Physiological strain, RPE, and perceived thermal
stress during auto extrication simulations by experienced urban firefighters

by

Benjamin Trace Soer

BSc., University of Victoria, 2003

A Thesis Submitted in Partial Fulfillment of the

Requirements for the Degree of

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in the School of Exercise Science, Physical and Health Education

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Supervisory Committee

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ABSTRACT

This study examined the physiological response of 22 participants (three groups of six, one group of four) during four auto extrication simulations (AES) wearing full personal protective equipment. Heart rate (HR) and core temperature (C_T) were monitored continuously from baseline thoughout the AES until 45-min recovery. Blood pressure (BP), ear canal temperature (EC_T), subjective measures of exertion and thermal stress were taken at baseline, post AES and clean-up, and at 45-min recovery.

The average extrication completion time was 33 minutes. Average AES HR was 118 beats•min^{-1}, a 50% increase over HR during hall duties (79 beats•min^{-1}). HR during AES was classified as 'heavy work.' C_T increased significantly from baseline 37.19°C to 37.83°C post AES. At 45-min recovery, C_T was significantly elevated from baseline (37.37°C; $p<0.05$). C_T and EC_T did not correlate well ($r=0.004$), and EC_T significantly underestimated C_T at all time points. C_T and HR were strongly correlated at all measurements ($r=0.89$). Mean rating of perceived exertion (RPE) post AES and post clean up was 14.0 (between 'somewhat hard ' and 'hard') on Borg 20 point scale. RPE showed strong relationships with physiological variables of peak HR expressed as % of age predicted max ($r=0.70$), and physiological strain index (PSI) ($r=0.76$). Rating of perceived thermal stress (RPTS) increased significantly from baseline (1.23 'comfortable') to post AES (4.4, 'hot'). RPTS had significant moderate strength relationships with PSI (r=0.56) and C_T (r=0.52). Differences did exist in all measurements between roles within the AES team with worker firefighters (n=14) demonstrating the highest HR, BP, rise in CT, and RPE. Medics (n=5) had the lowest recorded HR, BP, & RPE.

The results suggest that vehicle extrication is a physically demanding task for firefighters and 45 minutes recovery is sufficient for HR, BP, psychophysical measures, but not C_T to return to baseline. The findings have implications for those firefighters who may be presented with repeated AE and/or fires and other activities across a shift. It is recommended that ear canal temperature measurements not be used as a field measure of C_T as it had no relationship with C_T and significantly underestimated actual C_T. Future studies are needed to determine oxygen consumption and energy expenditure required to complete auto extrications.

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INTRODUCTION

Although public perception of the role of firefighters is that of fighting fires, and firefighter literature has focused on fire suppression activities, considerably more time is devoted to other tasks (Lusa, Louhevaara, & Kinnunen, 1994). One such task is auto extrication (Auto Ex) and victim rescue from motor vehicle accidents (MVA). Anecdotal evidence (S. Woodburn, personal communication, July 15, 2005; G. McLellan, personal communication, Aug 10, 2005) suggests that firefighters consider auto extrication to be one of the most physically and psychologically demanding jobs within their scope of duties.

Full PPE must be worn at all times when performing an auto ex from a motor vehicle accident, thus increasing core temperature (C_T), heart rate (HR), & physiological strain index (PSI). Increased C_T from a combined increase in metabolic activity and an uncompensable heat stress environment from PPE reduces the ability to perform work and can endanger the health of firefighters (Cheung, McLellan, & Tenaglia, 2000). To date, no other studies have examined the physiological demands of live or simulated extrication activities.

Gledhill and Jamnik (1992) measured HR and $VO_{2\ of}$ incumbent firefighters as they completed five discrete tasks associated with auto extrication (sand pail carry, acetylene equipment carry, first response extrication kit, extrication; cutter and spreader, and steering wheel removal). Extrication activities were reported to require 50% VO_2 of the most demanding fire suppression tasks. Live auto extrications and victim rescues, commonly performed by firefighters, are not separated into discrete tasks such as the study design of Gledhill and Jamnik (1992) and therefore the findings may have underestimated the physiological demand and intensity of auto extrication. Auto extrication and victim rescue is a continuous task that begins with the response to the alarm call and ends with extrication of the victim(s) and cleanup of all tools. Firefighters extricate under the 'golden-hour' principle (victims will receive emergency room treatment within 1 hour of incident), which drives the intensity and pace of the victim rescue.

The physiological demands of continuous auto extrication and victim rescue require further examination. Furthermore, differences in the physiological demands of the various roles within the AE team (workers vs. incident commanders vs. medics) have not been identified. Cardiac response, C_T, PSI, and ratings of perceived exertion and thermal stress to an auto extrication simulation have yet to be examined. Therefore the purpose of this research is to determine the physiological demands of an auto extrication simulation and if differences exist between roles during an auto extrication.

Statement of Problems

1. The physiological changes (HR, C_T, and blood pressure (BP)) during a full auto extrication scenario for firefighters have not been identified.
2. The length of time and rating of perceived exertion (RPE) and rating of perceived thermal stress (RPTS) of auto extrication scenarios for firefighters have not been identified.
3. The physiological and psychophysical demands have not been identified between roles (workers, incident commanders, medics) within the auto extrication team.

Purpose of the Study

1. To describe the physiological demands of an auto extrication simulation for firefighters.
2. To determine recovery time for HR, CT, and BP following an auto extrication simulation.

Rationale

Although Gledhill and Jamnik (1992) assessed HR and VO_2 of firefighters completing discrete auto extrication tasks, the present research design is the first to describe the physiological and thermal response of firefighters during a continuous auto extrication simulation. At present there is a lack of scientific research that describes the physiological changes in CT, HR, BP, and PSI that occurs with auto extrication. The use of a telemetric CT monitoring system allowed for the thermal response to live simulations to be described for the first time.

Hypotheses

1. Firefighters will exhibit significant physiological strain during extrication activities
2. C_T will increase with duration of the auto extrication simulation (AES).
3. Cardiac response and PSI will be role specific and greater for certain roles within the AE team.
4. Psychophysical measures (RPTS and RPE) will increase with time and will differ between roles for the AE team with some roles having higher values.

Delimitations

1. Participants were professional incumbent, experienced firefighters from the Victoria Fire Department.
2. Participants were all males between 22 and 55 years of age.

Limitations

1. Pre-test training status of the participants was not controlled.
2. Caffeine, food, and alcohol consumption was not tightly controlled prior to the extrication simulation.
3. PPE worn varied between firefighters. Different PPE (brand, model) imposed slightly different thermal challenges to firefighters.
4. Each rescue scenario was different. Extrication time varied depending on the requirements of the extrication and/or the experience of the rescue crew. An attempt to keep level of difficulty and extrication time similar between simulations was made.
5. Environmental conditions and air temperature were not controlled and were different over the test period and test day.
6. Within an AES team, there was one incident commander and one, sometimes two medics, thus limiting the n when calculating means for these roles.

Assumptions

1. That HR and telemetric C_T are accurate measurements for physiological strain index calculations.

2. That participants performed the simulation with intentions of extricating victims as quickly and safely and as close to accepted firefighter protocol as possible.
3. The 4 different rescue scenarios posed similar physiological challenges to firefighters with the same duties in the 4 different rescue crews.
4. That the physiological response to a simulated auto extrication was similar to the physiological response to a live motor vehicle rescue
5. That the range of perceptions between no exertion and maximal exertion were the same for all people and that maximal exertion on the Borg RPE scale means the same for everyone.

Operational Definitions

Auto Extrication Simulation (AES)

A simulated auto extrication exercise for firefighters. Simulations were performed in teams of six: two members from the rescue truck, and four members from the engine truck. The AES included any or all of the following tasks: blocking the vehicle, deflation of the tires, roof removal, glass cutting, springing of doors, removal of victims and placement onto a stretcher.

Motor Vehicle Accident (MVA)

A motor vehicle accident involving one or more automobiles and in the context of this paper will refer to those MVAs that require auto extrication and victim rescue.

Personal Protective Equipment (PPE)

The standard Personal Protective Equipment (PPE) worn by Canadian firefighters (National Fire Protection Association [NFPA] Standard 1500 [NFPA, 2002] PPE). PPE during this experiment consisted of boots, pants, jacket, gloves, and helmet.

Incident Commander

The firefighter in charge of the accident scene. He performed initial scene assessment and directed rescue crew procedures throughout the auto extrication.

Jaws of Life

Hydraulic spreading tools used for auto extrication.

Figure 1. Holmatro 3260UL Spreader tool.

Cutters

Hydraulic cutters/snips used for auto extrication.

Figure 2. Holmatro 3040 NCT Cutter tool.

METHODOLOGY

Participants

22 experienced firefighters volunteered as part of four, six-person rescue crews. Three groups of six firefighters and one group of four firefighters (*n = 22)* were recruited from the Victoria Fire Department. All participants were informed of test procedures and

completed a written informed consent form and PAR-Q. This project was conducted with the approval from Transportation Emergency Rescue Committee (TERC), National Fire Protection Agency (NFPA), and followed the Canadian Tri-Council Policy for ethical treatment of human participants as part of the Helsinki Declaration II. Institutional research ethics board approval from the University of Victoria was obtained prior to any experimentation.

Eligibility Criteria

- Males age 22 to 55 years
- Experienced in auto extrication protocol
- A member of one of the four selected rescue teams
- Not currently taking BP medication
- No known cardiovascular or cardio-respiratory pathology

Test Sequence & Parameters

A descriptive design was implemented for this study. To increase external validity, the time, location, and parameters of the auto extrication simulation was withheld from all participants. Four testing days were required to complete four extrication simulations for the four separate rescue crews. Testing began at the start of shift duty between 7:00 and 8:00 am. Anthropometric measures, nude & dry weight, height, resting BP, EC_T and thermal stress were assessed. C_T capsules (Minimitter) were swallowed with water and Polar HR monitors put on and synchronized with a master stopwatch. Capsules were swallowed immediately to allow a minimum of three hours for the capsule to move from the stomach into the GI tract. Following initial data collection participants were allowed to perform regular fire hall duties until the 'mock' alarm call for the auto extrication simulation was sounded. On all occasions the alarm call came between 10:00 and 11:30am. The six participant firefighters simulated a response to an alarm call and donned PPE. Both the rescue and engine trucks were dispatched to the simulation location indicated by the alarm dispatch. Four different simulation sites were used to ensure no prior knowledge of site location to participants.

During the simulation, HR was collected every five seconds and a 1-min average is reported. C_T was collected as often as possible during the AES and cleanup. Within one minute of completion of the AES, physiological measures were taken. Once physiological measures were complete, perceptual measurements for each participant were recorded. During tool cleanup and recovery, HR continued to be recorded. When possible, EC_T, BP, RPE and thermal comfort measurements were measured at 15-min intervals until 45-min post simulation. Figure 3 is a pictorial representation of the study measurement timeline.

Measurements

Baseline: Taken @ 7:00am when the volunteers first report to Yates St. Fire hall for duty.

- Resting HR
- Resting BP
- C_T (every minute)
- EC_T
- RPTS
- Height
- Dry Weight
- Σ5 Skin Folds

Rescue Scenario:

- HR (60s average of 5s recordings)
- C_T (as frequent as possible)

- Ambient air temperature & humidity
- Task duration
- Film AES and dictate times and activities onto the film from master stopwatch

Immediately Post-test:

- HR
- BP
- C_T
- EC_T
- RPE
- RPTS

Cleanup/Recovery: Up to 45 minutes post simulation.

- HR (60s average of 5s recordings)
- C_T
- EC_T
- BP
- RPE
- RPTS
- Simulation Satisfaction Likert Questionnaire

Every 15 minutes

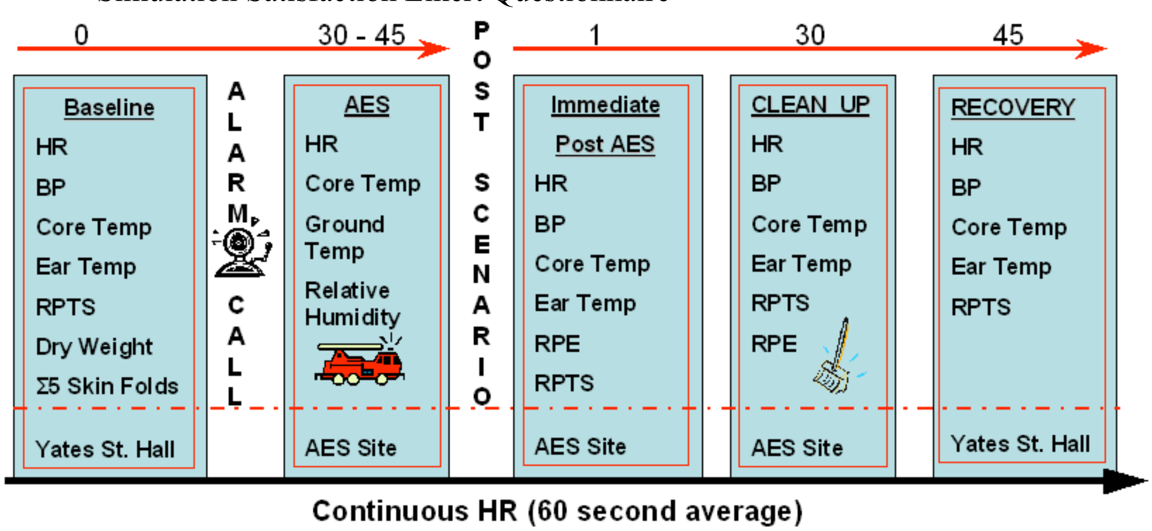

Figure 3. Testing timeline for each of four testing sessions.

Heart Rate (HR)

HR was monitored continuously (5s recordings) using a downloadable Polar S610 HR monitor (Polar Electro Inc., Port Washington, NY, USA). Resting HR was considered as the lowest 1-min average HR recorded during baseline measurements. Participants sat quietly for a minimum of five minutes prior and throughout baseline measurements of HR and BP. Peak HR was considered to be the highest 1-min average HR recorded during any portion of the auto extrication simulation. HR was sampled every 5s and 1-min means are reported. Adding each HR sample and dividing by 12 determined means. %HR max was determined by an age predicted max formula (220-age). %HR max was used to give relative HR intensities for the sample population which varied in age. %HR max was also used to classify work intensity (Astrand et al., 2003).

Blood Pressure (BP)

BP was assessed with an Omron (Omron Healthcare, Inc. Bannockburn, Illinois) Intellisense automatic inflation BP monitor (Model: HEM-712C). Participants sat quietly for five minutes during the baseline measurement period to attain a resting BP. BP was also recorded immediately following the rescue scenario, following cleanup and at each measurement point during the recovery period. All measurements were taken with the subjects seated.

Core Temperature Measurement

A baseline C_T was recorded two hours post-capsule ingestion. During the AES and recovery C_T was monitored at 15s intervals as often as could be sampled by the researchers. Measurements for each member of the AES team were made using the VitalSense (Mini Mitter Co., Inc., Bend, Oregon). The system consists of a receiver/monitor, and a thermistor-based ingestible capsule, Jonah core body temperature capsule (CBTC). The Jonah CBTC sends its unique ID number with each transmission allowing multiple capsules to be measured simultaneously without sensor ‘cross-talk’ or confusion. The VitalSense has a specified accuracy of 0.1 ºC and has been shown to correlate significantly with rectal probe measurements ($R^2 = 0.80$, $p < 0.05$) for all subjects and all data points (McKenzie & Osgood, 2004). When only the quiescent periods were considered the coefficient was $R^2 = 0.90$, $P<0.05$. Ethical C_T upper limit was set at 39.5 ºC.

