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Physiological Assessment of Firefighters undertaking Urban Search and Rescue

Fire Research Technical Report 17/2008

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James Carter PhD, Mark Rayson PhD,
David Wilkinson PhD, Victoria Richmond MSc

Optimal Performance Limited

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Department for Communities and Local Government

The findings in this report are those of the authors and do not necessarily represent those of the Department for Communities and Local Government

Communities and Local Government
Eland House
Bressenden Place
London
SW1E 5DU
Telephone: 020 7944 4400
Website: www.communities.gov.uk

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Executive Summary

Introduction

This document describes a study carried out by Optimal Performance Limited (OPL) in support of the Research and Statistics Division (RSD) of the Fire and Resilience Directorate (FRD) in the Department for Communities and Local Government. The project describes the thermal and cardiovascular responses to a simulated Urban Search and Rescue (USAR) scenario.

Objectives

The project aims were threefold:

1. To describe the thermal and cardiovascular responses associated with defined USAR activities

2. To evaluate the impact of the work load on the safe and effective completion of these activities

3. To recommend ways of optimising safety and performance in the USAR role.

Approach

Eighteen participants (USAR qualified firefighters) undertook a USAR trial, comprising a 3 hour (h) morning bout and a 3 h afternoon bout separated by a 90 minute (min) recovery period. The trials were carried out on Rig 3 BR inside the USAR training building at the Fire Service College, Moreton-in-Marsh. Each bout consisted of clearance and removal of building debris to allow access to the rescue area inside the Rig and the subsequent breaching through two concrete slabs using standard USAR techniques and equipment. Once the breaches had been successfully completed the participants extracted a casualty positioned just beyond each breach. During the bouts and recovery period the majority of participants had access to water *ad libitum*. However, those participants who had passed their first core temperature pill before the start of the bout (n = 4) had no access to water during the work bouts to prevent possible distortion of the core temperature readings.

Measurements were made of the total loads carried, the fitness of participants and the ambient temperature. Participants were monitored for core body temperature, skin temperature, heart rate and body mass changes and fluid intake to estimate sweat loss. In addition, subjective ratings of perceived exertion, thermal sensation and body discomfort were provided by participants before and after each bout.

The thermal and cardiovascular responses to the trial, including both work bouts, were described and compared using analysis of variance (ANOVA) or t-tests where appropriate. Generally, the physiological responses were unremarkable and there were few differences between morning and afternoon bouts.

Conclusions

The following conclusions are drawn:

1. Under the thermo-neutral conditions studied, all participants successfully coped with the physical demands imposed on them during both the morning and afternoon 3 hour bouts.

2. The thermal and cardiovascular responses to both bouts were moderate and unremarkable. No participant, at any time, exceeded Graveling's proposed upper limit for core temperature in firefighter training of 39°C.

3. Performance on the afternoon bout was not substantially degraded, with a greater proportion of successful casualties recovered compared to the morning bout. No differences in core or skin temperatures, heart rate or fluid loss were reported between bouts. These data indicate that the improved casualty recovery rate and faster split times in the afternoon bout were a consequence of familiarisation and learning from the morning bout.

4. As a result of the physical exertion experienced during the morning bout, participants reported greater subjective fatigue, thermal sensation and body discomfort during the subsequent afternoon bout. 65% of all body parts were reported as suffering from moderate or great discomfort following the afternoon bout, compared to 22% after the morning bout. Specific body parts significantly affected included the neck, upper and lower back and the front and rear of both knees. It is suspected, although not known, that this fatigue and discomfort would significantly impact on performance on subsequent days.

5. Voluntary rehydration was insufficient to replace all of the fluid lost during the morning bout and 90 min recovery period. Despite these subjective and quantitative findings, performance and physiological strain were unaffected on the afternoon bout.

6. A period of 90 min appears sufficient to allow almost complete thermal and cardiovascular recovery, but not local fatigue and discomfort recovery, between self-paced USAR bouts performed in thermo-neutral ambient conditions. The recovery period involved participants doffing their PPE after 15 min and consuming food and drink *ad libitum* in a warm indoor location, but undergoing no specific cooling intervention.

Recommendations

Based on the findings from this study, the following recommendations are made to further maximise performance and health and safety of firefighters performing USAR scenarios and to improve recovery between multiple USAR deployment bouts:

1. For single day deployments, the self-paced work rest schedules adopted by the USAR teams were found to be sustainable, with no apparent degradation of performance over the day. Given that the ambitious task objectives set for this study were often achieved, the SOPs would appear to be near optimal.

2. However, reported fatigue and substantial discomfort of some body parts (especially knees, back and neck) may well limit performance on subsequent days. Further work should be conducted to find ways to alleviate the discomfort experienced and to explore multiday deployments, as degradation of performance is anticipated on subsequent days.

3. Firefighters should drink more fluids during both the work and recovery periods. Firefighters could determine their personal sweat rates (using body mass change) and use this knowledge to improve their judgement on how much fluid they need to consume to ensure optimal rehydration before they are re-committed to a USAR scenario. In general, firefighters should consume 150% of fluid lost.

4. To encourage voluntary rehydration, a variety of fluids should be available to firefighters immediately after USAR activities. These should include water, flavoured water (orange squash etc) and sports drinks.

This study has provided valuable information concerning the physical demand of USAR activities; however, several questions remain unanswered. Firstly, what additional demands are placed on firefighters carrying out USAR activities in conditions of high ambient temperatures (~30°C)? Secondly, what are the physical demands of a USAR scenario requiring several (three to four) continuous days of activity by one team? These two scenarios (hot ambient conditions and consecutive days of deployment) represent real reasonable, worst case scenarios for Fire and Rescue Service USAR teams. It is recommended that further studies are carried out to address these areas of uncertainty.

Chapter 1

Introduction

1.1 Study background

The United Kingdom (UK) has a long and successful record of Urban Search and Rescue (USAR). While the requirement for the UK Fire and Rescue Service (UKFRS) to provide USAR capability is not new, the importance of the USAR role was boosted in the aftermath of the World Trade Centre incident on 11 September 2001. The Government's New Dimension initiative is a response to the events of 11 September, the intention of which is to ensure that the UKFRS is able to cope with a major incident. The New Dimension programme consists of a total of six capabilities each of which defines a variety of deliverables that together will result in the achievement of the programme outcomes. Three of these capabilities have been at the forefront of the New Dimension roll-out programme, namely Mass Decontamination, Urban Search and Rescue and Water (High Volume Pump and Safety).

Until spring 2004, USAR training on a large scale did not take place in the UK. Between June 2003 and April 2004, over 500 personnel from the UKFRS were trained at Texas A&M University to provide the UK with an interim USAR capability. The Fire Service College (FSC) used the Texas training to form the basis of its own courses, and it is now one of the principal providers of USAR training in the world. The FSC site at Moreton-in-Marsh claims to have the world's largest indoor USAR training facility costing £6.2m. All levels of USAR response training are available here, from 'hands-on', front-line response to strategic and tactical command in a multi-agency scenario.

Volunteers for USAR training are screened and selected by their FRS – though this process remains to be formalised and standardised across the country. It takes three weeks to train USAR operators in the various skills required, including shoring, cutting, drilling and the use of search cameras and listening devices. The USAR capability includes a number of items of heavy equipment to lift, cut and remove rubble from collapsed structures, and to find casualties. Add the burden of the operator's Personal Protective Equipment (PPE) and Respiratory Protective Equipment (RPE), the extremely confined space in which the operators are often required to work, and a hostile environment including heat, dust and danger, and the net result is an extremely demanding role.

In recent years Optimal Performance Ltd have undertaken physiological assessments of a variety of roles commissioned by the Building Disaster Assessment Group (BDAG) of the then Fire Research and Statistics Division of the Office of the Deputy Prime Minister (Carter et al, 2006[1], Rayson *et al*, 2003[2] and 2004[3]). This research was carried out to extend those evaluations and quantify the physical demands of USAR activities.

[1] Carter J, Wilkinson D, Richmond V, *et al* (2006). *Core temperature, recovery and redeployment during a firefighting search and rescue scenario.* Optimal Performance Ltd report for the Fire Statistics and Research Division in the Department for Communities and Local Government, 22 September 2006.

