THE INFLUENCE OF THE RATE OF TORSO SKIN TEMPERATURE CHANGE ON THERMAL PERCEPTIONS WHILST EXERCISING IN THE HEAT

Sarah L. Davey, Martin J. Barwood, Michael J. Tipton

University of Portsmouth, Department of Sports & Exercise Science, Portsmouth, UK.
Contact person: sarah.davey@port.ac.uk

INTRODUCTION

It is well established that regional cooling using personal cooling garments, such as ventilated or water perfused garments, can reduce thermal strain and improve thermal comfort whilst working or performing physical activity in a hot environment (McLellan *et al*, 1999). Traditionally, regional cooling delivered by personal cooling garments has been provided in a continuous manner. However, recently it has been reported that providing regional cooling intermittently is just as effective in reducing thermal strain as continuous cooling (Vernieuw *et al*, 2007). Providing cooling intermittently improves the overall power efficacy of the garments, therefore decreasing their reliance on heavy duty batteries, which results in a longer duration, more user friendly, garment. Even though the physiological effects of intermittent cooling in personal cooling devices worn during exercise have been established, its' effect on thermal perceptions is less well-known. To the authors' knowledge, results from the small amount of research undertaken indicate that intermittent cooling has the same effect on thermal perceptions as to continuous cooling (Vernieuw, *et al*, 2007). This is surprising considering the effects of regional fluctuating temperatures on thermal perceptions whilst people are at rest in moderate to hot conditions. Whilst the method of cooling maybe different i.e. not delivered by a cooling garment, fundamentally, fluctuating temperatures have been perceived as either more or less comfortable than continuous cooling (Tanabe & Kimura, 1984, Zhao, 2006), with the dynamic activity of the cutaneous thermoreceptors generally being used to explain this effect.

Thermal sensation is dependent upon several factors including: adapting temperature; rate of temperature change; absolute temperature change; area of stimulus and duration of stimulus (Hensel, 1981). The disparity in the perceptual responses to fluctuating regional cooling during exercise and when at rest, may be due to one of these factors. The aim of this investigation was to determine the influence of one of these factors, the rate of skin temperature change (specifically that of the torso) on thermal perception. It was hypothesised that thermal perceptions will have a positive correlation with both rate of torso temperature and absolute skin temperature change.

METHODS

Following ethical approval and written consent, a group of 12 physically active male participants (20.3 [1.3]yrs, 72.34 [8.26]kg, 1.80 [0.07]m, BSA = 1.92 [0.13]m^2 and Body fat = 15.19 (4.71) %) completed three, single blind, trials, in which they exercised at a moderate intensity (~30% $\dot{V}O_{2\,peak}$) in a hot environment (35^{o}C, 50% RH) for approximately 70 minutes. Each trial was separated by 2-4 days to eliminate any effects of acclimation and the order of the trials was randomly assigned (Latin square method). To investigate the effects of rate of torso skin temperature change on thermal comfort, the participants wore an air cooled vest (ACV) underneath a long sleeved cotton t-shirt and jogging trousers. After the participants ran for 10 minutes to reduce the time to reach thermal stability, the ACV was perfused with air that was at ambient (room) temperature (~35^{o}C [Air$_{amb}$]) for a period of 10 minutes to allow skin temperatures to stabalise. The flow rate of the air was 12 ft^{3}.min^{-1} and had a relative humidity of ~14%. To produce different rates of torso skin temperature change, the ACV was then ventilated for two periods (Cooling period 1 and Cooling period 2) with one of three lower temperatures (~15^{o}C [Air$_{15}$], ~20^{o}C[Air$_{20}$] and ~26^{o}C [Air$_{26}$]). Each period was separated by 15 minutes where the ACV was ventilated with Air$_{amb}$. Each trial was similar in that the cooler air was continuously ventilated until the abdominal skin temperature decreased by 2-3^{o}C.

Overall thermal comfort (TC), torso thermal comfort (TTC), temperature sensation (TS) and torso temperature sensation (TTS) were assessed by visual analogue scales (Davey *et al,* 2007), before the onset of exercise, after the 10 minute run, and before and after the cooling periods. Other measurements included rectal temperature (T_{re}), local skin temperatures ($T_{abdominal}$, $T_{oblique}$ T_{chest}) mean skin temperature ($\overline{T}_{skin}$) and mean torso temperature ($\overline{T}_{torsoskin}$).