The VitalSense has a proximity range of one-meter therefore posing a challenge to record C_T for each member of the rescue team during the 20-min scenario. The proposed method to solve this problem was to have two testers carry two receivers and move throughout the AES team to take as many readings from the workers, medics, and incident commander as possible during the extrication.

Physiological Strain Index

The formula used to calculate PSI weighs HR and C_T equally:

$$\mathbf{PSI = 5(T_{ret} - T_{re0}) \cdot (39.5 - T_{re0})^{-1} + 5(HR_t - HR_0) \cdot (180 - HR_0)^{-1}},$$

Rectal Temperature (T_{ret}) and HR_t are simultaneous measurements taken at any time during the exposure and T_{re0} and HR_0 are the initial measurements. Moran, Shitzer, & Pandolf (2000) assumed that the maximal Tre and HR rise during exposure to exercise heat stress from normothermia to hyperthermia was 3°C (36.5–39.5°C) and 120 beats/min (60–180 beats/min), respectively. The present study did not use rectal temperature as a measure of C_T and instead used the newly developed telemetric C_T monitoring system. PSI calculations determine the change in temperature and HR from one time to another; therefore the nature of a C_T measurement (rectally versus telemetric) is not expected to alter the results.

Ear Canal Temperature (EC_T)

EC_T was measured using an infrared thermometer placed in the ear canal and pointed towards the tympanic membrane (Thermoscan 4520 Exac Temp, Braun Proctor & Gamble, Cincinnati, Ohio). Measurements were taken at baseline, immediately following the AES, post-cleanup and at each recovery period.

Body Weight

Nude and dry body weight was measured at baseline to an accuracy of 50g using a precision digital scale (HL120, Avery Berkel, West Midlands, UK).

Anthropometric Measurements

Skin-fold thickness followed CPAFLA protocol (CSEP, 2003) and was measured to the nearest 0.2 millimetres at five sites (triceps, biceps, subscapular, iliac crest, and medial calf) using skin-fold calipers (Harpenden, John Bull British Industries Ltd., England) (Figure 3). Measurements were taken in duplicate and the mean of the two measures recorded. Sum of five skin folds was calculated and classified according to established norms (CSEP, 2003). BMI was calculated from height and weight.

Psychophysical Measurements

Participants were asked to visually point (silent method) to a specified RPE using the Borg 20 point RPE scale immediately following the rescue scenario, and following cleanup (Borg, 1982). Silent RPE indication was performed to prevent an influencing effect between different members of the rescue team. To gain further descriptive knowledge about the self-perceived effort during an AES, participants were asked to report on their maximal effort during the rescue simulation and their average effort during the rescue scenario.

Perceived thermal stress was evaluated at baseline, immediately upon finishing the rescue, post-cleanup and during each recovery measurement. Silent thermal stress indication prevented an influencing effect between different members of the rescue team. Following the AES, participants were once again asked to report on their maximal level of thermal stress during the rescue simulation and their average thermal stress during the rescue scenario.

Simulation Satisfaction Questionnaire

Following the completion of all recovery measurements, participants were asked to answer four questions (five-point Likert scale) aimed at determining the relatedness of the AES to a live MVA.

Statistical Analysis

All statistical analyses were completed with Microsoft Excel (2003), SPSS (v. 15.0); and Statistica and were considered significant at $p \leq 0.05$. Descriptive statistics were used to determine the mean, range, and standard error of physiological and psychophysical measurements for the four AES rescue crews. Repeated measure ANOVAs were performed to determine significant differences between four time points over the experimental timeline. Where appropriate, post-hoc paired t-tests were done to determine significant differences between different situations of the AES timeline. Values are reported as mean (standard error), ($p < 0.05$) unless otherwise stated.

RESULTS

Participant characteristics

The characteristics of the participants (n = 22) are summarized in Table 1. Two participants had faulty C_T capsules and the polar heart monitor data used on one of these participants was also defective. HR & CT data from these subjects were excluded from the repeated measures analysis, however all other physiological and psychophysical data for these subjects were included in the analysis. No trials were terminated due to the attainment of the ethical C_T limit (39.5°C). Incident commanders were the oldest, had the most years of firefighter experience, and had the highest weight, BMI & ∑5 skin folds compared to the other participants. The worker firefighter group ranked second in all measurements and the medics were the youngest, had the least years experience, were the lightest, and had the lowest BMI and ∑5 skin folds of the three roles.

Table 1

Mean, Range, and Standard Error (SE) for Age, Height, Weight, BMI and Duration of Fire Service Separated by Role within AES (n = 22).

Role in AES	N	Age (yr)	Fire Service (yr)	Weight (kg)	Height (cm)	BMI	Σ 5 Skin Folds (mm)
Worker	14	38.8	10.2	86.6	181.9	26.1	45.9
Incident Command	3	50	26.3	99.0	178.0	31.6	80.2
Medic	5	32.2	3.9	84.2	189.8	23.4	38.9
Mean	**22**	**38.9**	**11.0**	**88.0**	**183.0**	**26.4**	**49.4**
Range		23-50	.5-28	73-107	166-196.2	23-38.2	21.9-116.4
SE		1.6	1.7	1.9	1.5	0.8	4.4

Simulation Satisfaction Questionnaire

Table 2 summarizes the responses (AES group means, and total mean reported) to a four-question simulation satisfaction questionnaire scored on a five point Likert scale. Question one and question four, assessed how closely the auto extrication simulation represented existing extrication protocol, and how real the simulation was to a live MVA. Mean scores were 4.1 and 3.8 respectively, which correspond to 'agree' on the Likert scale. Questions two and three compared the stress level and sense of urgency during the simulation to real life MVAs with mean scores of 3.2 and 3.4 respectively. The percentage of ‘strongly agree’ or ‘agree’ responses is shown (Table 2). 100% of participants agreed or strongly agreed to extrication protocol responses while 73% agreed or strongly agreed to AES realness. 55% of participants agreed with sense of urgency while stress of the AES was the only question that did not have the majority of the responses agree or strongly agree (45%).

Table 2

Mean Simulation Satisfaction Questionnaire Results

		Question			
		1	2	3	4
	n	Extrication Protocol	Stress	Urgency	Realness of AES
Group 1	6	4.3	3.5	3.3	4.5
Group 2	6	4	3	3.3	3.2
Group 3	6	4	3.2	3.5	3.7
Group 4	4	4	3	3.5	4
Mean	**22**	**4.1**	**3.2**	**3.4**	**3.8**
% Agree or Strongly agree		100%	45%	55%	73%
Range		4 – 5	2 – 4	2 - 4	2 – 5
SE		0.06	0.18	0.16	0.16

(5=strongly agree, 4=agree, 3=undecided, 2=disagree, 1=strongly disagree).

Heart rate

Overall HR (mean ± SE) increased significantly from that during hall duties (79.3 [±1.0] bpm) to alarm call response (99.8 [±2.3] bpm) (Figure 4). HR fell to (81.0 [±1.0] bpm) during transit to the AES before climbing to the highest mean value of (118.2 [±1.4] bpm) during the AES ($p<0.01$). Significant decreases in HR followed at cleanup (105.3 [±1.6] bpm) and 45-min recovery (77.6 [±2.6] bpm). By 45- min recovery HR and hall duties HR were not significantly different (Figure 4). Table 3 separates mean HR by extrication group and situation of the AES timetable. HRs were not statistically different between groups ($p < 0.05$).

Table 4 separates average extrication HR data by role within the AES team. Workers had the statistically highest average extrication HR at 123.3 bpm which corresponded to 71% of an age predicted maximum HR (220-age). This average extrication HR corresponds to a work intensity rating of ‘heavy work’ (Astrand et al., 2003). Incident commanders also had an intensity rating of ‘heavy work’ with an average extrication HR of 116.8 bpm corresponding to 74% of age predicted max HR. During the AES medics showed the lowest average HR at 98.3 bpm which corresponded to 52% age predicted maximum and a work intensity of ‘moderate’.

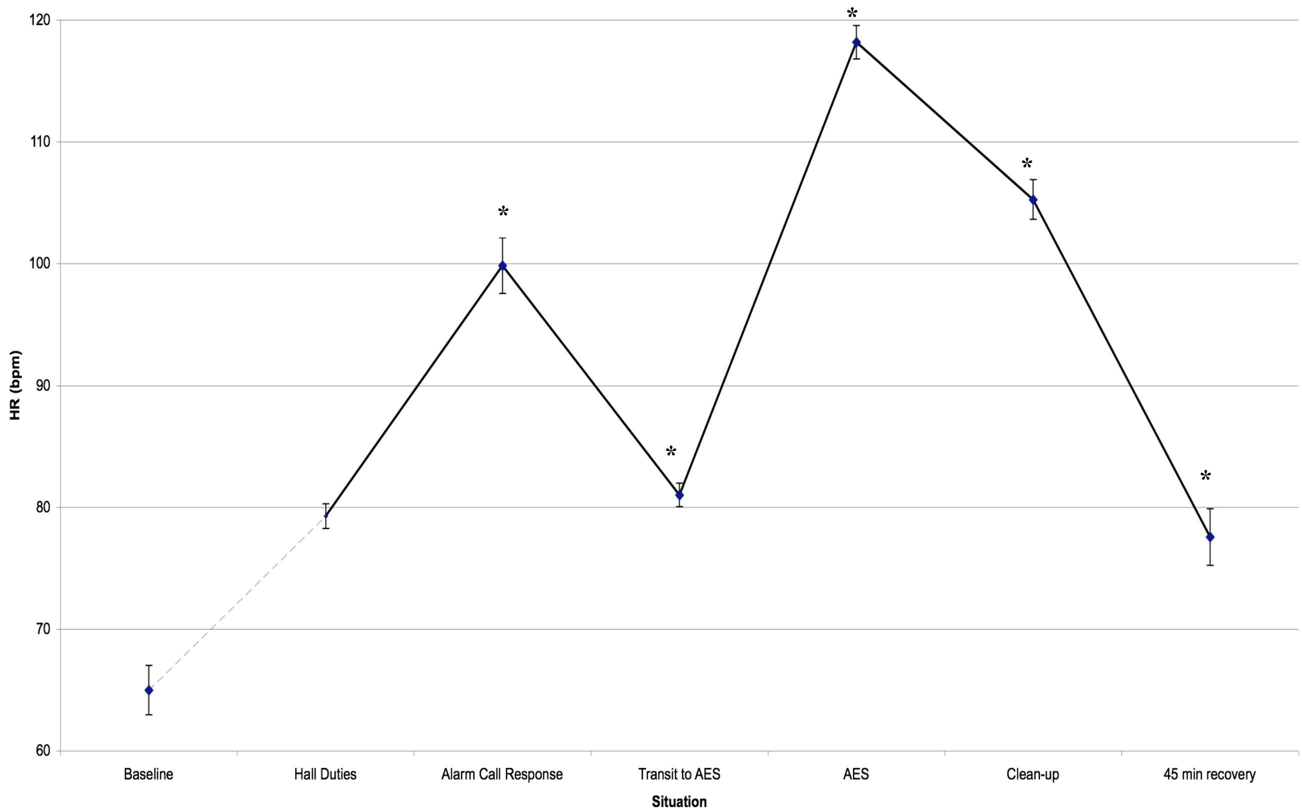

Figure 4. Mean (SE) HR for baseline and six discrete situations of the experimental timeline (n=21).

* Indicates p < 0.05 significant difference from the preceding measurement.

Table 3

Mean Heart Rate, for Baseline and Six Discreet Situations of the Experimental Timeline Separated by AES Group (n = 21).

Group	N	AES time (min)	Mean HR (bpm) Baseline	Hall Duties	Alarm Call Response	Transit to AES	AES	Clean-up	45-min Recovery
1	6	32.5	69	77	89	86	124	108	83
2	5	28	63	82	113	83	123	111	90
3	6	36	69	84	103	80	114	108	71
4	4	38	58	74	94	75	111	94	66
Mean	**21**	**33.6**	**65**	**79**	**100**	**81**	**118**	**105**	**78**

Table 4

Mean Extrication Heart Rate Expressed in bpm, % of Age Predicted Max HR, and Corresponding Work Intensity Separated by Role.

	N	Extrication Average HR (bpm)	% of age predicted max HR	Work Intensity*
Worker	14	123.3	71	heavy work
Medic	4	98.3	52	Moderate
Incident Command	3	116.8	74	heavy work

* (Astrand et al., 2003)

Mean arterial (MAP), systolic (SP) & diastolic (DP) pressures

Repeated measures ANOVA (RM ANOVA) revealed a significant time main effect [F(3,19) = 9.46] for MAP (Figure 5). MAP increased significantly (p<0.001) from baseline (94.8 [±1.7] mmHg) to post AES (103.3 [±1.7] mmHg) and decreased significantly at post cleanup (98.9 [±2.0] mmHg) and 45-min recovery (93.8 [±1.3] mmHg). MAP at 45-min recovery was not significantly different from baseline. RM ANOVA revealed a significant time main effect [F(3,19) = 15.34] for systolic BP (SP). There was a significant increase in SP between baseline (133.5 [±2.0] mmHg) and post AES (147.0 [±2.3] mmHg) (p<0.001). There was no significant difference between post AES and post cleanup, however a significant difference did exist between post-cleanup and 45-min recovery measurements (p<0.01). 45-min recovery SP was not significantly different from baseline. RM ANOVA also revealed a significant time main effect [F(3,19) = 4.16] for diastolic pressure (DP). There was a significant increase from baseline (75.4 [±2.0] mmHg) to post AES (81.5 [±2.1] mmHg and significant decreases post cleanup (77.7 [±2.1 mmHg]) and at 45-min recovery (74.8 [±1.4] mmHg). DP at 45-min recovery was not significantly different from baseline.

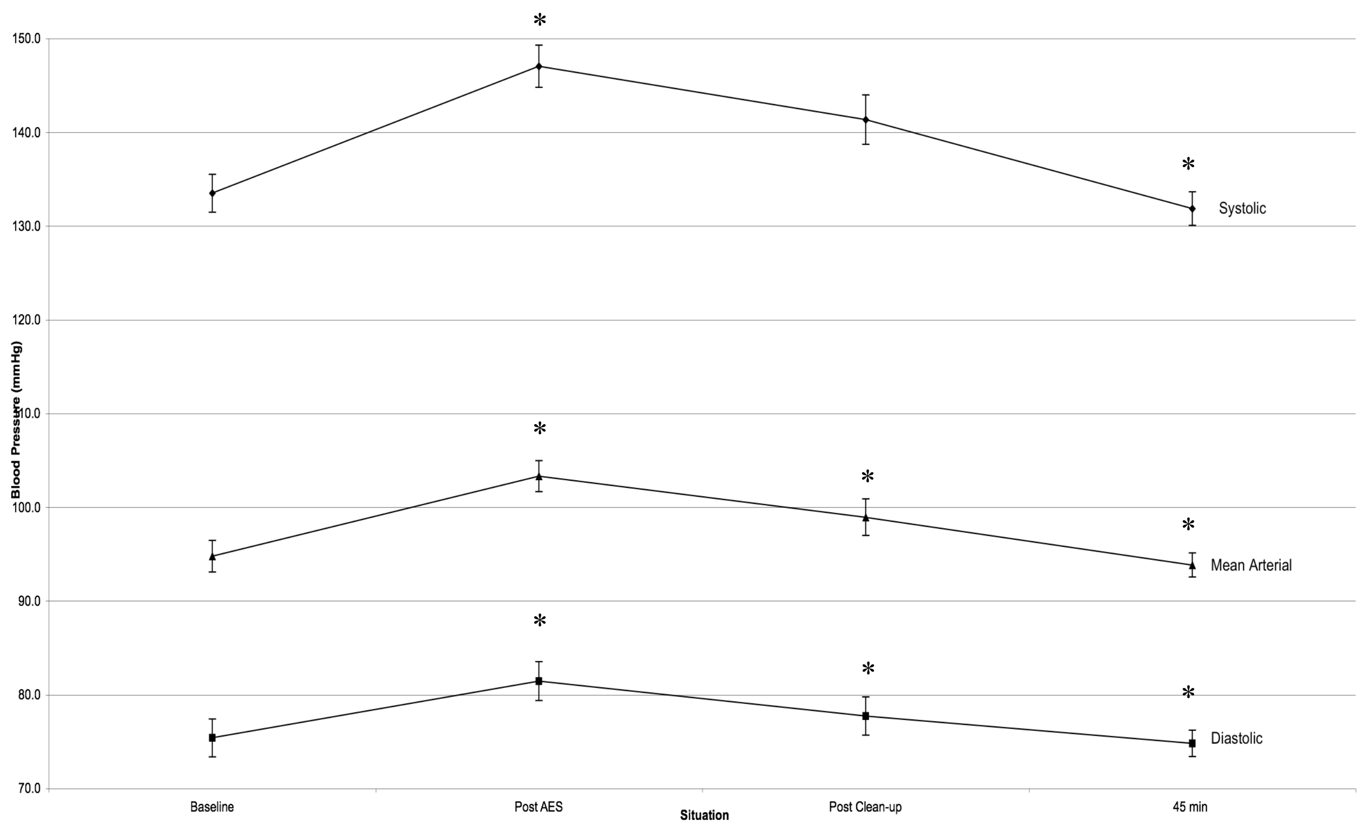

Figure 5. Mean (SE) SP, DP and MAP measured at baseline, immediately post AES, immediately post cleanup, and 45-min recovery (n = 22).