[2] Rayson M, Donovan K, Graveling R, *et al* (2003). *Operational physiological capabilities of firefighters: literature review and research recommendations*. Optimal Performance Ltd report for the Fire Statistics and Research Division in the Office of for Deputy Prime Minister, Final Report, 24 March 2003.

[3] Rayson M, Wilkinson D, Carter J, *et al* (2004). *Physiological assessment of firefighting in the built environment.* Optimal Performance Ltd report for the Fire Statistics and Research Division in the Office of for Deputy Prime Minister, Final Report, 1 December 2003.

Chapter 2

Study Objectives

The objective was to quantify the physical and physiological loads experienced by USAR operators and to evaluate the impact of that loading on the safe and effective conduct of USAR activities. Specifically, the objectives of this study were:

1. To describe the thermal and cardiovascular responses associated with defined USAR activities

2. To evaluate the impact of the work load on the safe and effective completion of these activities

3. To recommend ways of optimising safety and performance in the USAR role.

Chapter 3

Approach

3.1 Participants

Eighteen participants, comprising seventeen males and one female, participated in the trial. All participants were members of the UKFRS and all were USAR trained. Their physical characteristics are shown in Table A1 of Appendix A and are summarised as follows: (mean ± SD) age 39 ± 7 years; body mass 85 ± 10 kg; height 178 ± 6 cm; body fat 20 ± 4%; estimated maximal oxygen consumption (VO_2max) 45 ± 7 $ml.kg^{-1}.min^{-1}$. All participants were verbally briefed, issued with a participant information sheet and gave written informed consent. Ethics approval for the procedures was secured from the University of Birmingham's School of Sport and Exercise Sciences Ethics Sub-Committee. All participants were medically screened by questionnaire and any adverse responses were referred to a medical practitioner for an opinion concerning participation before the trial commenced.

3.2 Experimental conditions and procedures

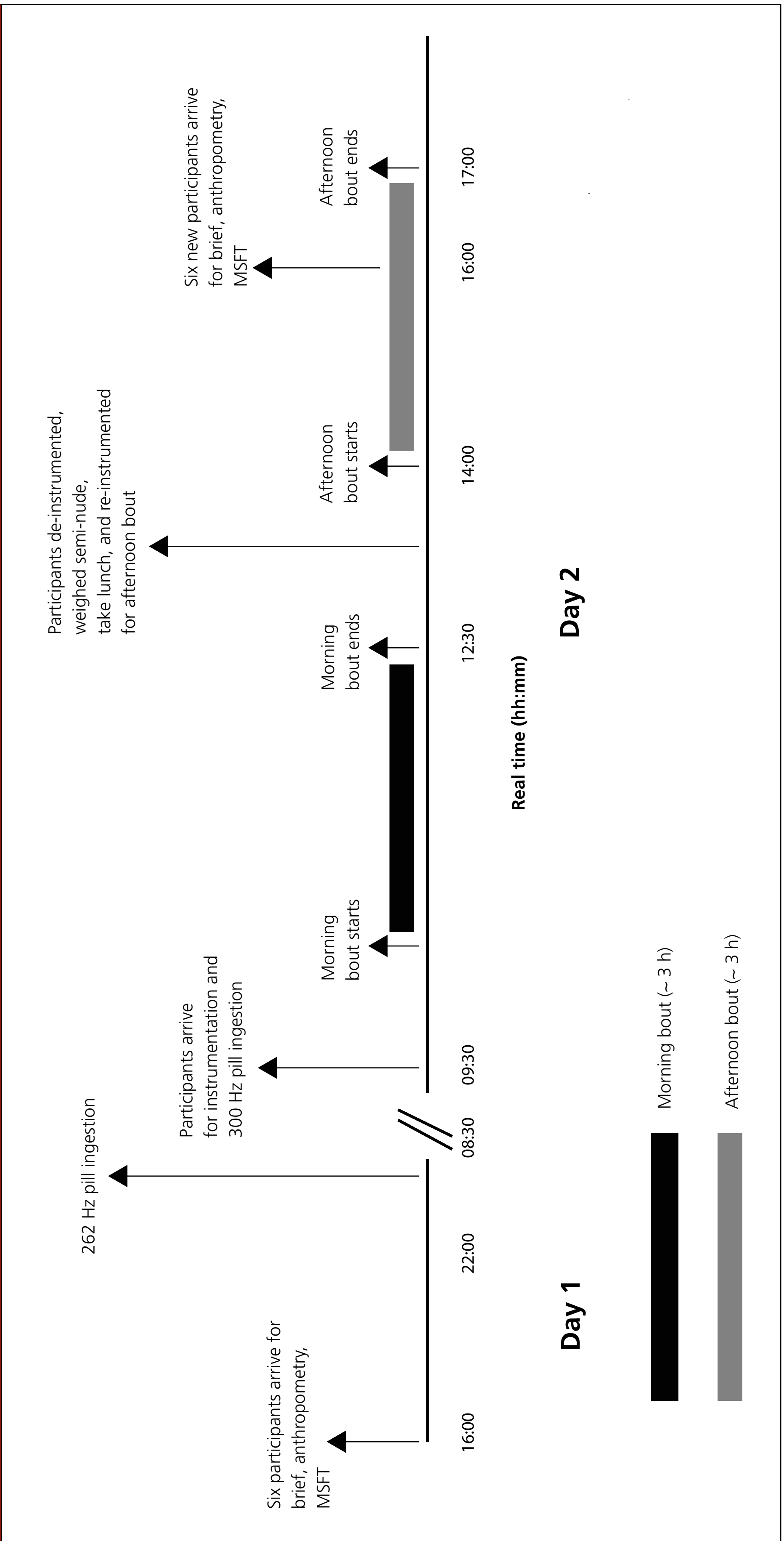
The study took place at the Fire Service College in Moreton-in-Marsh, Gloucestershire, England. Experimental trials, each involving six participants (one team), were carried out over three days. Each trial consisted of a morning and an afternoon bout separated by a 90 minute (min) recovery period, with each participant performing one trial only (two bouts – Figure 3.1). On the afternoon prior to their respective trial the team were given a study brief and performed the Multistage Fitness Test (MSFT) to volitional exhaustion. This allowed the determination of maximum heart rate and estimation of maximum oxygen consumption (VO_2max) to quantify the participants' aerobic fitness (Appendix A). Participants also had their body height, mass and composition measured during this period (Appendix A).

On the night before their trial participants swallowed a radio telemetry temperature pill (at approximately 22:00), enabling their core body temperature (Tcore) to be monitored as the pill passed through the gastro-intestinal tract (HQ Inc, Palmetto, Fl, USA). Participants also wore a heart rate monitor during sleep to measure their resting heart rate.

Each team arrived at least one hour (h) before performing each trial for instrumentation. Participants had been asked to abstain from eating for 2 h prior to the start of the trial and to ensure that they were in a state of good hydration. On arrival in the preparation room participants were weighed semi-nude and then asked to swallow another telemetry pill to ensure continuity of monitoring should they defecate the first pill during the day. The two pills relayed data on different frequencies (262 Hz and 300 Hz) to avoid interference. Participants were then instrumented for skin temperature on four sites (neck, shoulder, hand and shin) using temperature thermistors attached to a Squirrel SQ800 data logger (Grant Instruments Ltd, Cambridge, UK). These loggers were carried in custom built, adjustable pouches worn by each participant around their waist. Heart rate was recorded using the Polar Team System (Polar Electro Oy, Kempele, Finland). Each participant wore an ambient temperature probe also attached to the Squirrel SQ800 data logger. This probe measured the ambient temperature immediately surrounding the participant. Data were logged every 5 seconds (s) (heart rate) and 20 s (core, skin and ambient temperature), with Tcore also monitored in "real time" for safety reasons. Finally the firefighters dressed in their standard FRS USAR PPE[4] and were re-weighed.

