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Heat stress while wearing long pants or shorts under firefighting protective clothing

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It was the purpose of this study to examine whether replacing long pants (P) with shorts (S) would reduce the heat stress of wearing firefighting protective clothing during exercise in a warm environment. Twenty-four Toronto Firefighters were allocated to one of four groups that performed heavy (H, 4.8 $km\cdot h^{-1}$, 5% grade), moderate (M, 4.5 $km\cdot h^{-1}$, 2.5% grade), light (L, 4.5 $km\cdot h^{-1}$) or very light (VL, 2.5 $km\cdot h^{-1}$) exercise while wearing their full protective ensemble and self-contained breathing apparatus. Participants performed a familiarization trial followed by two experimental trials at 35°C and 50% relative humidity wearing either P or S under their protective overpants. Replacing P with S had no impact on the rectal temperature (T_{re}) or heart rate response during heavy or moderate exercise where exposure times were less than 1 h (40.8 ± 5.8 and 53.5 ± 9.2 min for H and M, respectively while wearing P, and 43.5 ± 5.3 and 54.2 ± 8.4 min, respectively while wearing S). In contrast, as exposure times were extended during lighter exercise T_{re} was reduced by as much as 0.4°C after 80 min of exercise while wearing S. Exposure times were significantly increased from 65.8 ± 9.6 and 83.5 ± 11.6 min during L and VL, respectively while wearing P to 73.3 ± 8.4 and 97.0 ± 12.5 min, respectively while wearing S. It was concluded that replacing P with S under the firefighting protective clothing reduced the heat stress associated with wearing the protective ensemble and extended exposure times approximately 10–15% during light exercise. However, during heavier exercise where exposure times were less than 1 h replacing P with S was of little benefit.

1. Introduction

In many occupational settings (e.g., firefighters, hazardous waste disposal, military), protective clothing is required to shield the individual from environmental hazards or from injury. Protective clothing, which is typically heavy, thick, multi-layered, and bulky, exacerbates the challenge of thermoregulation because of a limited water vapour permeability across the clothing layers, further decreasing the rate of heat exchange (Nunneley 1989, McLellan 1993). The cardiovascular and thermal strain associated with wearing a firefighting protective ensemble has been described for cool and hot environments while exercising at various work intensities (Duncan *et al.* 1979, Romet and Frim 1987, Sköldström 1987, Smith *et al.* 1996, 1997, Smith and Petruzzello 1998, Baker *et al.* 2000). Typically, heart rates increase to very high levels during heavy work efforts lasting less than 15 min (Duncan *et al.* 1979, White and

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Hodous 1987, Smith *et al.* 1996, 1997, Smith and Petruzzello 1998) but during lighter exercise with longer exposure times both heart rate (HR) and rectal temperature (T_{re}) increase to high levels (Sköldström 1987).

Under certain conditions of high ambient temperature and/or relative humidity, or with the wearing of protective clothing that restricts evaporative heat loss, the evaporative heat loss required to maintain a thermal steady state (E_{req}) can exceed the maximal evaporative capacity of the environment (E_{max}) during light exercise or even at rest. In these uncompensable heat stress (UHS) situations (Givoni and Goldman 1972), the body constantly stores heat. This results in body temperature continuing to increase until either exhaustion (or death) occurs, or else the severity of the set of environmental conditions decreases by removing clothing layers to promote greater evaporative heat loss, ceasing work or exercise, or seeking shade or a cooler environment.

While protective clothing is being continually improved and lightened, the requirement for adequate environmental protection is generally contradictory to the desire for adequate ventilation. For example, the requirement to meet National Fire Prevention Association (NFPA) standards for protective clothing has led to firefighting clothing ensembles that create greater heat stress for the individual than protective ensembles that were used before this standard was introduced in 1987 (Smith *et al.* 1995). One option that has been implemented by the New York City Fire Department and is being considered for implementation by the Toronto Fire Service is the replacement of the long pants that are worn under the protective overpants (or bunker pants) with shorts. Malley *et al.* (1999) reported that treadmill exercise time at 50% $\dot{V}O_{2max}$ was increased approximately 10% when the long-sleeved shirt and pants were replaced by a T-shirt and shorts worn under the protective bunker pants and jacket. T_{re}, however, was not significantly different following the 15–20 min of exercise that included 2-min warm-up and recovery phases in a comfortable hospital laboratory setting. Participants did report that they felt less discomfort and less restriction of movement when the shorts and T-shirt were worn. A subsequent prospective analysis of New York City firefighters between May and August revealed that replacing the long-sleeved shirt and pants with a T-shirt and shorts did not compromise the protection for the firefighter but these changes did reduce the medical leave required to treat cases of heat exhaustion (Prezant *et al.* 2000).