* Indicates $p < 0.05$ significant difference from previous measurement.

Core Temperature / Ear Canal Temperature

RM ANOVA for C_T revealed a significant main effect for time [$F(3,17) = 48.2$] (Figure 6). C_T increased significantly from baseline (37.19 °C) to post AES (37.83 °C) ($p < 0.01$). Mean C_T remained elevated at cleanup (37.87 °C) and then decreased significantly at 45-min recovery (37.37 °C) ($p < 0.01$), however this was still significantly higher than baseline C_T.

RM ANOVA revealed a significant time main effect for EC_T [$F(3,17) = 3.7$]. No significant differences in EC_T were observed between baseline and post AES, however, significant differences were observed between post AES (36.5 °C) and post cleanup (36.2 °C) and 45-min recovery (36.5 °C). A two (temperature measurements) by four (time) RM ANOVA found significant main and interaction effects. This indicates that these two measures are significantly different from one another and that they changed in different ways when compared to one another over the four time points. Paired t-tests revealed that core and EC_T were significantly different at all measurements ($p<0.01$).

C_T was not significantly correlated with EC_T ($R = 0.004$; Figure 7). This lack of relationship is highlighted at the post cleanup measurement (Figure 6) where C_T remained elevated, yet EC_T decreased significantly from the Post AES measurement.

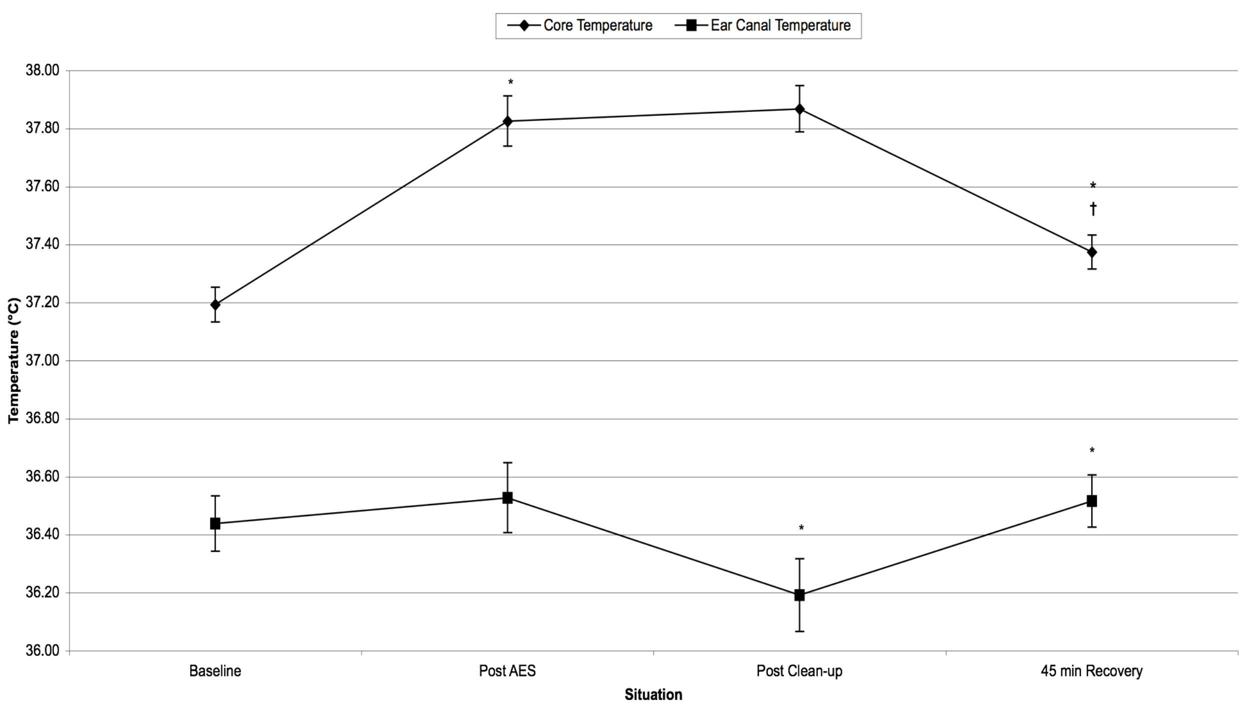

Figure 6. Mean (SE) C_T and EC_T at baseline, post AES, post cleanup, & 45-min recovery (n=20).

* Indicates $p < 0.05$ significant difference from previous measurement.

† at 45-min recovery indicates a significant difference ($p<0.05$) from baseline.

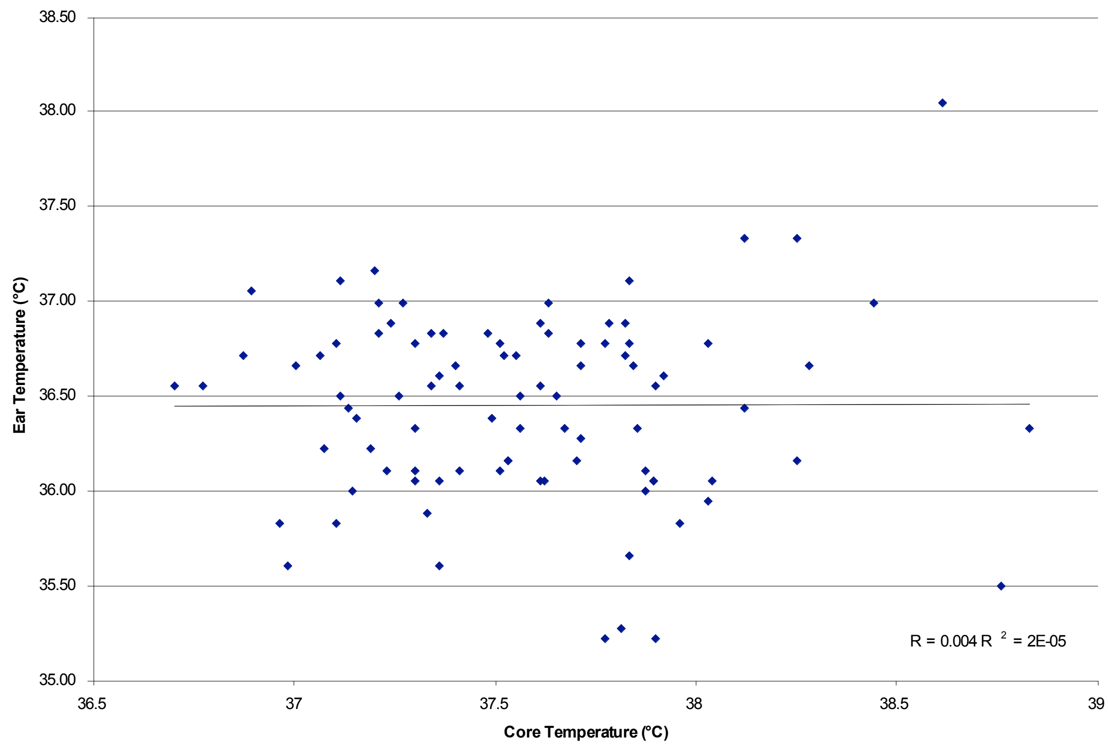

Figure 7. Correlation between C_T and EC_T measured at baseline, post AES, post cleanup, 30 & 45-min recovery (n = 20).

Figure 8 represents a sample HR and C_T response for a worker firefighter (age 30) during the experimental timeline. The dotted line represents 60% HRmax (114 bpm; as determined by an age predicted max calculation (220-age)). C_T increased sharply from baseline (37.81°C) during the AES (38.83°C). For this participant, C_T remained elevated throughout cleanup and was above baseline C_T 30 minutes after the completion of the

AES (38.76°C). HR increased 41 bpm at baseline (84 bpm) during the alarm call response (125 bpm). HR dropped during transit (7 min) to (99bpm) before beginning the AES. HR steadily increased during the AES and reached a peak HR of 174 bpm 14 minutes into the AES corresponding to extended operation of hydraulic Jaws of Life tool. HR decreased during the post AES measurements (109 bpm) as the participant sat for 5 minutes. HR rose to a max of 155 bpm during cleanup activities and decreased to 97 bpm post cleanup. HR was above 60% HRmax (114 bpm) for 100% of the extrication and clean-up.

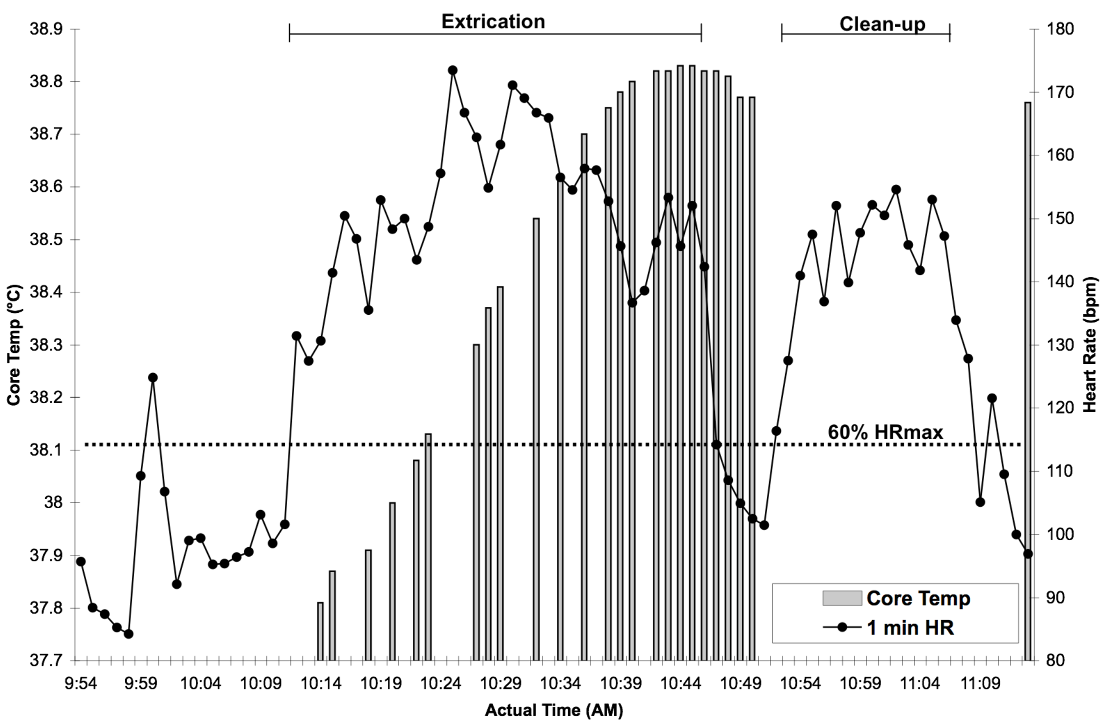

Figure 8. Sample C_T and HR for a worker subject (30 yrs) during group 3 AES experimental timeline.

Dotted horizontal line represents 60% HR_{max} (114 bpm) calculated from an age predicted maximum.

There was a significant positive correlation between C_T and mean HR throughout the AES evolution and recovery ($R = 0.890$, $p<0.01$; Figure 9).

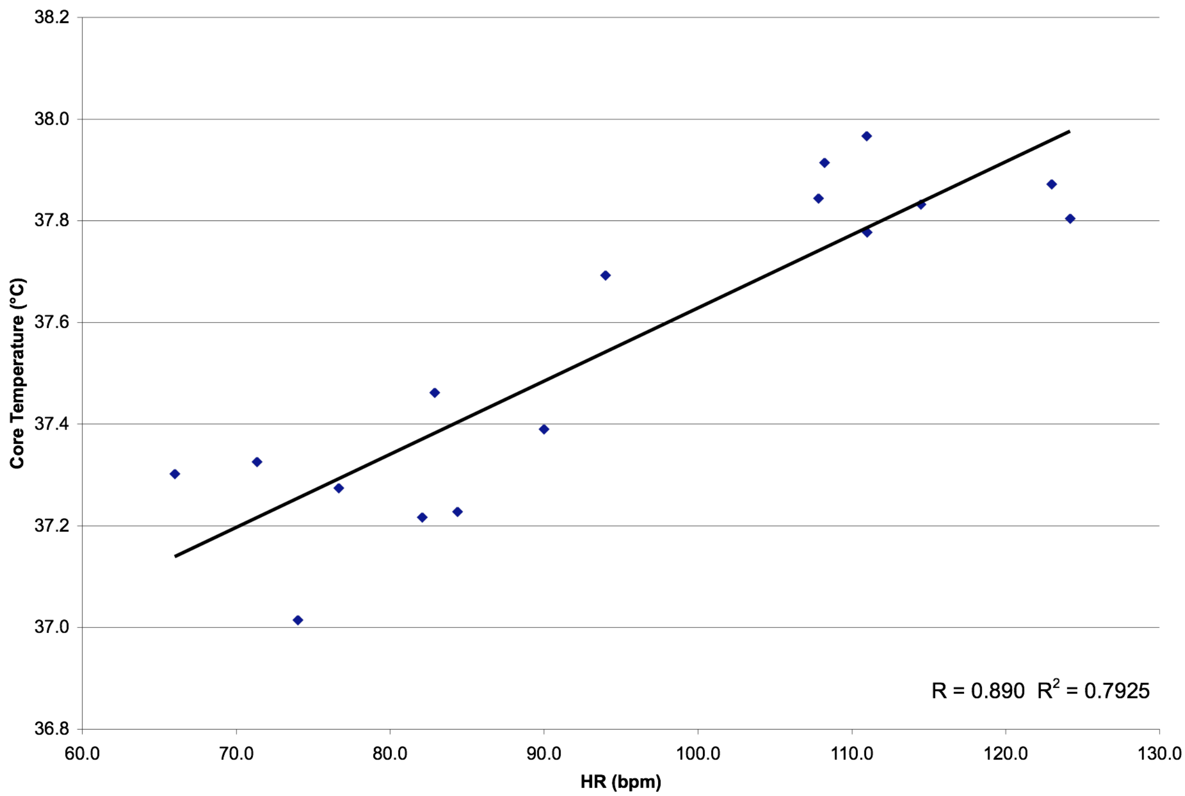

Figure 9. Correlation between C_T and mean 1-min HR across the four groups and four situations: baseline, AES, cleanup, & 45-min recovery (n = 20).