4 The PPE worn was as provided by each participant's FRS and conformed to the national USAR PPE specification.

Figure 3.1: Trial design and subject involvement



Immediately prior to the start of the bout (morning or afternoon), baseline measures of Tcore were recorded, as well as subjective ratings of perceived exertion[5], thermal sensation[6] and body discomfort (Appendices B-D). Thereafter, at 5 min intervals, readings of Tcore were taken via telemetry, both as a backup to the 20 s logged data and for safety reasons. If a Tcore of 39.0°C was reached, readings were taken every 2.5 min.

The morning and afternoon bouts were performed on Rig 3 BR (Figure 3.2) inside the USAR training building at the Fire Service College. Each bout comprised a 3 h sequence, in which the participants were expected to work together as a team performing search and rescue activities using recognised USAR techniques and equipment. Other than the machine tools used frequently throughout the bouts, the participants carried via their PPE and RPE a total load of 9.5 ± 0.7 kg, which equated to 11.3 ± 1.6 % of their body mass. The mean mass of the machine tools available to the participants was 12.4 kg, with a range of 4.8 to 37.1 kg (Figure 3.3 and Table 3.1). Within each bout there were two concrete slabs reinforced with steel bars that the participants had to penetrate, progress through and recover a casualty. The first slab to be breached was 10 cm thick, in a vertical position, and the second slab was 15 cm thick, secured at an angle requiring overhead working (Figure 3.4). Each casualty to be recovered had a mass of approximately 50 kg. Water was available *ad libitum* throughout the trials and intake was monitored for estimation of sweat rate. Four participants defecated their first temperature pill before instrumentation and they were not permitted to drink water during the bout as drinking would have influenced the temperature of the second pill ingested[7].

The teams were organised to operate as pairs and were detailed to work in those pairs where practicable. During the initial effort to clear access to the first slab and carry equipment to the scene all personnel were at work. After this point, typically, at any one time, two pairs were working inside the Rig and the third pair was resting outside the Rig but inside the building. The team would then rotate within their pairs every 10-15 minutes.

[5] Borg GAV (1982). 'Psychophysical bases of perceived exertion', *Medicine and Science in Sports and Exercise*, 14 (5), 377.

[6] Gagge, Stolwijk and Hardy (1967). 'Comfort and thermal sensations and associated physiological responses at various ambient temperatures', *Environmental Research*, 1 (1), 1-20.

[7] Wilkinson D, Richmond V, Carter J et al (2006). *The relationship between deep GI pill and rectal pill temperatures and the effect of water ingestion on shallow GI pill temperature*. Optimal Performance Ltd report for the Home Office's CBRN Science and Technology Program, 1 March.

Figure 3.2: USAR Rig 3 BR at the Fire Service College

If the team successfully recovered the second casualty within the 3 h time limit, a third casualty was introduced and the team was instructed to continue search and rescue activities until 3 h had elapsed. Immediately following completion of the morning and afternoon bouts, the participants were asked to remain in their PPE for a further 15 min to allow recovery Tcore to be monitored. After this additional period, participants doffed their PPE, completed the subjective questionnaires and were re-weighed semi-nude. During the remaining (approximately) 60 min period separating the morning and afternoon bout, participants had lunch and then underwent the same weighing and instrumentation procedure as described previously. In total, 90 min separated the end of the morning bout and the start of the afternoon bout.

There were three reasons for which a test could be terminated prematurely:

- attainment of a Tcore of 39.5°C
- if for any reason a safety officer felt the participant was either unsafe or unable to continue
- if for any reason a participant felt unable to continue with the trial.

A paramedic and three safety officers were onsite at all times during the study.

Figure 3.3: The equipment available to the USAR team

Figure 3.4: Participants working on the 15 cm breach within Rig 3 BR

Table 3.1: The equipment available to the USAR teams		
Tool	**Manufacturer**	**Mass (kg)**
Core Drill	Hilti DD130	9.8
Drill/Chipping Hammer	Hilti TE76-ATC	10.8
Reciprocating Saw	Hilti WSR 1800 PE	4.8
Lightweight Breaker	Dewalt D25900K	12.3
Breaker	Stanley BR67	37.1
Hand Breaker	Stanley CH15	9.0
Chainsaw	Stanley DS11	16.8
Rebar Cutter	Makita ORC19	10.6
Hammer Drill	Hilti TE2	6.0
Scene Lighting	Dragon Max M2	6.4
Mean (SD)		**12.4 (9.4)**

3.3 Data and statistical analysis

The results in this report are expressed as mean ± one standard deviation (SD), which should accommodate 67% of a "normally distributed" population. Comparative analyses were performed using standard parametric statistics (ANOVA or t-tests) run on Statistical Package for the Social Sciences (SPSS) version 14 for Windows. Post-hoc pair wise comparisons were made using t-tests or Tukey's honestly significant differences test where appropriate. Statistical significance was set a-priori at $p<0.05$; where $p<0.05$ indicates the probability that the difference documented occurred by chance is 0.05, or 5%. P values of 0.01 and 0.001 indicate significance at the 1% and 0.1%, respectively, indicating progressively increasing degrees of confidence in the differences reported. The terms 'approaching statistical significance' or 'tended' are used to denote a probability of less than 0.1 or 10% (but more than 0.05, or 5%).

Heart rate data were expressed as a percentage of Heart Rate Reserve (%HRR) as this index of cardiovascular strain is recommended by the American College of Sports Medicine, and it takes into account individually recorded sleeping heart rates measured overnight and maximal heart rates measured during the fitness test. The resultant %HRR data were applied to Howley's[8] classification system, quantifying the time in minutes and the percentage of time spent in five zones of intensity, corresponding to 'very light' (<20%), 'light' (20-39%), 'moderate' (40-59%), 'hard' (60-84%) and 'very hard' (>85%).

[8] Howley ET (2001). 'Type of activity: resistance, aerobic and leisure versus occupational physical activity', *Medicine and Science in Sports and Exercise*, 33: S364-S369.

Chapter 4

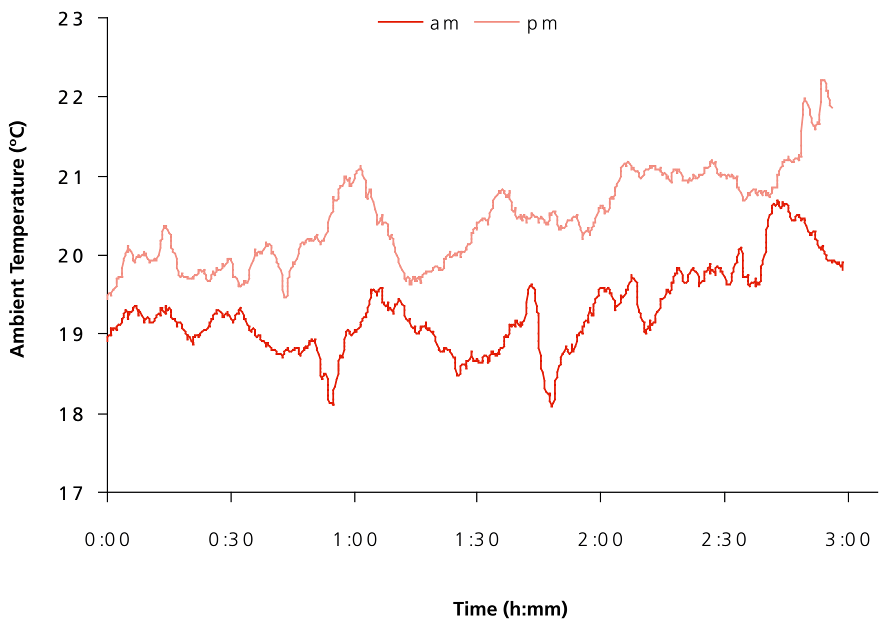
Results

4.1 Temperature and humidity

The mean ambient temperature inside the Rig measured by a static sensor positioned against a wall at approximately 1 m height from the ground was 16 ± 1°C and 17 ± 1°C in the morning and afternoon bouts, respectively ($p<0.001$). The higher mean temperature of 1 ± 1°C was unlikely to have had a significant impact on the resultant physiological strain experienced by the USAR teams in the afternoon bout. The mean relative humidity inside the Rig was 61 ± 5% and 57 ± 4% in the morning and afternoon trials, respectively ($p<0.001$). The difference in humidity between bouts, although statistically significant, was marginal (4 ± 5%) and its effect on the capacity for heat loss via evaporation of sweat would have been minimal due to the close-fitting and extensive (ie covering the vast majority of the skin's surface) PPE worn by participants.

