05</td>
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<tr>
<td>7</td>
<td>24</td>
<td>84</td>
<td>1.96</td>
<td>21.89</td>
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<tr>
<td>Mean</td>
<td>23.1</td>
<td>83.0</td>
<td>1.86</td>
<td>24.1</td>
<td>57.9</td>
<td>190.0</td>
<td>2.1</td>
</tr>
<tr>
<td>SD</td>
<td>3.3</td>
<td>5.0</td>
<td>0.1</td>
<td>2.3</td>
<td>8.3</td>
<td>5.5</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Results and Discussion

Table 2 summarizes the Tre, Tsk and HR data for the four different conditions. Baseline measurements following a stabilization period did not show any significant difference between conditions or ensembles. At 30 min, differences are shown in Tre, Tsk and HR which indicate that environmental conditions and ensembles impose a different degree of heat stress to the wearer. At the end of the exercise, those differences are higher between all the test sessions on the Tre, Tsk and HR.

Mean Tre is very similar in all the conditions during the baseline. The clothing and environmental conditions promote Tre increase at different rates, showing that ensemble B in neutral condition is significantly lower than the other 3 conditions over the time of the test session. At the end of 60 min of exercise, Tre showed statistically significant differences between the four conditions. Tsk and HR have a similar dynamic as Tre, with a faster increase in the first 30 min of exercise, as can be expected. All conditions are statistically different from each other at 30 and 60 minutes, which indicates that ensembles and environmental conditions affect the physiological responses to exercise.

Figures 1 and 2 show the temperature and humidity in the microclimate between the skin and the garment. Tmc and RHmc in ensemble B during neutral conditions is lower than the other three conditions. This produced a significantly lower sweat loss as it can be seen on Figure 3. The lower THL value of ensemble B allowed more heat dissipation in neutral conditions. However, in hot conditions ensemble B was not creating a barrier against the environment and it was about the same temperature inside and outside the ensemble. Ensemble A, on the other hand, with a higher THL created a high and humid microclimate in neutral conditions which exacerbated in hot conditions. Still those differences seen in Tmc and RHmc as well as SL explain only part of the large differences in the THL values.
Table 2. Mean (SD) of Tre, Tsk and HR for the two ensembles and two conditions. * superscripts designate statistically significant differences between ensembles and conditions at each exercise stage: ¹ Ensemble A Hot, ² Ensemble A Neutral, ³ Ensemble B Hot, ⁴ Ensemble B Neutral. (n=7). p<0.05.

<table>
<thead>
<tr>
<th>Time</th>
<th>Ensemble A Hot</th>
<th>Ensemble A Neutral</th>
<th>Ensemble B Hot</th>
<th>Ensemble B Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>36.9 (0.2)</td>
<td>36.9 (0.1)</td>
<td>36.8 (0.2)</td>
<td>36.7 (0.3)</td>
</tr>
<tr>
<td>30 min</td>
<td>37.7 (0.5)</td>
<td>37.4 (0.2)</td>
<td>37.6 (0.2)</td>
<td>37.2 (0.3)</td>
</tr>
<tr>
<td>60 min</td>
<td>39.7 (0.3)</td>
<td>38.1 (0.3)</td>
<td>38.5 (0.3)</td>
<td>37.4 (0.3)</td>
</tr>
<tr>
<td>Baseline</td>
<td>33.4 (0.6)</td>
<td>33.6 (0.7)</td>
<td>33.3 (0.6)</td>
<td>33.4 (0.8)</td>
</tr>
<tr>
<td>30 min</td>
<td>37.5 (0.3)</td>
<td>35.5 (0.4)</td>
<td>36.2 (0.5)</td>
<td>33.8 (0.8)</td>
</tr>
<tr>
<td>60 min</td>
<td>38.9 (0.8)</td>
<td>36.4 (0.4)</td>
<td>36.9 (0.7)</td>
<td>33.7 (1.2)</td>
</tr>
<tr>
<td>Baseline</td>
<td>66.7 (7.5)</td>
<td>65.1 (7.4)</td>
<td>66.7 (9.2)</td>
<td>66.7 (8.8)</td>
</tr>
<tr>
<td>30 min</td>
<td>150.9 (13.6)</td>
<td>119.8 (14.6)</td>
<td>132.6 (6.3)</td>
<td>103.1 (11.2)</td>
</tr>
<tr>
<td>60 min</td>
<td>187.5 (2.3)</td>
<td>150.0 (17.6)</td>
<td>164.3 (8.2)</td>
<td>108.9 (12.6)</td>
</tr>
</tbody>
</table>

Figure 1. Mean (±SD) Tmc across 60 min within each of the four sessions.

Figure 2. Mean (±SD) RHmc across 60 min within each of the four sessions.
The materials used to manufacture these ensembles were rated at a very low (ensemble A, 191 W/m²) and a very high THL value (ensemble B, 909 W/m²). The large difference in total heat loss (718 W/m²) from the materials is reflected in a different response in Tre, Tsk, and HR. The lowest THL value showed the highest increase on those variables, indicating a higher heat stress while wearing that ensemble. However, the difference in Tre at the 60 min hot conditions between ensemble A (39.7°C) and ensemble B (38.5°C) is 1.2°C, which probably is less in magnitude than the difference in THL value (718 W/m²). The same small difference in Tre (0.7°C) is found in neutral conditions, also less in magnitude than the THL difference. Besides ensemble materials being important in the wearer physiological responses, environmental conditions also play a significant role on increasing the Tre, Tsk and HR responses.

Conclusions
In summary, the results of this research indicate that the sweating hot plate THL value may be effective in distinguishing basic thermal characteristics of the protective materials manufactured; however the physiological responses showed that the magnitude of the difference in THL value may not accurately represent the different levels of heat stress during exercise when wearing a PE built from the materials with a specific THL value.

Disclaimer
The findings and conclusions of this abstract are those of the authors and do not necessarily reflect the views of the National Institute for Occupational Safety and Health.

References
**Evaluation of personal cooling systems for military use**

*John C. Elson*¹, Elizabeth A. McCullough¹, Steve Eckels¹

¹ Institute for Environmental Research, Kansas State university, Manhattan, KS 66506 USA  
*corresponding author: jelson@ksu.edu*

**Introduction**

There is a need for personal cooling systems (PCS) that can mitigate heat stress for soldiers deployed in extreme conditions where high air temperatures and the radiant load from the sun can cause the body to store thermal energy excessively. These environmental conditions, combined with the use of heavy personal protective equipment (PPE), can put a thermal strain on soldiers especially when their metabolic heat production increases due to work activities [1].

Body heat balance is achieved when the amount of heat produced by the body, is approximately equal to the amount of heat transferred to and from the environment and the body [2]. In environments where the environmental temperature is greater than the body temperature, the only way the body can lose excess heat is by the evaporation of sweat from the body surface. The rate of evaporative cooling is dependent upon the vapor pressure gradient between the skin surface and the environment and the rate of air movement around the body and between clothing layers. Unfortunately, protective clothing such as body armor can inhibit the evaporation of sweat. In addition, the mass, rigidity, and design of protective garments may increase the energy cost associated with wearing them during activity. Consequently, Soldiers operating in hot environments often experience heat stress symptoms that affect performance on extended operations. To mitigate these problems, the U.S. Army has been searching for advances in personal cooling systems that have been developed by manufacturers in the private sector. The cooling effectiveness of these systems needs to be quantified prior to testing them on soldiers in the field [3].

**Methods**

The purpose of this study was to evaluate personal cooling systems for potential use by dismounted soldiers, using a sweating manikin and human subjects under controlled conditions. The PCS represented three types: 1) ambient air systems which circulate air under the body armor, 2) phase change materials which absorb body heat and melt, and 3) refrigeration systems that circulate chilled fluid through tubes in a vest. (See Table 1.) The PCS were selected using a logistical model in consultation with military personnel. Each PCS was evaluated as part of the basic military ensemble which consisted of the Army combat shirt and pants, belt, underwear briefs, ACH helmet with internal pads, gloves, knee protectors, socks, and athletic shoes. The body armor worn was the Soldier Plate Carrier System with Kevlar® backed ESAPI front and rear plates and side ESAPI plates.

**Manikin Tests**, ASTM F 2371, Measuring the Heat Removal Rate of Personal Cooling Systems Using a Sweating Heated Manikin [4], was used to measure the cooling effectiveness of each PCS. The manikin (1.80 m² surface area, 177.2 cm height) has 20 computer controlled, independently heated thermal zones equipped with ports for continuous sweating. Power cables, measurement cables, fluid supply tubes, and fluid return tubes connect to his face.

The manikin’s skin temperature was controlled at 35°C, and his skin surface was saturated with water. The environmental conditions for the sweating manikin tests were: 35°C air temperature, 40% relative humidity, and 0.3 m/s air velocity. First, a baseline test was conducted on each ensemble with the PCS turned off. In the case of phase change materials, a “used” component of
the PCS was tested (e.g., cartridge of water at 35°C instead of ice, etc.). As soon as steady-state conditions had been reached, a 30 minute test was run. Steady-state was indicated by an evaporative resistance reading that had not changed more than 1%. The average power level to the manikin was recorded.