Rating of Perceived Exertion (RPE)

Two participants were removed from the RPE correlations (Figures 10 & 11). Data and video analysis indicated that one outlier severely underestimated his RPE, while the other outlier had overestimated his RPE. Unfamiliarity with the RPE scale to rate physical effort and work intensity was likely a large contributing factor to the erroneous ratings. The participant who underrated his RPE was an incident commander who reported max RPE as 11 (light), despite attaining a peak extrication HR of 91% age predicted maximum, and a PSI score of 5.7 (moderate-high).

Mean RPE (max) during the auto extrication simulation was 14.0, which falls between ‘somewhat hard’ (13.0) and ‘hard’ (15.0) (Table 5). Significant differences in RPE (max) during the AES exist between workers (15.1), medics (12.2) and incident commanders (11.7) (Table 5). There was a significant positive correlation between RPE and peak HR expressed as a percentage of age predicted max (R = 0.70; Figure 10) and physiological strain index (R = 0.7; Figure 11).

Table 5

Mean, Range, and SE for RPE Max, RPE Avg, RPTS Max, RPTS Avg, Peak CT, Peak HR, and PSI Separated by role during the AES (n=22).

Role	n	RPE Max	RPE Avg	RPTS Max	RPTS Avg	Peak CT (°C)	Peak HR (bpm)	PSI	PSI Rating
Worker	14	15.1*	12.5	4.6	3.8	38.0	145.7	5.3	Moderate
IC	3	11.7*	9.7	4.3	4.3	37.8	140.3	4.7	Low-moderate
Medic	5	12.2*	9.6	4.0	3.2	37.7	127.5	4.0	Low
Mean	**22**	**14.0**	**11.5**	**4.4**	**3.4**	**37.9**	**141.5**	**5**	**Moderate**
Range		9 - 17	7 - 15	1 – 7	1-5	37.41 - 38.83	107 - 180	3.0 - 7.7	
SE		0.46	0.41	0.3	0.25	0.008	4.2	0.32	

* indicates significant difference from each other ($p<0.05$)

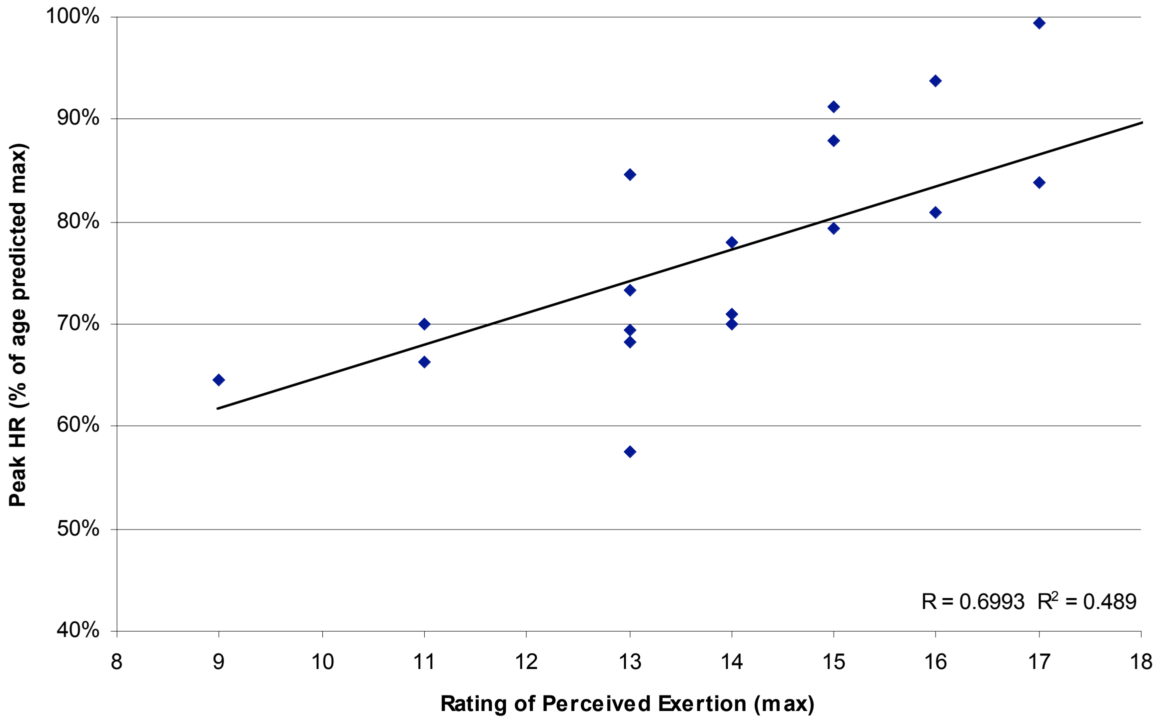

Figure 10. Correlation between ratings of perceived exertion (max) (Borg, 1982) and peak extrication HR displayed as percentage of age predicted maximum during the AES (n = 19).

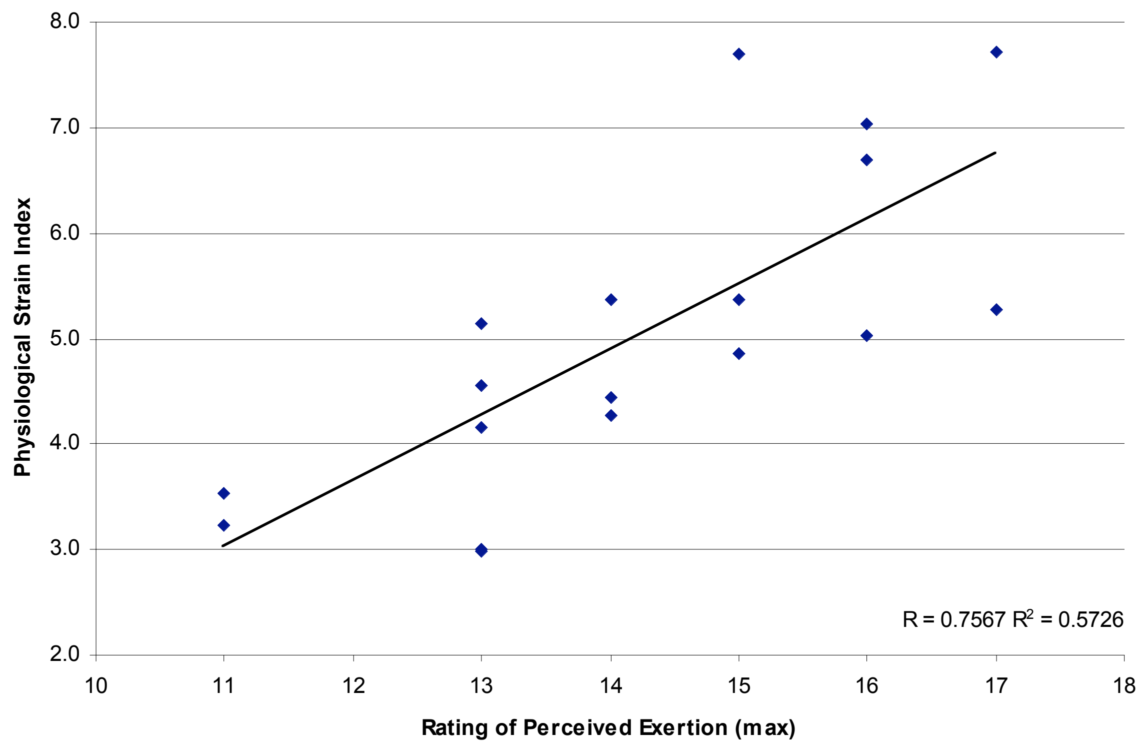

Figure 11. Correlation between RPE (max) (Borg, 1982) and PSI (Moran et al., 2000) during the AES (n = 20).

Rating of Perceived Thermal Stress (RPTS)

RM ANOVA revealed a significant time main effect [F(3,19) = 49.8] for mean RPTS. Figure 12 provides a visual display of the RPTS responses during the AES and recovery. RPTS increased from 1.23 (comfortable temperature) at baseline to 4.41 (between 'starting to get hot' (3) and 'hot' (5)) post AES ($p<0.01$). Mean RPTS decreased to 3.32 post cleanup and returned to baseline levels 1.09 at 45-min recovery ($p<0.01$; Figure 12). Thermal stress was not significantly different at 45-min recovery from baseline. A significant moderate strength relationship was found between RPTS and C_T ($R = 0.52$; Figure 13) and PSI ($R = 0.5$; Figure 14).

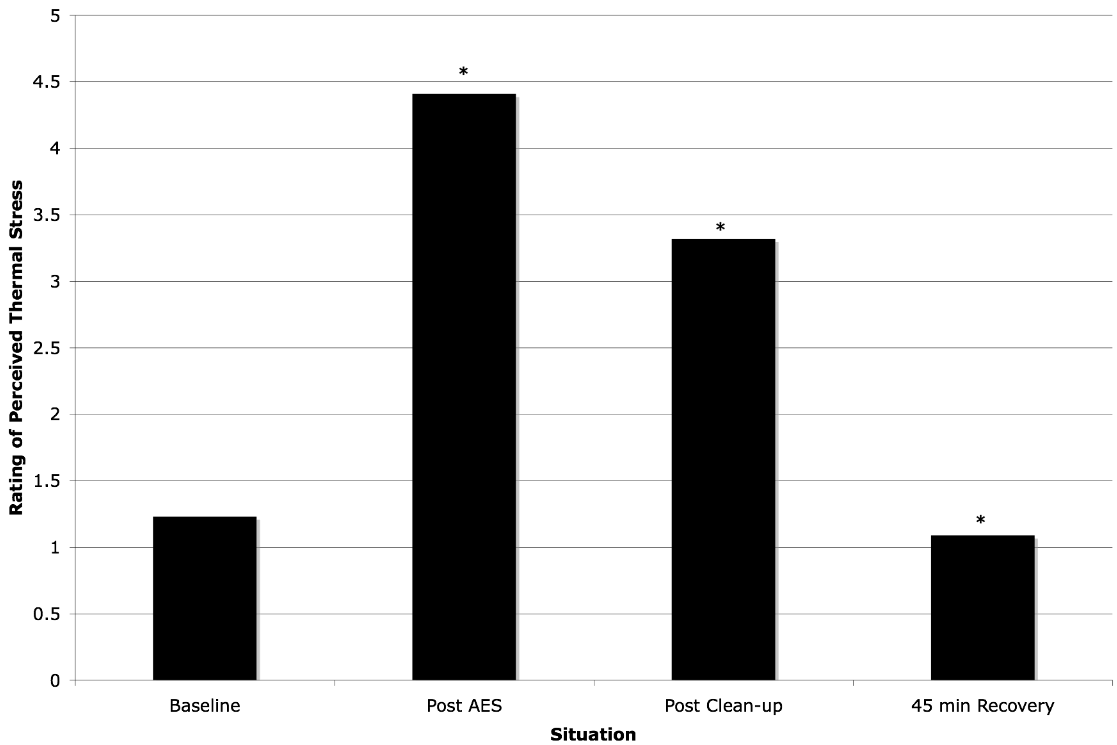

Figure 12. Mean (SE) RPTS at baseline, post AES, post cleanup and 45-min recovery, (n=22).

* Indicates p <0.01 significant difference from previous measurement.

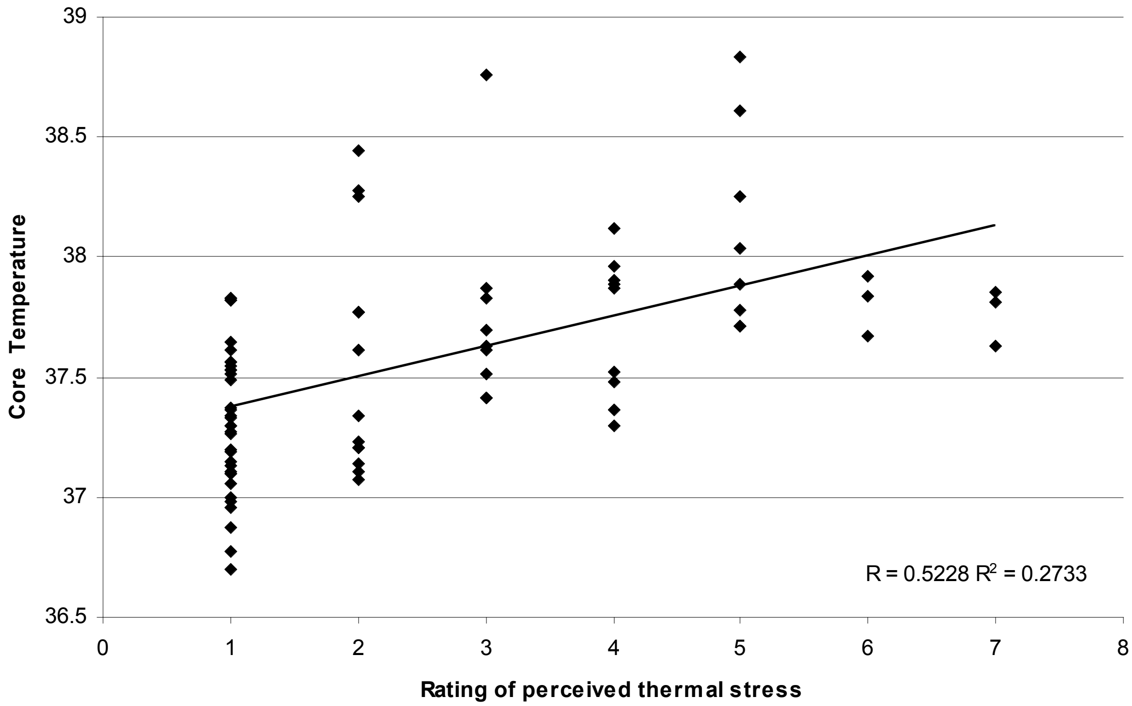

Figure 13. Correlation between RPTS and C_T (°C) at baseline, post AES, post cleanup, & 45-min recovery (n = 20).

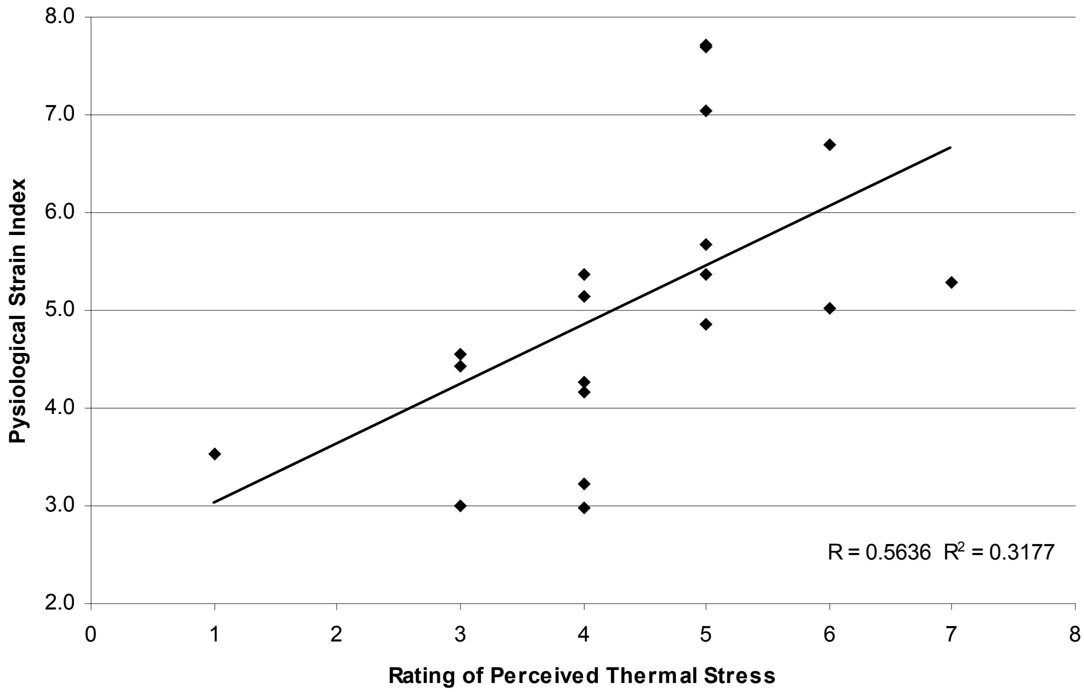

Figure 14. Correlation between RPTS and PSI post AES (n=19).