Replacing the long pants with shorts decreases the thermal resistance of the firefighter's protective ensemble approximately 10% from 0.249 to 0.225 $m^2 \cdot {}^\circ C \cdot W^{-1}$ (R. R. Gonzalez personal communication) but whether this change impacts on the resultant cardiovascular and thermal strain is unknown. Evaluation of the thermal resistance with a dry and articulating heated manikin has shown that the removal of both the combat pants and jacket worn under the military's biological and chemical defence overgarment decreases the total thermal resistance of the ensemble approximately 18% from 0.291 to 0.239 $m^2 \cdot {}^\circ C \cdot W^{-1}$ at a wind speed of 1.12 $m \cdot s^{-1}$ (Gonzalez *et al.* 1993). These changes have extended tolerance times up to 40% during exercise in environments between 30–40°C (McLellan *et al.* 1992, 1997, Levine *et al.* 1993, McLellan 1996). Therefore, a smaller improvement would be expected with the removal of only the firefighter's duty uniform pants and replacement of this clothing with shorts. It is also noteworthy that physiological manipulations such as heat acclimation (Aoyagi *et al.* 1994, 1995), endurance training (Aoyagi *et al.* 1994, Cheung and McLellan 1998b) and hydration (Cheung and McLellan 1998a) have all been shown to only exert an influence on exercise time in the heat while wearing protective clothing during lower metabolic rates where exposure times are extended beyond 60 min. Thus, the improvements seen by the replacement of long pants with shorts may be more evident during light exercise where the rates of heat production are low and exposure times are extended well beyond the 15–20 min protocol used by Malley *et al.* (1999).

Although the previous studies by Malley *et al.* (1999) and Prezant *et al.* (2000) provide useful information that ultimately affected current firefighting policy and guidance for commanders, data are not available that conclusively show that the thermal and cardiovascular strain associated with wearing firefighting protective clothing is reduced when the duty uniform long pants are replaced with shorts. Thus, it was the purpose of the present study to compare the cardiovascular and thermal strain associated with wearing the duty uniform long pants or shorts under the firefighter's protective pants. Trials were conducted over a range of metabolic rates to vary exposure times between 30–90 min and at an environmental temperature of 35°C to reflect a warm summer's day in Toronto. It was hypothesized that thermal and cardiovascular strain would be reduced when the shorts were worn and that this reduction would be most evident during lighter work intensities that prolonged heat exposure for more than 1 h.

2. Methods

2.1. *Participants*

Following approval from DRDC Toronto's Human Ethics Review Committee, volunteers from the Toronto Fire Service were informed of all details of the experimental procedures and the associated risks and discomforts. After a medical examination to ensure that there were no medical contraindications to their participation in the experiment, each volunteer gave their written informed consent prior to the first day of data collection. Twenty-two males and two women were selected from a larger pool of volunteers to give a range for fitness and body composition that would be representative of the members of the Toronto Fire Service.

2.2. *Baseline measurements*

Following the medical screening and informed consent procedures, participants were tested for aerobic fitness and body fatness. Peak oxygen consumption ($\dot{V}O_{2peak}$) was measured at a comfortable room temperature (22°C) using open-circuit spirometry on a motorized treadmill (McLellan *et al.* 1996). The test consisted of 3 min of steady-state running (0% elevation; wind speed $< 0.1\ m \cdot s^{-1}$) on a motorized treadmill (Quinton Instruments., Q65, Seattle Washington) at a self-selected pace, that was dependent on the aerobic fitness level of each subject. Thereafter, treadmill grade was increased $1\% \cdot min^{-1}$, up to 10% elevation. At this point, an alternating increase in speed ($0.22\ m \cdot s^{-1}$) and elevation (1%) each minute was implemented until the participant could no longer continue. $\dot{V}O_{2peak}$ was defined as the highest observed 30-s value for oxygen consumption ($\dot{V}O_2$) together with a respiratory exchange ratio $\geqslant 1.15$. HR was monitored during the treadmill protocol using a transmitter/telemetry unit (Polar Vantage XL, Finland). The highest value recorded at the end of the exercise test was defined as HR_{peak}. Body density was determined from underwater weighing (UWW) using body plethysmography (Clausen 1982) to determine residual lung volume and body fatness was then calculated using the Siri equation (Siri 1956).

2.3. *Definition of groups*

Participants were matched for fitness and body composition and equally divided into four groups that performed treadmill exercise defined as heavy (H, 4.8 $km{\cdot}h^{-1}$ and a 5% elevation), moderate (M, 4.5 $km{\cdot}h^{-1}$ and a 2.5% elevation), light (L, 4.5 $km{\cdot}h^{-1}$ and 0% elevation) and very light (VL, 2.5 $km{\cdot}h^{-1}$ and 0% elevation). One female participant was assigned to H and M.

2.4. *Experimental design*

All sessions were conducted in the fall and winter months. In addition, to control for the effects of circadian rhythm on rectal temperature, all sessions began in the morning around 0730 h (McLellan *et al.* 1999). Participants performed a familiarization session and two experimental sessions in a climatic chamber controlled at 35°C and 50% relative humidity with a wind speed less than 0.1 $m{\cdot}s^{-1}$. These sessions were separated by a minimum of 14 days with most trials for the males and all trials for the females scheduled once during a 28-day cycle. Participants were asked to refrain from hard exercise (i.e., running, swimming, cycling, and weight lifting), alcohol, nonsteroidal anti-inflammatories, and sleep medication 24 h before each session and also to refrain from ingesting caffeine or nicotine 12 h before each session. Donation of blood was prohibited within 30 days of any part of the experiment.

2.5. *Clothing*

Participants wore their own NFPA standard protective firefighting turnout gear, gloves, Nomex® flash hood, helmet, respirator and self-contained breathing apparatus (SCBA). Standard issue cotton station long pants (P) or shorts (S) and a cotton T-shirt were worn beneath the turnout gear, along with underwear, socks and running shoes. The Canadian Forces nuclear biological and chemical impermeable protective over-boot was worn in place of the standard rubber boot in order to simulate the impermeable characteristics of the rubber boot, while minimising discomfort due to prolonged walking on the treadmill. Participants wore P during their familiarization session. The total weight of the ensemble approximated 22 kg. The respirator was adapted to allow participants to breathe room air for metabolic gas collection, however, the SCBA was carried during all trials.