The temperature values recorded by the ambient temperature probes carried by the participants in pouches around their waists are shown in Figure 4.1. The mean ambient temperature immediately surrounding the participants was 19 ± 1°C and 21 ± 1°C in the morning and afternoon bouts, respectively ($p<0.001$). The higher temperatures surrounding the participants compared to the temperature solely within the Rig can partly be attributed to the rest period which was spent outside the Rig and in the building. A further contribution might be expected from accumulation of the team's own body heat in the confined spaces prevailing within the Rig. The difference in temperature between the Rig and building also accounts for the fluctuating temperatures shown in Figure 4.1. The higher temperature surrounding the participants during the afternoon compared to the morning (2 ± 1°C) bout was likely due to the outside ambient temperature increasing as the day progressed and the building warming up.

Figure 4.1: Mean temperature surrounding the participants (n=18)



4.2 Outcome, work duration and external load

The objective of the trial was to ensure each USAR team worked for approximately 3 h in each bout and, within this time, rescue two casualties. The 3 h work time was achieved in all six bouts, with the work time slightly reduced in all three afternoon bouts due to the teams completing all required tasks. In four bouts both casualties were successfully recovered, although only one team recovered the second casualty during the morning bout. All split times were reduced in the afternoon compared to the morning bout (ignoring time of second casualty rescue). For example, the time of the first casualty rescue was 70 ± 10 min and 44 ± 6 min in the morning and afternoon bouts, respectively. The task and layout of the Rig were identical between bouts; therefore a learning effect from the morning bout was likely to have contributed to the faster split times reported in the afternoon bout. The participants would also have been more familiar with the equipment and their surroundings following the first bout and would have had a greater understanding of the task and the necessary physical demands. Combined, these factors would have enabled the participants to work with more efficiency and greater confidence in the second bout.

Table 4.1: Bout outcome and split times (min)

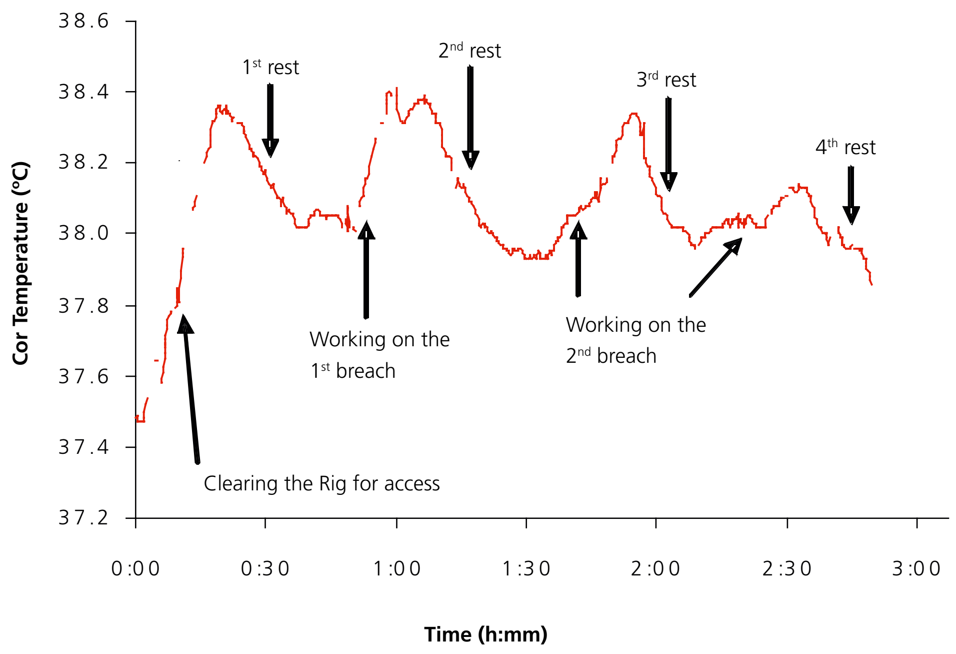
Time	Team	Start 1st Breach (min)	Take 1st Rest* (min)	Rescue 1st Casualty (min)	Start 2nd Breach (min)	Rescue 2nd Casualty# (min)	Total Duration (min)
am	1	25	25	76	78	No	180
am	2	24	39	76	80	No	180
am	3	16	33	58	83	110	179
Mean (SD)		**22 (5)**	**32 (7)**	**70 (10)**	**80 (3)**	**110 (0)**	**180 (1)**
pm	1	13	27	44	50	157	169
pm	2	11	16	47	56	118	173
pm	3	8	16	41	44	110	176
Mean (SD)		**11 (3)**	**20 (7)**	**44 (3)**	**50 (6)**	**128 (25)**	**173 (4)**

*'Take 1st Rest' refers to the time when the first two participants within the USAR team began the first rest period.
#'No' refers to the casualty not being successfully recovered within 3 h.

4.3 Core temperature response

A typical Tcore response to the afternoon bout is shown in Figure 4.2. This participant was involved with clearing the Rig for access for approximately 15 min before starting the work-rest rotation in their pair. During the afternoon bout this pair had four separate work-rest periods, which were responsible for the fluctuating Tcore response.

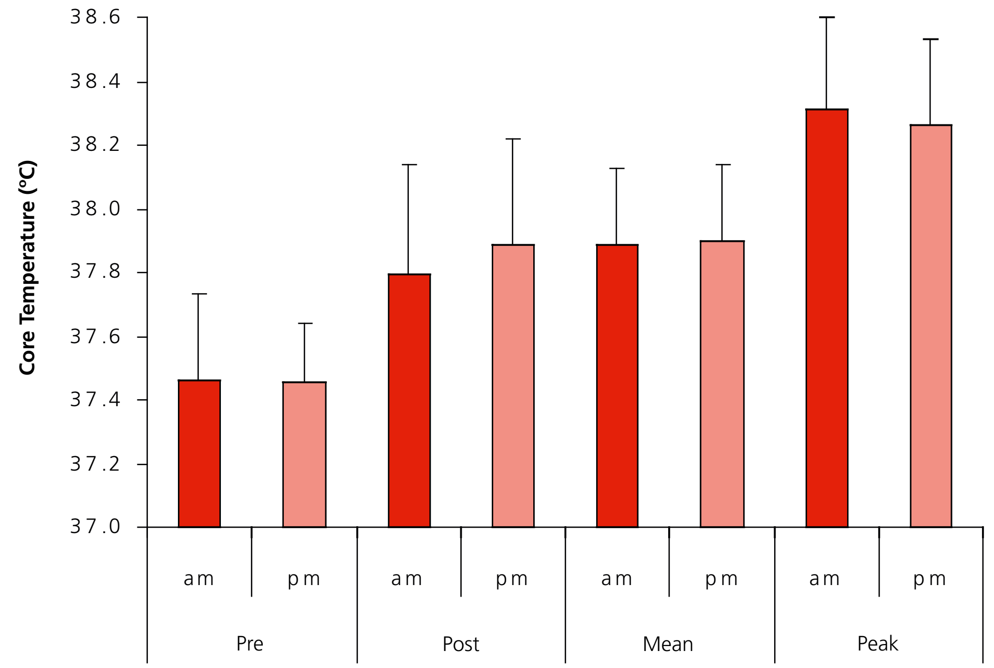
Figure 4.2: A typical core temperature response from one participant (number 12) to the afternoon bout



The breaks in the curve indicate interruptions in the Tcore data caused by the logger being temporarily out of range of the telemetry pill (due to the participant moving the elasticised pouch around their waist).