DISCUSSION

The purpose of this study was to describe the physiological (cardiovascular & thermoregulatory) and psychophysical (RPE & RPTS) responses of professional firefighters to an auto extrication simulation. To the researchers' knowledge this is the first study to measure such responses to a full continuous auto extrication simulation. To further understand the physiological and psychophysical responses during the AES, data were also grouped between the different roles firefighters assume within an auto extrication team: worker firefighters, medics, and incident commanders.

HR, and C_T responses indicate that auto extrication tasks were performed in an uncompensable heat stress environment that imposed physiological challenges to working firefighters. Between baseline and post AES measures significant differences existed in HR, MAP, and C_T, but not EC_T. The average time to complete the AES was 33.3 (27.5-38) minutes and the average total time that personal protective equipment was worn during the AES was 76 minutes.

The majority of the existing firefighter literature discusses metabolic response (ie. oxygen consumption) as the primary determinant of the physiological challenge to working in an uncompensable heat stress environment and/or with self contained breathing apparatus (SCBA). Very little research has used live or simulated firefighting tasks to determine the cardiovascular and thermal challenges of firefighter tasks. The present research design did not measure VO_2 directly, nor would this be practical in a live simulation research setting where six members of the AES team are working simultaneously. Therefore direct comparisons to this literature are not made.

HR to predict VO_2 has been used extensively in sport and occupational settings (Astrand and Rodahl, 1977). However the linear relationship that exists between HR and VO_2 is potentially affected by isometric & isotonic muscle contraction, upper and lower body work, and heat (Sothmann et al., 1991). Sothmann et al., (1991) determined that VO_2 was significantly overestimated by treadmill 'HR estimation' and suggest that prediction of energy expenditure from HR is not appropriate for firefighting activities. The nature of auto extrication activities, heavy lifting (both isometrically and isotonically), lower and upper body work, and the presence of heat (uncompensable heat stress environment of PPE) pose a serious threat to the validity of using HR to estimate VO_2 and energy expenditure. Auto extrication requires a careful, methodical process as victim safety is of prime concern. Short bouts of heavy lifting, sustained holding of heavy equipment, and tight space movement are more representative of auto extrication than longer bouts of continuous aerobic activity.

Following the AES, firefighters answered four questions aimed at determining the similarity of the AES (extrication protocol & crash realness) to a real motor vehicle accident, and the similarity of the stress level and sense of urgency of the AES to a real motor vehicle accident. The results for extrication protocol (100% agree or strongly agree) and crash realness indicate (73% agree or strongly agree) that the participants thought the auto extrication simulation was representative of a motor vehicle extrication that they would experience while on a typical shift. A smaller percentage of participants agreed or strongly agreed that the AES was representative of the 'situation stress' and 'sense of urgency' of a live MVA. Stress and sense of urgency responses indicate that, although the experimental design is typical of a live motor vehicle accident, the emotional stress of an emergency situation was not replicated. The external validity of the study however could be considered high and future studies should employ strategies to increase the emotional stress of live MVAs. Smith et al. (1997) report that the hormonal response to an emergency situation can place increased stress on the body. Combining an increased hormonal response with a greater sense of urgency during the extrication, it is therefore plausible to assume that the physiological response during an actual MVA extrication would be greater than reported in this experiment.

To determine the mean cardiovascular demand, 1-min HR was averaged for all firefighters during six discrete situations of the auto extrication simulation timeline. HR response during the experimental timeline indicated that alarm call response, extrication, and cleanup were all significantly elevated from baseline values. To increase the external validity of the present study, participants were asked to carry out their daily duties as on any shift. Regular hall duties resulted in a mean HR that was significantly elevated relative to resting HR taken at baseline. The response time to the alarm call was 2.75 minutes with a demonstrated increase in HR of 27%. From resting HR the alarm response reflects a 54% increase. This HR response to alarm is expected as it has been previously reported that 15 to 30s after an alarm, HR showed a mean increase of 47 bpm (Barnard & Duncan, 1975). The HR responses observed immediately after an alarm are suggested to be due to a combination of a state of high anxiety and the vigorous movement to load into the fire trucks used to travel to the scene (Barnard & Duncan, 1975; Kuorinka & Korhonen, 1981). In the present study, during transit (7.5 min) to the AES location, mean HR decreased to 81 bpm, a 2.5 percent increase from regular hall duties. This is an expected response during transit as the firefighters were seated, non-active and possibly less emotionally excited. The sharp increase in HR in response to the 'mock' alarm of the present study may indicate that despite prior knowledge that this was a simulated call, the participants treated the call as real and responded accordingly. This would further strengthen the external validity of the AES as a research platform for live vehicle extrication.

While performing the extrication, mean 1 min HR for all firefighters of the AES team was 118.2 bpm (range 64-186), with an average extrication time of 33 min. In four fire suppression evolutions with an outside ambient temperature of 16ºC, Romet and Frim (1987) reported average working times of 29 min and mean HRs of 131 bpm. During 16 minutes of simulated fire fighting activity in a thermoneutral (13.7 ºC) environment Smith et al (1997) reported mean HR as 139 bpm. However, following 16 min of the same simulated fire fighting activity in a hot environment (89.6ºC) mean HR was significantly more elevated at 175.5 bpm (Smith et al., 1997). The HR response to an AES is, therefore, comparable to that of other firefighting training evolutions performed without the presence of external environmental heat from live fires.

There were significant differences in average HR during the extrication amongst the roles of the AES team. Worker firefighters had the highest HR (123 bpm), which corresponds to a 'heavy work' classification for extended work durations (Astrand et al., 2003). Incident commanders had a non significantly lower mean extrication HR (117 bpm) that also can be classified as 'heavy work.' The work classification for incident commanders should be viewed with caution, as emotional stress is likely the larger contributor to the HR response versus actual physical work. Medics had the lowest mean extrication HR (98 bpm), which falls into the 'moderate work' classification.

Throughout the extrication simulation, many of the tasks performed by the workers were very demanding and involved heavy lifting, heavy hydraulic tool operation, and swift movements around the extrication site including to and from the fire trucks. Incident commanders maintained an elevated HR throughout the extrication even though their primary role was to manage the rescue operation and they seldom participated in actions that would typically be classified as 'heavy physical work.' Scene management, firefighter, victim, and public safety, and extrication team leadership would not normally be classified as being intense physical work, but does involve high levels of mental stress and state-anxiety. Barnard & Duncan (1975) have previously reported that high anxiety and stress levels elevated and sustained HR during emergency response situations in firefighters. Medics had the lowest observed HR during the extrication resulting from the stationary position maintained throughout the extrication simulation and very little if any heavy lifting. During an extrication, securing cervical spine (c-spine) and establishing victim contact is a primary task of the medic and rescue team (Calland, 2005). C-spine is maintained by the medic while the rest of the team works to free the victim from the vehicle. In the current study, following standard extrication protocol, once c-spine was established, medics moved only to reposition c-spine control, or when the victim was being placed on the spine board and removed from the vehicle. The lower HR observed reflects a lower level of physical exertion, the stationary nature of the medic role, and that the simulatory nature of the crash scenario which did not present the stress of an actual medical emergency to the medic.

Although BPs (SP, MAP, & DP) all increased significantly from baseline to post AES the absolute increase is physiologically insignificant. The small increase in DP pressure reported is unexpected as the typical DP response with exercise is to remain unchanged or decrease slightly due to a decrease in peripheral resistance following the vasodilation of arteriole beds or working muscle during exercise (Astrand et al., 2003). Emotional stress from the AES could account for the small increase in DP. Emotional stress increases hormone release which causes vasoconstriction, increasing total peripheral resistance and DP (McArdle, Katch & Katch, 2000). The study design attempted to get as accurate a BP measure as possible by assessing it immediately post AES, however, a sensitive physiological response such as BP is affected by time. Future studies should attempt to measure BP during the AES simulation to avoid inaccurate measurements and also to determine the actual BP when firefighters are performing extrication tasks that require tool operation, heavy lifting and increased muscular force for prolonged periods.

A strong positive correlation (R = 0.89) was noted between C_T and HR supporting the theory that an increase in HR is one of the primary acute physiological responses to physical work in a thermally challenging environment. Rowell (1974) stated that an increase in C_T will result in an increased HR to maintain cardiac output. The personal protective equipment (PPE) designed to decrease the transfer of heat from intolerable environments to the body place the body in an uncompensable heat stress environment as the body cannot dissipate endogenous heat production through the skin (Smith & Petruzzello, 1998). In the present study C_T increased significantly from baseline to post cleanup (0.63 °C). The average time firefighters wore PPE (alarm call response to post cleanup) was 76 minutes. Romet and Frim (1987) reported an increase of 0.5ºC in rectal temperature following 29 minutes of simulated work, slightly shorter than the current

AES (33 min). Smith et al. (1997) reported a C_T increase of .31ºC in a thermoneutral environment and a 3.15ºC increase in the hot environment. The elevation in C_T following auto extrication activities is, therefore, comparable to other simulated firefighting activities performed in a thermoneutral environment.

Completing the AES in a PPE-induced heat stress environment places competing demands on the cardiovascular system to reduce C_T by the shunting of blood to the periphery, while maintaining blood flow to active muscles to complete extrication activities. This challenge to the cardiovascular system is further pronounced in hot and/or humid external environments such as a fire, or extremely hot ambient environmental conditions. The average ambient conditions in the present study were 18°C (16-20°C) and 36% (34-39%) humidity and thus did not present significant environmental thermoregulatory challenges to the firefighters. The present research data was collected during the Spring in Victoria, BC, which is considered mild by Canadian environmental conditions. A similar study design conducted in Summer in warmer and more humid conditions likely would influence the physiological response to an AES.

The current research was not designed to determine the extent of the hyperthermia post AES from the insulative properties of the PPE or from the increased physical activity and energy production of the AES. Vehicle extrication protocols always require firefighters to wear insulating PPE, therefore understanding the specific contribution of PPE to C_T increases has limited practical application.

Correlation between C_T and EC_T showed no relationship existed even though they are purported to measure the same thing (Erickson & Kirklin 1993). At four simultaneous measurement periods (baseline, post AES, post cleanup & 45-min recovery), EC_T significantly underestimated C_T by a mean of 1.10°C. The underestimation was greatest post AES & post cleanup (1.30°C & 1.68°C respectively). The lack of relationship between the two measurement methods was highlighted at the post cleanup measurement when mean C_T increased slightly (0.04ºC) whereas mean EC_T significantly decreased (0.35ºC). Erickson & Kirklin (1993) reported that EC_T provided a relatively close estimate of pulmonary artery temperature (core temperature) but underestimated it by 0.41°C. Although previous research has documented an underestimation of C_T using ear canal thermometry, the large difference between the two measures in the present study requires further explanation. Post AES and post cleanup EC_T measurements were performed outdoors at the extrication location. This potentially could influence the measurement as wind and outside air temperature cannot be controlled. Ambient conditions, however, cannot account for the large discrepancy between ear canal and C_T at baseline and recovery measurements (0.75°C & 1.10°C respectively), as they were both conducted indoors in a quiet thermoneutral environment. The current findings agree with those of others who have suggested that infrared ear thermometry is not sufficiently accurate, nor consistent, when compared with established methods of temperature measurement. Further the findings indicate that infrared ear thermometry should not be used in situations where body temperature needs to be measured with precision (Craig et al., 2002). The underestimation of C_T by ear canal measures is also of particular interest to the firefighter population as emergency medical technicians (EMTs) use this methodology to determine if a firefighter is ready to return to duty while fighting a fire or during an extremely long MVA extrication.

The mean rating of maximum perceived exertion during the AES for the entire AES team was 14.0, which lies in between ‘somewhat hard’ and ‘hard’ on the Borg 20 point RPE scale (Borg, 1982). RPE correlated well with peak HR (as percentage of age predicted maximum) recorded during the AES. Differences were noted between reported RPE for different roles within the AES team with workers reporting higher RPEs than the other firefighters. This is expected as workers produced higher HRs throughout the AES and performed the majority of physical work during the AES.

The RPE scores for two participants were removed from the data analysis. The incident commander in the second AES scenario was removed due to a gross underestimation of his effort. Two possible contributing factors to the mismatch between RPE and actual HR for this participant were 1) the high stress of incident command and scene management, and 2) participant age. Barnard & Duncan (1975) reported that the increased stress of incident command significantly increases HR without an accompanying increase in physical exertion. Though the participant may not have felt he was working very hard because he was more involved in decision-making versus heavy physical activity, incident command stress and the thermal stress of his PPE created high HR. The participant was 50 years old, which could contribute to an “artificially low max HR” when using an age predicted maximum estimation, and thus a higher than actual peak HR (when reported as percentage of age predicted maximum). The participant who overestimated RPE rated his average RPE during the AES as 13, but his maximum RPE as 17. Peak HR was 76% age predicted max, and his PSI score was 3.6. Upon review of the extrication video analysis and all physiological data for this participant it was decided that he had overestimated his physical exertion during the extrication.

A correlation between RPE max and physiological strain scores indicated a strong significant positive relationship (R = 0.76; Figure 11). Baker et al. (2000) reported a correlation coefficient of 0.98 between RPE (Borg 10 point scale) and PSI during 60 minutes (repeated measures every ten minutes) of treadmill exercise in PPE. The continuous nature of the AES in this study limited repeated measures of PSI and RPE, however, the correlation that existed between RPE and PSI scores post AES is promising as a self-regulatory measurement tool for firefighters. Currently there are no procedures in place to monitor HR and C_T while performing firefighting duties. If firefighters were trained to use RPE scales to monitor physiological strain, it could be a valuable safety procedure while performing emergency response duties.

Cleanup is normally performed under less stressful conditions compared to other periods within an auto extrication as the victims have been extricated and removed from the accident scene. Nevertheless, in the AES, mean HR remained elevated over baseline, and mean RPE indicated firefighters were still exerting some effort. Mean RPTS for cleanup was 3.3 corresponding to ‘starting to get hot.’ This result is particularly interesting as it was a significant decrease from mean RPTS post AES (4.4), despite an increase in mean C_T of 0.1°C. Tikuisis, McLellan, & Selkirk (2002) reported that HR was the largest fractional influence of perceived thermal sensation for exercise in an uncompensable heat stress environment. Therefore, the lower HR observed during the cleanup could possibly explain the lower RPTS despite the small increase in actual C_T.

Although the RPTS scale was explained individually to each firefighter at baseline, no prior training on the use of this scale was performed. It was likely that this was the first time that the participants had used such a scale and, therefore, results should be viewed with caution. Ratings of perceived thermal stress were conducted retrospectively for both the extrication and clean-up time periods while seated away from the extrication site. Protective jackets were also removed prior to RPTS assessment to assess collect BP measures which may have influenced the results as cutaneous receptors send afferent input to the hypothalamus about skin temperatures and account for approximately 50% of perceived thermal stress & comfort (Frank et al., 1999). Future studies should attempt repeated RPTS measurements during the extrication and cleanup to determine how the perception of thermal stress is influenced while performing extrication activities and wearing full PPE.