2.6. *Exercise and recovery phases*

Each trial was divided into an exposure and recovery phase. The exposure phase consisted of repeated 30-min cycles that involved 20 min of exercise at the prescribed H, M, L or VL metabolic rate followed by a 10-min walk and rest period to simulate a bottle change. This simulation consisted of 3 min of level treadmill walking at 2.5 $km{\cdot}h^{-1}$, followed by 4 min of standing and a subsequent 3 min of walking at 2.5 $km{\cdot}h^{-1}$. During the 4 min of standing participants removed their helmet, flash hood, respirator facepiece and gloves. The exposure phase continued until T_{re} reached 39.0°C, HR reached or exceeded 95% of HR_{peak} for 3 min, nausea or dizziness precluded further exercise or the investigator or participant terminated the trial. Upon the attainment of one of these end-point criteria, a dressed weight was obtained. Participants then removed their helmet, flash hood, gloves, SCBA, jacket and respirator and were seated at

35°C for a 30-min recovery period or until one of the end-point criteria were reached. However, for the non-encapsulating recovery period, the end-point criterion for T_{re} was 40°C. Although the protective overpants were not removed during this recovery period, participants were allowed to undo the Velcro® on the front of the pants.

Exposure time was defined, for all trials, as the elapsed time from the beginning of the exercise to the attainment of one or more of the end-point criteria that resulted in the termination of the exposure phase and placement into the 30-min recovery phase. Immediately prior to entering the climatic chamber and beginning the exposure phase, during each 4-min period of standing during the simulated bottle change and at the beginning of the seated recovery period, participants were given 5 $ml \cdot kg^{-1}$ of cool water at approximately 15°C to consume. If T_{re} was greater than 38.5°C during the exposure phase or if the participant felt that they could not continue for at least another 10 min, water was not administered for the remainder of the exposure period.

2.7. *Dressing procedures*

Participant preparation, insertion of the rectal thermistor and placement of skin thermistors have been detailed previously (Aoyagi *et al.* 1994). Upon entering the chamber, the participant's thermistors and rectal thermistor monitoring cables were connected to a computerized data acquistion system (Hewlett-Packard 3497A control unit, 236–9000 computer and 2934A printer) and the session began. Mean values over 1-min periods for T_{re} and skin temperature were recorded and printed by the data acquisition system. A 7-point weighted mean skin temperature ($\bar{T}_{sk}$) (Hardy and DuBois 1938) was subsequently calculated. HR was recorded every 5 min from the display on the telemetry receiver (Polar® CE0537).

Differences in nude and dressed weights before and after each trial were corrected for respiratory and metabolic weight loss (see below). The rate of sweat production was calculated as the difference between the corrected pre-trial and post-trial nude weights, divided by total exposure and recovery time.

2.8. *Gas exchange*

Open-circuit spirometry was used to determine expired minute ventilation ($\dot{V}_E$), $\dot{V}O_2$ and carbon dioxide production ($\dot{V}CO_2$) for corresponding metabolic measurement periods during the exposure (min 17–20 and min 20–23) and recovery (min 7–10 and min 27–30) phases. An additional metabolic measurement was taken during the first 4-min standing period of the simulated bottle change to determine a resting metabolic value for the trial. Values were averaged from a 2-min sampling period for each participant following a 1-min washout period. In order to determine $\dot{V}_E$, the current SCBA facepiece exhaust valve was modified to incorporate the attachment of an adaptor that directed expired air to a 5L-mixing box and then through a ventilation module (Alpha Technologies VNN 110 Series, Laguna Hill, CA, USA). An aliquot of dried expired gases was pumped via a sampling line to an O_2 and CO_2 analyser (Ametek Instruments S-3A/I and CD-3A, respectively, Pitts, PA, USA). Gas analysers were calibrated before each trial using precision-analysed gas mixtures of known concentrations of oxygen and carbon dioxide, and the ventilation meter was calibrated using a 3-L syringe. After analogue-to-digital conversion (Hewlett Packard 59313A A/D converter, Pitts, PA, USA), $\dot{V}_E$ and, $\dot{V}O_2$ and $\dot{V}CO_2$ were calculated and displayed on-line at 1 min intervals. Two min means of $\dot{V}_E$, $\dot{V}O_2$ and $\dot{V}CO_2$ were calculated and recorded. Respiratory water loss was calculated using the $\dot{V}O_2$ measured during the trial and the equation presented by Mitchell *et al.* (1972). Metabolic weight loss was calculated from $\dot{V}O_2$ and the respiratory exchange ratio using the equation described by Snellen (1966).

2.8. *Ratings of perceived exertion and thermal comfort*

Following the gas exchange measurement, participants were asked to provide a rating of perceived exertion (RPE) between 6 and 20 for the whole body (Borg 1970) and a rating of thermal comfort (RTC) between 1 (so cold I am helpless) and 13 (so hot I am sick and nauseous) for the whole body (Gagge *et al.* 1967).

2.9. *Blood measurements*

Prior to beginning the dressing procedure, but after the insertion of the rectal thermistor, a 5 ml venous blood sample was taken while the participant was in the supine position and the serum was later analysed for osmolality (Advance Micro Osmometer, Model 3300, Advanced Instruments Inc., Norwood, MA, USA).