Next the “heat difference” program quantified the cooling rate of the PCS by subtracting the average power level during the baseline test from the power used to keep the manikin’s skin temperature at 35°C when the PCS was turned on. Data were collected for two hours. Two replications of the tests were conducted.

Human Subject Tests. ASTM F 2300, Standard Test Method for Measuring the Performance of Personal Cooling Systems Using Physiological Testing [4], was followed except that hotter environmental conditions were used. Groups of four subjects – two in the morning and two in the afternoon – evaluated two personal cooling systems and the baseline condition without a PCS, over a six-day period. The design of the experiment was a 3 x 3 Latin square design where each subject wore all three PCS configurations in a different order. The fourth subject repeated the test sequence of the first subject. This experimental design was replicated three times with different subjects for a total of 12 test subjects in a three-week session to test two PCS. This overall plan was repeated again with two different PCS and 12 new subjects for a total of 24 subjects evaluating four PCS.

The volunteer subjects were soldiers from Ft. Riley, Kansas, that met the selection criteria for a total of 22 men and 2 women. The subjects were recruited after the protocol was approved by the proper institutional review boards. They included various races and ranged in age from 19-32 years, in height from 1.60-1.88 m, and in mass from 55.3-98.4 kg. The environmental conditions for the human subject tests were 42.2°C air temperature, 20% relative humidity, 2.0 m/s air velocity, and 54.4°C mean radiant temperature (to simulate a solar load).

Each group of four subjects exercised on treadmills in the environmental chamber for three days prior to the collection of data to familiarize themselves with the hot conditions and the experimental protocol. Then they wore two PCS and the basic ensemble with no PCS in a random order during the last three days. Each subject walked on the treadmill for two hours at a predetermined speed and 1% incline that would result in a metabolic heat production of approximately 350 W at the beginning of the experiment. A nurse monitored the subjects constantly inside the chamber during the test session, and she periodically gave the soldiers 37°C water to drink so as not to affect the core temperature reading. An engineer monitored the soldiers’ physiological responses and environmental conditions with the data acquisition system. The following dependent variables were measured: exposure time (duration of test if the subject was removed prior to two hours); core temperature measured continuously with an HQ Inc. CorTemp® ingestible pill sensor; mean skin temperature measured continuously with Omega Engineering® thermocouples taped to the skin in seven locations; heart rate measured every minute with a Polar™ heart rate strap; oxygen consumptions and metabolic rate measured periodically with the ParvoMedics True One® met cart; whole body sweat rate measured by weighing the subjects before and after the experiment (accounting for water input and urine output); and soldiers’ perceptions of comfort and their opinions about each PCS.

The soldiers were removed from the experiment early if they reached any of the removal criteria given in the standard, and the time was recorded. After each session, their clothing and instrumentation was cleaned for the next session.
Results and Discussion

Manikin Tests. The standard defines the cooling rate as the time average of the power input to the manikin from the time the PCS was activated and data collection was started until the effective power (power to the manikin minus the baseline power level) decreased to 50 W for a maximum test of two hours. All of the PCS reported here achieved at least 50 W throughout the two-hour test. (See Table 1.)

**Table 1. Results for the Personal Cooling Systems on the Sweating Manikin Tests**

<table>
<thead>
<tr>
<th>Personal cooling system</th>
<th>System type</th>
<th>Mass (kg)</th>
<th>Cooling effectiveness (W)</th>
<th>Cooling power/mass ratio (W/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1 Ventilation Vest (Entrak)</td>
<td>Air circulation</td>
<td>0.995</td>
<td>100.3</td>
<td>100.5</td>
</tr>
<tr>
<td>#2 Cool UnderVest (Steele)</td>
<td>Phase change material</td>
<td>3.499</td>
<td>113.0</td>
<td>32.3</td>
</tr>
<tr>
<td>#3 PCVZ-KM Vest (Polar)</td>
<td>Phase change material</td>
<td>2.778</td>
<td>96.9</td>
<td>34.9</td>
</tr>
<tr>
<td>#4 Hummingbird II (CTS)</td>
<td>Refrigeration</td>
<td>5.108</td>
<td>124.6</td>
<td>24.3</td>
</tr>
</tbody>
</table>

PCS #1 is a very lightweight air circulation system that functions by blowing air between the body armor and the clothing layers to increase evaporative heat loss. Although it provided about 100 W of cooling in the manikin test, this result is somewhat misleading because air circulation systems can remove more heat from the manikin’s surface than can from a human being. The manikin’s flow rates are adjusted to keep his skin surface 100% saturated during a test. It would take some time for the soldier to accumulate that much sweat on the torso, and it is unlikely that he/she could sweat continuously at that rate for a long period of time. Still, air circulation systems are generally lightweight and have long run times because the fans require relatively little power to function.

PCS #2 and #3 contained phase change materials (PCM) and provided an acceptable amount of cooling. These PCM systems provided a high amount of cooling initially, but the heat loss decreased to around 50 W at the end of the two-hour test. The amount of cooling provided by phase change material PCS is proportional to the amount of mass of the PCM used in the vest. These systems tend to have a low cooling power-to-mass ratio and are exhausted after two-to-three hours of use. However, they require no moving parts, and consequently, make no noise; however, they require a freezer and begin melting when they are removed.

System #4 is a prototype, proof-of-concept, direct expansion refrigeration system which circulates chilled, expanding refrigerant through tubes in a vest worn under the body armor. This PCS provided constant cold-boundary cooling for over two hours. The system was heavy and not ergonomically designed for use on a soldier. However, it did save mass by allowing the refrigeration process to take place next to the body. Expanding vapor in a tube suit was used to cool the body instead of a liquid (i.e., water or glycol), which is commonly used with refrigeration systems. Because of this, the mass was reduced slightly; however, a good portion of the system mass actually came from the use of a MIL-2590 battery.

Since the four PCS provided about 100-125 W of cooling for two hours in the manikin test, they were chosen for testing on human subjects.

**Human Subject Tests.** Most of the soldiers were able to complete the two-hour test session; however, there were nine instances where subjects either quit due to discomfort or were
removed by the nurse when their core temperature reached 39.0°C. The effect of PCS on metabolic rate was not statistically significant because we adjusted each subject’s treadmill speed so that the work rate was about the same for all subjects (i.e., 365-390 W at the end of the experiment). The other physiological variables are shown in Table 2.

Table 2. Results for the Personal Cooling Systems on the Human Subject Tests

<table>
<thead>
<tr>
<th>Personal cooling system</th>
<th>Final core temperature (°C)</th>
<th>Change in core temperature over test (°C)</th>
<th>Final heart rate (bpm)</th>
<th>Average torso skin temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Session Baseline (no PCS)</td>
<td>38.21</td>
<td>1.21</td>
<td>139.8</td>
<td>37.08</td>
</tr>
<tr>
<td>#1 Ventilation Vest (Entrak)</td>
<td>38.07</td>
<td>0.83*</td>
<td>132.5*</td>
<td>36.03</td>
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<tr>
<td>#2 Cool UnderVest (Steele)</td>
<td>37.79*</td>
<td>0.50*</td>
<td>120.5*</td>
<td>33.83*</td>
</tr>
<tr>
<td>Next Session Baseline (no PCS)</td>
<td>38.30</td>
<td>0.97</td>
<td>141.8</td>
<td>36.61</td>
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<tr>
<td>#3 PCVZ-KM Vest (Polar)</td>
<td>37.56*</td>
<td>0.24*</td>
<td>117.8*</td>
<td>35.68</td>
</tr>
<tr>
<td>#4 Hummingbird II (CTS)</td>
<td>37.60*</td>
<td>0.33*</td>
<td>120.3*</td>
<td>29.13*</td>
</tr>
</tbody>
</table>

*The PCS result was statistically different from the baseline ensemble with no PCS (p<0.05).

When the soldiers were wearing the phase change PCS (#2-3) and refrigeration PCS (#4), they had a significantly lower heart rate, final body core temperature, and change in core temperature over the two-hour test as compared to wearing no PCS. The air circulation PCS #1 significantly affected the heart rate and change in core temperature of the subjects, but not the final core temperature. The change in core temperature accounted for variability in the initial core body temperature. PCS #2 and #4 also produced a significantly lower skin temperature on the torso (under the body armor and PCS) than the baseline condition did.

Conclusions
The four PCS provided an average of about 100-125 W of cooling during the two-hour manikin test. In the human subject tests, the cold-boundary PCS (#1, 2, and 3) made significant improvements in the body core temperature and heart rate of the soldiers as compared to the baseline conditions with no PCS. The air circulation system improved the physiological responses of the subjects also, but to a lesser degree. It is clear from the results on these four systems that the manikin test was a relatively good predictor of the effectiveness of the PCS when used by soldiers.

The usefulness of each type of PCS in the field will depend upon the individual needs of the soldier and the conditions in which it is used. The Hummingbird II provides a high level of cooling. However, unlike PCS #1-3 which are already commercially available, the Hummingbird II needs to be ergonomically refined and ruggedized.

References
Does changing a sweat-saturated t-shirt influence thermoregulation, and is this dependent upon fabric composition / cost?