A unique observation of this research was of two participant firefighters who reported feeling slightly sick on their respective AES days. They were not running fevers and were not sufficiently unwell to miss their shift. These two individuals had the highest peak HRs during the AES (180 & 174 bpm), the highest C_T s attained (38.61 & 38.83°C), and the highest PSI (7.8 & 7.6) corresponding to high/very high on the PSI rating scale. The self-perceived rating of thermal stress for these two participants during the AES corresponded to ‘hot,’ but was not significantly different from the mean RPTS score for all other participants. However, the testing team did report that these participants visually appeared to be under greater thermal stress than the rest of the participants. They appeared to be very hot, and to be suffering a greater effect from the physical and thermal stresses of the AES. Both these participants were very flushed, sweating profusely, and breathing heavier and harder than other participants. Whatever illness was ailing these firefighters, while not strong enough to prevent them from reporting for duty, was strong enough to alter their response to physiological and thermal stresses of firefighting duties. The high incidence of heart attack and heat induced illness of firefighters on the job highlights the importance of this finding and the need to further explore illness and the resulting physiological response while performing occupational duties.

Conclusions

HR and C_T increased significantly during the auto extrication simulations and remained elevated throughout cleanup. All physiological, and psychophysical measures returned to baseline at 45-min post AES, except for C_T which was still significantly elevated above baseline. This has implications for those firefighters who may be presented with repeated AE and fires and other activities continuously across a shift. This indicates that auto extrication is a physically demanding task for firefighters that warrants further exploration of the physiological demands.

Based on the finding of this study, it is recommended that ear canal temperature (ear canal thermometry) should not be used as a field measure of C_T as it showed little relationship with C_T and significantly underestimated actual C_T. Psychophysical measures of exertion and thermal stress had moderate to strong correlations with HR, C_T, and PSI. With training, RPE could be a useful safety measure for firefighters to self-monitor, as currently HR and C_T are not monitored while on duty. Positive responses on the simulation satisfaction questionnaire indicate that the study design and extrication scenario used in this experiment adequately simulates a real motor vehicle accident and would thus serve as an appropriate platform for further studies involving auto extrication. It can be assumed that these physiological variables would be elevated to an equal or greater degree during auto extrication from a live MVA.

Future studies are needed to assess the physiological changes that occur from an auto extrication of a live MVA, maximum time allowed for a firefighter during auto extrication, and optimal recovery time following auto extrication. Subsequent studies could focus on intervention strategies such as cooling, work cycling, and enhanced recovery strategies. Measuring the metabolic challenges during an AES would allow for work intensity comparisons with fire suppression and contribute to the literature that describes the occupational requirements of urban firefighting.

The potential for reduced capacity to perform tasks under stress and in a fatigued condition may impact safety and efficiency, which may endanger the individual firefighter, co-workers, victims, and the public. Understanding the physiological responses to auto extrication tasks will influence the manner in which EMT personnel monitor firefighters during MVAs, and help direct development of appropriate training guidelines and auto extrication protocols.

REFERENCES

Astrand, P.O., & Rodahl, K. (1977). *Textbook of Work Physiology* (2nd ed). New York, NY: McGraw Hill.

Astrand, P.O., Rodahl, K., Dahl, H., Stromme, S. (2003). *Textbook of Work Physiology: Physiological Basis of Exercise* (4th ed). Dubuque, IA: Human Kinetics.

Baker, S.J., Grice, J., Roby, L., & Matthews, C. (2000). Cardiorespiratory and thermoregulatory responses of working in fire-fighting protective clothing in a temperate environment. *Ergonomics, 43*(9), 1350-1358.

Barnard, R.J., & Duncan, H.W. (1975). Heart rate and ECG responses of firefighters. *Journal of Occupational Medicine, 17,* 247-250.

Borg, G.A.V. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise, 14*(5), 377-381.

Calland, V. (2005). Extrication of the seriously injured road crash victim. *Emergency Medicine Journal, 22*(11), 817-821.

Canadian Society for Exercise Physiology (2003). *The Canadian physical activity fitness & lifestyle appraisal.* Ottawa: CSEP.

Carter, J.B., Banister, E.W., & Morrison, J.B. (1999). Effectiveness of rest pauses and cooling in alleviation of heat stress during simulated fire-fighting activity. *Ergonomics, 42*(2), 299-313.

Cheung, S.S., McLellan, T.M., & Tenaglia, S. (2000). The thermophysiology of uncompensable heat stress: Physiological manipulations and individual characteristics. *Sports Medicine, 29*(5), 329-359.

Craig, J., Lancaster, G., Taylor, S., Williamson, P., & Smyth, R. (2002). Infrared ear thermometry compared with rectal thermometry in children : a systematic review. *The Lancet, 360,* 603-609.

Davis, P.O., & Dotson, C.O., (1987 Physiological aspects of fire fighting. *Fire Technology, 23*(4), 280-291.

Erickson, R.S., & Kirklin, S.K. (1993). Comparison of ear-based, bladder, oral, and axillary methods for core temperature measurement. *Critical Care Medicine, 21*(10), 1528-1534.

Frank, S.M., Raja, S.N., Bulcao, C.F., & Goldstein, D.S. (1999). Relative contribution of core and cutaneous temperatures to thermal comfort and autonomic responses in humans. *Journal of Applied Physiology, 86*(5), 1588-1593

Gledhill, N., & Jamnik, V.K. (1992). Characterization of the physical demands of firefighting. *Canadian Journal of Sport Science, 17*(3), 207-213.

Kuorinka, I., & Korhonen, O. (1981). Firefighter reaction to alarm, an ECG and heart rate study. *Journal of Occupational and Environmental Medicine, 23*(11), 762-766.

Lemon, P.W.R., & Hermiston, R.T. (1977). The human energy cost of firefighting. *Journal of Occupational Medicine, 19,* 558-562.

Louhevaara, V., Smolander, J., Tuoumi, T., Korhonen, O., & Jakkola, J. (1985). Effects of an SCBA on breathing pattern, gas exchange, and heart rate during exercise. *Journal of Occupational Medicine, 19*, 213-216.

Lusa, S., Louhevaara, V., & Kinnunen, K. (1994). Are the job demands on physical work capacity equal for young and aging firefighters? *Journal of Occupational Medicine, 36*(1), 70-74.

McArdle, W.D., Katch, F.I., & Katch, V.L. (2000). *Essentials of exercise physiology.* Philadelphia, PA: Lippincott, Williams & Wilkins.

McKenzie, J.E., & Osgood, D.W. (2004). Validation of a new telemetric core temperature monitor. *Journal of Thermal Biology, 29,* 605-611.

Moran, D.S., Shitzer, A., & Pandolf, K.B. (1998). A physiological strain index to evaluate heat stress. *American Journal of Physiology, 275*(44), R129-R134.

Romet, T.T., & Frim, J. (1987). Physiological responses to fire fighting activities. *European Journal of Applied Physiology, 56*, 633-638.

Rowell, L.B. (1974). Human cardiovascular adjustments to exercise and thermal-stress. *Physiological Reviews, 54*(1), 75-159.

Smith, D.L., Manning, T.S., & Petruzzello, S.J. (2001). Effect of strenuous live-fire drills on cardiovascular and psychological responses of recruit firefighters. *Ergonomics, 44*(3), 244-254.

Smith, D.L., Petruzzello, S.J., Kramer, J.M., & Misner, J.E. (1997). The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill. *Ergonomics, 40*(4), 500-510.

Smith, D.L., & Petruzzello, S.J. (1998). Selected physiological and psychological responses to live-fire drills in different configurations of firefighting gear. *Ergonomics, 41*(8), 11-41-1154.

Sothmann, M., Saupe, K., Raven, P., Pawelczyk, J., Davis, P., Dotson, C., Landy, F., & Siliunas, M. (1991). Oxygen consumption during fire suppression: Error of heart rate estimation. *Ergonomics, 34*(12), 1469-1474.

Tikuisis, P., McLellan, T.M., & Selkirk, G. (2002). Perceptual versus physiological heat strain during exercise-heat stress. *Medicine & Science in Sports & Exercise, 34*(9), 1454-1461.

APPENDIX A

Review of Literature

Auto Extrication and Victim Rescue

Auto extrication and victim rescue are considered to be some of the most physiologically and psychologically demanding tasks within the scope of duties for urban firefighters (S. Woodburn, Victoria Fire Department, personal communication, July 15, 2005; G. McLellan, Langford Fire Department, personal communication, Aug 10, 2005). Auto extrication requires a methodical, systematic team approach to extricate victims of motor vehicle accidents (MVAs) safely and quickly. A high sense of urgency prevails for all rescue team members to complete the extrication as quickly as possible as they work within the 'Golden Hour' principle; which states that victims will have a greater chance of survival if they reach medical treatment from a hospital within one hour of incurring injury. Scene assessment is first completed by the incident commander. Upon completion, the rescue team unloads tools and equipment from the fire trucks, secures the crashed vehicle(s), and establishes medical contact with the victim(s). Tools used to carry out victim rescue include hydraulic 'Jaws of Life', cutters, rams, and come-alongs to open-up twisted, compacted cars in order to remove the victim from the vehicle. Tool weight can exceed 27 kg (Holmatro, USA; 2007). Typically auto extrication and victim rescue takes 25-35 minutes, followed by tool and site clean up and return to the fire hall. (S. Woodburn, personal communications, July 15th, 2005).

Gledhill and Jamnik (1992) had incumbent firefighters complete various auto extrication tasks while time to completion, HR, and VO_2 were measured. Five tasks associated with auto extrication (sand pail carry, acetylene equipment carry, first response extrication kit, extrication; cutter and spreader, & extrication: steering wheel removal) were completed by incumbent firefighters (*n* varied from 2 to 12). The average completion time for the tasks ranged from 26 seconds to 239 seconds. HR varied from 106 beats•min^{-1} for steering wheel removal to 161 beats•min^{-1} for first response extrication kit, with a HR average of for the five extrication tasks of 132 beats•min^{-1}. VO_2 ranged from 19.2 ml•kg^{-1}•min^{-1} for steering wheel removal to 22.1 ml•kg^{-1}•min^{-1} for cutter and spreader extrication, with an average for the five extrication tasks of 50% of the VO_2 of the most demanding firefighter tasks.

Live auto extrications and victim rescues, commonly performed by firefighters, are not separated into discrete tasks as set up by Gledhill and Jamnik (1992). Auto extrication and victim rescue is a continuous task that begins with the response to the alarm call and ends with extrication of the victim(s) and cleanup of all tools.

Occupational Injury

Firefighting work is characterized by long periods of inactivity, interspersed with short bouts of intense, physically demanding work. This work is most often in alarm response, thus there is added psychological stress to the high physical demand (Smith & Petruzzello, 1998). Mean HR has been shown to increase 47 beats•min^{-1} (range 12-117 beats•min^{-1}) in the 15-30 seconds following an alarm call (Barnard & Duncan, 1975). The HR responses observed immediately after an alarm are due to a combination of a state of high anxiety and the vigorous movement to the fire trucks used to travel to the scene (Barnard & Duncan, 1975; Kuorinka & Korhonen, 1981). HR and BP both increase in response to alarm calls, leading to a five fold increase in the relative risk of coronary heart disease during alarm response. This pattern of work may contribute to the high risk of heart attack or sudden death for at risk firefighters (Kales et al., 2003).

According to National Fire Protection Agency (NFPA) 1993 statistics, 50.6% of firefighting deaths were attributed to heart attack and that 95% of these were due to stress or over-exertion. Washburn, Leblanc, & Fahy (1996) reported that 53% of firefighter deaths were due to heart attack and that 48% of the deaths were due to heat stress. American firefighter injury rate statistics indicate that 52% of injuries occur while fighting fires and that of these, 22% are due to over-exertion (Karter & Leblanc, 1995). Although deaths due to heart attack have decreased in the last 10 years, 2003 NFPA statistics still indicate that 44.8% of all firefighter deaths were due to heart attack.

Cardiopulmonary Demands of Firefighting

Firefighting is a physically demanding occupation requiring high aerobic fitness to successfully carry out occupational demands (Lemon & Hermiston, 1977; Davis & Dotson, 1987; Misner, Plowman & Boileau, 1987; Gledhill & Jamnik, 1992). Researchers have consistently measured and reported maximal oxygen consumption (VO_{2max}) to determine the occupational requirements of firefighting. Lemon & Hermiston (1977) reported that firefighting tasks consisted of heavy work and required oxygen consumptions of 60 to 80% VO_{2max}, even when external stresses such as heat, humidity, and emotional stress were eliminated.

Gledhill & Jamnik (1992) measured HR and VO_2 of incumbent firefighters as they performed a representative sample of physically demanding firefighting operations. The most demanding firefighting tasks (ten percent of the operations examined) required a mean VO_2 of 41.5 ml/kg•min^{-1}. Ninety percent of firefighting tasks required a mean

VO_2 of 23 ml/kg•min^{-1}. These aerobic requirements correspond to 85 and 50% VO_{2max} respectively. The authors recommended that a minimum VO_{2max} of 45 ml/kg•min^{-1} is required to support performance of firefighting work. O'Connell et al. (1986) reported that stair climbing in firefighting gear corresponded to an oxygen consumption of 80% VO_{2max} and that 39 ml/kg•min^{-1} is a minimum relative value for successful firefighting.

High HRs approaching maximal or near maximal have been reported during both live and simulated firefighting work (Barnard & Duncan, 1975; Romet & Frim, 1987; Gledhill & Jamnik, 1992; Smith, Petruzzello, Kramer & Misner, 1997; Smith & Petruzzello, 1998). The HR range reported for the battery of firefighting operations was 106-181 beats•min^{-1} (Gledhill & Jamnik, 1992). One of the most interesting studies examining the HR responses during firefighting duties was conducted by Barnard & Duncan (1975) where 35 firefighters wore ECG monitors and recordings were taken over a 24 hour period. Alarm response increased HR significantly and this response was independent of firefighting experience, indicating that the HR response to alarm is preparatory response for an expected increase in physical activity. High HR following the alarm did not appear to be a transient effect, as HR was 150 beats•min^{-1} when firefighters reached the scene, 3.5 minutes post alarm call. During firefighting activities, ranging between 15-90 minutes, high HRs were observed between 175-195 beats•min^{-1}.

Differences in HR have been reported to vary between firefighting roles. Building search and rescue resulted in an average HR of 153 beats•min^{-1} for worker firefighters, whereas the crew captain who directed the firefighting had a mean HR of 122 beats•min^{-1} (Romet & Frim, 1987). Sothmann et al. (1991) reported an average VO_2 of 31.0 ml/kg•min^{-1} at a HR of 176 beats•min^{-1} for a simulated fire suppression protocol.

However, this VO_2 was significantly less than the VO_2 that would have been predicted by treadmill testing at a corresponding HR indicating that the prediction of energy expenditure from HR is not straightforward in fire suppression activities. Firefighting work, which includes isometric and isotonic muscle contraction, upper and lower body work, and increased heat stress from protective clothing confound VO_2 and energy expenditure estimates from HR (Sothmann et al., 1991).

