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URBAN SEARCH AND RESCUE OPERATIONS IN TROPICAL CLIMATES

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ABSTRACT

The physiological burden of Urban Search and Rescue (USAR) operations in the tropics is poorly understood. Sixteen trained USAR personnel (90.4kg, 1.81m, 39.6yrs) participated in a 24hr simulated exercise conducted during November in Northern Australia. Participants provided written informed consent for this study and were recruited from NT Fire and Rescue and QLD Fire and Emergency Services, resulting in 8 heat acclimatised (HA) and 8 non-heat acclimatised (NHA) responders. Physiological monitoring included core temperature (T_c) through the use of ingestible thermometers based on established protocols[1]. The initial 4 hour shift (ambient 34.0°C, 48% relative humidity) resulted in 15 of the 16 participants exceeding the ISO9886 T_c safe working limit of 38.5°C. From the 80th minute of the initial shift, HA sustained a significantly ($p<0.01$) higher T_c (38.6°C) than the NHA cohort (38.1°C) despite both groups perceiving their body temperature equally as hot. Following the initial shift, only 2 participants exceeded T_c 38.5°C, likely due to crews suffering from the heat strain endured during the first 4 hours. Seven (5 NHA, 2 HA) of the 16 participants presented to medical staff during this period with symptoms of headache, nausea and exhaustion. Pacing of effort was apparent for non-heat acclimatised personnel. Year round heat acclimatisation through physical training is likely to improve operational capability of deployed teams. More frequent rotation of crews to permit monitoring through a rehabilitation sector, inclusive of active cooling options, is likely to reduce physiological strain and heat related illness during deployment to tropical regions.

INTRODUCTION

Emergency and disaster response in austere environments, particularly extreme heat, pose significant challenges to response teams. Urban Search and Rescue (USAR) teams, are expected to respond within a matter of hours to an earthquake affected site and provide rescue for those entrapped in collapsed buildings. Teams work long hours, inclusive of night and day shifts for up to 14 days, in confined space and sometimes impermeable protective clothing irrespective of the climatic conditions or individual heat acclimatisation status. Australia's proximity to the earthquake prone Asia-Pacific region (Simpson et al., 2008) increases the likelihood of USAR response to hot climates that are conducive to body heat storage, increasing the likelihood of acute heat illness and/or cumulative heat stress and impacting operational capability.

While emergency responders have been studied exercising at standardised workloads in climate control chambers (McLellan and Selkirk, 2006), little is known of their physiological and perceptual responses to working in tropical field conditions. Unlike laboratory trials, field based simulations incorporate self-pacing. Hot and humid field settings are yet to be examined to determine if non-heat acclimatised (NHA) emergency responders experience greater physiological perturbation than their heat acclimatised (HA) counterparts, potentially impacting upon productivity due to pacing of effort. Therefore, this investigation examined the physiological and perceptual responses of heat and non-heat acclimatised USAR personnel during a 24-hour exercise in tropical field conditions.

METHOD

Sixteen USAR personnel provided written informed consent prior to participating in a simulated 24hr exercise at the Yarrawonga training facility on the outskirts of Darwin, Northern Territory (NT), Australia. Five heat acclimatised men were recruited from NT Fire and Rescue with the remaining 11 men from Queensland Fire and Rescue. Of the Queensland (QLD) recruits, three were from the

Northern tropics and considered heat acclimatised, resulting in groups of eight heat and eight non-heat acclimatised (Table 1). The QLD recruits travelled via Brisbane, QLD to Darwin on the morning of the exercise, the four hour commercial flight simulated travel to deployment region. Immediately following collection of equipment and supplies, the crew travelled from Darwin Airport to the USAR training facility where they met with the research team and the five local USAR responders to commence the exercise. The exercise was conducted in mid-November, known for its harsh tropical environment with high ambient temperatures and elevated humidity, replicating conditions experienced within the Asia-Pacific region. The exercise commenced at 1300, with the afternoon period considered the hottest part of the day. Two groups of eight USAR personnel with equal allocation of HA and NHA participants were formed and worked in unison for the initial ~3.5 hour period. Thereafter, the teams rotated such that each team worked ~14.5 hours of the 24 hour exercise.