2.10. *Statistical analyses*

Data are presented as mean values and the standard error of the mean. A one factor between (group) and one factor within (clothing) ANOVA was used to compare the dependant measures of osmolality, exposure time and sweat rate. Due to differences in exposure time among the groups, a two factor within (clothing and time) ANOVA was performed separately for each group for the other dependant measures including T_{re}, $\bar{T}_{sk}$, HR, RPE, RTC and $\dot{V}O_2$. However, since the recovery period was constant for all groups, a one factor between (group) and two factor within (clothing and time) ANOVA was performed on these same dependant measures during the recovery period. To correct for the violation of the sphericity assumption with the repeated factors, a Huynh-Feldt correction was applied to the F-ratio. When a significant F-ratio was obtained, a Newman-Keuls post-hoc analysis was used to isolate differences among treatment means. For all statistical analyses, the 0.05 level of significance was used.

3. Results

3.1. *Physical characteristics of participants*

There was no difference among the groups for any of the physical characteristics shown in table 1.

3.2. *Osmolality*

Osmolality was similar among the groups during both sessions with means of 290.1 ± 0.8 and 288.2 ± 0.8 mosmol·kg^{-1} H_2O for P for S, respectively.

3.3. *Gas exchange*

Wearing S had no effect on the cost of treadmill walking for any of the groups. After 20 min of exercise, $\dot{V}O_2$ in l·min^{-1} was 1.97 ± 0.11, 1.63 ± 0.06, 1.24 ± 0.06 and 0.96 ± 0.03 for H, M, L and VL, respectively for P and 2.00 ± 0.12, 1.61 ± 0.08, 1.33 ± 0.05 and 0.99 ± 0.04 for H, M, L and VL, respectively for S. These values approximated 46%, 40%, 29% and 21% $\dot{V}O_{2peak}$ for H, M, L and VL, respectively.

Table 1. Age, stature, mass, surface area (A_D), peak heart rate (HR_{peak}), peak aerobic power ($\dot{V}O_{2peak}$) and body fatness (BF) for the Heavy (H), Moderate (M), Light (L) and Very Light (VL) groups and for all subjects combined. Values are means (± SE).

Group	Age (yr)	Stature (cm)	Mass (kg)	A_D (m^2)	HR_{peak} ($b{\cdot}min^{-1}$)	$\dot{V}O_{2peak}$ ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)	BF (%)
H	40.2	183.3	84.7	2.07	184.8	51.4	18.3
(n = 6)	(0.9)	(3.0)	(4.7)	(0.07)	(2.4)	(2.0)	(1.7)
M	39.0	174.5	83.0	1.98	189.5	49.6	17.8
(n = 6)	(1.9)	(4.3)	(5.7)	(0.09)	(5.5)	(2.4)	(1.6)
L	39.0	183.9	88.8	2.11	190.8	51.1	17.2
(n = 6)	(2.0)	(3.5)	(4.1)	(0.06)	(3.7)	(1.5)	(1.8)
VL	38.3	180.2	90.1	2.10	189.2	52.6	17.1
(n = 6)	(1.0)	(0.9)	(3.7)	(0.04)	(3.6)	(2.4)	(0.9)
Overall	39.1	180.5	86.6	2.06	188.6	51.2	17.6
(n = 24)	(0.7)	(1.7)	(2.2)	(0.03)	(1.9)	(1.0)	(0.7)

3.4. *Heart rate*

As shown in figure 1, replacing P with S had not effect on the HR response during exercise for groups H and M. However, as exposure time was extended with groups L and VL, HR was significantly lower while wearing S. There was a main effect of clothing for L where overall HR was reduced from 119.6 ± 2.7 $b{\cdot}min^{-1}$ while wearing P to 113.3 ± 2.7 $b{\cdot}min^{-1}$ while wearing S. For VL, the impact on S was even more evident with HR being reduced approximately 10–15 $b{\cdot}min^{-1}$ throughout the exposure.

There was no effect from replacing P with S on the HR response during the 30-min recovery period. Heart rate decreased from 160.9 ± 3.7 $b{\cdot}min^{-1}$ at time 0 to 112.8 ± 2.8 $b{\cdot}min^{-1}$ after 30 min of recovery for P and from 164 ± 3.3 $b{\cdot}min^{-1}$ at time 0 to 113.8 ± 3.1 $b{\cdot}min^{-1}$ at the end of the recovery period.

3.5. *Rectal temperature*

Figure 2 presents the changes in T_{re} during the exposure period for the four groups. Data are shown as a delta T_{re} to normalize small differences in T_{re} at the beginning of the exposure. Shorts had no impact on the increase in T_{re} for groups H or M, but wearing S was associated with a significantly slower increase in T_{re} for both groups L and VL. For group L, a lower T_{re} was evident after 30 min of exposure whereas for group VL the differences between P and S were significant after 35 min. Although S slowed the rate of increase in T_{re} for groups L and VL, wearing S had no effect on the T_{re} recorded at the end of the exposure period for any group (table 2).

The impact of wearing S during the recovery period is shown in figure 3. There was a significant clothing and time interaction that revealed a lower T_{re} while wearing S during the last 15 min of recovery.

