

Physiological, perceptual and cognitive responses to conducting nuclear decommissioning related activities when wearing a pressurised breathing air suit (PBAS) in moderate and hot conditions.

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INTRODUCTION

When conducting nuclear decommissioning activity workers wear an airfed encapsulating impermeable suit, known as a pressurised breathing air suit (PBAS), to protect against particulate material. Although ventilation reduces thermal strain (Raven *et al.*, 1979), the impervious nature of these garments reduces heat transfer and dependent on specific working conditions (e.g. work rate and environmental temperature; Rowlands, 1970) could result in the worker experiencing uncompensable heat stress (UHS) and the associated impairments of physical and psychological performance (UHS; Cheung *et al.*, 2000). Accordingly the need for combined physiological and psychological investigations to understand the magnitude of risk involved and how risk may vary with shift duration and different environmental conditions has been highlighted in a recent review (Frost and Mogridge, 2008). Although the evaluation of airfed suit use over a range of ambient temperatures has been recommended for at least thirty years (Raven *et al.*, 1979) there is no recognised industry specific protocol or standard to apply when evaluating physiological and psychological responses to decommissioning activity when wearing airfed suits. Therefore the aim of this study was to design and implement a nuclear decommissioning job related activity protocol and to describe the physiological, perceptual and cognitive responses of PBAS wearers during moderate (20°C) and hot (40°C) temperatures.

METHODS

With local ethical committee approval six healthy and non acclimated male participants (age mean \pm SD = 25 \pm 7 years; body mass = 74.3 \pm 7.1 kg) undertook, whilst wearing a pressurised breathing air suit (PBAS; Professional Protection Systems, UK) with an air supply of 180 L·min⁻¹, one habituation (HB) trial at 20°C and two experimental trials conducted at 20°C and 40°C in a randomised cross-over type design. Laboratory visits were separated by at least one week and were at the same time of day on each occasion.

The protocol was defined by conducting a job task analysis. This was based on the investigators reviewing footage of decommissioning work, discussion with two experienced operatives and a review of literature relevant to this task (e.g. Davies, 1962). After the protocol was designed (outlined below) it was performed by a practising nuclear decommissioning

operative who reported it to be representative of the type of activities, work: rest intervals and exercise intensities commonly experienced during decommissioning tasks.

The protocol consisted of conducting six 30 min activity cycles (3 hr total duration) of job related tasks within a 5 m × 4 m enclosed area. In brief each activity cycle consisted of 4.5 min lifting and walking (6 × 45 sec circuits incorporating holding a cutting tool whilst walking forward and back along a 2.5 m ladder, marked on the floor, with 6 equally spaced rungs; lifting a 10 kg weighted box from a 1.5 m surface to the floor and back again in a standardised manner); 5 min stepping activity (25 cm box at 14 steps·min⁻¹); 5 min standing rest; 5 min manual dexterity task (consisting of unscrewing nuts from bolts of decreasing sizes [12, 10, 8] from a 10 mm thick vertical surface using a round ended spanner and screwing them up again on an opposite panel; performance was scored against defined criteria with a maximum score of 12 being available); the final 10 min of each 30 min cycle incorporated a touch screen based psychological test (spatial working memory [SWM]; Cantab, Cambridge Cognition, UK; ≈6 min to complete) with any remaining time spent standing at rest. Rates of lifting and walking and stepping were controlled by instructing participants to move on the beat of a metronome (56 beat·min⁻¹; Seiko DM-20, Japan). All participants were familiarised with the timing of activities and the SWM test prior to conducting any trials.

Heart rate (HR; Polar Vantage, Finland), rectal temperature (T_c) and mean skin temperature (T_{sk} ; Grant Instruments, Cambridge, UK) were monitored continuously and recorded in the last 30 sec of each component of the activity cycle. Evaporative efficiency was estimated as the change in dressed mass divided by the change in nude mass. Heat storage was calculated according to Havenith *et al.*, (1995). Rating of perceived exertion (RPE; 6-20 scale) was sought during the final 30 sec of stepping activity and thermal sensation (TS) and thermal comfort (TC) were requested on 9 point 0-8 scales during the first minute of the rest period. General symptoms were sought (0 none to 3 severely incapacitating) for headache, sickness, dizziness, mental confusion, tiredness and difficulty breathing. A physiological strain index (PhSI) was calculated from normalised increases in HR and T_c and a perceptual based strain index (PeSI) was calculated from normalised increases in RPE and TS, both of which are described on a 0 (no strain) to 10 very high strain) scale (Tikusis *et al.*, 2002).