Due to the repetitive work-rest schedule of the USAR bouts, of which the frequency and duration varied between teams and pairs, it is difficult to quantify the Tcore response to the task. It is not sufficient to report the pre and post Tcore of each participant and the rate of rise as we have done previously for Emergency Service tasks (refer to footnotes 1-4 in section 1.1). Presenting the data in this manner would underestimate the physiological demand of USAR activities as the sharp peaks of Tcore mid-trial (as indicated in Figure 4.2) would be ignored. Consequently, the Tcore results are presented as pre, post, mean and peak temperatures (Figure 4.3) as well as the amount of time spent above 38, 38.5 and 39°C (Table 4.2).

Figure 4.3: The pre, post, mean and peak core temperatures during the morning (am) and afternoon (pm) bouts (mean + SD)



There were no significant differences in pre, post, mean and peak temperatures between bouts. The similar pre (baseline) temperatures between bouts indicate that the 90 min recovery was sufficient to allow participants to cool adequately. The range of peak temperatures attained by the participants was 37.8 to 38.8°C in the morning trial and 37.8 to 39.0°C in the afternoon trial. The time spent above 38, 38.5 and 39°C Tcore is shown in Table 4.2.

Table 4.2: Duration spent with a core temperature in excess of 38, 38.5 and 39°C (mean ± SD)

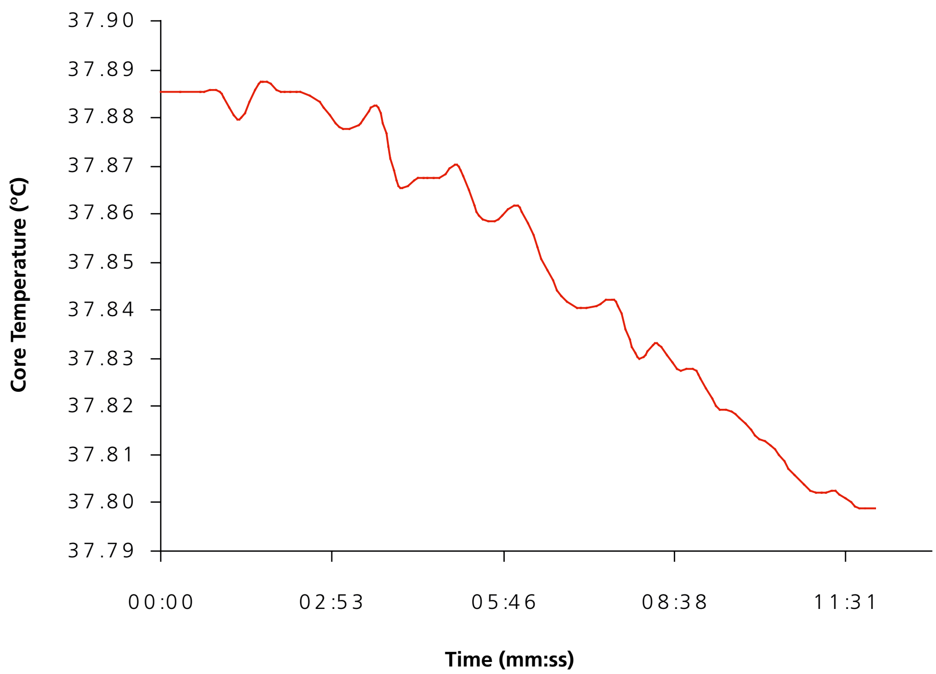
Tcore Threshold	Morning Bout (min)	Afternoon Bout (min)
> 38.0°C	70 ± 58 (n = 16)	63 ± 51 (n = 18)
> 38.5°C	6 ± 14	6 ± 25
> 39.0°C	0 ± 0	0 ± 0

The reduced sample size in the morning bout was due to two corrupted data sets.

There were no significant differences in time spent above any of the Tcore thresholds between morning and afternoon bouts. No participant at any stage of either bout exceeded 39°C. The relatively large SD values reported for the time spent above 38 and 38.5°C indicate the large inter-subject variability in Tcore response. Factors such as work rate, body composition, differences between participants PPE (variation in sub layers worn and the thickness of the outer PPE), acclimation status and aerobic fitness can contribute to this variability.

The Tcore response in the 15 min period immediately following the end of the morning and afternoon bouts is shown in Figure 4.4. There was no difference between bouts in the mean delta change in Tcore or in the mean rate of decline of Tcore in the recovery periods. Consequently, the data from the morning and afternoon recovery periods were combined. Data are shown for 12 min of recovery, which was common for all subjects. Although the gradient showing the mean decline in Tcore is steep, the scale of the y axis is relatively narrow (0.11°C) and the delta change was only -0.1 ± 0.2°C. The mean rate of Tcore decline was -0.006 ± 0.013°C.min^{-1}.

Figure 4.4: The recovery mean core temperature following the morning and afternoon bouts combined

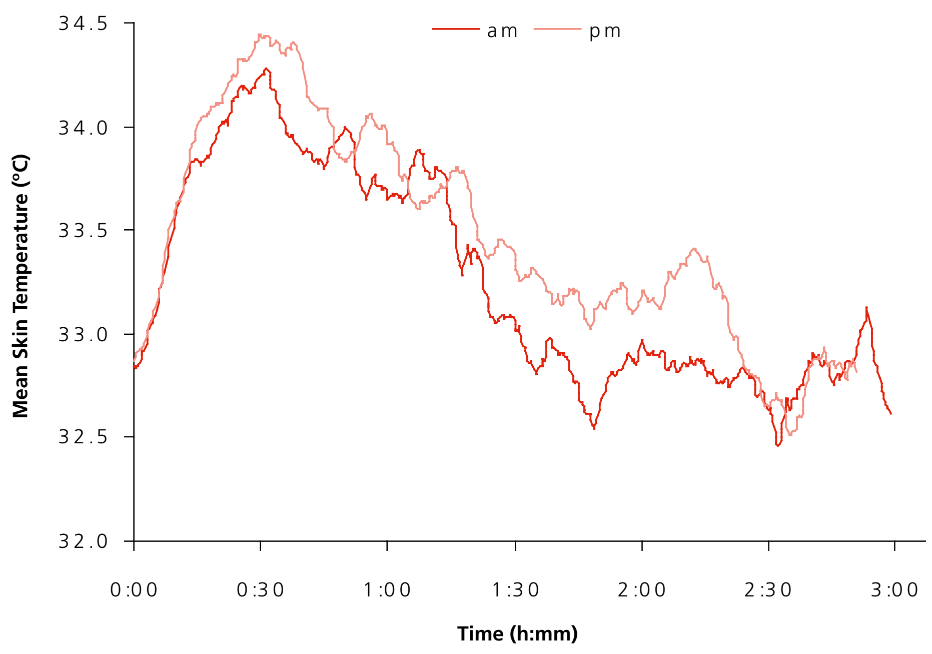


Care should be taken in placing any significance on this apparently low rate of cooling post-bout. Reference to plots of temperature such as that shown in Figure 4.2 clearly show that considerable body cooling occurred during rest periods within the bouts and the low starting temperature in Figure 4.4 strongly suggests that much of the recovery of Tcore had already occurred in the closing stages of the bout.

4.4 Skin temperature response

The mean skin temperature response during the morning and afternoon bouts are shown in Figure 4.5. The first 15-30 min was common to all participants and represents where each USAR team worked together to clear access to the Rig. This activity resulted in a relatively sharp increase in skin temperature (and Tcore – Figure 4.2). Beyond this point, each pair commenced regular work-rest intervals and consequently any rises in skin temperature during the work bouts within the Rig are masked by concomitant decreases in skin temperature of those pairs who were resting. The average mean skin temperature in the morning and afternoon bouts was 33.3 ± 0.5°C and 33.5 ± 0.4°C, respectively, with no difference between bouts. The peak mean skin temperature attained by the participants was 34.9 ± 0.5°C (range: 33.7 to 35.6°C) and 35.1 ± 0.4°C (range: 34.4 to 36.1°C) in the morning and afternoon bouts, respectively ($p>0.05$). Skin temperature is an important contributor to subjective ratings of thermal sensation (section 4.7), although the mean and peak temperatures reported in the USAR bouts were unlikely to have caused significant discomfort for the participants.