Ella Walker*, James R. House

Extreme Environment Laboratory, Department of Sports and Exercise Science, University of Portsmouth, Portsmouth, United Kingdom.

*corresponding author: ella.walker@myport.ac.uk

Introduction

Some athletes undertaking extensive periods of exercise change their clothing, particularly t-shirts when they become sweat saturated; e.g., tennis players competing in warm / hot climates which are occasionally humid and / or with a high radiant heat load. Changing a sweat saturated t-shirt, may reduce evaporative cooling (due to the removal of a sweat saturated fabric from the skin coupled with the increase in insulation of a dry shirt), but improve their thermal comfort by reducing the feeling of skin wetness. Manufacturers of technical sports clothing often claim that their product will keep the wearer cooler, dryer and more comfortable for longer periods. Moreover, the price of such garments can sometimes be six times that of a basic non-technical fabric, even when made from the same base fabric type (e.g., polyester). This study was conducted to assess the hypotheses that both a technical fabric and not changing the t-shirt would improve thermoregulation, but that changing the t-shirt would improve thermal comfort.

Methods

Following ethical approval, eight healthy male volunteers (mean (SD) age 25 (4.9) years, height 1.80 (0.08) m, and mass 70.0 (14.2) kg) completed four conditions on separate days; wearing either technical or non-technical polyester t-shirts for two hours continuously, or changing them every 40 minutes. To ensure standardised heat production, the participants stepped at 20 steps-min⁻¹ onto a 22 cm high bench in an air temperature of 35 °C and 20 % relative humidity in all conditions for three 40 minute periods, each separated by 2 minutes rest. When the condition demanded, the t-shirt was changed during the rest periods and weighed to estimate sweat trapped. Rectal and skin temperatures [1] and heart rate were measured every minute. Perceptions of thermal comfort, skin wetness, thermal sensation and rating of perceived exertion were recorded every 15 minutes.

Results and Discussion

There were no significant differences in heart rate (p=0.819), or mean skin (p=0.812), mean body (p=0.781) and rectal (p=0.778) temperatures. There were no significant differences in perceptual measures between conditions at the end of each work period (p>0.05). Within conditions, participants felt hotter in the 2nd and 3rd work periods compared to the 1st when changing the technical t-shirt (p=0.008 & 0.033) and hotter in the 3rd work period compared to the 2nd when changing the non-technical (p=0.003) t-shirt (but not when the t-shirts were not changed). Therefore, whether the t-shirt is changed or not during exercise, the individual will feel the same thermal sensation. However, achievement of peak thermal sensation may occur earlier if the t-shirt is not changed. Changing either t-shirt did not inhibit evaporative cooling, nor compromise thermoregulation. The technical fabric t-shirt did not afford any thermoregulatory or perceptual benefits.

References

Evaporative cooling efficiency of one-layer tight fitting sportswear: A sweating torso manikin study

Faming Wang*, Simon Annaheim, Matthew Morrissey, René Rossi
Laboratory for Protection and Physiology, EMPA-Swiss Federal Laboratories for Materials Science and Technology, Lerchenfeldstrasse 5, 9014, St. Gallen, Switzerland
*corresponding author: faming.wong@gmail.com

Introduction
In hot environments, sweating is the most important heat loss mechanism for people who are working, training or doing leisure activities. Generally, only some of the produced sweat can evaporate, due to the limited evaporative capacity of the micro and macro environments [1,2]. The remaining sweat will either drip off the body or be absorbed by the material of any overlying clothing. The dripped sweat does not contribute to cooling the body while absorbed sweat by clothing still can contribute to evaporative cooling [3]. Moisture management materials are currently very popular and are often used to produce tight fitting functional sportswear. Unfortunately, the evaporative cooling efficiency will reduce as the moisture moves away from the skin surface into the clothing layer. If the wicking properties of the chosen clothing materials are too aggressive (e.g., strong transplanar wicking [4]), the evaporative cooling efficiency will be reduced greatly. It is still unclear how the evaporative cooling efficiency decreases when moisture is transported from the skin surface to the clothing layers. Therefore, we performed experiments with the sweating torso manikin to mimic different phases of moisture absorption.

Methods
Four sportswear materials, including cotton, COOLMAX® (profiled cross section polyester fibre), merino wool and sports wool (50% wool, 50% polyester) were selected for this study. The characteristics of these four clothing materials are described in Table 1. A moisture-saturated fabric ‘skin’ was used to simulate fully wet skin. The total moisture added to the ‘skin’ and clothing layer was kept constant while the moisture content ratio in the fabric ‘skin’ and in the clothing layer was changed. Three ratios were chosen: 100%/0% (i.e. SK100, all moisture is in the fabric ‘skin’ and the outer layer is dry), 50%/50% (i.e., SK50) and 0%/100% (i.e., SK0). The surface temperature of the sweating torso was controlled at 35 °C, as was the ambient temperature inside the climatic chamber. The relative humidity and air velocity were 53 ± 2% and 0.4 m/s, respectively. Each test scenario was repeated at least four times. The evaporative cooling efficiency (η) of each sample at three different scenarios was computed using Eq.(1) [5,6]

\[
\eta = \frac{H_{\text{heat}}}{\lambda \times \frac{dm}{dt}} \quad \text{Eq.}(1)
\]

where, \(H_{\text{heat}}\) is the observed heat loss from the sweating torso, in W; \(dm/dt\) is the mass loss rate, in g/h; \(\lambda\) is the heat of vaporisation at the measured ‘skin’ temperature, which is 0.673 W·h·g⁻¹ (at 35°C)[7,8].
Table 1. Characteristics of clothing materials.

<table>
<thead>
<tr>
<th>Code</th>
<th>Clothing material</th>
<th>$R_{cl}$, K·m$^{-2}$·W$^{-1}$</th>
<th>$R_{ecl}$, Pa·m$^{-2}$·W$^{-1}$</th>
<th>$W_f$, g·m$^{-2}$</th>
<th>$AP$, L·m$^{-2}$·s$^{-1}$</th>
<th>$d$, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM</td>
<td>100% polyester (Coolmax®)</td>
<td>0.009</td>
<td>1.49</td>
<td>95</td>
<td>&gt;1667</td>
<td>0.53</td>
</tr>
<tr>
<td>MW</td>
<td>100% merino wool</td>
<td>0.043</td>
<td>4.81</td>
<td>190</td>
<td>1307</td>
<td>1.21</td>
</tr>
<tr>
<td>SW</td>
<td>sports wool, 50% polyester, 50% merino wool</td>
<td>0.020</td>
<td>2.60</td>
<td>152</td>
<td>1393</td>
<td>0.80</td>
</tr>
<tr>
<td>CO</td>
<td>100% cotton</td>
<td>0.021</td>
<td>3.31</td>
<td>225</td>
<td>706</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Note: Clothing fabric intrinsic thermal resistance $R_{cl}$ and intrinsic water-vapor resistance $R_{ecl}$ were measured on a sweating guarded hotplate according to ISO 11092 (1993); $W_f$, fabric weight, i.e., mass per unit area; $AP$, air permeability, this was determined on an air permeability tester according to ISO 9237 (1995); $d$, fabric thickness, this was measured on a thickness tester according to ISO 5084 (1996), the pressure was 10.2 g·cm$^{-2}$ and the diameter of the pressure foot was 50.8 mm.

Data are presented as mean±SD (standard deviation). Dependent variables such as the evaporative cooling efficiency $\eta$, the apparent heat loss $H_{\text{heat}}$ and mass loss rate $d_m/dt$ were analyzed by a two-way ANOVA and followed with Tukey’s HSD (honestly significant difference) post hoc tests. The independent factors are three test scenarios (i.e., SK100, SK50, SK0) and four clothing materials (i.e., CM, MW, SW and CO). Statistical analyses were performed using SPSS Statistics version 19.0 (IBM, Armonk, NY, USA). The level of significance was set to $p<0.05$.

Results and Discussion

![Figure 1](image)

**Figure 1.** Apparent evaporative cooling efficiency under three different test scenarios: SK100, SK50 and SK0. *$p<0.05$; **$p<0.005$.

The results demonstrated that, for all clothing materials, the apparent evaporative cooling efficiency linearly decreases with the increasing ratio of moisture being transported away from skin surface to clothing layer (Adj. R-square>0.972). In addition, clothing fabric thickness has a negative effect on the apparent evaporative cooling efficiency (Adj. R-square=0.87). Clothing CM and SW showed a good ability in maintaining evaporative cooling efficiency. In contrast, clothing
MW made from thicker fabric had the worst performance in maintaining evaporative cooling efficiency. It is thus suggested that thin fabric materials such as CM and SW should be used to manufacture one-layer tight fitting sportswear.

Conclusion
The findings will contribute to the body of knowledge on how to balance wicking sweat away from skin whilst maintaining a sufficiently high evaporative cooling efficiency. In addition, the data presented in this study may have important applications for clothing design and human heat balance calculations.