GASTROINTESTINAL TEMPERATURE, HEART RATE AND RESPIRATORY RATE

Participants had gastrointestinal temperature (T_{gi}) measured by an ingestible temperature sensor (Jonah, VitalSense, Respronics, Pittsburgh, Pennsylvania, USA) consumed with food ~45 minutes prior to data collection. It's likely that the ingestible pill transmitted stomach temperature during the first hour of the exercise. Stomach temperature is susceptible to fluctuations with fluid consumption, however water was stored in ambient conditions that minimised the gradient between T_{gi} and water temperature. The initial stages of the ingestible pill has been validated as a measure of core temperature (McKenzie and Osgood, 2004), and transmitted T_{gi} to a wearable receiver (SEM, Equivital, Hidalgo Ltd, Cambridge, UK) that also recorded heart rate and respiratory rate for storage.

Figure 1. Participants transporting a victim during the initial shift of the exercise.

FLUID BALANCE VARIABLES

Urine specific gravity (USG) was assessed with a calibrated refractometer (Atago UG-α, Tokyo, Japan) as an indice of hydration status pre- and post-exercise.

Dehydration was estimated from body mass change during the initial shift and from to start to end of the exercise. Prior to commencing the exercise, participants were weighed semi-nude on a portable calibrated platform scale (UC321 A&D Mercury, Adelaide, SA, Australia), accurate to 0.05kg. Following the initial shift and at the conclusion of the exercise, participants removed attire and towelled non-evaporated perspiration from the skin and hair prior to body mass measurement. The resultant dehydration estimation was expressed as a percentage of pre-exercise body mass according to the following equation:

Dehydration (%) = (Body Mass Loss x 100)/(Pre-Study Body Mass)

USAR personnel had ad libitum access to their drink bottle and/or fluid reservoir during the exercise. Non-refrigerated bottled water was provided for participants and stored at ambient temperature in the 'clean zone', remote from operations. Each team delivered water to personnel in the 'work zone' at regular intervals. Fluid consumption was monitored by determining the mass of individual hydration reservoir and/or bottle(s) pre- and post-consumption. It was assumed that 1 kg was equal to 1 L of fluid, and the difference in mass was the volume of fluid consumed. Fluid consumption was measuring the difference between pre- and post-initial shift drink bottle mass/hydration reservoir mass according to the following formula:

Fluid Consumption (kg) = (Pre Drink Bottle/Reservoir Mass – Post Drink Bottle/Reservoir Mass)

Fully clothed body mass was determined immediately prior to and following toilet breaks, with the body mass difference equalling urine volume.

Sweat loss and sweat rate were calculated by the following respective equations:

Sweat Loss (L) = Dehydration + Fluid and Food Consumption – Urine and Faecal Output.

Sweat Rate (L.hour^{-1}) = Sweat Loss/Hours.

PERCEPTUAL VARIABLES

Perceptual ratings of thermal sensation and discomfort were assessed prior to and following each shift via the modified numeric and descriptive scales of Gagge et al. (1967). Participants were asked "How does your body temperature feel?", with a numerical rating of 7 corresponding with the descriptor 'neutral'. Ratings of 1–6 equated to unbearably cold to slightly cool, while 8–13 corresponded with slightly warm to unbearably hot. Thermal discomfort was assessed by asking "How does your body temperature make you feel?" A rating of 1 was comfortable whereas 5 represented extreme discomfort.

ENVIRONMENTAL CONDITIONS

Ambient environmental dry bulb temperature (DBT), wet bulb temperature (WBT), relative humidity (RH) and black globe temperature (BGT) were continuously assessed and recorded by an environmental monitor (QuesTemp 36, Quest Technologies, Onoconomac, WI, USA). The unit will be positioned in full sunlight adjacent to the work zone throughout the study. The monitor calculated the Wet Bulb Globe Temperature (WBGT) (Yaglou and Minard, 1957) index by the following equation.

$$WBGT\ (^{o}C) = (0.7*WBT) + (0.2*BGT) + (0.1*DBT)$$

STATISTICAL ANALYSIS

A clustered linear regression, controlling for participant body mass and time, was performed for each phase, to determine differences between the HA and NHA cohorts for T_{gi}, HR and RR.