3.6. *Mean skin temperature*

Figure 4 depicts the $\bar{T}_{sk}$ response during the exposure period for the four groups. For H and M wearing S did not affect $\bar{T}_{sk}$. However, for both L and VL there was a significant main effect of wearing S during the exposure. During recovery, wearing S also significantly lowered $\bar{T}_{sk}$. Values decreased from

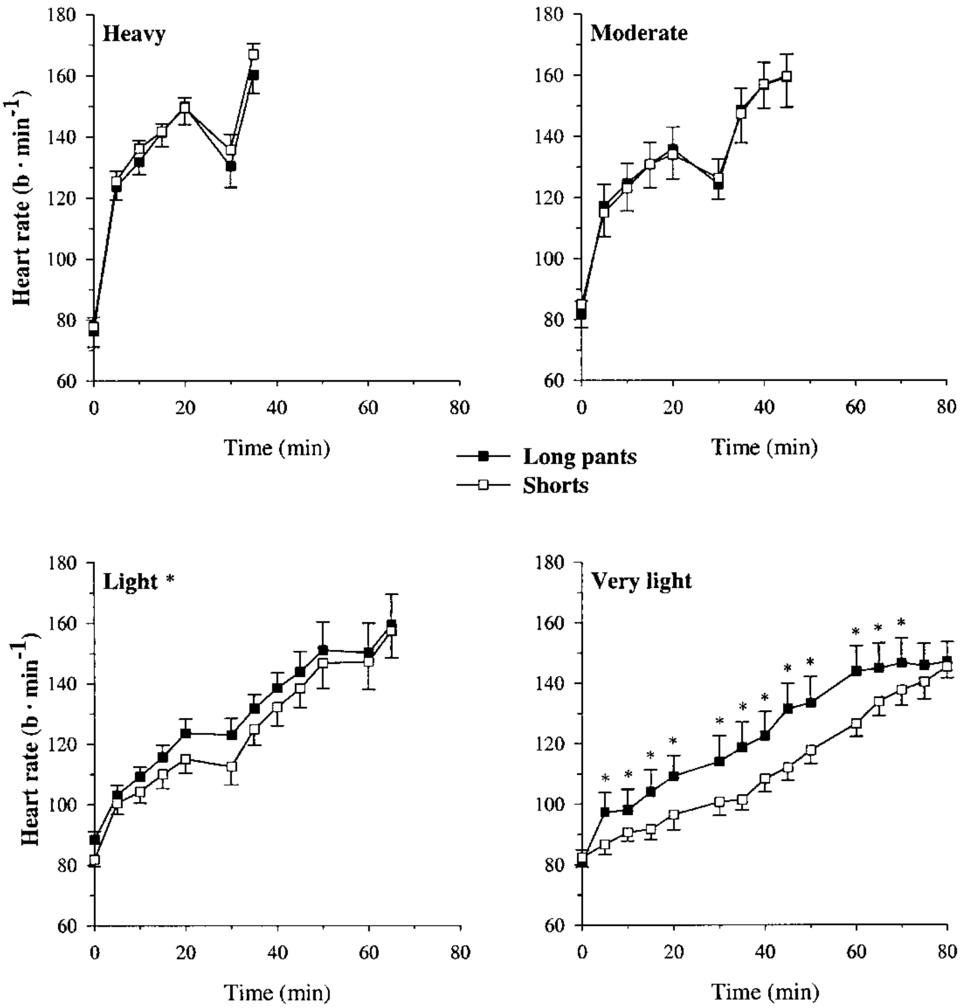

Figure 1. Heart rate responses for firefighters while wearing either pants or shorts under the bunker pants during very light, light, moderate or heavy exercise at 35°C. The asterisk indicates a significant difference when pants or shorts are worn. For the light exercise group this difference represented a main effect of clothing whereas for the very light exercise group there was a significant clothing and time interaction effect. Values are mean $\pm$ SE and represent $n = 6$ to 30 min and $n = 5$ at 35 min for heavy exercise, $n = 6$ to 40 min and $n = 5$ at 45 min for moderate exercise, $n = 6$ to 45 min and $n = 5$ from 50 to 65 min for light exercise, and $n = 6$ to 70 min and $n = 4$ at 75 and 80 min for very light exercise.

38.4 ± 0.1°C at time 0 to 37.8 ± 0.1°C after 30 min of recovery for P and from 38.2 ± 0.1°C at time 0 to 37.5 ± 0.1°C at the end of recovery for S. The major contributor to the lower $\bar{T}_{sk}$ while wearing shorts occurred on the lower leg where skin temperature was significantly reduced by 0.5°C during the exposure period for L and VL and 0.7°C for all groups during recovery. The upper leg skin temperature was also significantly reduced by 0.4°C for group VL throughout the exposure period.