References
Clothing habits during tourism and leisure activities in urban areas. The case study of Warsaw (Poland)

Katarzyna Lindner-Cendrowska\textsuperscript{1,}*, Krys Błażejczyk\textsuperscript{2}

\textsuperscript{1} Faculty of Geography and Regional Studies, University of Warsaw, Warsaw, Poland
\textsuperscript{2} Institute of Geography and Spatial Organization, Polish Academy of Sciences, Warsaw,

*corresponding author: klindner@uw.edu.pl

Introduction

It is generally accepted that clothing greatly influences human well being, because it helps in maintaining thermal comfort. The relations between clothing and current thermal conditions have been described in several studies [1-2], although there are not many reports concerning human clothing habits in specific regions of the world and in various types of weather. Another understudied issue is that the kind of garment which people usually use while spending leisure time outdoors is affected by actual weather conditions, cultural context and individual preferences.

The present study provides information about clothing used in Warsaw by tourists and residents during leisure activities outdoors. Some specific features of clothing habits typical in urban environment are pointed out.

Methods

To collect information about clothing preferences and relate it to weather conditions four field studies were conducted in the most popular tourist area in Warsaw - the Old Town. The meteorological measurements and questionnaire surveys were simultaneously carried out at the Old Town Market Place for 2-4 days during each of the four seasons from 11 a.m. to 4 p.m. (local time), when the most tourists visited the Old Town and the whole place was well insulated. Respondents (n = 667) were randomly selected from the group of people that declared they were staying at the location of experiment for tourism and recreational purposes. Interviewees were asked to assess their thermal sensations and describe the type of garment they wear. They were also questioned about personal characteristics, like sex, age or place of residence. Total thermal insulation (lcl) of respondents’ clothes was assessed on the basis of garment insulation values described in ISO standard [3], assuming that with all items of clothing were made from typical permeable materials. Total insulation values were calculated in accordance with above mentioned ISO standards.

Insulation of clothing used by respondents was compared with the Predicted Insulation Index (lclp), that specifies clothing insulation necessary to maintain thermal balance of the human organism at given weather conditions [4]. lclp was calculated from meteorological data collected during field research, using the following formula:

\[ lclp = \frac{0.082 \cdot [91.4 - (1.8 \cdot t + 32)]}{(0.01724 \cdot M)} - \frac{1}{(0.61 + 1.9 \cdot v^{0.5})} \]

where \( t \) is air temperature (in °C), \( v \) is wind speed (in m/s) and \( M \) is metabolic heat production (in W/m\(^2\)), specified for each person and depending on prevailing physical activity.

Results and Discussion

Differentiation of thermal insulation in seasons

People during outdoor leisure activities freely regulate their thermal sensations by adjusting clothing to fluctuating atmospheric conditions. The strongest relationship was observed between clothing insulation and air temperature (Figure 1). For the winter season in Warsaw, clothes of lcl
around 1.4 clo were used, while during summer, when air temperature was above 25°C, light clothing of 0.4 clo was worn.

![Figure 1. Mean respondents’ total clothing insulation (clo) in 1°C ranges of actual air temperature in particular seasons in Warsaw. The coefficient of determination is very high (0.96) and was statistically significant (p<0.001).](image)

Mean values of clothing total thermal insulation used by people satisfied with their thermal state and declaring in the questionnaire that they felt neutral (0 – the middle category on ASHRAE scale) with the corresponding weather parameters are presented in Table 1.

**Table 1.** Total clothing thermal insulation (clo) of people having neutral thermal sensations in particular seasons and weather conditions

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Total thermal insulation (clo)</th>
<th>Mean air temperature (°C)</th>
<th>Mean vapour pressure (hPa)</th>
<th>Mean wind speed (m·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>1.3</td>
<td>-2.5</td>
<td>3.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Spring</td>
<td>0.9</td>
<td>14.3</td>
<td>8.3</td>
<td>0.8</td>
</tr>
<tr>
<td>Summer</td>
<td>0.4</td>
<td>26.7</td>
<td>13.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Autumn</td>
<td>1.1</td>
<td>10.2</td>
<td>8.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

It is stated that personal features, like sex or age may influence the way people are dressing in various situations [5]. In our studies neither sex nor age had statistically significant impact on clothing insulation. Surprisingly no differences in clothing habits occurred between international tourists and Warsaw residents or Polish tourists.

**Specific features of urban casual clothing**

There were noticeable differences between Predicted Insulation Index (Iclp) values and total thermal insulation (Icl) of clothing used by respondents, especially in summer and winter (Figure 2). Tourists and residents staying outdoors for their own pleasure are expected to wear comfortable and non-formal clothes, which can be easily adjusted depending on weather conditions. This study proves that in an urban environment people often, by choice or under constraint, do not match their clothing to actual atmospheric conditions to maintain thermal
comfort. In summer reducing thermal insulation of a garment to under 0.4 clo is sometimes impossible, due to the social and individual limits relating to modesty and acceptance of scant clothing. While in winter a phenomenon of wearing too lighter clothes (so called “under-dressing”) may be observed, which may be related to spending the majority of time indoors or in public transport and therefore favouring clothing that is meant only to move from one location to another, instead of staying outdoors for a long time.

Figure 2. Differences between thermal insulation of clothing (Icl) used and predicted insulation (Iclp) necessary to maintain thermal balance for a human organism in winter and summer

Conclusions
The results confirm that even in an urban environment, weather conditions strongly influence clothing habits. Thermal insulation of clothes increases or decreases along with the changes of air temperature, but independently of one’s age, sex or thermal adaptation. Although in general people adjust their garment in accordance with long-term weather changes, they often, especially in winter and summer, do not use proper clothing to maintain thermal balance, feeling comfortable at the same time due to non-environmental reasons.

References
Endothermic salts integrated in impermeable suits do not reduce heat strain during exercise

Hein A.M. Daanen1,2*, George Havenith3, Manuel Bühler4, Aike W. Wypkema5, Stephen S. Cheung6
1 TNO Behavioural and Societal Sciences, Soesterberg, The Netherlands
2 MOVE research group, Faculty of Human Movement Sciences, VU University, Amsterdam, The Netherlands
3 Loughborough University, Environmental Ergonomics Research Centre, Loughborough, UK
4 Empa, Swiss Federal Laboratories for Materials Science and Technology, St. Gallen, Switzerland
5 TNO Technical Sciences, Eindhoven, The Netherlands
6 Department of Kinesiology, Brock University, St. Catharines, Ontario, Canada
*corresponding author: Hein.Daanen@tno.nl

Introduction
Wearing impermeable garments during work inherently leads to heat strain, even in cold environments [1]. Phase change materials (mainly paraffin’s or salt [4]) may be used as a thermal buffer (e.g. [2]) to reduce initial heat stress. Salts can also be used to absorb sweat, which may enhance the cooling power from the skin.

Recently, specific encapsulated salts utilising KSCN (potassium thiocyanate) have been developed that consume energy when the KSCN dissolves in water. The heat consumed when the KSCN (present inside 150 g of capsules containing 60% KSCN salt) dissolves in water is 22410 J (249 J/g * 60% * 150 g). When this dissolving takes place over a period of 30 minutes, the average power transfer is 12 W. One (1) g of KSCN-containing capsules absorbs close to 1 g of moisture. If we assume that 150 g sweat extra can be evaporated from the skin, this yields an extra cooling power of 182 W for 30 minutes. However this evaporated water from the skin is subsequently absorbed by the KSCN in the capsules. During this absorption from the gas phase, the condensation heat is released to the KSCN salt: about 182 W for 30 minutes. However, we hypothesise that this condensation heat will be partly transferred to the body and partly to the environment [3], providing a net benefit to the body.

Thus, the total cooling effect due to the salt capsules is composed of two parts:

- The cooling effect of about 12 W due to the heat consumption by the dissolving of the salts in water;
- The cooling effect of maximal 182 W, which equals the difference between the evaporative heat and the condensation heat. The latter is generated in the salt capsules that transfer part of the heat to the environment.

The overall cooling effect should therefore be in between 12 W and 194 W.

The purpose of our study was to test the efficacy of a KSCN-based absorbing salt as a PCM for use within impermeable protective clothing. We tested the PCM during 20 min of moderate exercise in a hot (35°C, 40% relative humidity) environment, and hypothesized that thermal strain would be lower in the PCM compared to the non-PCM condition.

Methods
Nine males (age [mean (±SD)] 24 (4) y, height 181 (6) cm, body weight 78 (12) kg) participated in the study. The experiment was a repeated measures design, with each participant performing a session using the salts (S) and control (C) garments and the order of the experimental conditions
counter-balanced. The garment was a thin, air impermeable, synthetic coverall, complete with hood, weighing approximately 500 g without salts (Microgard Microchem 4000, Microgard, Kingston Upon Hull, United Kingdom). The garment was supplied in the specified size and the subjects were only wearing a slip underneath. The S garment had additional salt packages containing 30 g 60% KSCN salt packages at the back, two similar packages at the sides of the coverall, and two at the upper legs. The protocol was approved by the local TNO ethics committee.

Participants were weighed nude and dressed to an accuracy of 1 g (Sartorius F300S, Göttingen, Germany) just prior and after the 30 minutes heat exposure to determine sweating rate and evaporative rates, respectively. The subjects were instrumented with eight iButtons type DS 1922L (Maxim, San Jose, USA) according to ISO 9886 (ISO 9886 2004) and inserted a rectal probe (YSI 400 series, Yellow Springs, USA) prior to the experiment 10-12 cm beyond the anal sphincter. Instrumentation and suit donning occurred in a room of 30°C, where they stayed for about 5 minutes and then entered the climatic chamber (35°C, 40% relative humidity).