Figure 4.5: The mean skin temperature response during the morning (am) and afternoon (pm) bouts



4.5 Heart rate response

The mean heart rate response for the morning and afternoon bouts and the time spent in each zone of intensity are shown in Table 4.3. The mean HRR for both bouts corresponded to Howley's 'moderate' intensity zone. There was a tendency (p=0.07) for the afternoon bout to have a higher mean HRR compared to the morning bout; a difference equating to 3 ± 5% HRR. However, when the data were expressed as amount of time the participants spent working in Howley's different zones of intensity, there was no difference between bouts (p=0.20). This suggests that participants, on average, spent a similar amount of time working in each zone of activity in both bouts. The greatest amount of time was spent in the light (20-39% HRR) and moderate (40-59% HRR) intensity zones.

Table 4.3: The mean heart rate response during the morning and afternoon bouts (mean ± SD, n = 18)

	Intensity	Morning Bout	Afternoon Bout
Mean HRR (%)		44 ± 6	47 ± 6
Time < 20% HRR (min)	Very Light	3 ± 5	3 ± 6
Time 20-39% HRR (min)	Light	70 ± 28	55 ± 26
Time 40-59% HRR (min)	Moderate	76 ± 17	81 ± 18
Time 60-84% HRR (min)	Hard	30 ± 20	34 ± 24
Time ≥ 85% HRR (min)	Very Hard	1 ± 1	0 ± 0

4.6 Body mass changes and fluid intake

The mean body mass change and fluid intake in the morning and afternoon bouts are shown in Table 4.4. There were no differences between bouts for mean fluid intake, estimated sweat loss and estimated sweat rate (p>0.05). Of note, participants began the afternoon bout with a significantly lower body mass compared to the morning bout (-0.4 ± 0.5 kg). This difference suggests that participants did not consume sufficient fluid during the lunch break to replace fluid lost during the morning trial. The fluid deficit (0.4 kg) was likely to be greater as participants also consumed food during the recovery period. In this instance, the dehydration (at least 0.5% loss in body mass) was not severe enough to cause physiological impairment during the afternoon trial. However, one participant commenced the second bout with a 2.2% loss in body mass. A fluid loss equivalent to a 2% loss in body mass is considered sufficient to cause cognitive and physiological decrements in performance[9]. Of note, none of the participants who were restricted fluid during the bouts due to passing their first pill began the second bout significantly dehydrated. Fluid and food consumed during the lunch break was not monitored and so inter-individual differences can not be commented on.

[9] Jeukendrup A and Gleeson M (2004). *Human nutrition: an introduction to energy production and performance,* Human Kinetics, Champaign, IL.

The estimated sweat rates reported in both bouts (0.007 $L.min^{-1}$) equate to approximately 0.42 $L.h^{-1}$. In order to replace such a sweat loss, and to account for future sweat and urinary loss, participants would need to consume at least 0.63 $L.h^{-1}$ (150% of sweat loss[10]).

Table 4.4: Body mass changes and fluid intake during the morning and afternoon bouts (mean ± SD, n = 18)

	Morning Bout	Afternoon Bout
Pre Body Mass (kg)	84.9 ± 9.6 *	84.5 ± 9.6
Mean Fluid Intake (L)	0.599 ± 0.476	0.803 ± 0.617
Estimated Sweat Loss (L)	1.3 ± 0.5	1.1 ± 0.4
Estimated Sweat Rate ($L.min^{-1}$)	0.007 ± 0.003	0.007 ± 0.002

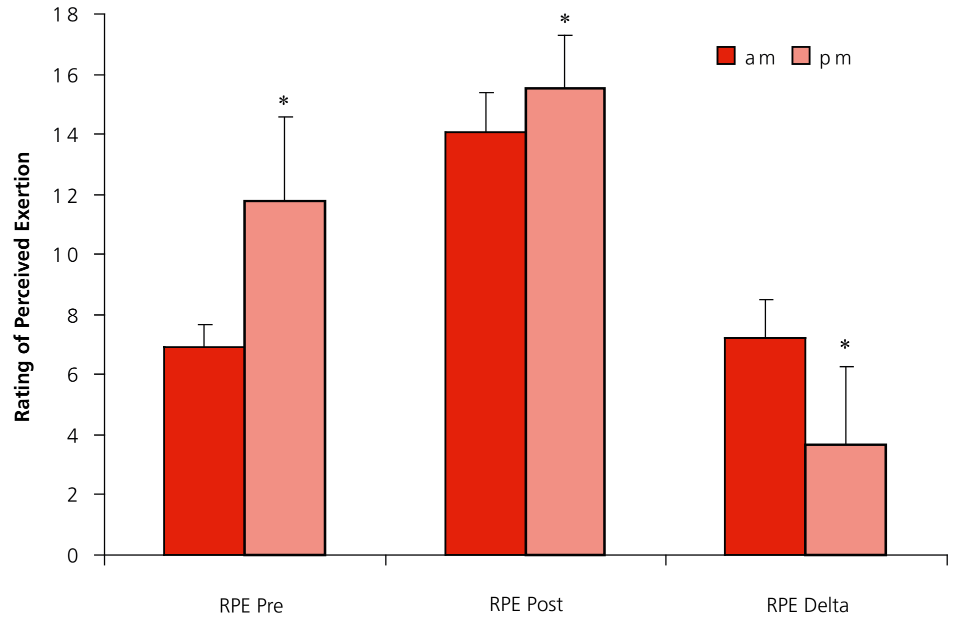
Where * refers to $p = 0.003$ (significantly different from corresponding afternoon value – no other variable differed significantly between bouts) and L refers to litres.

4.7 Subjective responses of perceived exertion, thermal sensation and body discomfort

The subjective ratings of perceived exertion are shown in Figure 4.6. The delta change in perceived exertion was greater for the morning bout, which may indicate that participants found that bout more physically demanding than the afternoon bout. This finding is not in agreement with the physiological data reported previously and it can be explained by the difference in 'pre' ratings (am: 7.0 ± 1 vs. pm: 12 ± 3) between bouts. The 'pre' ratings equated to 'extremely light' (am bout) and 'light' to 'somewhat hard' (pm bout) on the Borg scale and suggested that participants in the afternoon were still feeling residual fatigue from the morning's bout. Participants did report higher 'post' ratings following the afternoon trial, providing additional support that the morning bout was not more physically demanding compared to the afternoon bout. The 'post' ratings were 14 ± 1 ('somewhat hard' to 'hard') and 16 ± 2 ('hard' to 'very hard'), in the morning and afternoon bouts, respectively. In summary, participants started the afternoon bout partially fatigued and finished it more so.

[10] Shirreffs SM and Maughan RJ (2000). 'Rehydration and recovery of fluid balance after exercise', *Exercise and Sport Sciences Reviews*, 28: 27-32.

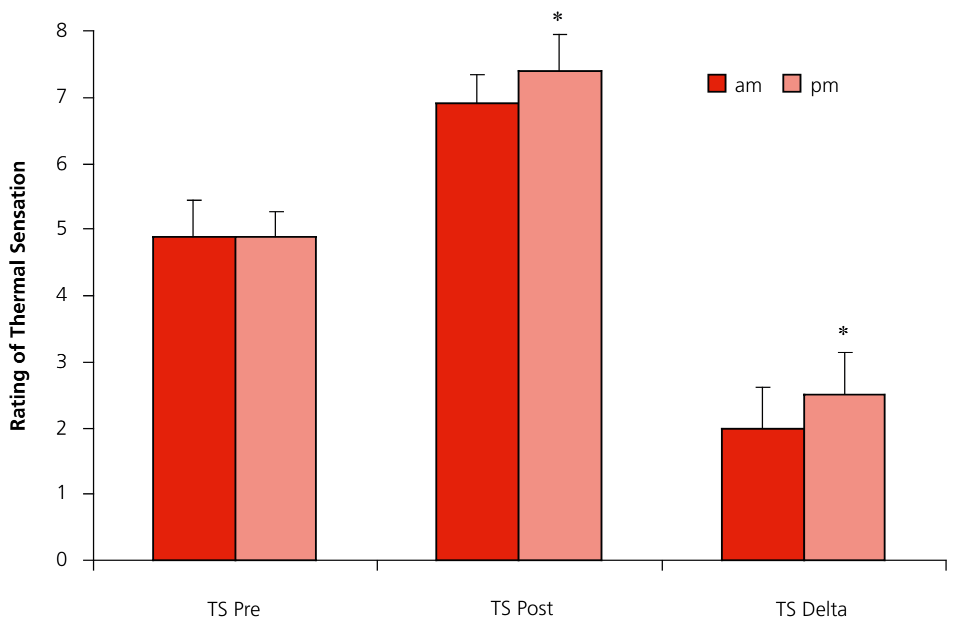
Figure 4.6: The subjective ratings of perceived exertion (mean + SD)



Where * indicates significantly different from the corresponding 'am' value (p<0.001).