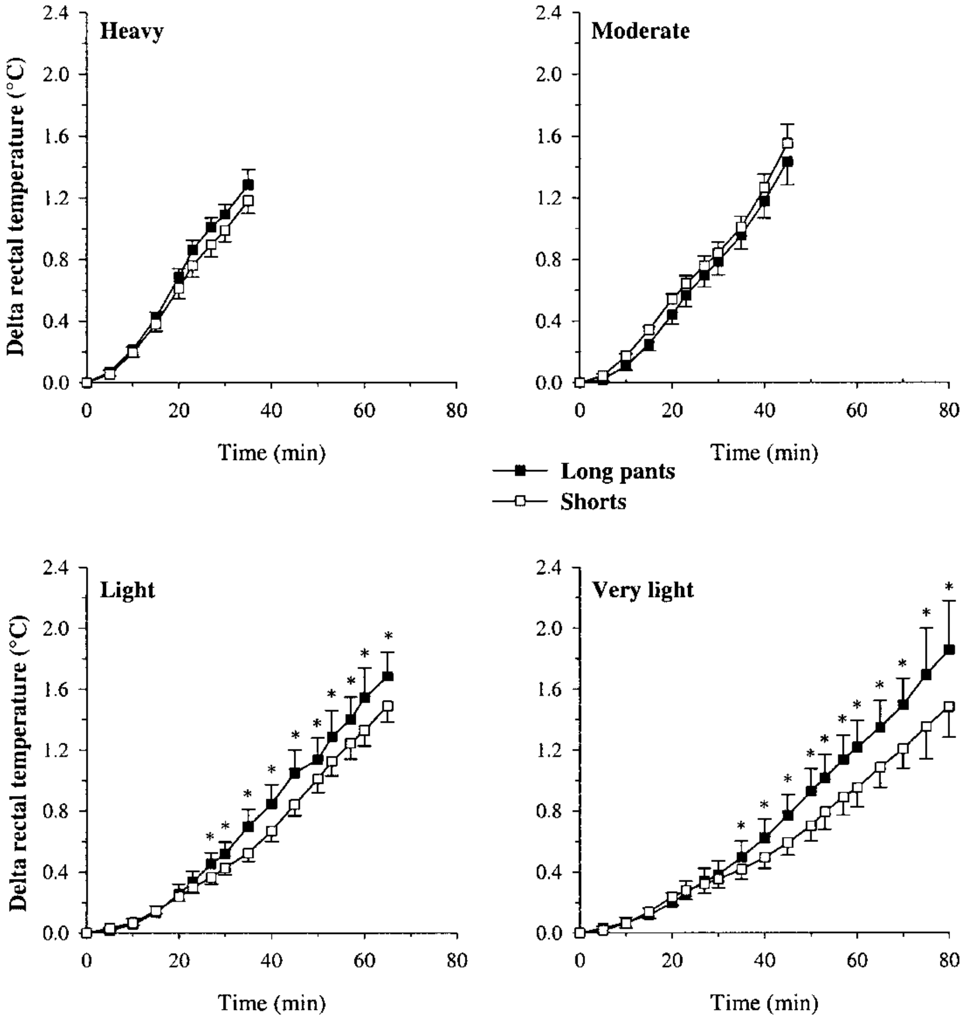

Figure 2. Delta rectal temperature responses for firefighters while wearing either pants or shorts under the bunker pants during very light, light, moderate or heavy exercise at 35°C. The asterisk indicates a significant difference when pants or shorts are worn. For both the light and very light exercise groups there was a time and clothing interaction effect. Values are mean ± SE and subject numbers are as described for figure 1.

3.7. *Sweat rate*

There was a small but significant increase in sweat rate for all groups while wearing S (0.52 ± 0.03 kg·m^{-2}·h^{-1}) compared with P (0.49 ± 0.03 kg·m^{-2}·h^{-1}).

3.8. *Ratings of perceived exertion and thermal comfort*

Wearing shorts had no impact on RPE during the exposure period and no impact on RTC during either the exposure or recovery. Values for both RPE and RTC differed among the groups after 20 min of exposure. However, during recovery the decrease in RTC from 10.8 ± 0.2 at time 0 to 8.4 ± 0.2 after 30 min was similar for all groups.

Table 2. Final exercise rectal temperature (T_{re}), exposure time and reasons for termination of the sessions for the heavy (H),moderate (M), light (L) and very light (VL) exercise groups while wearing either pants (P) or shorts (S) under the protective overpants. Values are mean ± SE.

	H		M		L		VL	
	P	S	P	S	P	S	P	S
Final exercise T_{re} (°C)	38.55 (0.20)	38.60 (0.20)	38.94 (0.05)	39.00 (0.00)	38.79 (0.15)	38.89 (0.11)	38.85 (0.10)	38.77 (0.11)
Exposure time (min)	40.8 (2.4)	43.5 (2.2)	53.5 (3.7)	54.2 (3.4)	65.8 (3.9)	73.3* (3.4)	83.5 (4.7)	97.0* (5.1)
Reasons for termination of trial	HR (4) T_{re} (2)	HR (4) T_{re} (2)	T_{re} (4) Exh (2)	T_{re} (6)	HR (1) T_{re} (4) Exh (1)	HR (1) T_{re} (4) Exh (1)	T_{re} (4) Exh (2)	T_{re} (3) Exh (3)

HR, heart rate; Exh, exhaustion. The numbers in parentheses defining the reasons for termination of the trial represent the number of subjects. *Significantly different from P.

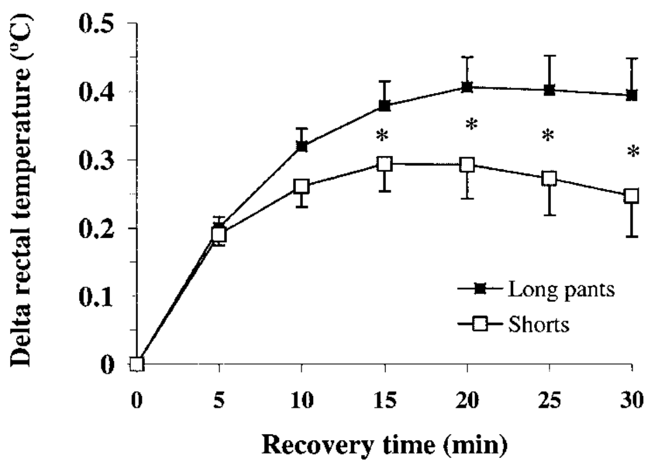

Figure 3. Delta rectal temperature responses for firefighters while wearing either pants or shorts under the bunker pants during 30 min of recovery following very light, light, moderate or heavy exercise at 35°C. The helmet, face shield and respirator, breathing apparatus, flash hood, gloves and jacket were removed during this recovery period. The asterisk indicates a significant difference when pants or shorts are worn. Values are mean ± SE for 24 subjects.