The experimental protocol consisted of 5 min of sitting, 20 min of cycling exercise at 2 W/kg body weight (Lode Excalibur, Lode, Groningen, The Netherlands), and another 5 minutes of sitting. Oxygen uptake was determined using open-circuit spirometry (Oxygen Pro, Carefusion, San Diego, US). Heart rate was monitored using telemetric sensors and transmitters (RS400, Polar Electro, Kempele, Finland). Five minute averages were calculated for all physiological variables. Rating of Perceived Exertion (RPE), thermal sensation (ISO 10551), and thermal comfort [2] were assessed every 5 minutes.

Analysis of variance was performed with participants as random independent factor and time (every 5 minute) and suit (with/without salt) as fixed independent factor (GLM module, Statistica version 8). The dependent variables were heart rate, rectal temperature, mean skin temperature, body weight loss, weight of the suit, thermal sensation, RPE and thermal comfort.

Results
The C and S garments were different in weight (512 (14) g versus 793 (16) g) due to the salt within the S garment and the attachment materials. However, the extra weight of S did not result in a significantly higher metabolic cost of exercise, with no difference in oxygen uptake between C (2262 (150) mL·min⁻¹) and S (2180 (315) mL·min⁻¹).

The physiological and perceptual responses during the final 5 min period of the exercise using the C and S are presented in Table 1. Overall, no significant main effects or interactions were observed for any variable. Rectal temperature increased significantly and equally by 0.87 (0.26)°C and 1.01 (0.28)°C with C and S, respectively. No differences were observed in sweat rate or evaporation rate between C (0.97 [0.26] and 0.45 [0.16] L·h⁻¹) and S (1.01 [0.26] and 0.51 [0.16] L·h⁻¹). Importantly, even at the sites where the salt packages were directly in contact with the skin (chest, back and thighs), no beneficial effects of the salts in lowering local skin temperatures were evident.
In this project we carefully evaluated which salts may provide optimal cooling. Unlike sodium sulphate, KSCN is an endothermic salt that will not generate heat when a phase change occurs. Moreover, it has the advantage that water vapour is absorbed and thus the water vapour content in the air space between the skin and the protective garment reduces. Therefore, evaporation of sweat should be enhanced and cooling should be improved. Even though the choice of salts and the exercise protocol were optimized to get cooling effects, in our study no benefits of the salts were observed. The added weight and volume may constitute an extra load of about 1-2% metabolic rate increase per kg [7], albeit invisible in oxygen uptake data. The assumption that extra sweat can evaporate due to a drier air space is probably not true. Even the skin locations just next to the salt pads showed no differences in temperature with the control suit.

We conclude that adding the endothermic salt KSCN in protective clothing does not lead to a reduction in heat strain during heavy work in the heat.

Table 1. Results averaged over the nine subjects for the last five minute of exercise. $T_{re}$ = rectal temperature, $T_{sk}$ = mean skin temperature, RPE = rating of perceived exertion, TC = thermal comfort, TS = thermal sensation.

<table>
<thead>
<tr>
<th>variable</th>
<th>unit</th>
<th>Control</th>
<th>Salts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std.Dev</td>
<td>Mean</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>bpm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T_{re}$</td>
<td>°C</td>
<td>38.1</td>
<td>0.3</td>
</tr>
<tr>
<td>$T_{sk}$</td>
<td>°C</td>
<td>37.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Tforehead</td>
<td>°C</td>
<td>37.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Tback</td>
<td>°C</td>
<td>38.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Tchest</td>
<td>°C</td>
<td>38.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Tupper arm</td>
<td>°C</td>
<td>38.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Tlower arm</td>
<td>°C</td>
<td>37.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Thand</td>
<td>°C</td>
<td>36.7</td>
<td>0.6</td>
</tr>
<tr>
<td>Tthigh</td>
<td>°C</td>
<td>38.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Tcalf</td>
<td>°C</td>
<td>37.9</td>
<td>0.4</td>
</tr>
<tr>
<td>RPE</td>
<td></td>
<td>15.9</td>
<td>2.6</td>
</tr>
<tr>
<td>TC</td>
<td></td>
<td>3.1</td>
<td>1.2</td>
</tr>
<tr>
<td>TS</td>
<td></td>
<td>3.2</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Conclusions
Although humans have an excellent mechanism for heat dissipation through evaporation of sweat, this mechanism is seriously compromised during work in impermeable protective clothing, due to the inability for sweat to evaporate into water vapour and dissipate heat through the clothing. Phase change materials (PCMs) from ice through to multiple varieties of absorbent salts, may form an alternative due to their relatively lower level of complexity and weight, along with ease of replacement [4-6]. When the air space between undergarment and protective clothing is relatively dry, more sweat can evaporate from the skin, and more cooling power is generated on top of the PCM effect.
Acknowledgements
This project was performed in the FP7 project Prospie (www.prospie.eu).
S.S. Cheung was supported by a Canada Research Chair.

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Stay slightly cool to stay warm in the mountains

Nick Draper¹*, C. Corry², S. Fryer¹, T. Dickson¹, Mike Hamlin³, Jeremy Shearman⁴, Helen C Marshall⁵
¹ University of Canterbury, Christchurch, New Zealand
² Chichester University, Chichester, UK
³ Lincoln University, Christchurch, New Zealand
⁴ Christchurch Polytechnic Institute of Technology, Christchurch, New Zealand
* corresponding author: nick.draper@canterbury.ac.nz

Introduction
The old adage ‘stay slightly cool to stay warm in the mountains’ provides a useful maxim as a guide for the clothing systems employed by mountaineers operating in cold environments. Mountaineers use specific clothing systems as strategies to decrease heat loss while allowing for the evaporation of sweat during exercise. Research by clothing manufacturers has led to the development of highly technical garments to enhance these properties for use in the mountains. Manufacturers have tended to recommend one traditional system of layering. More recently Twight and Martin [1] highlighted an alternative layering approach.

The traditional layering system consists of three items, a base layer worn next to the skin, an insulative layer and a protective outer shell [2]. In a mountaineering context, despite the thermoregulatory qualities offered by the layering system, a thermal balance is often very hard to achieve due to the stop-start nature of the sport and the consequent changes in energy expenditure [3]. As a consequence, use of the traditional layering system can result in increased journey time or lead to excessive sweating during exercise and the enhancement of heat loss during stationary periods. Twight and Martin [1] advocated for the use of a base layer and outer shell during exercise, with the addition of a thermal layer, such as a synthetic or down jacket, during stationary periods.

The aim of this study was to compare the two different clothing systems, in simulated alpine conditions, to examine differences in physiological responses and effects on manual dexterity/skilful movement.

Methods
Participants
Ten healthy males, mean ± (SD): age 21.6 ± 1.9 y, height 1.81 ±0.09 m, and mass 80 ± 3.4 kg, completed written informed consent and a medical health history questionnaire prior to taking part in the study. The study was approved by the institutional ethics committee.

Clothing
Layering system
The participants wore a thermal base layer. The mid layer was made up of a 100-weight fleece (Momentum jacket, The North Face). The outer shell layer consisted of Latok event over trousers (Rab) and an Alpha SL GORE-TEX® Paclite jacket, (Arcteryx).

The Twight System
The participants wore thermal base layer and a soft shell (Mammut) throughout the test and added a 650 fill down jacket (Mountain Equipment) during each rest period. Participants also wore Latok event over trousers (Rab) during the test.
**General**

In both tests all participants wore Wind Stopper fleece gloves (Extremities), 2-3 season walking boots with one pair of thick winter socks, and a Targa climbing harness (Arcteryx).

**Temperature Chamber**

An environmental chamber (Tiss, Blackpool, UK), temperature set to −10°C, was used to simulate a likely temperature experienced in an alpine environment. The test was stopped if any of the following occurred: The participant’s core body temperature changed by 2°C; the participant asked for the test to be stopped; the participant felt nauseous or dizzy, or the participant fainted.

**Procedure**

Twenty-four hours prior to testing, participants were asked to refrain from strenuous exercise and to avoid alcoholic or caffeinated drinks. Each participant completed the test protocol twice; once using each clothing configuration. The tests were completed 7 d apart, and ordering of conditions was randomised. Heart rate (HR), oxygen consumption and core temperature were measured constantly throughout the test using a Polar FS1 heart rate monitor (Polar Electro Oy, Kempele, Finland), K4b² analyser (Cosmed, Rome, Italy) and rectal thermistor (Smith’s Medical, Ashford, UK).

The test protocol was conducted on a Woodway treadmill (Waukesha, Wisconsin, USA) and included a 5 min warm-up (4 km hr, 9% gradient) before the participants completed two 20-min steady state exercise periods (4 km h⁻¹, 9% gradient), each followed by a 10-min stationary (rest) period. A thermal sensation scale (rating 1 extremely cold to 10 extremely hot) was attached to the wall in front of the treadmill to enable participants to rate their thermal sensation, every 5 min. At the start of each rest period, to assess manual dexterity, participants had to complete tying into the harness to enable participants to rate their thermal sensation, every 5 min. Once completed the participant was unclipped from the delay point and continued to rest for the remaining time.