A general linear model analysis of variance (ANOVA) was applied to examine main effects for condition (differences between habituation, 20 and 40°C trials), activity cycle (changes between activity cycles within each trial) and condition × activity cycle (differences in the pattern of change over time between habituation, 20°C and 40°C trials). When a significant P value ($P \leq 0.05$) was obtained Tukey post hoc analysis was used to locate significant differences between individual groups (e.g. 20°C vs. 40°C) and across condition comparisons between activity cycles (e.g. 20°C cycle 6 vs. 40°C cycle 6).

RESULTS

All participants completed the 20°C trial (180±0 min) whereas two participants failed to complete the 40°C trial (165±26 min). Thermal variables were very similar in the 20°C HB compared to the 20°C experimental trial. However HR was greater ($P < 0.05$) throughout the HB trial at rest (e.g. cycle 6, 119±12 vs. 101±20 bt·min⁻¹) and whilst stepping (cycle 6, 157±13 vs. 138±17 bt·min⁻¹) highlighting the importance of including the HB trial prior to comparing responses to 20°C vs. 40°C in the cross-over study.

HR and T_{sk} were higher ($P<0.05$) in 40°C compared to 20°C by the end of the first lifting and walking activity and continued to diverge thereafter. However it took in excess of 45 min for T_c in 40°C to increase beyond that in 20°C. Physiological and perceptual variables were higher in 40°C compared to 20°C trials for the remaining duration with the largest difference occurring in the final activity cycle (Table 1). Physiological strain (Figure 1) increased with duration in the

Table 1: Physiological and perceptual variables (\pm SD) from activity cycle 6 at 20°C and 40°C.

Variable	20°C		40°C	
	Rest	Stepping	Rest	Stepping
Rectal Temp (°C) ^{#, †, ϕ}	37.76 \pm 0.41	37.78 \pm 0.44	38.25 \pm 0.40	38.32 \pm 0.34
Mean Skin Temp (°C) ^{#, †, ϕ}	34.11 \pm 0.88	34.27 \pm 1.06	36.39 \pm 0.70	36.72 \pm 0.66
Heat Storage (J·g ⁻¹) ^{#, †, ϕ}	0.59 \pm 0.87	0.71 \pm 0.82	2.76 \pm 0.56	3.05 \pm 0.44
HR (bt·min ⁻¹) ^{#, †, ϕ}	101 \pm 20	138 \pm 17	140 \pm 10	172 \pm 9
PhSI ^{#, †, ϕ}	2.4 \pm 1.1	3.7 \pm 1.2	5.6 \pm 0.8	6.9 \pm 0.7
RPE Overall [†]	-	15 \pm 3	-	15 \pm 4
Thermal Sensation ^{#, †, ϕ}	5.5 \pm 1.1	5.7 \pm 1.1	7.0 \pm 0.9	7.5 \pm 0.6
Thermal Comfort ^{#, †}	5.3 \pm 1.1	5.6 \pm 1.1	6.9 \pm 1.0	7.3 \pm 1.0
PeSI ^{#, †, ϕ}	-	6.8 \pm 1.6	-	7.9 \pm 1.4

[#] main effect for condition; [†] main effect for cycle; ^{ϕ} interaction condition \times cycle ($P\leq 0.05$).

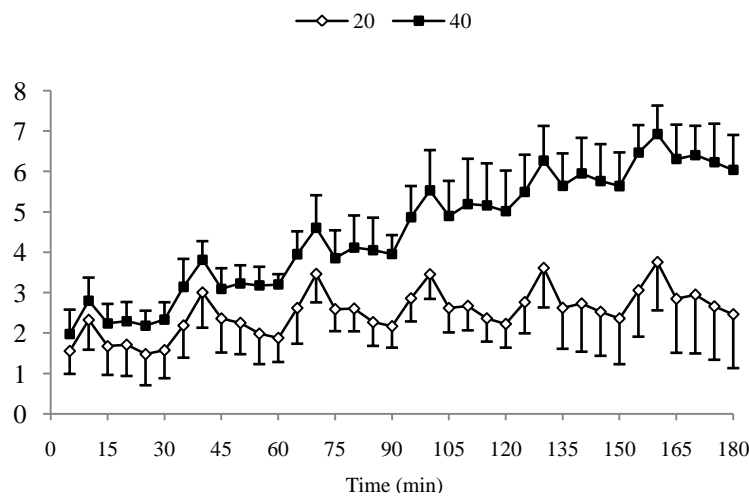


Figure 1: PhSI (\pm SD) in the last minute of each activity throughout both 20°C and 40°C trials (6 \times 30 min activity cycles). 20°C vs. 40°C $P<0.01$.