Influence of Personal Protective Equipment (PPE)

Personal protective equipment (also known as turn out gear) is required to shield firefighters from environmental hazards and injury. Almost all firefighting duties, including auto extrication, require firefighters to wear full personal protective gear that includes protective boots, protective pants and jacket, helmet, gloves, and flash hood. Firefighters are subject to the PPE paradox: personal protective equipment is designed to slow heat transfer from the environment to the body, however this heat shielding eliminates the transfer of endogenous heat production to the environment (Smith & Petruzzello, 1998). There are three methods by which PPE increases heat production: 1) firefighters have an increased metabolic rate due to the extra weight of PPE (~50 lbs) (Skoldstrom, 1987); 2) firefighters experience reduced movement efficiency due to friction and bulkiness of the PPE, and 3) the elimination of evaporative and radiant heat loss from the PPE creates an uncompensable internal heat stress environment (Smith & Petruzzello, 1998). As a result C_T will rise as metabolic heat production exceeds the exchange capacity of the surrounding environment. Wearing PPE increases the likelihood of heat strain because PPE causes heat strain at much lower environmental temperatures (Havenith, 1999). The inability to hydrate during emergency situations and the resulting state of hypohydration following longer bouts of firefighting work exacerbates the inability to thermoregulate while wearing PPE and may lead to severe increases in C_T and a resulting reduction in work intensity (Cheung & McLellan, 1998).

Firefighter's wearing PPE face an uncompensable heat stress environment where core and skin temperatures increase with greater intensity work regardless of external environmental conditions (Baker et al., 2000; Carter, Banister, & Morrison, 1999). The inner impermeable layer of PPE and endogenous heat production from working muscles creates a microclimate air layer next to the skin (Cheung, McLellan, & Tenaglia, 2000). With moderate activity, internal air temperature can exceed 35°C, above which, evaporative cooling can no longer occur and storage of heat in the body cannot be avoided (Rossi, 2003). The inability to dissipate heat leads to a C_T elevated above the normothermic level of 37°C. Skin temperature, HR, oxygen consumption, and sweat rates of firefighters have also been shown to increase with PPE (Holmer, 1995; Pascoe, Shanley, & Smith, 1994).

Increases in C_T, skin temperature, HR, and rate of perceived exertion (RPE) have been reported from rest conditions (McLellan, 1993), and from firefighting work in thermo-neutral environments (Duncan, Gardner & Barnard, 1979; Faff & Tutak, 1989; White, Vercruyssen, & Hodous, 1989; White, Hodous, & Vercruyssen, 1991). A live fire burn building study by Romet & Frim (1987) reported that lead hand firefighters (first firefighters to enter into fire scenes) had higher initial HRs and skin temperatures than secondary hands (firefighters not initially entering the fire) or the crew captain. Lead hand firefighters were standing ready in full PPE before the secondary hands and crew captain, indicating that increases in load and uncompensable heat stress imposed by PPE effects skin temperature and HR independently of environmental heat stress and work intensity.

The energy cost of moderate work while wearing PPE was elevated 33% compared to the same task without PPE (Davis & Santa Maria, 1975). During 15 minutes of light treadmill walking (4.0 km·h^{-1}) in PPE, HR and VO_2 were increased by 37.5% and 46.8% respectively compared to the same exercise without PPE (Duncan et al., 1979). Six minutes of treadmill walking at 7 km·h^{-1} in full PPE resulted in a HR and VO_2 of 171 beats•min^{-1} and 39.9 ml/kg•min^{-11} respectively, compared to walking in no gear (146 beats•min^{-1} and 36.1 ml/kg•min^{-11} respectively) (Baker et al., 2000). The PPE induced increase in HR was 17.1%, and VO_2 was 10.5%.

Thermal Response to Work in Hyperthermic Conditions

EC_T increased 3.15°C following 16 minutes of an overhead pike pole task in a hot (89.6°C). EC_T increased only 0.31°C following the same task performed in a thermoneutral environment (13.7°C), a difference of 2.9°C between conditions (Smith et al., 1997). Rise in rectal temperature following 15 minutes of treadmill waking differed significantly in both the turn-out gear (0.23°C) and turn-out gear sauna (0.56°C) from regular clothing (0.06°C) (Duncan et al., 1979).

Rossi (2003) reported a C_T increases of 0.6°C (31.0°C ambient temperature), and 1.0°C (38°C ambient temperature) following 15 minutes of simulated firefighting activity in PPE. Sweat rates ranged between 0.75 and 2.08 l•h^{-1} with sweat evaporation percentages ranging between 52 and 84%. Carter et al. (1999) reported mean group rectal temperature increases of 1.5°C for normal recovery and 0.8°C for enhanced recovery following two bouts of 10 minute stepping exercise wearing PPE in simulated hot (40°C) and humid (70%) conditions. The stepping exercise bouts were separated by 10 minutes of passive rest. In the enhanced recovery condition, participants sat in front of a fan blowing cool air with coat unbuttoned. The absolute rise in rectal temperature was attenuated by passive cooling, and the rate of rectal temperature rise during the second exercise bout decreased. This indicates promise for cooling as a strategy to reduce heat stress associated with PPE and exercise in hyperthermic conditions.

Thermal Homeostasis

C_T in humans is maintained within a narrow range, which corresponds to optimal temperatures for efficient body function (Blatteis, 2001). Heat gain is the product of endogenous (metabolic) and exogenous (environmental) thermal loading. Heat loss or body cooling is the result of thermal exchange with the environment through conduction, convection, radiation and evaporation of sweat from the skin. During exercise, heat gain often occurs due to an increased metabolic rate and increased muscle activity (Blatteis, 2001). Increases in C_T occur when heat production exceeds heat dissipation, however the body is usually able to maintain thermal homeostasis at this elevated C_T. Heat produced by working skeletal muscles is transferred primarily through convective heat flow of blood from the core to the skin, where it is then dissipated to the surrounding environment through conductive, convective, radiative and evaporative transfer.

Afferent & Efferent Thermoregulatory Control Mechanisms

Cutaneous temperature receptors and C_T receptors provide afferent input to the hypothalamus for the regulation of body temperature (Blatteis, 2001). Cutaneous receptors provide feedback to the hypothalamus about skin temperatures and ambient environmental conditions, whereas C_T receptors, located in the anterior portion of the hypothalamus and carotid bodies, offer afferent information about blood temperature perfusing the receptor site. The hypothalamus regulates C_T by integrating both afferent thermal inputs and sending out efferent signals that direct the thermoregulatory effectors and provide physiological adjustments.

Heat Stress

Heat illness is most common in hot, humid environments, but may also occur under thermoneutral conditions if there is excessive endogenous heat production and/or heat loss impairment. Wearing PPE during firefighting tasks limits the body's ability to dissipate heat and presents an environment where heat gain exceeds heat loss.

Hyperthermia increases the physiological strain on the body, which can decrease exercise performance, lead to exhaustion, heat injury and death (Cheung & McClellan, 1998). Furthermore, it has been demonstrated that elevated C_T of (≥39.5ºC) increases cardiovascular, thermal and perceptual strain, and consequently is a limiting factor during exercise (Cheung and McLellan 1998; Gonzalez-Alonso et al. 1999; Olschewski and Bruck 1988; Walters et al. 2000).

The mechanisms behind hyperthermia-induced fatigue are not fully understood, but two emerging theories have been proposed. The critical internal temperature theory suggests that a temperature exists (~40°C) where exhaustion is reached regardless of initial temperature, passively or actively induced temperature rise, or rate of heat storage (Gonzalez-Alonzo, 1999; Nybo and Nielsen 2001). Gonzales-Alonso et al. (1999) reported that high internal body temperature (>38°C) caused fatigue in trained subjects during prolonged exercise in uncompensable hot environments. All subjects reached exhaustion at similar internal temperatures (~40°C), however time to exhaustion was significantly shorter for subjects during a high rate of heat storage compared to a lower rate. These results demonstrated that high internal body temperature per se caused fatigue in trained subjects during prolonged exercise in uncompensable hot environments.

The teleoanticipation theory suggests that an elevation in C_T reduces central activation of muscle independent of skin temperature, cardiovascular strain, or psychophysical strain (Morrison, Sleivert, & Cheung, 2004). This protective teleoanticipation response is specific to exercise and incorporates higher brain centers with the predicted end point of exercise, feed forward planning, learned experience, and afferent feedback from metabolic structures and the external environment (Blatteis, 2001). It was once thought that both peripheral and central thermoregulators contributed equivalent afferent input to the hypothalamus and thus efferent thermoregulatory response. However, Frank et al. (1999) independently manipulated skin and core temperature while measuring thermal comfort, vasomotor changes, metabolic heat production and systemic catecholaminergic responses. They reported that although skin and core thermoreceptors contribute equally to perceived thermal comfort and sensation, C_T dominates the regulation of the autonomic and metabolic responses. They also support the teleoanticipation theory by suggesting that cutaneous thermoreceptors will detect environmental sources of heat stress before central receptors and thus will offer higher brain centers the opportunity to modify behaviors to avoid increased heat stress. It is therefore possible that the critical temperature and teleoanticipation theories are not mutually exclusive and that together the physiological response to hyperthermic fatigue is described but the underlying mechanisms behind impairment in performance have yet to be determined.

Influence of Body Composition

Investigations into the interrelations between human morphology and thermoregulation are complex and have yet to provide conclusive evidence in the relative contributions of skin, adipose tissue, muscle tissue, and surface area (Anderson, 1999). Fat tissue has a lower heat capacity than non-fat tissue, which may thereby decrease the time to reach exhaustion temperatures (McKardle, Katch & Katch, 2000). Thus the percentage and distribution of body fat will influence the rate of change in body temperature at any given rate of heat storage (Selkirk & McLellan, 2001). Havenith, Coenen, Kistemaker, & Kenney (1998) reported that body fatness significantly affected rectal temperature in the cool condition only, but not in the hot condition. In the cool condition, low skin blood flows due to the insulative effect of fat was pronounced (measured as increases in forearm blood flow), whereas in the warmer environments, high skin blood flows to increase cooling offset the resistance offered by peripheral adipose tissue. However, McLellan (1998) concluded that the thermoregulatory disadvantage of exercise in PPE of females compared to males was due to a higher percentage of body fatness and the lower specific heat of adipose tissue versus non-adipose tissue. In much of the heat stress literature, the interplay between body fatness and aerobic fitness has not been controlled; it has therefore been difficult to conclusively determine their relative influence.

Influence of Aerobic Fitness

In an elegant study, Selkirk & McLellan (2001) examined the independent and combined importance of aerobic fitness and body fatness on physiological tolerance and exercise time during exercise in PPE. The researchers matched for body fatness and aerobic fitness, with aerobic fitness being expressed per kilogram of lean body mass to eliminate the influence of body fatness on the expression of fitness. Subjects with higher aerobic fitness had a greater ability to tolerate high C_Ts with a 0.9°C difference between fit and unfit participants. The high fitness, low body fat group terminated exercise at the ethical ceiling, a C_T of 39.5°C and the low fitness, low body fat group terminated exercise at 38.6°C. It has been documented that high fit individuals generally terminate exercise trials due to the attainment of the ethical limit for C_T (as determined by research ethics boards; typically 39.5 to 40.0ºC) while moderately fit participants cease exercising due to exhaustion (Cheung and McLellan, 1998). At exercise end-point, trained individuals perceptually underestimated their physiological strain (HR & CT) whereas untrained consistently perceived their physiological strain correctly (Tikuisis, McLellan & Selkirk, 2002). It is therefore plausible that if trained individuals underestimate their physiological strain they may be placing themselves at risk for heat strain injuries if they continue to exercise in the heat according to their perception of heat stress.

Brain Activity

Although brain temperature has yet to be measured in humans, brain activity during hyperthermic conditions indicates impairment of functioning. 30 minutes of maximal cycling in a hot condition (42°C) compared to cycling in a cool condition (19°C) was associated with an increased α/β index, indicating a suppressed level of arousal. EEG frequencies shifted to slower frequency α-waves typically associated with sleepiness and drowsiness, indicating a lower arousal state (Nielsen et al. 2001). Hyperthermia induced alterations to maximal voluntary activation are equivocal. Nybo & Nielsen (2001) reported that following cycling to hyperthermia (C_T 40.0ºC) the reduction in maximal voluntary activation and force production occurred regardless of whether the muscle was exercised (knee extensors) or not (hand grip muscles). It was concluded that the impaired ability to generate force during hyperthermia is associated with a reduction in the voluntary activation percentage. In contrast, Saboisky et al. (2003) reported muscle specific reductions in maximal voluntary activation following exhaustive exercise of the leg extensors in the heat. The central activation ratio (CAR) of the leg extensors decreased from 94.2 ± 1.3 % before exercise to 91.7 ± 1.5 % ($P < 0.02$) following exercise-induced hyperthermia. However, the CAR for the forearm flexors remained at similar levels before and after exercise. The data suggest that the central nervous system selectively reduces central activation to specific skeletal muscles as a consequence of exercise-induced hyperthermia. The central nervous system response to hyperthermia requires further investigation, however the decrease in central activation and force production may partially explain higher subjective ratings of exertion during exercise in hyperthermic conditions. Any increase in physiological strain or impairment in mental functioning due to clothing induced uncompensable heat stress may place the firefighter at an increased risk of accident (Hancock, 1982; Enander & Hygge, 1990).

Physiological Strain Index (PSI)

Moran, Shitzer, & Pandolf (2000) developed a physiological strain index (PSI), based on rectal temperature (Tre) and HR. The index was to be used in hot environments and considered sensitive enough to differentiate between similar exposures differing in one variable (clothing, metabolic rate, climate). The index scores the physiological strain on a universal scale of 0–10. Baker et al., (2000) compared PSI, calculated from HR and T_{rectal}, to RPE following an hour of treadmill walking in full PPE. They reported a very high correlation coefficient $r = 0.98$, indicating the potential for RPE to be a very useful measure of self perceived heat strain.

Conclusions

The majority of firefighter literature describes the physiological challenges of fire suppression or simulated fire suppression tasks. Although Gledhill and Jamnik (1992) assessed HR and VO_2 of firefighters completing discrete auto extrication tasks, the research design did not assess the physiological and thermal response of firefighters during a continuous auto extrication simulation. At present there is a lack of scientific research that describes the physiological changes in C_T, HR, BP, and PSI that occurs with auto extrication. Psychophysical indices have not been used for firefighters performing auto extrication activities. Psychophysical indices such as RPE and RPTS may be valuable tools for firefighters to self monitor cardiovascular and thermoregultory responses while engaged in firefighting activities. The competing demands placed upon the cardiovascular system to engage in auto extrication activities and thermoregulate in an uncompensable heat stress environment, coupled with additional emotional stress of an emergency situation provides compelling reasons to examine the physiological and thermoregulatory response of auto extrication simulations.

REFERENCES

Anderson, G.S. (1999). Human morphology and temperature regulation. *International Journal of Biometeorology, 43*(3), 99-109.

Baker, S.J., Grice, J., Roby, L., & Matthews, C. (2000). Cardiorespiratory and thermoregulatory responses of working in fire-fighting protective clothing in a temperate environment. *Ergonomics, 43*(9), 1350-1358.

Barnard, R.J., & Duncan, H.W. (1975). Heart rate and ECG responses of firefighters. *Journal of Occupational Medicine, 17,* 247-250.

Blatteis, C.M. (2000). Thermoregulation in complex situations: combined heat exposure, infectious fever and water deprivation. *International Journal of Biometeorology, 44*(1), 31-43.

Carter, J.B., Banister, E.W., & Morrison, J.B. (1999). Effectiveness of rest pauses and cooling in alleviation of heat stress during simulated fire-fighting activity. *Ergonomics, 42*(2), 299-313.

Cheung, S.S., & McLellan, T.M. (1998). Influence of hydration status and fluid replacement on heat tolerance during uncompensable heat stress. *European Journal of Applied Physiology, 77*, 139-148.

Cheung, S.S., McLellan, T.M., & Tenaglia, S. (2000). The thermophysiology of uncompensable heat stress: Physiological manipulations and individual characteristics. *Sports Medicine, 29*(5), 329-359.