A two sample t-test with equal variances analysed post-exercise USG, sweat rate (mL.hour^{-1}.kg body mass^{-1}) and dehydration (% body mass) for differences between the HA and NHA groups. All statistical analyses were performed with Stata (version 13.1, StataCorp, College Station, TX, USA).

RESULTS

PARTICIPANT CHARACTERISTICS

The characteristics of the HA and NHA cohorts are summarised by table 1. The NHA cohort had significantly higher age, body mass and body mass index than the HA group ($p<0.05$).

Table 1. Participant composition.

	Heat Acclimatised	Non Heat Acclimatised
n	8	8
Age (years)	37.9	41.3*
Body Mass (kg)	86.2	95.7*
Height (m)	1.79	1.83
Body Mass Index (kg.m^{-2})	26.9	29.2*

* denotes significantly different ($p<0.05$).

ENVIRONMENTAL CONDITIONS

The mean environmental conditions of the initial 4 hour shift were 34.0 ^{o}C DBT, 48% RH and WBGT of 31.4 ^{o}C, confirming the hostile climate for thermoregulation. Mean environmental conditions for the exercise were 29.4 ^{o}C DBT, 72% RH and WBGT of 27.9 ^{o}C.

INITIAL SHIFT RESPONSES

The results of the initial shift demonstrated the greatest physiological perturbation and are considered crucial to the responses observed in the subsequent stages of the exercise. While the combined mean T_{gi} during the initial shift was 38.2^{o}C, the maximal T_{gi} was 39.6 ^{o}C, with 6 participants attaining a T_{gi} of 39.0 ^{o}C or more.

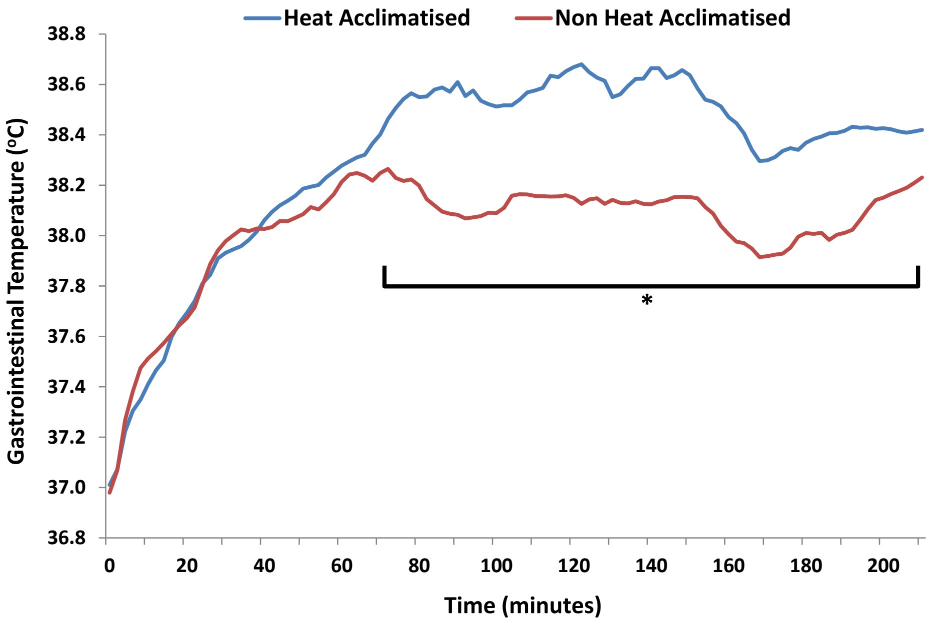
During the initial shift, the HA cohort exhibited a slightly higher mean T_{gi} (38.3 ^{o}C) than the non-heat acclimatised group (38.1 ^{o}C) ($p=0.09$), while sustaining similar mean heart ($p=0.35$) and respiratory rates ($p=0.41$) (Table 2). Figure 4 highlights the significantly higher mean T_{gi} sustained by the HA (38.5 v 38.1 ^{o}C) cohort from the 70th minute of the initial shift ($p<0.01$). Just one of the 16 participants failed to attain a T_{gi} of 38.5 ^{o}C during this shift, the recommended upper limit for T_{gi} of medically monitored, heat acclimatised employees by ISO9886. While individual workload was not quantified by this study, average HR of 130.9 beats.min^{-1} confirms the considerable workload of the participants during the initial shift. Perceptual ratings from the first shift revealed that both cohorts rated their body temperature as hot, causing them to feel uncomfortable.