Statistical analyses

The data were analysed using one-way and two-way analyses of variance for repeated measures. A $T_{abdominal}$, fall of 2^{o}C was achieved in all the trials, with a fall of 3^{o}C only being obtained in Air$_{15}$, Air$_{20}$, therefore the thermal perceptions between the three trials was compared at a 2^{o}C fall. To investigate the effects of absolute temperature, thermal perceptions were also compared in Air$_{15}$, Air$_{20}$ between the falls of 1, 2 & 3^{o}C in $T_{abdominal}$,. A significant *F*- test was further analysed with a Bonferroni post hoc test to detect differences among means. Statistical significance was set at a level of $\alpha < 0.05$. The data are presented as mean (SD).

RESULTS

Deep body and Skin Temperatures

The initial and final rectal temperatures were similar between the three conditions with an average increase of 0.66 (0.34)^{o}C to 38.12 (0.40)^{o}C (P>0.05). The initial and final local skin temperatures, $\overline{T}_{skin}$ and $\overline{T}_{torsoskin}$, were also similar between the three trials, between the cooling periods, and for each the temperature drops of 1 and 2^{o}C in $T_{abdominal}$ (P>0.05). Figure 1 illustrates the skin and rectal temperature responses typically experienced by the participants in response to Air$_{15}$, Air$_{20}$ and Air$_{26}$.

During cooling period 2, the rates of $\Delta\overline{T}_{skintorso}$ significantly differed between the three trials (Air$_{15}$ = -0.00820 [0.0018]^{o}C.s^{-1}, Air$_{20}$ = -0.00513 [0.0006]^{o}C.s^{-1}, Air$_{26}$ = -0.00223 [0.0006]^{o}C.s^{-1} [n=6]) (P<0.05). In cooling period 1, the rates of $\overline{T}_{skintorso}$ change differed between the three rates, except for Air$_{15}$ and Air$_{20}$ (P> 0.05) (Air$_{15}$ = -0.00630 [0.0007]^{o}C.s^{-1}, Air$_{20}$= -0.00465 [0.0009]^{o}C.s^{-1}, Air$_{26}$ -0.00250 [0.0005]^{o}C.s^{-1} [n=6]).

In both the cooling periods, there was a significant difference in the rate of $\overline{T}_{skin}$ decline between the three trials, (P< 0.05), except for between Air$_{20}$ and Air$_{26}$ (P> 0.05). The mean rates of change in $\overline{T}_{skin}$ in cooling period 1 were; Air$_{15}$ = -0.00233 (0.0004) ^{o}C.s^{-1}, Air$_{20}$ = -0.00137 (0.0006) ^{o}C.s^{-1}, Air$_{26}$ = -0.00121 (0.0006) ^{o}C.s^{-1} (n=6).