40°C trial, commensurate with a greater rate of heat storage (Table 1), compared to relatively consistent values from the third cycle onwards in 20°C indicating that heat balance was achieved. Perceptual strain (Figure 2) was higher in 40°C in the first activity cycle (4.5 ± 0.8 vs. 5.5 ± 0.9 in 20°C) and then increased at a similar rate in both conditions for the remainder of the trial period (Table 1). Although sweat loss doubled in 40°C (1.5 ± 0.5 vs. 0.8 ± 0.3 L in 20°C) evaporative efficiency did not vary (0.7 ± 0.2 in 40°C vs. 0.7 ± 0.3 in 20°C).

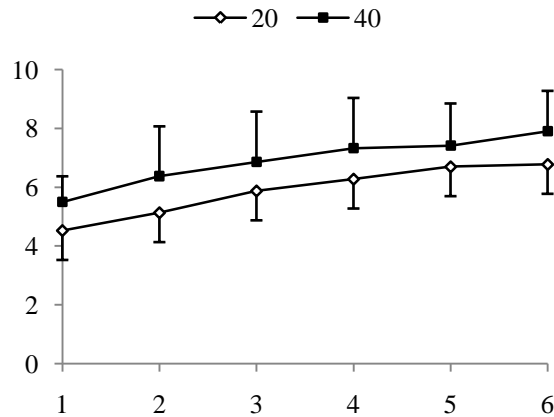


Figure 2: PeSI (\pm SD) in each activity cycle (calculated from HR in stepping and T_c recorded at rest in the following stage) throughout both 20°C and 40°C trials (6×30 min activity cycles). 20°C vs. 40°C $P < 0.01$.

General symptoms were nominal at 20°C however, amongst other things tiredness, sickness and headache symptoms were particularly prevalent from 2 hours onwards in the 40°C. In addition participants reported feeling ‘irritable’ and becoming confused, particularly during the walking and lifting task at this point in 40°C. The total number of errors in the SWM test had also increased ($P < 0.05$) by cycle 4 from that during cycle 1 at 40°C providing quantitative evidence of cognitive fatigue at 2hrs, this test also took longer to complete in 40°C (Table 2). Furthermore the error rate decreased with duration at 20°C. SWM strategy did not vary with time

Table 2: Spatial working memory and manual dexterity scores (\pm SD) in cycle 1 and 6.

Variable	20°C		40°C	
	Cycle 1	Cycle 6	Cycle 1	Cycle 6
Test duration (min) [#]	5.79±0.92	4.91±0.51	6.32±1.24	5.64±0.68
Total errors ^{#, ϕ}	8.8±9.1	1.4±2.2	5.6±6.9	9.3±16.2
Strategy	22.5±7.7	27.0±7.2	24.8±6.3	28.3±7.4
Manual dexterity ^{#, †}	7.0±2.0	9.2±2.1	8.9±2.6	8.7±1.1

[#] main effect for condition; [†] main effect for cycle; ^{ϕ} interaction condition × cycle ($P \leq 0.05$).

or between trials. Manual dexterity also improved with duration at 20°C and did not vary between cycle 1 and 6 at 40°C whereas scores were higher for cycle 1 in 40°C compared to 20°C (Table 2). It is plausible that the above changes could impact on an operative's ability to safely perform specific occupational tasks.

CONCLUSIONS

These findings indicate that working for 3 hrs in a PBAS at 20°C does not result in adequate physiological and psychological strain to increase risk. However it is of interest that PhSI did not increase from the third activity cycle onwards whereas PeSI continued to rise indicating an effect of duration on perception of effort and thermal sensation when working in 20°C. Work in 40°C resulted in UHS, as indicated by the continued increase in PhSI with duration, and was associated with potential risk enhancing reductions in performance at 3 hrs. Wetter cotton undergarments, as indicated by larger sweat losses at 40°C and the same evaporative efficiency in both conditions, may have been a factor contributing to the higher TC score (more unbearable) at 40°C. Since general symptoms, mood and SWM performance only worsened from 2 hrs at 40°C it is apparent that a 2 hr exposure time, when undertaking activities equivalent to the protocol applied in this study, would seem reasonable at this temperature. Considering the external validity of this protocol it is recognised that the PBAS workers role is varied and that the protocol used in this study will not always be representative of an operative's activity pattern. To accommodate, elements of the current protocol (walking and lifting and stepping) could be modified to manipulate work rate and thus facilitate comparisons between varied work and environmental situations.

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