The subjective ratings of thermal sensation are shown in Figure 4.7. The 'pre' values were similar between bouts (5 ± 1) and corresponded to 'neutral' on the thermal sensation scale. The 'post' rating of thermal sensation and the delta change were greater for the afternoon compared to the morning bout. This indicates that on average, the participants felt hotter during the second bout of the day. However, although the difference in the delta change was statistically significant, a difference of 0.5 on the thermal sensation scale is of little physiological importance.

Figure 4.7: The subjective ratings of thermal sensation (mean + SD)



Where * indicates significantly different from the corresponding 'am' value (p<0.01).

The results of the subjective ratings of body discomfort are shown in Table 4.5. For body part reference, it may help to use the diagram contained in Appendix D. The data in Table 4.5 represent the percentage of participants who rated body part discomfort as moderate (2) or great (3) immediately before or after the morning and afternoon bouts. As expected, there were no body parts suffering moderate or great discomfort immediately before the morning bout. Following the morning bout, eight body parts were reported as experiencing significant discomfort. These body parts included the neck and lower back, right shoulder and arm and both the front and rear of the knees. The 90 min break separating the two bouts was adequate to allow recovery for all body parts except the lower back – 11% of participants reported moderate or great discomfort of the lower back immediately prior to commencing the afternoon bout.

A marked increase in body discomfort was reported immediately after the afternoon bout, with 65% of all body parts reported by participants as experiencing moderate to great discomfort. Body parts most affected included the neck, upper and lower back, right and left arm and right and left thigh, and especially the front and rear of both knees.

In summary, participants reported greater discomfort following the afternoon bout, although this discomfort did not appear to impact negatively upon task success or the physiological burden. Protracted kneeling, prolonged and unusual body posture and the handling of heavy and vibrating tools are the likely causes of these high degrees of discomfort.

Table 4.5: Percentage responses rating moderate or great discomfort on the Body Map during the morning and afternoon bouts. Values of 10% and over are shown in bold

Body Area	Right Shoulder	Right Arm	Right Hand	Right Upper Thigh	Right Mid Thigh	Right Knee	Right Shin	Right Ankle	Right Foot	Head	Neck	Left Shoulder	Chest	Left Arm	Stomach	Left Hand	Left Upper Thigh	Left Mid Thigh	Left Knee	Left Shin	Left Ankle	Left Foot
Bout	**FRONT VIEW OF BODY**																					
AM Pre	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	6	0	0	0
AM Post	**11**	**11**	6	6	6	**28**	0	0	6	0	6	6	6	6	0	6	6	6	**33**	0	0	0
PM Pre	0	0	6	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
PM Post	6	**22**	**11**	**11**	**11**	**44**	6	0	**11**	**17**	0	0	0	**17**	0	6	**11**	**11**	**50**	6	0	6

Body Area	Left Shoulder	Left Elbow	Left Upper Thigh	Left Mid Thigh	Left Knee	Left Calf	Neck	Right Shoulder	Upper Back	Right Elbow	Lower Back	Right Upper Thigh	Right Mid Thigh	Right Knee	Right Calf
Bout	**VIEW OF BODY**														
AM Pre	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AM Post	0	6	0	0	**17**	0	**11**	0	6	6	**22**	0	0	**17**	0
PM Pre	0	0	0	0	0	0	0	0	0	0	**11**	0	0	0	0
PM Post	6	**11**	**11**	**11**	**22**	**11**	**22**	6	**11**	**11**	**17**	**11**	**11**	**22**	**11**

4.8 Summary of findings

The following summary points are made:

1. All eighteen participants self-paced and achieved the 3 h work limit in each USAR bout under the conditions investigated. The average ambient temperature immediately surrounding the participants was 19.3 ± 0.5°C and 20.5 ± 0.6°C in the morning and afternoon bouts, respectively. These ambient temperatures would be considered thermo-neutral and somewhat below those of a reasonable worst-case scenario encountered in the UK during the summer months.

2. Only one team in the morning successfully recovered both casualties, whereas there was a 100% success rate in the afternoon. Spilt times (start first breach, take first rest, rescue first casualty and start second breach) were markedly faster in the afternoon compared to the morning bout. The improved performance in the afternoon was attributable to familiarisation and learning, as the task and Rig layout were identical between bouts.

3. The Tcore response to both bouts was unremarkable and there were no significant differences in pre, post, mean and peak temperatures between bouts. The mean peak temperature attained by participants was 38.3 ± 0.3°C and 38.3 ± 0.3°C in the morning and afternoon bouts, respectively. Participants spent on average 6 min per bout in excess of 38.5°C, and no participant exceeded Graveling's[11] proposed upper limit for core temperature in firefighter training of 39°C.

4. The mean rate of decline of Tcore in the 12 min period after the bouts was -0.006 ± 0.013°C.min^{-1}. This relatively low rate of cooling during the recovery was probably due to significant cooling having already occurred during the closing stages of the bouts.

5. The skin temperature response was also unremarkable, with mean skin temperatures similar in the morning (33.3 ± 0.5°C) and afternoon (33.5 ± 0.4°C) bouts. The peak mean skin temperature attained by the participants was 34.9 ± 0.5°C and 35.1 ± 0.4°C in the morning and afternoon bouts, respectively ($p>0.05$).

6. The mean HRR for both bouts corresponded to Howley's 'moderate' intensity zone. There was a tendency ($p=0.07$) for the afternoon bout (47 ± 6%) to have a higher mean HRR compared to the morning bout (44 ± 6%). The greatest amount of time was spent in the light (20-39% HRR) and moderate (40-59% HRR) intensity zones. Durations in these zones were similar between bouts.

[11] Graveling RA, Stewart A, Cowie HA, Tesh KM, George JPK (2001). *Physiological and environmental aspects of firefighter training.* Fire Research Division of the Office of the Deputy Prime Minister Research Report Number 1/2001.

7. There were no differences between bouts in mean fluid intake (0.700 ± 0.553 L), estimated sweat loss (1.2 ± 0.4 L) or estimated sweat rate (0.007 ± 0.002 $L.min^{-1}$). Voluntary rehydration during the recovery period was insufficient to replace fluid loss from the morning trial, although this dehydration (at least 0.5% loss in body mass) was not sufficient to impair the physiological response of participants during the afternoon bout. One participant began the afternoon bout with a fluid deficit beyond the threshold (≥ 2% loss in body mass) known to effect performance negatively.

8. The 'post' ratings of perceived exertion, delta changes in thermal sensation and ratings of body discomfort were greater in the afternoon bout compared to the morning bout. These results indicate participants experienced residual fatigue and continued discomfort from the morning bout, and that this fatigue and discomfort deteriorated during the afternoon bout to high levels.

Chapter 5

Conclusions and Recommendations

The following conclusions are drawn:

1. Under the thermo-neutral conditions studied, all participants successfully coped with the physical demands imposed on them during both the morning and afternoon 3 hour bouts.

2. The thermal and cardiovascular responses to both bouts were moderate and unremarkable. No participant, at any time, exceeded Graveling's proposed upper limit for core temperature in firefighter training of 39°C.

3. Performance on the afternoon bout was not substantially degraded, with a greater proportion of casualties successfully recovered compared to the morning bout. No differences in core or skin temperatures, heart rate or fluid loss were reported between bouts. These data indicate that the improved casualty recovery rate and faster split times in the afternoon bout were a consequence of familiarisation and learning from the morning bout.