3.9. *Exposure time*

There was a significant clothing and group interaction for exposure time as shown in table 2. Whereas replacing P with S had no effect on exposure time for groups H and M, wearing S significantly prolonged exposure time for the groups performing lighter exercise. There was no indication that wearing S altered the reasons for termination of the session for any group. With the heaviest exercise more subjects terminated their session having attained a HR that reached or exceeded 95% of their peak value, whereas in the other exercise groups the

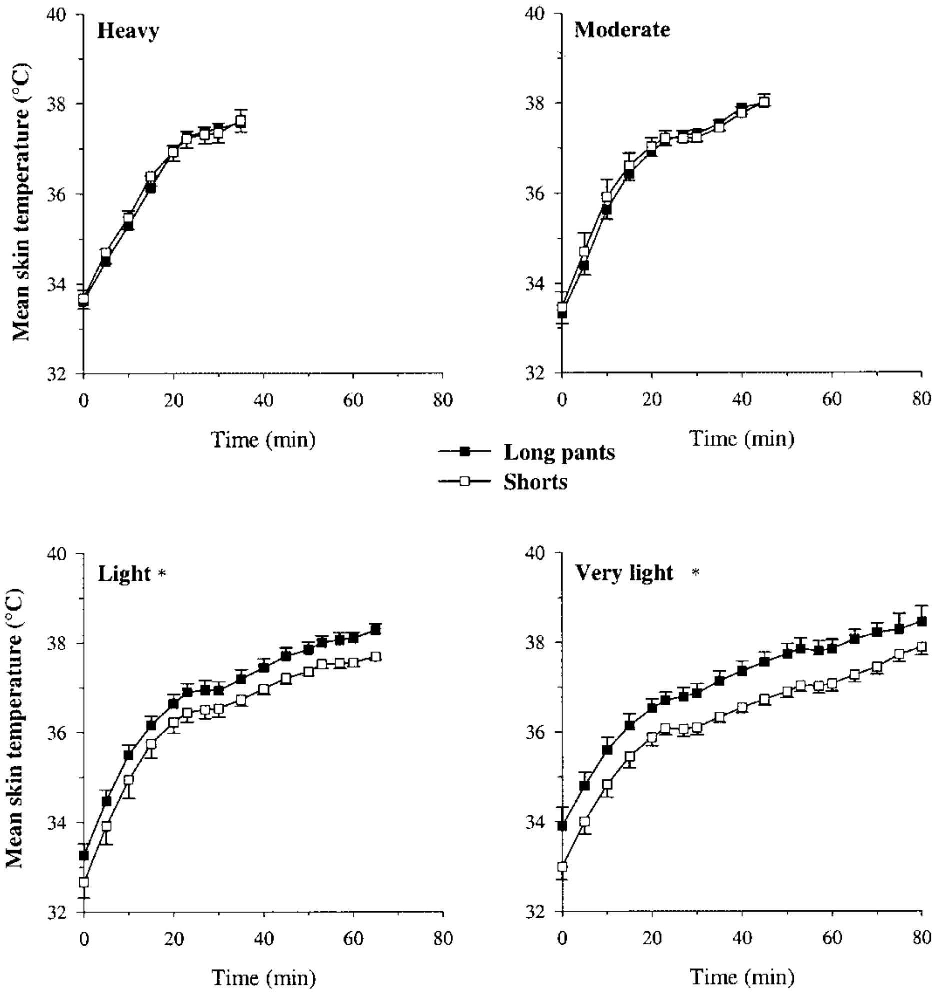

Figure 4. Mean skin temperature responses for firefighters while wearing either pants or shorts under the bunker pants during very light, light, moderate or heavy exercise at 35°C. The asterisk indicates a significant difference when pants or shorts are worn. For both the light and very light groups there was a significant main effect of clothing. Values are mean ± SE and subject numbers are as described for figure 1.

majority of subjects terminated their sessions due to exhaustion or because T_{re} reached 39.0°C. All subjects completed the 30 min of recovery in the 35°C environment.

4. Discussion

One option to reduce the heat stress of wearing firefighting protective clothing is the replacement of the long pants that are worn under the protective overpants with shorts. This option has been implemented by the New York City Fire Department and is being considered for implementation by the Toronto Fire Service. To the authors' knowledge the findings from the present study are the first to document the reductions in cardiovascular and thermal strain for firefighters while wearing shorts under their protective overpants during exercise in a warm environment.