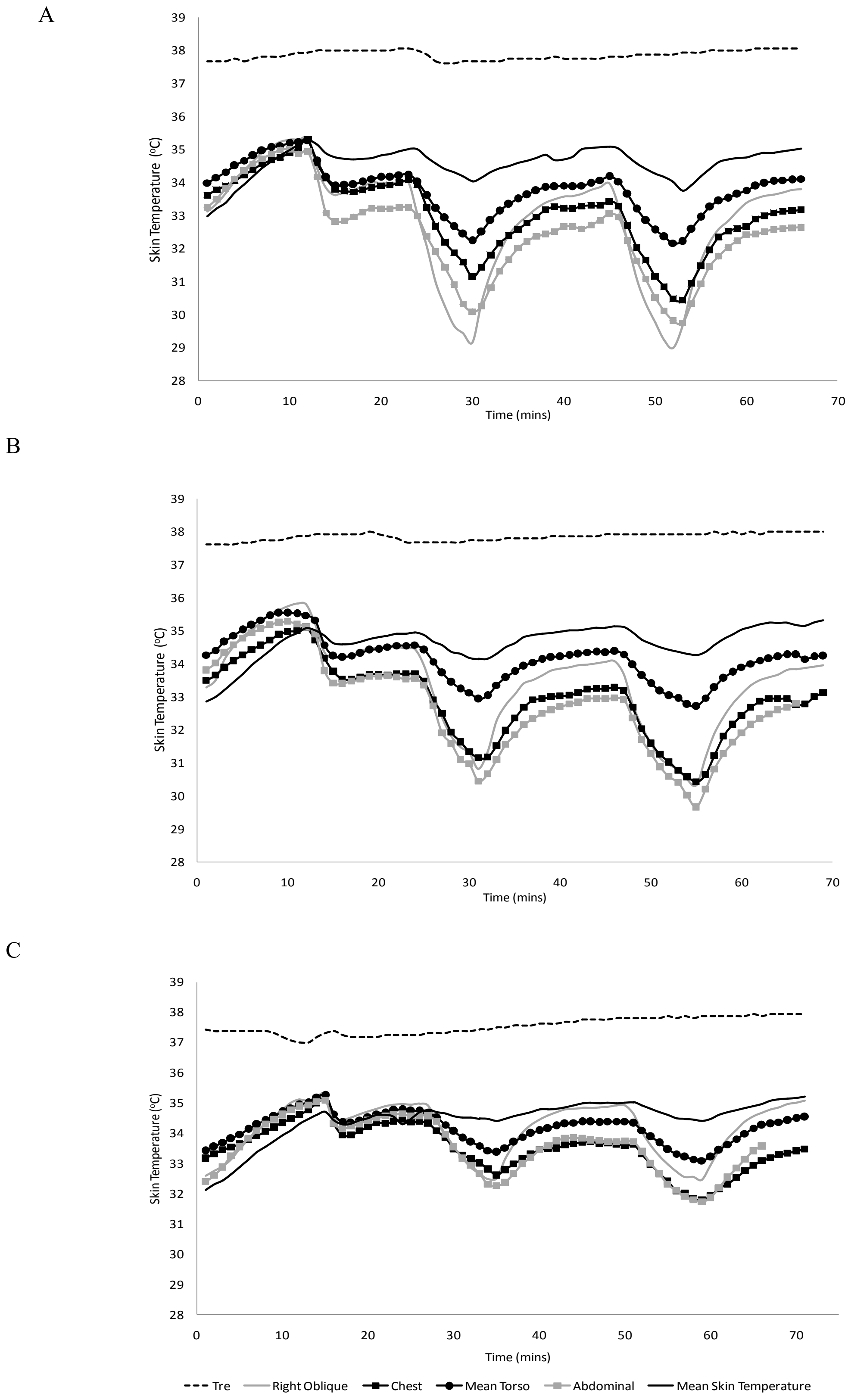

Figure 1. Comparison of one participant's (#8) skin temperature responses to the three different Air Temps. A= Air$_{15}$, B= Air$_{20}$ and C = Air$_{26}$. The initial drop in temperature corresponds to the initial insertion of air, whilst the subsequent two drops in skin temperatures correspond to the two cooling periods of cooled air.

The rates of change in $\overline{T}_{\text{skin}}$ and $\overline{T}_{\text{skintorso}}$ were significantly greater when Air_{amb} was initially ventilated through the ACG, than that seen with the air cooled period that elicited the largest perceptual response; $\overline{T}_{\text{skin}}$ = -0.00469 (0.0021)^{o}C.sec^{-1} vs. -0.0023 (0.0004) ^{o}C.sec^{-1}and $\overline{T}_{\text{skintorso}}$ = -0.01300 (0.004)^{o}C.s^{-1} vs. -0.00630 (0.0007)^{o}C.s^{-1}($P<0.05$).

Thermal Perceptions

The initial jog of 10 mins made all the participants hotter and more uncomfortable than when at rest (TTC = Just-uncomfortable, 100.89 [35.96]; TC = Just- uncomfortable, 98.39 [35.00]; TTS = Hot, 133.63 [13.52]; TS = Hot, 131.14 [13.46]). Fifteen minutes after the ventilation of Air_{amb} into the ACG the participants were cooler and more comfortable (TTC = Just-comfortable to Just-uncomfortable, 71.50 [31.73]; TC = Just-comfortable to Just-uncomfortable, 77.47 [31.59]; TTS = Slightly warm 95.69 [25.99]; TS = Slightly warm to Warm, 105.77 [23.01], with an average decrease of -28.88 (22.49), -20.92 (18.75), -37.94 (22.47), -26.91 (18.16), respectively.

The rate of skin temperature decline in $\overline{T}_{\text{skin}}$, $\overline{T}_{\text{skintorso}}$ or $T_{\text{abdominal}}$ had no significant influence on any of the thermal perceptions (TC, TTC, TS and TTS) during both cooling periods ($P>0.05$) ($n=9$). The largest thermal perceptual changes produced by Air_{15}, Air_{20} and Air_{26} were, TTC = -19.00 (19.97), TC = -10.29 (14.40), TTS = - 30.29 (25.52), TS = -19.57 (17.32), which were not statistically different to that produced by the initial ventilation of Air_{amb} after the ten minute jog ($P>0.05$) ($n=9$).