4. As a result of the physical exertion experienced during the morning bout, participants reported greater subjective fatigue, thermal sensation and body discomfort during the subsequent afternoon bout. Notably, 65% of all body parts were reported by participants as suffering from moderate to great discomfort following the afternoon bout, compared to 22% after the morning bout. Specific body parts significantly affected included the neck, upper and lower back and the front and rear of both knees. It is suspected that this fatigue and discomfort would significantly impact on performance on subsequent days.

5. Voluntary rehydration was insufficient to replace all of the fluid lost during the morning bout and 90 min recovery period. Despite these subjective and quantitative findings, performance and physiological strain were unaffected on the afternoon bout.

6. A period of 90 min appears sufficient to allow almost complete thermal and cardiovascular recovery, but not local fatigue and discomfort recovery between self-paced USAR bouts performed in thermo-neutral ambient conditions. The recovery period involved participants doffing their PPE after 15 min and consuming food and drink *ad libitum* in a warm indoor location, but undergoing no specific cooling intervention.

Based on the findings from this study, the following recommendations are made to further maximise performance and health and safety of firefighters undertaking USAR scenarios and to improve recovery between multiple deployment bouts:

1. For single day deployments, the self-paced work rest schedules adopted by the USAR teams were found to be sustainable, with no apparent degradation of performance over the day. Given that the ambitious task objectives set for this study were often achieved, the SOPs would appear to be near optimal.

2. However, reported fatigue and substantial discomfort of some body parts (especially knees, back and neck) may well limit performance on subsequent days. Further work should be conducted to find ways to alleviate the discomfort experienced and to explore multiday deployments, as degradation of performance is anticipated on subsequent days.

3 Firefighters should drink more fluids during both the work and recovery periods. Firefighters could determine their personal sweat rates (using body mass change) and use this knowledge to improve their judgement on how much fluid they need to consume to ensure optimal rehydration before they are re-committed to a USAR scenario. In general, firefighters should consume 150% of fluid lost.

4. To encourage voluntary rehydration, a variety of fluids should be available to firefighters immediately after USAR activities. These should include water, flavoured water (orange squash etc) and sports drinks.

This study has provided valuable information concerning the physical demand of USAR activities; however, several questions remain unanswered. Firstly, what additional demands are placed on firefighters carrying out USAR activities in conditions of high ambient temperatures (~30°C)? Secondly, what are the physical demands of a USAR scenario requiring several (three to four) continuous days of activity by one team? These two scenarios (hot ambient conditions and consecutive days of deployment) represent real reasonable, worst case scenarios for the USAR teams in the UKFRS. It is recommended that further studies are carried out to address these areas of uncertainty.

Chapter 6

Acknowledgements

We wish to acknowledge the logistical and moral support to this project provided by Mr John Fay from Fire and Resilience Directorate at Communities and Local Government and by Mr Bob Rea and his team at the USAR training facility in the Fire Service College.

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Our gratitude also goes to our friends and colleagues Dr Richard Graveling from the Institute of Occupational Medicine and Dr Steve Cole, Human Factors advisor to Communities and Local Government, for their peer review of this report and visits to the trial.

Appendix A

Fitness Data

Table A1: Participant physiological characteristics

FF No.	FF Sex	Age (y)	Height (m)	Mass (kg)	Body Fat (%)	HR max (beats .min^{-1})	MSFT (L/S)	VO_{2max} (mL. kg-1. min^{-1})	VO_{2max} (L.min^{-1})
1	m	35	1.745	84.9	21.3	198	10/1	47.1	3.999
2	m	43	1.720	77.4	23.0	173	11/2	50.8	3.932
3	m	36	1.770	101.2	25.9	186	8/8	42.4	4.291
4	m	25	1.820	82.2	15.6	183	12/1	54.0	4.439
5	m	38	1.805	93.8	20.7	204	9/5	44.9	4.212
6	m	44	1.845	83.1	19.7	183	10/4	48.0	3.989
7	m	40	1.685	82.1	22.4	190	11/6	51.9	4.261
8	m	41	1.860	88.9	13.4	186	10/1	47.1	4.187
9	m	47	1.750	83.7	23.1	186	6/7	35.3	2.955
10	m	47	1.820	97.9	24.2	163	6/3	33.9	3.319
11	m	44	1.730	80.6	18.4	194	11/8	52.5	4.232
12	m	28	1.765	66.1	12.4	201	10/3	47.7	3.153
13	m	42	1.840	99.2	21.7	195	7/3	37.5	3.720
14	f	35	1.640	69.9	28.3	190	7/3	37.5	2.621
15	m	41	1.740	85.8	20.0	178	9/11	46.8	4.015
16	m	45	1.835	81.4	16.6	185	5/6	31.8	2.589
17	m	31	1.850	91.2	17.9	185	9/8	45.8	4.177
18	m	31	1.725	77.1	17.6	203	10/6	48.7	3.755
Mean		**38.5**	**1.775**	**84.8**	**20.1**	**188**	**9/0**	**44.7**	**3.769**
SD		**6.6**	**0.063**	**9.5**	**4.2**	**11**	**2/0**	**1.6**	**0.587**

Where m refers to male, f refers to female, HR refers to heart rate, MSFT refers to multistage fitness test, L refers to level, S refers to shuttle and VO_{2max} refers to maximal aerobic power (estimated from MSFT score).

Appendix B

Borg Perceived Exertion Scale

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (Heavy)
16	
17	Very Hard
18	
19	Extremely Hard
20	Maximal exertion

Appendix C

Thermal Sensation Scale

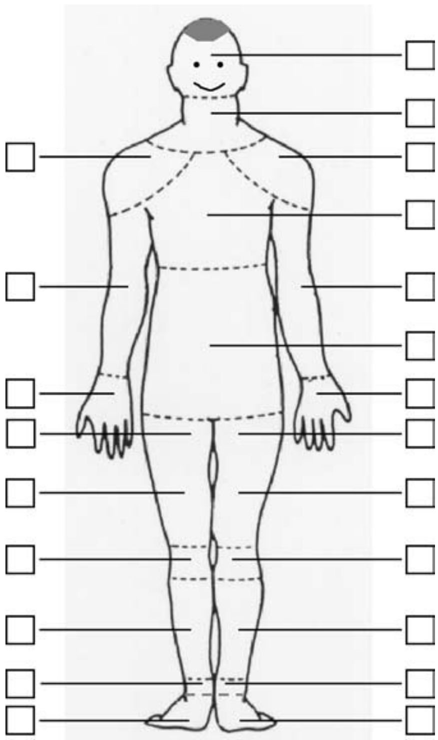
0	–	Coldest you've ever been
1		
2		
3		
4		
5	–	Neutral, neither hot nor cold
6		
7		
8		
9		
10	–	Hottest you've ever been

Appendix D

Body Map

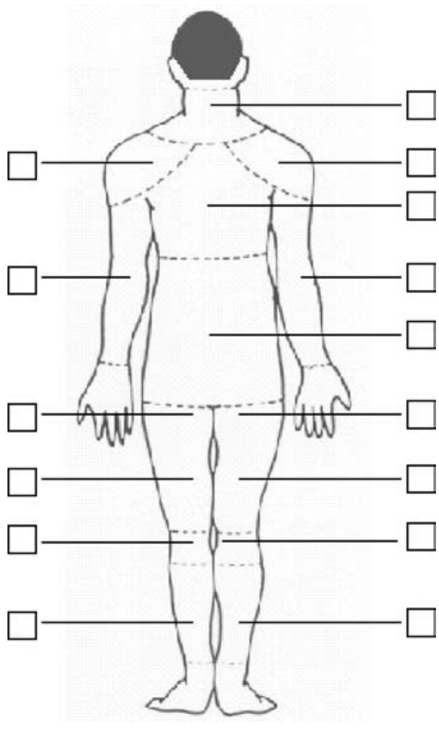
Please indicate on the body maps below in EACH marked area the number that most closely describes how that area of your body feels

BODY MAP (VIEWED FROM THE FRONT)



- **0** No discomfort
- **1** Slight discomfort
- **2** Moderate discomfort
- **3** Great discomfort

BODY MAP (VIEWED FROM THE BACK)



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