Table 2. Summary of physiological responses to the initial shift for the heat and non-heat acclimatised cohorts.

Physiological Variable	Non Heat Acclimatised	Heat Acclimatised	p value
Pre Shift USG	1.014 (0.009)	1.010 (0.008)	0.32
T_{gi} (°C)	38.3 (0.5)	38.1 (0.4)	0.09$^{\varphi}$
HR (beats.min^{-1})	130.3 (18.8)	131.6 (24.2)	0.35
RR (breaths.min^{-1})	27.4 (6.1)	25.7 (6.8)	0.41
T_{gi} >38.5 °C	8	7	-
T_{gi} >39.0 °C	4	2	-
Fluid Consumption (L.h^{-1})	0.77 (0.21)	0.83 (0.19)	-
Fluid Consumption (mL.h^{-1}.kg^{-1})	8.1 (2.5)	9.6 (2.1)	0.31
Sweat Rate (L.h^{-1})	0.84 (0.12)	0.98 (0.31)	-
Sweat Rate (mL.h^{-1}.kg^{-1})	8.8 (0.9)	11.0 (3.2)	0.07$^{\varphi}$
Dehydration (%)	0.5	0.8	0.64
Thermal Sensation	10.2 (1.0)	10.1 (0.8)	0.89
Thermal Discomfort	3.0 (1.1)	3.1 (0.7)	0.89

$^{\varphi}$ Denotes a statistical trend ($p<0.10$)

*Figure 2. Gastrointestinal temperature response of heat acclimatised and non-heat acclimatised USAR cohorts during the initial shift. * denotes significantly different (p<0.01).*



Pre-shift hydration was classified as minimally dehydrated (USG 1.013). Sweat losses ranged between 3.0 and 7.5L, averaging 4.8L for the initial shift, or $0.89L.h^{-1}$, compared to fluid consumption of 4.3L or $0.80L.h^{-1}$. Dehydration at the cessation of the first shift was 0.6% body mass with no difference between cohorts (p=0.64). The HA cohort averaged a higher sweat rate of $0.98L.h^{-1}$ than the NHA ($0.84L.h^{-1}$) despite weighing a mean of 10.6kg less. When expressed as a factor of body mass, sweat rate was $11.0mL.hr^{-1}$ per kg body mass for HA that trended higher (p=0.07) than the $8.8mL.hr^{-1}$ per kg body mass for NHA.

OVERALL RESPONSES

Responses during the subsequent work shifts demonstrated lower physiological strain due to the cooler environmental conditions and a marked decrease in work rate (subjectively rated by research team). Of the 16 crew, just one participant exceeded 38.5°C during the evening/early morning shift, while one of the 14 participants (2 crew had passed pills during morning session) exceeded 38.5°C during the morning shift. The crews appeared to be suffering from the perturbation endured during the initial shift, a view supported by presentations to the medical team (Table 3).

ILLNESS

Seven of the 16 participants reported to the medical team during the exercise with symptoms detailed by table 2. Presentations commenced 9.5 hours from commencement of the exercise and cannot be explained on the basis of their acute physiological observations or those of the preceding two hours (Table 3).

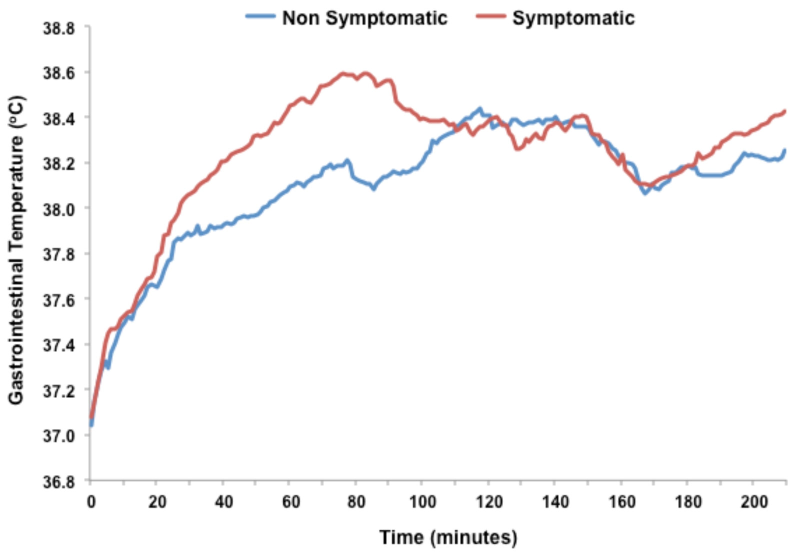
Table 2. Summary of presentations to the medical team during the exercise

