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Bomb Disposal in the Tropics: A Cocktail of Metabolic and Environmental Heat

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Abstract

Bomb technicians perform their work while encapsulated in explosive ordnance disposal (EOD) suits. Designed primarily for safety, these suits have an unintended consequence of impairing the body's natural mechanisms for heat dissipation.

Purpose: To quantify the heat strain encountered during an EOD operational scenario in the tropical north of Australia.

Methods: All active police male bomb technicians, located in a tropical region of Australia (n=4, experience 7 ± 2.1 yrs, age 34 ± 2 yrs, height 182.3 ± 5.4 cm, body mass 95 ± 4 kg, VO_{2max} 46 ± 5.7 $ml \cdot kg^{-1} \cdot min^{-1}$) undertook an operational scenario wearing the Med-Eng EOD 9 suit and helmet (~32 kg). The climatic conditions ranged between 27.1–31.8°C ambient temperature, 66-88% relative humidity, and 30.7-34.3°C wet bulb globe temperature. The scenario involved searching a two story non air-conditioned building for a target; carrying and positioning equipment for taking an X-ray; carrying and positioning equipment to disrupt the target; and finally clearing the site. Core temperature and heart rate were continuously monitored, and were used to calculate a physiological strain index (PSI). Urine specific gravity (USG) assessed hydration status and heat associated symptomology were also recorded.

Results: The scenario was completed in 121 ± 22 mins (23.4 ± 0.4% work, 76.5 ± 0.4% rest/recovery). Maximum core temperature (38.4 ± 0.2°C), heart rate (173 ± 5.4 bpm, 94 ± 3.3% max), PSI (7.1 ± 0.4) and USG (1.031 ± 0.002) were all elevated after the simulated operation. Heat associated symptomology highlighted that moderate-severe levels of fatigue and thirst were universally experienced, muscle weakness and heat sensations experienced by 75%, and one bomb technician reported confusion and light-headedness.

Conclusion: All bomb technicians demonstrated moderate-high levels of heat strain, evidenced by elevated heart rate, core body temperature and PSI. Severe levels of dehydration and noteworthy heat-related symptoms further highlight the risks to health and safety faced by bomb technicians operating in tropical locations.

Introduction

Bomb technicians have reported suffering severe symptoms of heat illness [1]. Heat illness occurs when the body becomes unable to regulate internal body temperature, most commonly in response to extreme environmental conditions. Although the most frequent presentations are minor, prolonged or severe exposure to a hot environment can be life threatening [2]. Additionally, neurological symptoms reported by bomb technicians such as irrational behaviour, confusion and loss of consciousness [1], although not fatal in themselves, could have significant implications in the explosive ordnance disposal (EOD) setting.

Environmental conditions have a significant effect on the heat stress individuals operate under [3]. High air temperatures and humidity, and low wind speeds, will slow the rate of heat loss from the body, quickening the onset of heat stress. Normally, heat dissipation is achieved through evaporation of sweat into the external environment and hastened by wind currents against the surface of the skin. However, wearing EOD personal protective equipment (PPE) creates a barrier between the skin surface and the environment creating a microenvironment [4]. Under such conditions, it is extremely difficult to effectively remove heat produced by the body during activity. To compound the issue the weight of the EOD PPE, which must be carried by the wearer during work tasks, considerably increases metabolic heat production. The end consequence is a rapidly increasing core temperature occurring in the context of an environment that does not facilitate heat loss.

To the authors knowledge there exists only one previous field study [1] examining the physiological response of EOD technicians performing simulated operations. This study was conducted in the south-west of Australia, at latitude of 32°S, and highlighted high levels of heat strain in mild (23-25°C ambient temperatures) environmental conditions. Therefore, the purpose of the current study was to examine the heat strain encountered during an EOD simulated operation, in more challenging environmental conditions, in the tropical north of Australia.

Methods

All active police bomb technicians (n=4), located in a tropical region of Australia participated in the study. The bomb technicians were aged 34.0 (31-35) years, height 182.3 (178-190) cm, weight 95.1 (89.9-99.4) kg, and had a maximal aerobic capacity of 46 (38-48)

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ml.kg^{-1}.min^{-1}, all data are mean with range in brackets. The procedures carried out in this study were approved by the Queensland University of Technology Human Research Ethics Committee. Participants were informed of the procedures and had any questions answered to their satisfaction prior to giving their written and verbal consent to participate. The participants undertook testing over two consecutive days. Day one involved the determination of physical fitness levels. Day two comprised the participants undertaking an operational training scenario.