**Statistical Analysis**

Analyses were conducted using the SPSS software program (version 17.0, Chicago, IL, USA). Results of a one-sample Kolmogorov-Smirnov goodness-of-fit test indicated that all variables displayed normal distribution. Two-way repeated measures ANOVAs were conducted to assess for differences in thermal sensation, oxygen consumption, heart rate, core temperature and time to complete tying into the harness. An α level of 0.05 was set for accepting statistical significance, and if found, post-hoc t-tests with Bonferroni correction were applied.

**Results**

Results for thermal sensation can be seen in Figure 1; there was a significant interaction effect \( F_{(3,24)} = 21.50, p <0.0005 \), with post-hoc testing indicating significant differences at the end of each period except the second exercise period. Although oxygen consumption was on the whole, lower in the Twilight layering condition these differences were not significant. A similar trend was seen with HR slightly lower during the Twilight condition, but was also statistically non-significant. After the first exercise period core body temperature was marginally, but not statistically significantly higher, in the Twilight condition. Finally, there were no significant differences between the conditions for the tying-in exercise conducted at the start of each rest period.
Figure 1. Mean ± standard deviation for the thermal comfort scale.

Discussion
The Twilight system [1] has been proposed as an alternative clothing strategy for mountaineers. The aim of this study was to examine potential benefits of the Twilight system over traditional layering during exercise in a simulated alpine environment. Results of the study indicated there were significant benefits with regard to thermal sensation but these were not realised in statistical differences for the physiological or skill-related measures (oxygen consumption, HR, core temperature, tying-in time). The length of the protocol could be usefully extended in a future study to examine these parameters in a longer duration protocol more akin to the days experienced by mountaineers. Such a study might result in the differences in thermal perceptions being also seen in the physiological and skill-related measures.

Take Home Message
The Twilight layering system appears to offer thermal sensation advantages which might lead to physiological, psychological and performance differences during the longer duration of a typical mountain day.

References
ULTRA-ENDURANCE, TRACKING AND FATIGUE

Physiological impact of adventure racing: The 2012 GODZone field study

Monique E. Francois1*, Sam D. Cosgrove2, Nicole M. Walker2, Samuel J.E. Lucas1,3, Katherine E. Black2

1 School of Physical Education, 2Department of Human Nutrition and 3Department of Physiology, University of Otago, Dunedin, NZ
*corresponding author: monique.francois@otago.ac.nz

Introduction
Ultra-endurance exercise, specifically multisport adventure racing, presents a unique multifaceted stress to many of the body’s physiological systems. Tightly regulated variables, including blood glucose, blood pressure, and fluid balance are challenged over the 3-5 days of continuous submaximal exercise [1, 2]. The GODZone event is a multi-day, continuous, expedition-style adventure race in which four-person teams (minimum of one female member) navigate through rugged and unfamiliar terrain utilising different outdoor disciplines (e.g., trekking, kayaking (sea and whitewater) and cycling (road and mountain biking). Adventure racing is one of the fastest growing sports, with increasing numbers of entrants across a wide range of age and abilities. The aim of this observational field study was to describe blood glucose responses during 4-5 days of racing, and examine haemodynamic, autonomic, fluid and electrolyte changes across the race.

Method
Eight participants in two teams, one experienced (aged 55 ± 3 y, body fat 8.6 ± 1.6%) and one inexperienced (aged 35 ± 7 y, body fat 10.9 ± 6.1%), completed 350 km in 120.6 h and 302 km in 111.6 h, experienced and inexperienced, respectively.

Measurements: Continuous blood glucose monitors (Medtronic iPro2 CGM) were inserted on the day prior to the race and remained in place throughout (or until dislodged). All other measures were taken on the day before and within 24 hours following race completion. Blood pressure and heart rate variability (HRV) were analysed across the last 3-min of data obtained during 10 min of seated rest, using beat-to-beat blood pressure (finger photoplethysmography, Finapres) and three-lead electrocardiography (ECG) measures. Urine samples were analysed for solutes using urine specific gravity (USG; Atago, Tokyo, Japan) and Combur10 Test* urine dip sticks (Roche Diagnostics). In addition, venous blood samples were obtained from four participants post race and analysed for oxidative stress, based on Monoaldehyde (MDA) concentration.

Statistics: Changes in [glucose] across the 5 days of racing, and the day before were examined using repeat measures ANOVA (SPSS). Pre- and post-race measures were analysed by paired t-tests, with α set at 0.05.

This project was approved by the Otago University Ethics Committee.

Results
The [glucose] tended toward more time below 4.5 mmol·L⁻¹ as the race progressed (p=0.14); specifically, on days 4 and 5, 39 ± 15 and 58 ± 22% of the day, respectively, was spent below 4.5 mmol·L⁻¹, compared to 16 ± 10% of the control day before the race (p≤0.15). The minimum [glucose] recorded during the race was 3.1 mmol·L⁻¹, and was observed in two participants during long trekking stages. There was neither a trend, nor an appreciable change in mean [glucose] across the 5 days (mean change across days: ~0.2 mmol·L⁻¹, p=0.37). However, the glycaemic
variability (i.e., variation in [glucose] across the day) also tended towards being greater during the days of racing compared to the control day (0.8 ± 0.2 vs. 0.5 mmol·L⁻¹, p=0.16).

Blood pressure was reduced in participants post-race, albeit not reliably so for mean arterial and diastolic blood pressure parameters (p<0.10), while heart rate variability was not significantly altered (Table 1).

Table 1. Measures of blood pressure, heart rate variability and fluid balance obtained from participants before, and after the GODZone adventure race

<table>
<thead>
<tr>
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<th>Pre</th>
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<tr>
<td>Body mass Kg</td>
<td>74 ± 11</td>
<td>76 ± 11</td>
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<tr>
<td>USG</td>
<td>1.018 ± 0.001</td>
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<td>[MDA], µ mol·L⁻¹</td>
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<td>[Na⁺], mmol·L⁻¹</td>
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<td>[K⁺], mmol·L⁻¹</td>
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<td>SBP, mm Hg</td>
<td>119 ± 9</td>
<td>102 ± 23†</td>
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<tr>
<td>DBP, mm Hg</td>
<td>61 ± 17</td>
<td>51 ± 17</td>
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<tr>
<td>LF ms² (nu)</td>
<td>747 ± 467 (67 ± 10)</td>
<td>744 ± 516 (67 ± 15)</td>
</tr>
<tr>
<td>HF ms² (nu)</td>
<td>416 ± 563 (29 ± 11)</td>
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<tr>
<td>LF/HF</td>
<td>2.7 ± 1.4</td>
<td>3.2 ± 2.4</td>
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</tbody>
</table>

All values mean ± SD. USG, urine specific gravity; MDA, Monoaldehyde; Na⁺, urine [Sodium]; K⁺, urine [Potassium]; MAP, mean arterial pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; LF, Low Frequency; HF, high frequency. † Different from control pre-race day measure (p≤0.05)

Following the race, urinalysis revealed traces of protein (n=8), Leukocytes (n=5), ketone bodies (n=4) and urobiolinogen (n=3). There were no significant differences in urine solutes (Na⁺ or K⁺, Table 1) following the race.

Conclusion

While there was an impact on some physiological parameters (blood pressure and blood glucose) others remained within the physiological norms (Heart rate variability, electrolyte balance, body mass). These findings are consistent with previous reports [2] and show that despite the significant stress imposed on the homeostatic regulatory systems during adventure racing, homeostasis is retained for most physiological parameters.

References

Effects of partial sleep deprivation on exertional heat strain: A study for prevention of heat stroke in the construction worker in a hot environment

Ken Tokizawa*, Tetsuo Tai, Tatsuo Oka, Akinori Yasuda, Masaya Takahashi, Shin-ichi Sawada

National Institute of Occupational Safety and Health, Kawasaki, Japan
*corresponding author: tokizawa@h.jniosh.go.jp

Introduction

Heat stroke and illness incidents in exertional workers happen every summer in Japan. Half of the incidents were seen in the construction industry. It is considered that sleep deprivation is one of the risk factors for the development of heat stroke and illness. However, it remains unclear how sleep deprivation affects exertional heat strain in the construction industry and what the coping strategy is. The construction workers maintain moderate exertion from the morning to the evening with 30-min break time each AM and PM and an hour lunch break. Although the ‘siesta habit’ is strongly associated with hot and tropical regions, it is possible that daytime sleep could have a preventive effect on exertional heat strain. The aim of the present study was two-fold: 1) to evaluate heat strain in day-long exertion after a night of partial sleep deprivation, and 2) to examine the effects of taking a nap after lunch on exertional heat strain in the evening.