Davis, P.O., & Dotson, C.O., (1987 Physiological aspects of fire fighting. *Fire Technology, 23*(4), 280-291.

Davis, P.O., & Santa Maria, D.L. (1975). Energy Costs of Wearing Fire Fighter's

Protective Equipment. *International Fire Chief, 41*,10-11.

Duncan, H.W., Gardner, G.W., & Barnard, R.J. (1979). Physiological responses of men working in fire fighting equipment in the heat. *Ergonomics, 22,* 521-527.

Enander, A.E., & Hygge, S. (1990). Thermal stress and human performance. *Scandinavian Journal of Work and Environmental Health, 16*(Suppl 1), 44–50.

Faff, J., & Tutak, T. (1989). Physiological-responses to working with fire fighting equipment in the heat in relation to subjective fatigue. *Ergonomics, 32*(6), 629-638.

Frank, S.M., Raja, S.N., Bulcao, C.F., & Goldstein, D.S. (1999). Relative contribution of core and cutaneous temperatures to thermal comfort and autonomic responses in humans. *Journal of Applied Physiology, 86*(5), 1588-1593

Gledhill, N., & Jamnik, V.K. (1992). Characterization of the physical demands of firefighting. *Canadian Journal of Sport Science, 17*(3), 207-213.

Gonzalez-Alonso, J., Teller, C., Andersen, S.L., Jensen, F.B., Hyldig, T., & Nielsen, B. (1999). Influence of body temperature on the development of fatigue during prolonged exercise in the heat. *Journal of Applied Physiology, 86*(3), 1032-1039.

Hancock, P.A. (1982). Task categorization and the limits of human performance in extreme heat. *Aviation Space and Environmental Medicine, 53*(8), 778-784.

Havenith, G. (1999). Heat balance when wearing protective clothing. *Annals of Occupational Hygiene, 43*(5), 289-296.

Havenith, G., Coenen, J.M., Kistemaker, L., & Kenney, W.L. (1998). Relevance of individual characteristics for human heat stress response is dependent on exercise intensity and climate type. *European Journal of Applied Occupational Physiology,* *77*(3), 231-241.

Holmer, I. (1995). Protective clothing and heat-stress. *Ergonomics, 38*(1), 166-182.

Kales, S.N., Soteriades, E.S., Christoudias, S.G., & Christiani, D.C. (2003). Firefighters and on-duty deaths from coronary heart disease: a case control study. *Environmental Health*, *2*(1) 14

Karter, M.J., & LeBlanc, P. R. (1995). U.S. fire fighter injuries in 1994, *NFPA Journal*, *89*, 63-70.

Kuorinka, I., & Korhonen, O. (1981). Firefighter reaction to alarm, an ECG and heart rate study. *Journal of Occupational and Environmental Medicine, 23*(11), 762-766.

Lemon, P.W.R., & Hermiston, R.T. (1977). The human energy cost of firefighting. *Journal of Occupational Medicine, 19,* 558-562.

McArdle, W.D., Katch, F.I., & Katch, V.L. (2000). *Essentials of exercise physiology.* Philadelphia, PA: Lippincott, Williams & Wilkins.

McLellan, T.M. (1998). Sex-related differences in thermoregulatory responses while wearing protective clothing. *European Journal of Applied Physiology and Occupational Physiology, 78*(1), 28-37.

Misner, J.E., Plowman, S.A., and Boileau, R. (1987). Performance differences between males and females on simulated firefighting tasks. *Journal of Occupational Medicine, 29,* 801-805.

Moran, D.S., Shitzer, A., & Pandolf, K.B. (1998). A physiological strain index to evaluate heat stress. *American Journal of Physiology, 275*(44), R129-R134.

Morrison, S., Sleivert, G.G., & Cheung, S.S. (2004). Passive hyperthermia reduces voluntary activation and isometric force production. *European Journal of*

Applied Physiology, 91(5-6), 729-736.

Nybo, L. & Nielsen, B. (2001). Perceived exertion is associated with an altered brain activity during exercise with progressive hyperthermia. *Journal of Applied Physiology, 91*(5), 2017-2023.

O'Connell, E.R., Thomas, P.C., Cady, L.D., & Karwasky, R.J. (1986). Energy costs of simulated stair climbing as a job related task in firefighting. *Journal of Occupational Medicine, 28,* 282-284.

Olschewski, H, & Bruck, K. (1988). Thermoregulatory, cardiovascular, and muscular factors related to exercise after precooling. *Journal of Applied Physiology, 64*(2), 803-811.

Pascoe, D.D., Shanley, L.A., & Smith, E.W. (1994). Clothing and exercise: Biophysics of heat transfer between the individual, clothing and environment. *Sports Medicine, 18*(1), 38-54.

Romet, T.T., & Frim, J. (1987). Physiological responses to fire fighting activities. *European Journal of Applied Physiology, 56*, 633-638.

Rossi, R. (2003). Fire fighting and its influence on the body. *Ergonomics, 46*(10), 1017 1034.

Skoldstrom, B. (1987). Physiological-responses of fire fighters to workload and thermal-stress. *Ergonomics, 30*(11), 1589-1597.

Smith, D.L., Petruzzello, S.J., Kramer, J.M., & Misner, J.E. (1997). The effects of different thermal environments on the physiological and psychological responses of firefighters to a training drill. *Ergonomics, 40*(4), 500-510.

Smith, D.L., & Petruzzello, S.J. (1998). Selected physiological and psychological responses to live-fire drills in different configurations of firefighting gear. *Ergonomics, 41*(8), 11-41-1154.

Sothmann, M., Saupe, K., Raven, P., Pawelczyk, J., Davis, P., Dotson, C., Landy, F., & Siliunas, M. (1991). Oxygen consumption during fire suppression: Error of heart rate estimation. *Ergonomics, 34*(12), 1469-1474.

Tikuisis, P., McLellan, T.M., & Selkirk, G. (2002). Perceptual versus physiological heat strain during exercise-heat stress. *Medicine & Science in Sports & Exercise, 34*(9), 1454-1461.

Walters, T.J., Ryan, K.L., Tate, L.M., & Mason, P.A. (2000). Exercise in the heat is limited by a critical internal temperature. *Journal of Applied Physiology, 89*(2), 799-806.

Washburn, A.E., LeBlanc, P.R., & Fahy, R.F. (1996). 1995 firefighter fatalities. *NFPA Journal, 90*(4):63-5, 68-70, 77.

White, M.K., Vercruyssen, M., & Hodous, T.K. (1989). Work Tolerance and subjective responses to wearing protective clothing and respirators during physical work. *Ergonomics, 32*(9), 1111-1123.

White, M.K., Hodous, T.K., & Vercruyssen, M. (1991). Effect of thermal environment and chemical protective clothing on work tolerance, physiological responses, and subjective ratings. *Ergonomics, 34*(4), 445-457

APPENDIX B

Information Sheet for Participants

Physiological strain, RPE, and perceived thermal stress during auto extrication simulations by experienced urban firefighters.

Thank you for showing an interest in this project. Please read this information sheet carefully before deciding whether or not to participate. If you have any questions, please, do not hesitate to ask. If you decide to participate we thank you. If you decide not to take part there will be no disadvantage to you of any kind and we thank you for considering our request.

Purpose of the Study

This project is being undertaken as part of the requirements for a Masters degree at the School of Physical Education, University of Victoria. It is being conducted under the supervision of Dr. Lynneth Wolski and Dr. Catherine Gaul. You may contact my supervisors through email or phone at lwolski@uvic.ca, 721-7884 or kgaul@uvic.ca, 721-8380.

This research is being partially funded by the Michael Smith Foundation for Health Research (MSFHR), Social Sciences and Humanities Research Council of Canada (SSHRC) and the University of Victoria.

This study is investigating the physiological demands of an auto extrication and victim rescue simulation. Primary physiological measurements will include heart rate (HR) and core temperature (C_T) to determine physiological strain, and ratings of perceived exertion (RPE). Heat stress and physiological strain are the most reported challenges facing firefighters wearing personal protective equipment (PPE). PPE is designed to protect the firefighter from the heat encountered during fires, however, PPE limits the thermoregulation of the body as excess heat generated from activity cannot be dissipated through the skin.

A considerable body of literature exists which documents the physiological demands and thermal challenges that exist for firefighters during fire-suppression and treadmill walking. There isn't however, any literature to our knowledge that documents the physiological demands from auto extrication rescue scenarios. Firefighters are required to wear full PPE including: pants, jacket, boots, gloves, and helmet with visor when they perform auto extrication. The physical demands and pressure to work quickly of auto extrication increase stress levels.

Test protocols will assess baseline physiological measures, and the change in these measures during the call response and extrication simulation. Baseline measurements will be taken at the Yates St. Fire Hall, followed by a return to regular work duty. Six participants (2 rescue truck and 4 engine truck) will respond to an auto extrication 'mock' call at the simulation location. The 6 participants will assess the situation following standard protocol with the intention of extricating the victim as quickly as possible. Physiological measures will be made during the extrication simulation, cleanup, and return to Yates St. Hall. This will allow the researchers to not only assess the physiological measures during auto extrication, but also to assess recovery time and the return to baseline for HR, C_T, and BP.

The aim of this project is to gain a better understanding of the physiological demands of auto extrication for a firefighter rescue team.

Type of participants

Firefighters as part of a rescue team.

Eligibility Criteria

- Male firefighters from the Victoria Fire Department
- Age 25-50 with ability to provide written informed consent
- Ability to swallow core-temperature capsule

Ineligibility Criteria

- Currently taking BP or heart medications
- Existing cardiovascular or respiratory pathology

Should you agree to take part in this project, you will be asked to....

- Complete a PAR-Q with no positive responses
- Participate in 1 testing session of approximately 2 hours
- Testing sessions will include:
    - Pre rescue measurements determining your nude dry weight, resting HR and BP, C_T, EC_T, and thermal stress.
    - Post rescue measurements of HR, BP, C_T, EC_T, RPE, and thermal stress.

Possible Side-effects and Risks

The participation in this study should not pose any major risks to the participants.

Please be aware that you are free to decline participation at any time during the study without any potential repercussions.

Expected Benefits to Subjects and Others

No personal benefit to you is expected from participation in this study. The information from this study may help firefighters and fire departments in the future. Improvements to vehicle rescue protocols, recovery strategies, and rescue equipment may result from your participation in this study.

Data Information Required

- Name, address, and phone number: For contact reasons.
- Age, height, weight, $\Sigma 5$ skin folds
- HR, BP, C_T, EC_T, RPE, thermal stress.
- Agreement between auto extrication simulation and live auto rescue will be determined by Likert agreement scale questionnaire.

Compensation for Injury

In the event you are injured as a consequence of participation in the study due to study procedures, your medical condition will be evaluated and medical care will be provided by one of the investigators or you will be referred for appropriate treatment.

If you are injured as a result of participating in this study, the costs of your medical treatment will be paid for by your provincial medical plan and/or The Workers Compensation Board of BC. You do not waive any legal rights by signing this consent form

Remuneration/Compensation

You will not receive any payment for taking part in this study.

Conflict of Interest

The investigators and sponsor disclose no conflict of interest related to this study.

All data obtained will be used solely for the purpose of analyzing the physiological demands of both unlimited and limited auto rescue scenarios. Results of this project may be published, but any data included will not be linked to a specific participant. Your data will be assigned a personal identification number to ensure anonymity in both the analysis and documentation of results. The data obtained in this study will only be available to Benjamin Soer, Dr. Lynneth Wolski, Dr. Catherine Gaul, Dr. David Docherty, and Dr. John Anderson who are all members of the thesis supervisory committee.

Contact Information

Please feel free to contact us at any time with questions and concerns you may have about participating in this research study.

Benjamin Soer
Master of Science Candidate
School of Physical Education

Or

Dr. Lynneth Wolski
Supervisor, School of Physical Education.
University of Victoria

University email: bsoer@uvic.ca Email: lwolski@uvic.ca

If you wish to contact an independent person regarding any aspect of your participation in this study please contact:
Dr. David Docherty, Acting Director, School of Physical Education, UVic
Phone: 721-8376 or email docherty@uvic.ca

APPENDIX C

Informed Consent

Physiological strain, RPE, and perceived thermal stress during auto extrication simulations by experienced urban firefighters.

Documentation of Consent

This document will be kept together with our research records for this study. The information contained in the document will be used only for our research purposes. A second copy will be given to you for your personal records.

Your signature on this consent form means the following:

- The study has been fully explained to you and all of your questions have been answered
- You understand the requirements of this study.
- You agree to take part in this study

________________________________ ____________________
Signature and Printed Name of Subject Date of Signature

________________________________ ____________________
Signature and Printed Name of Witness Date of Signature

________________________________ ____________________
Signature and Printed Name of Investigator Date of Signature
or his/her Qualified Designated Representative

If this consent process has been done in a language other than that on the written form, with the assistance of a translator, please indicate: (language)

____

__________________________________ _____________________
Signature and Printed Name of Translator *Date of Signature*

APPENDIX D

Instrumentation

Figure 1. Polar heart rate monitor to be worn during rescue scenarios.

Figure 2. VitalSense core temperature monitoring system with Jonah CBTC.

Figure 3. Braun Thermoscan 4520.

Figure 4. Omron® Intellisense arm blood pressure monitor (Model #: HEM-712C)

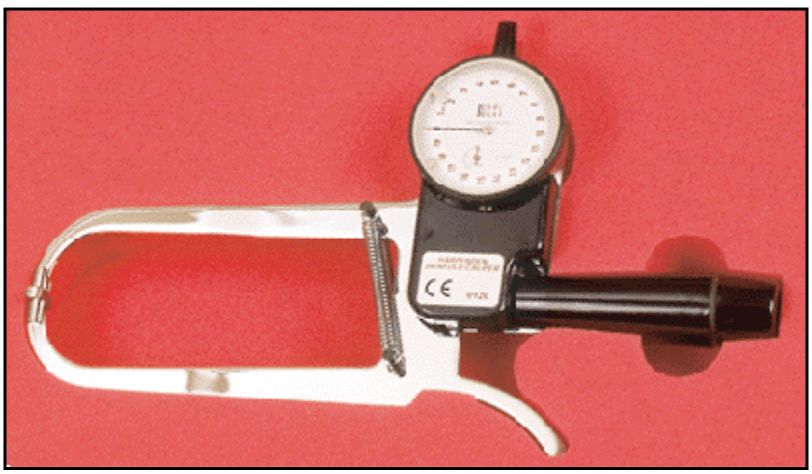

Figure 5. Harpenden skin fold calipers.

APPENDIX E

Rating of Perceived Exertion Scale

Rating of Perceived Exertion	6	No exertion at all
	7	Extremely light
	8	
	9	Very Light
	10	
	11	Light
	12	
	13	Somewhat Hard
	14	
	15	Hard
	16	
	17	Very Hard
	18	
	19	Extremely Hard
	20	Maximal Exertion

(Borg, 1982).

APPENDIX F

Rating of Perceived Thermal Stress Scale

Rating of Perceived Thermal Stress	1	Comfortable temperature
	2	
	3	Starting to get hot
	4	
	5	Hot
	6	
	7	Very hot
	8	
	9	Unbearably hot

APPENDIX G

Simulation Satisfaction Questionnaire

Please answer all questions as honestly as possible

1) The auto extrication simulation performed today represented protocol for a live auto extrication?

5	4	3	2	1
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

2) The stress level throughout the simulation was similar to a live auto extrication?

5	4	3	2	1
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

3) The sense of urgency throughout the simulation was similar to a live auto extrication?

5	4	3	2	1
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

4) The crash scenario represented a typical motor vehicle accident? (degree of smash, car placement, etc).

5	4	3	2	1
Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree

APPENDIX H

Pictures from Data Collection


E1
LIEUTENANT