Training

The training took place at 12.5°S latitude and was broken into five discrete stages on the same day from 11 am to 2 pm. Stage one involved walking ~50 metres to a two story building with five rooms, searching for and locating a target hidden in one of the rooms. Stage two required the bomb technician to carry equipment in order to take an X-ray of the target located on the ground floor. Stage three involved carrying, positioning and disrupting the target. Stage four required a clearance of the site. The final training stage required the bomb technician to carry an EOD robot (~50 kg) over 50 metres.

Personal protective equipment

All participants wore the Med-Eng EOD 9 suit (Allen Vanguard, USA), which included a jacket, integrated groin protector, trousers and boot covers plus the EOD 9 helmet. The weight of the whole ensemble was approximately 32 kg. All participants wore police coveralls under their suits. Participants removed the EOD 9 helmet and jacket only between the four stages.

Outcome measures and procedures

Physical fitness appraisal: Aerobic fitness ($VO_{2\,max}$) was evaluated using a sub maximal stepping protocol [5].

Core temperature: Participants were issued with an ingestible temperature sensor (CorTemp, HQ Inc, Palmetto FL, USA) and instructions were given to swallow the sensor before going to bed the night before the training scenario. All temperature sensors were calibrated [6], and a linear regression of each sensor was used to correct raw data. The data logger for the core temperature sensor was attached to the participant's EOD suit and set to record core body temperature at fifteen second intervals.

Heart rate: Prior to dressing for the operational scenario, a heart rate monitor (Polar S625x, Polar, Kempele, Finland) was strapped to the participant's chest and wrist to record heart rate at fifteen second intervals throughout the scenario.

Hydration: Urine samples were analysed to estimate the participant's hydration status before and after the scenario. Urine specific gravity was measured by a digital refractometer (PAL-10s, ATAGO, Tokyo, Japan) as previously reported [7]. Urine colours darker than three, and urine specific gravity values higher than 1.020 are indicative of dehydration with values >1.030 representing clinical dehydration [8].

Physiological Strain Index (PSI): The PSI provides a single numerical number to provide a quantitative measure of physiological burden [9]. By taking into consideration an individual's core body temperature and heart rate response, individuals are scored to a number 1-10, indicating strain ranging from none (zero) through to moderate (five) to very high respectively (ten).

Heat illness questionnaire: Following the completion of the scenario participants completed the heat illness symptoms index [10].

Environmental conditions: Ambient temperature and humidity were both recorded for the duration of the scenario, using a digital weather meter (Kestrel 4000, Kestrel Weather Australia, Australia).

Results

The training was completed in 120 ± 22 mins (24 ± 0.4% work, 76 ± 0.4% rest/recovery; Table 1). The climatic conditions during the scenario ranged between 27.1–31.8°C ambient temperature, 66-88% relative humidity, and 30.7-34.6°C wet bulb globe temperature (WBGT). The physiological response to the training scenario is provided in figure 1 and table 1, while the heat associated symptomology is presented in table 2.

Discussion

This study examined the heat strain encountered during an EOD operational training scenario. To our knowledge this is the first field based study that sought to assess the potential for excessive heat strain during EOD training in a tropical climate.

The scenarios, work/rest duration and intensity employed in this study are typical of the physical and varied occupational demands of EOD training in Australia [1]. The durations of the work scenario lasted for an average of 120 minutes over the course of the day. Interestingly, despite the variation in the time it took each participant to complete the different training scenarios, the work (23-24%) to rest (76-77%) ratios were very similar. All training, and subsequent rest periods, were completed in tropical environmental conditions (27.1–31.8°C ambient temperature, 66-88% relative humidity, 30.7-34.6°C WBGT).

Despite a combination of the extreme environmental conditions, the metabolic cost of activity and the microclimate, created by the PPE, the maximum core temperature achieved during the course of training was 38.5°C (table 1). The physiological strain also resulted in all bomb technicians displaying heart rates in excess of 90% of their age predicted maximal heart rate during the scenario. Both core temperature and heart rate responses were similar to those previously reported [1] for an EOD training scenario occurring in a significantly cooler environment (WBGT 25.7°C). These similar results highlight that, irrespective of external environmental conditions, the internal rate of heat production

Participant	Scenario Duration (min)	Work / Rest (%)	Average HR (bpm)	Maximal HR (bpm)	Average Tc (°C)	Maximal Tc (°C)	Average PSI	Maximal PSI
1	128	24 / 76	137	176	37.5	38.4	4.1	7.0
2	145	23 / 77	101	167	38.2	38.5	4.7	7.5
3	117	23 / 77	133	179	37.6	38.4	4.5	7.2
4	93	24 / 76	133	170	37.8	38.1	4.2	6.5
Mean ± SD	121 ± 22	23.4/76.5	126 ± 17	173 ± 5	37.8 ± 0.3	38.4 ± 0.2	4.4 ± 0.3	7.1 ± 0.4

HR-Heart rate; Tc- Core temperature; PSI- Physiological Strain Index

Table 1: Individual physiological responses to the training scenario (n=4).