Methods

Eight healthy subjects were studied on four occasions: following one night of partial sleep deprivation (PS: 4 h, 0200-0600) and normal sleep (NS: 7-8 h), each with or without taking a nap during the experimental day. The laboratory test consisted of 80 min-walking (3.5 km/h) in the hot room (35°C, 40%RH) with a 30-min half time break (28°C, 30%RH) in the morning and evening, respectively. The nap was taken after lunch for 30 min. Rectal and skin temperature, heart rate, blood pressure were continuously monitored. Ratings of thermal sensation, pleasantness, thirst and fatigue sensation, and sleepiness were measured using visual analog scales. The 5-min Psychomotor Vigilance Task (PVT) was conducted before (in the break room) and after (in the hot room) the walking tasks. All the experimental procedures were approved by the Human Research Ethics Committee of the Institute. The study was also conducted in accordance with the guidelines of the Helsinki Declaration.

Results and Discussion

The increases in rectal temperature during walking did not differ between the NS and PS conditions in the morning. However, in the evening, the increase was greater in the PS than in the NS (37.7±0.1°C vs. 37.4±0.1°C, p<0.05). Mean skin temperature was also higher in the PS than in the NS during walking both in the morning and evening (35.5±0.1°C vs. 35.1±0.1°C, p<0.05). No differences were observed in heart rate and blood pressure between the night sleep conditions. The rating score of thermal pleasantness was lowered in the PS than in the NS in the evening (-7.8±0.8 vs. -5.9±1.3, p<0.05). For psychological fatigue and sleepiness, the scores were greater in the PS than in the NS both in the morning and evening (psychological fatigue, 5.4±1.2 vs. 2.4±0.9; sleepiness, 5.3±1.4 vs. 1.2±0.5, p<0.05, respectively). PVT response speed after walking was slower in the PS than in the NS (250±26 ms vs. 198±9 ms, p<0.05), whereas that before walking was not different between the night sleep conditions.

The nap intervention did not affect any physiological parameters in the evening both in the NS and PS conditions. The rating scores of psychological fatigue and sleepiness were less marked following the nap than the no-nap in the PS condition (psychological fatigue, 5.4±1.0 vs. 3.2±1.0;
sleepiness, 5.6±1.4 vs. 2.4±0.6, \(p<0.05\), respectively). Furthermore, the decreased PVT response in the PS was removed by the nap (250±33 ms vs. 205±9 ms, \(p<0.05\)).

Conclusions
These results suggest that partial sleep deprivation augments physiological and psychological strain and reduces vigilance performance in heat. Taking a nap would be effective for reducing psychological strain and inhibiting the decreased vigilance performance.
Effects of ambient heat stress on athletes’ critical power curves

Robert Creasy1*, Remco Muitjens2, Samuel J.E. Lucas1, Paul B. Laursen3, James D. Cotter1
1 University of Otago, Dunedin, New Zealand
2 Wageningen University, Wageningen, The Netherlands
3 High Performance Sport New Zealand, Auckland, New Zealand
*corresponding author: rob.creasy@triathlon.org.nz

Introduction

Many elite triathletes have noted that race performance is hindered and perceived effort increased when racing in temperatures >25°C. In support of such anecdotal reports, marathon performance has been shown to be 2-3% slower when WBGT > 20°C [1]. Further, several triathletes at elite level have been unable to finish races in ambient temperatures >25°C despite being highly motivated to finish. Laboratory-based experiments have shown sprint power output (<10 s) to be greater in warm environments compared with temperate environments due to elevated muscle temperature [2,3], whereas power output over short (3-10 min) [4,5] and prolonged durations (~60 min) [6,7,8,9] is hindered in these environments. The purpose of this study was to determine the impact of ambient heat stress on high-intensity cycling exercise in a warm compared with a temperate environment, across ecologically-relevant critical power curves.

Methods

Participants provided informed consent and completed medical questionnaires for this ethically approved study. Twelve triathletes competing at elite or international age-group level (8 male, 4 female; aged: 24 ± 5 years (mean ± SD); height: 176 ± 8 cm; mass: 68 ± 8 kg; VO2 peak: 59 ± 4 mL·kg⁻¹·min⁻¹) completed cycling simulation trials in COOL (18°C, 40% relative humidity, 760 mm Hg) and HOT (33°C, 60%, 760 mm Hg) laboratory conditions. Performance tests included a 10-s seated sprint, five-minute time trial (5TT), and a 60-minute cycle race simulation (60TT; 1:50 min:s) at first ventilatory threshold, 10 s at 200% Wmax, repeated 20 times (FIXED), then 1:50 at self-selected intensity and 10-s maximal effort repeated 10 times (FREE) on a Velotron cycle ergometer (Racermate, USA). Power output was recorded continuously and collapsed into 1-s bins within Microsoft Excel™. Performances were terminated at exercise completion unless participants reached volitional exhaustion. Repeated-measures ANOVA was used to determine the effect of environment (COOL vs HOT) on power output across the three performance durations (10-s Sprint, 5TT, 60TT). The change in relative power output between environmental conditions is reported as the percentage change ± standard deviation (95% confidence interval).

Results

Overall, there was a trend for an interactive effect between environmental condition and power output across the performance durations (p=0.115). Specifically, no significant difference between environmental conditions for 10-s power output was observed (COOL: 8.76 ± 2.04 (1.16) W/kg, HOT: 9.36 ± 1.86 (1.05) W/kg, p=0.247); however 10 out of 12 participants achieved higher power outputs in HOT. In contrast, power output was significantly higher in COOL for 5TT (COOL: 5.12 ± 0.30 (0.17) W/kg, HOT: 4.94 ± 0.29 (0.17) W/kg, p=0.012) and 60TT (COOL: 3.52 ± 0.24 (0.14) W/kg, HOT: 3.19 ± 0.29 (0.16) W/kg, p<0.001) performance trials.
Discussion

Power output for very short duration (10 s), high-intensity performance for most participants (10/12) was higher in HOT compared with COOL, though the difference was not significant. This finding is consistent with pervious research involving sprint cycling performance and is likely attributable to elevated muscle temperature [3]. However, power outputs for 5TT and 60TT were significantly lower in HOT compared with COOL. The mechanisms underpinning reduced power output may include decreased cardiac output and reduced oxygen delivery [5,10] for 5TT, and central nervous system fatigue [5,11] and reduced oxygen delivery and energy turnover in contracting skeletal muscle for the 60TT [5].

Conclusions

Participants produced different power outputs over time in COOL vs HOT conditions. Short-duration high-intensity (5TT) and prolonged (60TT) duration high-intensity cycling power outputs were significantly reduced in warm environmental conditions, with no difference for 10s sprint.

References

Substrate oxidation and muscle adaptations in ultra-endurance exercise

Jørn Wulff Helge
Xlab, Centre for Healthy Aging. Dept. of Biomedical Sciences, Univ. of Copenhagen, Denmark.
Corresponding author: jhelge@sund.ku.dk

During exercise, energy production is sustained primarily by oxidation of carbohydrate and fat, whereas the oxidation of protein is negligible and remains unaltered under normal exercise conditions. The substrate utilisation during exercise is influenced by several factors; exercise intensity, mode, duration, training status and the endogenous substrate stores. Despite extensive effort, the mechanisms that control substrate partitioning during exercise are still not fully resolved. During very prolonged exercise – whether of a repeated or sustained ultra-endurance exercise pattern - the ability to maintain substrate stores and energy balance will have a key influence on substrate oxidation and the ability to maintain work output. In a recent study, we followed six older men who biked 2770 km in 14 days; studying their adaptation and response towards performing 10 to 11 hours of exercise per day. The present talk will use these new data as a starting point in focusing on the substrate oxidation during such exercise and the muscle adaptations incurred by prolonged repeated exercise and ultra endurance exercise.
Musculoskeletal symptoms and their associations with ergonomic physical risk factors of the women engaging in regular rural household activities: A picture from a rural village in Bangladesh

Saleh Ur Rahman*, Monjurul Habib
Department of Occupational Therapy, Bangladesh Health Professions Institute, Centre for the Rehabilitation of the Paralysed
*corresponding author: Bappy_crp@yahoo.com

Introduction
This study explored the prevalence of Musculoskeletal Symptoms (MSS) and the work disruption due to them, commonly affected body parts and the association of MSS with the ergonomic physical risk factors among women engaging in regular household activities in a rural village of Bangladesh.

Methods
Participants were women involved in regular household activities aged from 20-45 years of a small village in Bangladesh. A total of 73 women were surveyed through door-to-door home visits. The Standardized Nordic Questionnaire (SNQ) was used to determine the prevalence of MSS. Then, 46 women was found who have MSS which were assessed by using the Musculoskeletal Disorder (MSD) risk assessment provided by the Industrial Accident Prevention Association (IAPA) 2009, in order to determine the association between physical risk factors and MSS.

Results and Discussion
From the 73 women initially surveyed, 50 (68.49%) women reported having MSS during last 12 months and 37 (50.7%) of the respondents were prevented from normal daily activities due to MSS. Most commonly affected regions were upper and lower back, wrist, knees and elbows. Awkward posture, bending, repetition, lifting and working in squatting position were associated with the prevalence of MSS in different body parts of the women.