Participant	Elapsed Time (Hours)	Acute Observations (HR/T_{gi})	Mean Observations Previous 2 hours (HR/T_{gi})	Presenting symptoms	Treatment or Outcome
3*	9.5	104/37.3	114/37.5	N,H	Paracetamol and rested x20 minutes
15	9.5	131/37.8	113/37.3	N,H,F	Paracetamol and rested x20 minutes
1*	9.6	101/38.2	121/38.0	N,H	Paracetamol and rested x20 minutes
12	13.5	96/37.2	Sleeping	H,V	Ondansetron sublingual 8mg and continued work
16	18.0	117/37.4	96/37.3	N,H,F	Paracetamol and rested x20 minutes
10	20.7	132/38.2	130/37.4	N,H,F	Paracetamol and rested x20 minutes
13	21.3	125/37.4	113/37.3	N,H,F	Paracetamol and rested x20 minutes

*denotes HA participant; N=Nausea; H=Headache; F=Fatigue; V=Vomiting

During the first hour of exercise, the likelihood of reporting to the medical team during the exercise was 1.5 times higher for every 10 beats.min^{-1} increase in HR (p=0.05), and 1.9 times higher (although not statistically significant p=0.11) for every 0.3 ^{o}C increase in T_{gi}. Figure 3 represents the T_{gi} response of the symptomatic and non-symptomatic participants during the initial shift.

Figure 3. Gastrointestinal temperature response of symptomatic and non-symptomatic participants



DISCUSSION

INITIAL SHIFT

This study simulated a 24 hour USAR deployment to a tropical region, with the initial work shift permitting comparison of HA and NHA cohorts as all 16 participants worked the initial 3.5 hour shift. Based upon the HR data, a relatively high workload was sustained during the initial shift, an expected result given that well-being and motivation during such exercises are generally highest during the early stages. The outcome of the physical workload, combined with personal protective ensemble and the tropical climate manifested in substantial body heat storage beyond limits recommended for occupational groups during the initial stage. With 15 of the 16 responders exceeding ISO9886 recommendations for T_{gi} limits, the initial shift represented a substantial physiological load. More moderate responses were observed for medical teams responding to a 3 hour simulated disaster in the tropics during milder conditions (Brearley et al., 2013), where mean T_{gi} peaked at 37.8^{o}C. In that study, the medical team were chronically HA and wore lightweight ventilated PPE, considered less insulative than the protective attire of the current investigation. Work rates of the medical responders based upon heart rate data appear substantially lower than the USAR personnel. Mean T_{gi} during short duration (<3 hours) simulated field operations can approach 39.0 ^{o}C (Brearley et al., 2011; Walker et al., 2014), however, it's intuitive to expect lower T_{gi} during longer duration exercises as responders pace their workload through the duration of deployment.

HEAT ACCLIMATISATION

Appropriate pacing of effort requires an understanding of tasks, number of personnel available, timeframe for completion, anticipated climatic conditions and by factoring individual physical fitness, experience and acute physiological status (Edwards et al., 2010). While workload could not be accurately measured during this study, the physiological responses are indicative of pacing. Despite significantly higher T_{gi} of the HA responders from the 70th minute of the initial shift, the NHA and HA cohorts demonstrated similar HR, RR, thermal sensation and thermal discomfort. It's likely that responders selected their pace based upon their perception of body temperature in conjunction with physiological feedback to sustain their response. The result was a mean T_{gi} difference of 0.4 ^{o}C between cohorts. In laboratory settings with fixed physical workloads, excess body heat storage and higher cardiac frequency are observed for NHA due to an inferior ability to dissipate body heat (Lorenzo et al., 2010). This study is the first to show lower body heat storage of NHA in the field during a realistic simulation of emergency response.