Symptom	Percentage of participants reporting symptom	Symptom rating (Scale 0-10)	
		Mean	Range
Feeling Tired	100	5.3	4-7
Cramps	25	7	7
Nausea	0	-	-
Dizziness	25	1	1
Thirst	100	6	5-7
Vomiting	0	-	-
Confusion	25	1	1
Muscle Weakness	75	2.6	1-5
Heat Sensations	75	1.6	1-3
Chills	0	-	-
Light-headed	25	3	3

0 –No symptoms, 3 – Mild symptoms that did not interfere with work, 5 – moderate symptoms,
7- Severe symptoms requiring a break from work, 10 – Had to stop work

Table 2: Symptoms of heat illness experienced during the training scenario (n=4).

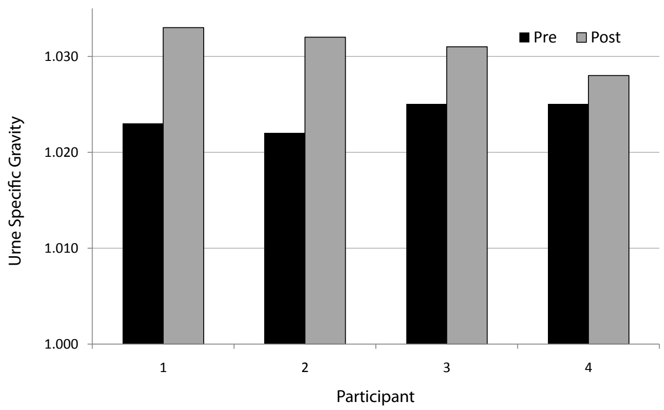

Figure 1: Urine specific gravity pre and post the training scenario (n=4).

(i.e. workload) is the predominant factor in thermal strain in situations of uncompensable heat stress; as reported previously in studies of chemical, biological, radiological and nuclear PPE [11,12].

International standards [13] recommend core body temperature should not exceed 38°C for medically selected and acclimatised personnel in occupational settings. Consequently, at least one of the participants in the current study was at the upper limit of these standards. Moreover, the fact that all participants core temperature continued to rise during the initial period of recovery, may have implications for the design of work/rest intervals and the implementation of appropriate recovery protocols in similar environmental settings [14,15].

Although core temperature did not exceed the recommended standards, all participants displayed moderate-to-high levels of physiological strain. The PSI takes into account both heart rate and core body temperature and is regarded as a useful tool in the evaluation of thermal strain. A high level of PSI is classified by a threshold value greater than seven. In the current study three of the four participants were considered to have a high level of physiological strain. These findings are similar to those reported in our previous investigation of EOD training.

One of the most interesting findings of the current study was the hydration status of the bomb technicians before and after the training. All participants in the current investigation commenced training dehydrated (USG>1.020) and this was exacerbated at the end of the day despite fluid being consumed ad libitum. It is well established that when performing physical work, sweat output often exceeds fluid intake, producing a body water deficit or voluntary dehydration. Based on the relatively high levels of physiological strain and core body experienced; adequate hydration before, during and after EOD scenarios, plus education of its importance, is critical. As current research indicates that decrements in physical, visuomotor, psychomotor, and cognitive performance can occur when 2% or more of body mass is lost due to heat, and/or physical exertion; the level of dehydration experienced in the current study could have significant implications in an occupational setting for a bomb technician.

Heat illness symptomology

The heat illness symptom index highlighted that moderate-severe levels of fatigue and thirst were universally experienced, with muscle weakness and heat sensations also experienced by 75% of the bomb technicians. Neurological symptoms of light-headedness, dizziness and confusion were also reported. These symptoms support previous findings in EOD and highlight that cognitive impairment may be occurring before severe levels of physiological thermal strain are reached. Any level of cognitive impairment could have significant ramifications in an EOD operational setting.

Limitations and future research

Although the study involved all the active police EOD technicians in the geographical region, the findings are limited to a small sample. Moreover, these findings are only applicable to this particular EOD PPE ensemble in tropical environmental conditions. Further laboratory controlled studies are warranted to examine the physiological and cognitive effects of wearing this type of EOD PPE ensemble in different environmental conditions and at different workloads.

Conclusions

This investigation provides novel data detailing the physiological strain on bomb technicians undertaking EOD training in a tropical environment. All technicians experienced moderate to high levels of physiological strain, heat illness symptomology and core body temperatures close to the upper limits of current international standards. Further, controlled laboratory studies are required to develop safe tolerance times and work/rest schedules for bomb technicians operating in hot and humid environments, as any decrement in physical or cognitive performance may have severe occupational consequences.

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