Recent studies by Malley *et al.* (1999) and Prezant *et al.* (2000) have provided support for the decision to replace the duty uniform with shorts and a T-shirt for the New York City Fire Department. In the former study, Malley *et al.* (1999) had firefighters exercise on a treadmill at room temperature at workrates that led to exhaustion in 15–20 min. Although exercise time was significantly extended from 15–17 min when shorts were worn there was no effect on the core temperature increase over this short duration of activity. The findings from the present study would extend this null effect to include moderate and heavy workrates that lead to exhaustion in less than 60 min. Under this set of conditions where the E_{req} is high because of high rates of heat production, small changes in the E_{max} of the environment that result from changes in the thermal resistance of the clothing ensemble have a very small impact on the overall heat stress index or ratio of E_{req} to E_{max}. In addition, approximately 30 min is required before the microenvironment within the clothing layers is similar to the E_{max} defined for the environment (McLellan *et al.* 1996). Thus under conditions where exhaustion has occurred because of a cardiovascular limitation for oxygen delivery (Malley *et al.* 1999) it is likely that replacing P with S would have a negligible impact on the thermal strain associated with this type of exercise. In contrast, limits for work while performing light exercise and wearing protective clothing in hot environments are related more to the core temperature that can be tolerated (Selkirk and McLellan 2001). Thus as tolerance times are extended because of lower rates of heat production, there is a greater opportunity for changes in the thermal resistance of the clothing ensemble to impact on the heat loss to the environment. As a result, thermal strain is reduced and exposure times are extended as they were for groups L and VL in the present study. A differential impact of metabolic rate on exposure time has also been noted following physiological manipulations such as heat acclimation (Aoyagi *et al.* 1994, 1995), endurance training (Aoyagi *et al.* 1994, Cheung and McLellan 1998b) and hydration (Cheung and McLellan 1998a) while wearing biological and chemical protective clothing and exercising in the heat.

If the benefits for replacing P with S are only evident during activities that last beyond 60 min is this relevant for firefighters? Firefighting activities can demand a very high percentage of $\dot{V}O_{2max}$ (Gledhill and Jamnik 1992, Lemon *et al.* 1977) that can lead to exhaustion in less than 20 min. However, self-pacing and the implementation of work and rest schedules could easily extend the involvement of the firefighter well beyond 20 min. Commanders might also rotate personnel between heavier and lighter duties following exchange of air bottles every 20 min to maximize their availability. Further there are numerous situations where firefighters are required to wear their protective ensemble with or without their SCBA that does not involve fire suppression activity. In these situations such as emergency response, accident investigation and building clean-up and overhaul following fire suppression the intensity of the work effort may be equal to or lower than those involved with the demands of fire suppression. In all of these situations where exposure time while wearing the firefighting protective ensemble would be extended beyond 60 min, the current findings would suggest that the replacement of P with S would reduce the thermal and cardiovascular strain and extend exposure time approximately 10–15%. These are not huge improvements, but they are comparable to the relative improvements noted following heat acclimation (Aoyagi *et al.* 1995) or fluid replenishment (Cheung and McLellan 1998a) when protective clothing is worn while performing light exercise in a hot environment.

Of perhaps greater concern for those responsible for authorizing the replacement of P with S is whether the protection of the ensemble is in any way compromized such that the firefighter would be at greater risk to injury. The recent prospective analyses of New York City firefighters would suggest that the burn incidence and severity were not affected by replacing P with S (Prezant *et al.* 2000). Indeed, this prospective analysis also suggested that days lost for medical leave due to heat exhaustion were significantly reduced when S was worn (Prezant *et al.* 2000). Taken collectively, therefore, the findings from the present study and those from Malley *et al.* (1999) and Prezant *et al.* (2000) would support the recommendation to replace P with S.

It is interesting that the reductions in thermal and cardiovascular strain noted for groups L and VL in the present study were not paralleled by reductions in RTC and RPE during the exposure period. Recent studies have suggested that the use of these perceptual ratings might be an effective means to indicate the physiological strain (Baker *et al.* 2000, Tikuisis *et al.* 2002) during exercise and heat-stress. The present findings would suggest that perceptual ratings are not sensitive enough to discern the physiological changes that were observed for this group of firefighters. This is somewhat surprising given the magnitude of the HR and T_{re} reductions (see figures 1 and 2) for group VL. It is possible that the decision to record RPE and RTC only in conjunction with gas exchange measurements was insufficient, especially during the latter stages of the heat-stress exposure, and did not allow changes in perceptual ratings to be noted that would be consistent with the more frequent recordings of HR and T_{re}.

The participants in the present study were selected from a larger pool of volunteers to be representative for the age and fitness level of firefighters within the Toronto Fire Service. The sample varied in age from 33–45 years, 11–25% body fat and had $\dot{V}O_{2peak}$ values that varied from 42 to 62 $ml \cdot kg^{-1} \cdot min^{-1}$ indicating a variety of active and inactive lifestyle behaviour choices for the participants. Interestingly, the sample population was quite similar to those New York City firefighters who volunteered for the study by Malley *et al.* (1999) although participation of firefighters who were over the age of 45 was not allowed because of medical safety concerns. In addition, participants' responses were purposely assessed over a range of metabolic rates that would allow the issue of heat stress while wearing P or S to be addressed. The interest was not in assessing metabolic rates that would lead to exhaustion in less than 15 min since cardiovascular rather than thermal strain would be the main factor involved in the termination of the exercise. The authors were also not interested in performing arm exercise to simulate certain firefighting duties since the smaller muscle mass and local muscle fatigue would have again limited exposure times. Heat storage is a function of the absolute and not the relative rate of heat production (Sawka *et al.* 1984a,b). Thus, treadmill walking was selected to recruit a large muscle mass such that exposure times could be manipulated between 30 and 90 min in this warm environment of 35°C. It was felt that the conclusions are valid for any set of environmental conditions and rates of heat production that require firefighters to remain encapsulated in their protective ensemble for durations in excess of 60 min.

5. Conclusion

In conclusion, the present study has shown that replacing the duty uniform long pants that are worn under the protective overpants with shorts will reduce the cardiovascular and thermal strain during exercise that lasts in excess of 60 min. Together with the previous work conducted in support of the New York City Fire Department (Malley *et al*. 1999, Prezant *et al*. 2000) the authors would recommend the implementation of this practice for the Toronto Fire Service and other fire departments considering this option.

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