Regular elevations in T_{gi} and associated sequale including elevated skin temperature, cardiovascular adjustments and perceptual strain induce physiological and psychological adaptations that manifest in superior tolerance of thermal stress. Such adaptations are beneficial when responding locally during seasonally hot conditions and to the Asia Pacific region that can be hot and humid year round. The lack of heat acclimatisation status of USAR personnel deploying from temperate regions will likely impact their ability to dissipate body heat and sustain moderate to high workloads, and should be factored into the overall operational capability of the team. In this regard, heat acclimatisation status can be considered a vulnerability of USAR personnel based in temperate regions. One group of emergency responders address heat acclimatisation on an individual basis. Australian Medical Assistance Team (AusMAT) members are encouraged to undertake training year round to maintain a level of physical fitness and operational readiness for tropical regions, and are provided individual guidelines for heat acclimatisation prior to deployment. Such an approach would assist USAR teams to dissipate body heat and limit pacing of effort during deployment.

ILLNESS

The reporting of seven participants to the on site medical team highlights the physiological toll of responding in the tropics. Illness was not only an issue for NHA (5/8), but also the HA cohort (2/8). The acute HR and T_{gi} measurements could not explain the presentations, nor could the mean of the observations for the two hours preceding reporting ill. Interestingly, trends exist for higher HR or T_{gi} during the initial hour of the exercise influencing illness that was reported ~8 to 19 hours later. This is a novel finding worthy of additional research to identify the inflammatory response to working in the heat. Based upon the limited data available, excess heat exposure/body heat storage during the initial shift may have precipitated symptoms of headache and nausea, or what may be referred to as a 'heat hangover'. While more work is required, it's likely that limiting body heat storage during the initial stages of the response would mitigate the risk of illness during the latter stages of the exercise.

FLUID BALANCE

It is not clear whether the trend for higher sweat rate relative to body mass for the HA cohort is due to the enhanced sweat production due to heat acclimatisation and/or the higher T_{gi}. Despite the substantial sweat rates, mean fluid consumption of 0.80L.h^{-1} resulted in the crews minimising dehydration to less than 0.8% body mass during the initial shift. Ad libitum fluid consumption generally results in replacement of a lower proportion of fluid losses (Hendrie et al., 1997; Nolte et al., 2010), indicating the proactive distribution of the unlimited supply of bottled water on site. Such fluid consumption rates are not likely to be matched during deployment unless USAR teams implement a structured approach to fluid provision. While fluid consumption is recognised as a strategy to limit the impact of dehydration however, hydration does not confer immunity against the development of exertional heat illness (Cuddy and Ruby, 2011). Prevention of significant dehydration in combination with strategies that limit body heat production and augment body heat loss (cooling, heat acclimatisation) are more likely to limit the health impacts of USAR response in harsh environmental conditions.

COOLING STRATEGIES

A wide range of heat stress mitigation strategies that include establishing shade, rotation of teams, movement of air (fans), removal of PPE during rest periods, use of air conditioning, application of cold towels to torso, water immersion and ingestion of crushed ice are some of the cooling strategies available to transfer body heat of USAR personnel to the environment (Brearley et al., 2011). The applicability of strategies will be site and resource dependant, however, a rehabilitation sector is recommended irrespective of resourcing.

Overall, the outcomes of this study highlight the substantial challenge faced by USAR responders deployed into a tropical region. The combination of preparation for hot climates and heat stress mitigation strategies are required to maintain operational capability in the tropics.

RECOMMENDATIONS

Based upon the findings of this study, we recommend the annual delivery of heat awareness and management training to USAR personnel, and year round physical training to induce serial elevations of core body temperature and maintain a base level of heat acclimatisation irrespective of season. Monitoring of the environmental conditions during deployment and monitoring of responder work rate, body mass and medical observations are required to effectively manage the workload of crews.

Rotation of responders through a rehabilitation sector to facilitate monitoring and cooling are strongly recommended. Medically trained responders are urged to prioritise monitoring of USAR personnel while minimising their personal physical workload during the initial days of response in hot climates.

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