Musculoskeletal symptoms and disorder related problems are highly prevalent among different workforces around the world. However data from developing countries is very limited. Women are at a higher risk for developing musculoskeletal symptoms than men [1] for reasons including: biological factors [2], structural differences of the body [3, 4], structure of the tissue [5] and strength [6]. Through literature review, it was found that studies related to musculoskeletal symptoms and or disorders of the women engaging in household activities are limited [7-11]. In a study conducted in Hong Kong [12], 60% of homemakers had at least one musculoskeletal symptom in any part of the body, and importantly over the spine, upper or lower extremities in the 12 months preceding the study. Out of 1266 married full-time homemakers in Lebanon 2002-2003 [13], 19% reported having at least one musculoskeletal disorder. Another study also conducted in the same year in Lebanon [14] reported that 305 (32%) married women of total 1869 whose age ranged between 15-59 years reported musculoskeletal problems as their most important health concern, and 66% of them considered their problems as chronic. It was also reported from one of the studies conducted in Lebanon that 77% women who mostly came from low-income families and had not completed secondary school reported having musculoskeletal pain in a twelve months prevalence [13].

Conclusion
The prevalence rate of self reported musculoskeletal symptoms among the respondents was found to be considerably high and it lasted for over a year for majority of the respondents. More
importantly, they reported that they were prevented from their regular daily activities during last 12 months due to the musculoskeletal symptoms. Various physical risk factors particularly awkward posture, bending, repetition, lifting and working in squatting position were associated for musculoskeletal symptoms in different body parts. This study is the first of its kind in Bangladesh, further research is needed.

References
Effects of different colours of monochromatic light on time perception

Tetsuo Katsuura\textsuperscript{1*}, Ya-li Xia\textsuperscript{1}, Soomin Lee\textsuperscript{1}, Yoshihiro Shimomura\textsuperscript{1}, Naoshi Kakitsuba\textsuperscript{2}

\textsuperscript{1}Chiba University, Chiba, Japan
\textsuperscript{2}Meijo Unilever, Nagoya, Japan

\*corresponding author: katsu@faculty.chiba-u.jp

Introduction
Light has a wide range of effects on living things including human beings. For example, the light-dark cycle of sunlight repeated every 24 hours is a key factor in our body’s 24-h circadian rhythms. It is a well-known fact that light affects not only psychological functions but also physiological functions. Therefore, the light environment is one of the most important factors of the human environment.

It has been reported that the perception of short-interval timing is affected by several psychological and physiological factors—e.g., age [1] [2], sex [1], time of day [3], and the menstrual cycle [4]. However, it has not been confirmed whether the light environment affects the time perception of short intervals.

In our previous study [5], we measured the effects of monochromatic light on time perception and the central nervous system of nine subjects who were exposed to red and blue fluorescent light, and found that the 180-s produced time interval (i.e., subject’s perception of 180 s) was significantly shorter in the red-light condition than the blue-light condition. However, the number of the subjects in the study was limited, and the spectral distribution of the light source was rather broad.

Therefore, we thought it was necessary to further study the effects of monochromatic light on the time perception by using a light source of narrow spectral distribution, and more subjects. We also measured a central nervous system factor to clarify the mechanism of the influence of light on the time perception.

Methods
Twenty healthy young male volunteers with dark eyes participated in the present study. They were screened for normal color vision, using the Farnsworth Munsell 100 Hue Test. Each subject gave his informed consent to participate in the study. The Ethics Committee of the Graduate School of Engineering, Chiba University approved the protocol of the study. Subjects’ physical characteristics were (mean ± SD) age: 26 ± 4 years, body height: 173 ± 6 cm, body mass: 69 ± 7 kg.

| Table 1. Characteristics of each monochromatic light condition. |
|-------------------|--------------------|-----------------|-------------------|-------------------|
| Peak wavelength (nm) | Full-width at half-maximum (nm) | Irradiance (μW/cm\(^2\)) | Photon density (10\(^{12}\) photons/cm\(^2\)/s) | Photopic illuminance (lx) |
| Blue | 458 | 19 | 49.9 | 116.2 | 27.9 |
| Green | 503 | 28 | 49.9 | 127.9 | 160.7 |
| Yellow | 591 | 14 | 50.2 | 148.9 | 258.5 |
| Red | 659 | 16 | 50.1 | 165.2 | 32.4 |

The experiment was conducted in a climatic chamber in which the air temperature and relative humidity were set at 25 °C and 50%, respectively. Each subject sat on a chair with his head facing a
“ganzfeld” or full-field dome in which light-emitting diodes (LEDs) were arrayed on a uniform, patternless reflecting surface. The subject was exposed to blue (peak wavelength = 458 nm), green (503 nm), yellow (591 nm) and red (659 nm) monochromatic light using LEDs installed in the ganzfeld dome. The irradiance of the four types of monochromatic light at the subject’s eye level was almost the same, around 50 µW/cm² (Table 1).

During the first 26-min exposure, the subject sat quietly in a relaxed manner, and faced the ganzfeld dome at about 30 cm distant from the opening of the dome. Then, he moved his face closer to the ganzfeld dome to ensure that the light irradiated his entire visual field, and gazed at a fixed target dot in the center of the dome for 26 min. The subject conducted an oddball task to extract P300 event-related potentials and a 180-s time-production task during this period.

For the oddball task, standard (1000 Hz, 70 dB SPL) and target (2000 Hz, 70 dB SPL) auditory stimuli were presented through a headphone. The target stimuli occurred randomly with a 0.2 probability. The subject was instructed to react to the target stimulus as quickly as possible by pressing a key. Electroencephalogram (EEG) activities at Fz, Cz, and Pz were measured by a biological amplifier system. The band pass filter was set at 0.032-30 Hz, and the EEG signals were digitized at a sampling rate of 1000 Hz for 600 ms with a pre-stimulus baseline of 100 ms. The P300 waveforms were averaged from at least 25 artifact-free recordings. The P300 amplitude was measured relative to the pre-stimulus baseline and was defined as the largest positive-going peak occurring within the latency between 250 and 500 ms.

After the oddball task, the subject was asked to produce a 180-s time interval by pressing a stopwatch button. The display of the stopwatch was covered by a seal to mask the time indicators. The subject started the stopwatch at the cue of the experimenter and stopped it when he thought that 180 s had passed. The subject received no feedback at any point during the experiment.

The P300 waveform for four subjects could not be obtained, so the P300 data from the other 16 subjects were analysed. One-way repeated measures ANOVA was used to evaluate the effects of the monochromatic light condition on these measurement values. When any significant effect was found, multiple comparisons of the monochromatic light condition were performed using the Bonferroni procedure. The level of statistical significance was set at 0.05.

The experiments were carried out during 1000 h-1200 h, 1300 h-1500 h or 1500 h-1700 h in June and July. The experiments with the four monochromatic light conditions for each subject were conducted at the same time period but on four different days. The order of the four monochromatic light conditions was counterbalanced among the subjects.

Results and Discussion
Figure 1 shows the 180-s time intervals produced by 20 subjects in the four monochromatic light conditions. The main effect of the color of monochromatic light on the 180-s produced time interval was significant ($p=0.013$). The 180-s produced time interval in the red-light conditions was found to be significantly ($p=0.002$) shorter than that in the blue-light condition. This results are consistent with our previous study, which showed that the 180-s produced time interval in red fluorescent light was significantly shorter than that in blue fluorescent light [5].
The main effect of the monochromatic light condition for the peak latency of P300 was not found to be significant. However, the main effect of the monochromatic light condition for the amplitudes extracted at Fz was significant \((p=0.038)\). The P300 amplitude in the red-light condition \((15.0 \pm 4.2 \, \mu V)\) tended \((p=0.081)\) to be larger than that in the blue-light condition \((11.1 \pm 4.0 \, \mu V)\) as shown in Figure 2. In our previous study, we could not find significant effects on the P300 amplitude, but found that the P300 latency in the red-light condition was significantly shorter than that in the blue-light condition [5]. In general, it is recognised that a larger P300 amplitude and a shorter latency indicate higher activity level of the cortex [6].

Using fMRI and EEG, Ueda et al. [7] measured the brain activity of subjects who watched the reflections of red, blue, and white colors created on a computer monitor. They found that the priority of excitement intensity was red>white>blue in Brodmann’s area 17 (the primary visual
area) of the occipital lobe and that the EEG beta wave intensity in the occipital lobe was red>white>blue. These findings showed that the activity level of the cortex might be higher in red-light than in blue-light exposure.

It can be assumed that the higher level of brain activity in the red-light condition might accelerate the endogenous clock. Morell [8] suggested that the interval timing clock is located in the structures of the brain called striato-cortical loops—i.e., the neural network including the frontal cortex and basal ganglia (caudate nucleus, putamen, substantia nigara, etc.). This means that the level of cortex activity could affect the interval timing clock. Although the precise mechanism is unknown, it is assumed that the visual pathway (retina - lateral geniculate body - primary visual cortex) might be involved in this effect. This supposition is supported by the result of fMRI measurements showing that excitement in the primary visual cortex was higher in red color exposure than in blue [7].

Conclusions
We confirmed the effects of monochromatic light on time perception of short intervals and brain activity, using LEDs with a narrow spectral distribution in 20 subjects. The visual pathway might be involved in this effect.

Acknowledgements
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