Significant improvements in TTS, TS and TC were found as absolute Δ $T_{\text{abdominal}}$ increased ($P<0.05$) (n=9). However, these improvements were not meaningful as the mean differences in the thermal perceptions between the 1^{o}C falls in $T_{\text{abdominal}}$ were lower than that of the variability of the VAS.

In post-trial interviews, all of the subjects commented that the largest improvement in their thermal comfort was experienced in response to the initial ventilation of Air_{amb} after the run. Interestingly, five of the subjects stated that the potential effect of the ACG on overall comfort was negated by the hot and sweaty sensations felt in the rest of the body, especially in the hands and head. Some commented that the contrast of having a cool, dry torso, but hot and sweaty rest of the body, felt strange and unpleasant.

DISCUSSION & CONCLUSIONS

The main finding from this study is that the rate in mean torso skin temperature, decreased by intermittently ventilating an air cooled vest with ambient and cool conditioned air (i.e. air that has been cooled), does not significantly influence thermal perceptions of the whole body or torso. Therefore, the first experimental hypothesis is rejected. However, the results do suggest that that a rate of fall in torso skin temperature between -0.0046 ^{o}C.sec^{-1} and -0.0130 ^{o}C.sec^{-1} is required to significantly improve thermal perceptions and this can be achieved with the simple addition of ambient air, rather than energy consuming conditioned air. The second experimental hypothesis was also rejected, as an absolute temperature of between 1-3^{o}C also did not have any meaningful influence on perceptual measures. Several factors may help explain these results.

The magnitude of difference between the different rates in mean torso skin temperature change may not have been large enough to illicit signals that differed by sufficient magnitudes to be translated into significantly different thermal perceptions. The same reason may account for the insignificant result found in absolute change in local skin temperature; a previous investigation found that during regional cooling an absolute temperature decrease of between 3-5°C is required to illicit significant changes in thermal perceptions (Zhang, 2003).

The inability to distinguish between the three different rates of decline in skin temperature may have been confounded by the temperature and skin-wettedness sensation of the rest of the body, especially that of the head. The skin temperature of the face is reported to be one of the most influential regions for overall thermal comfort, and is more sensitive to temperature than the torso (Zhang, 2003; Zhang & Zhao, 2006). Unlike, temperature sensation, overall skin wettedness (caused by an increase in water vapour pressure) has recently been found to have more of an influence overall thermal comfort than local skin-wettedness. It was also found that the extremities were more sensitive to skin wettedness than that of the torso (Fukazawa & Havenith, 2009). In addition, non-uniformity in the feeling of temperature sensation within the bodily regions can increase thermal discomfort (Fanger, 1970).

REFERENCES

Davey, S., Reilly, T., Newton, M., Barwood, M., Tipton, M. (2007) The reproducibility and validity of visual analogue scales (VAS) that assess thermal perceptions in stable and dynamic, asymmetric environments. *Proceedings of the 12th International Conference of Environmental Ergonomics*. August 19-24, 2007, Piran Slovenia.

Fanger, P.O. (1970) Thermal Comfort: Analysis and Applications in Environmental Engineering. McGraw-Hill, New York.

Fukazawa, T & Havenith, G. (2009) Differences in comfort perception in relation to local and whole body skin wettedness. *Eur J Appl Physiol*. 106: 15-24.

Hensel, H. (1981) *Thermoreception and temperature regulation*. Academic Press, London. (Monographs of the physiological society; nr. 38).

McLellan, TM., Pope, JL., Cain, J.B., Cheung, S.S. (1999). Effects of metabolic rate and water vapour pressure on eat strain in protective clothing. *Eur J Appl Physiol Occup Physiol*. 74 (6): 518-27.

Tanabe S and Kimura, K. (1994) Effects of air temperature, humidity, and air movement on thermal comfort under hot and humid conditions. ASHRAE trans 100. Pt 2 p 953 - 969.

Vernieuw, C.R., Stephenson, L., Kolka, M. (2007) Thermal comfort and sensation in men wearing a cooling system controlled by skin temperature. *Human Factors* 49 (6): 1033-1044.

Zhang, H. (2003) Human Thermal Sensation and Comfort in Transient and Non-Uniform Thermal Environments. PhD Thesis. University of California, Berkley, CA, 94720-1839, USA.

Zhang, Y. & Zhao, R. (2006) Effect of local cooling on human responses I - Effect of local thermal sensation on overall thermal sensation. *Proceedings of healthy buildings*. 75-80.

Zhou, X., Ouyang, Q., Lin., G., Zhu, Y. (2006) Impact of dynamic airflow on human thermal response. *Indoor air* 16: 348-355.