Heat stress of tactical assault, fragmentation and load-bearing vests worn over combat clothing

Tom M. McLellan

Natalie J. Sleno

Linda L. Bossi

Jan I. Pope

Jameel J. Adam

John J. Thompson

Christina Narlis

Defence R&D Canada – Toronto

Technical Report

DRDC Toronto TR 2003-033

June 2003

Author

Tom M. McLellan, Ph.D.

Approved by

Pang N. Shek, Ph.D.

Head, Operational Medicine Section

Approved for release by

K. M. Sutton

Chair, Document Review and Library Committee

Abstract

This study evaluated the heat stress associated with wearing webbing (WEB) or a new tactical assault vest (TV) worn alone or in combination with a fragmentation protection vest (FPV). In addition, the heat stress of wearing a new load-bearing vest (LBV) was assessed. Seven subjects (25.6 ± 4.2 years, 82.8 ± 10.2 kg) performed a familiarization trial and 5 randomly ordered experimental sessions that involved walking at 6 km/h on a treadmill at 40ºC and 30% relative humidity. This exercise continued for a maximum of 3 hours or until rectal temperature (T_{re}) reached 40.0°C, heart rate remained at or above 95% of HR_{peak} for 3 min, nausea or dizziness precluded further exercise, the subject asked to be removed from the chamber, or the investigator removed the subject from the chamber. Wearing the fragmentation vest increased the cardiovascular and thermal strain and significantly reduced exercise time approximately 30 min from 111.9 ± 33.4 and 111.1 ± 38.9 min for the TV and WEB configurations, respectively, worn without the FPV to 84.9 ± 14.4 and 81.3 ± 18.5 min for the same respective configurations worn with the FPV. There was little difference in heat stress among the WEB, TV or LBV (122.0 ± 38.1 min) configurations worn without the FPV. However, if fragmentation protection must also be provided then the additional heat stress of wearing the FPV would significantly impair work performance when either the WEB or TV was used.

Résumé

L'étude en question a évalué le stress thermique lié au port d'un harnais ou d'un nouveau gilet tactique d'assaut, seul ou en combinaison avec un gilet pare-éclats, ainsi que le stress thermique lié au port d'un nouveau gilet à matériel. Sept sujets (25,6 ± 4,2 ans, 82,8 ± 10,2 kg) ont été soumis à un essai de familiarisation et, dans un ordre aléatoire, à cinq expériences comprenant une marche à 6 km/h sur un tapis roulant à une température de 40 ºC et à une humidité relative de 30 %. Cet exercice a duré un maximum de trois heures ou jusqu'à ce que la température rectale (T_{re}) atteigne 40 ºC, que la fréquence cardiaque demeure à 95 % ou plus de la fréquence cardiaque maximale pendant 3 minutes, que la nausée ou des étourdissements empêchent la poursuite de l'exercice, que le sujet demande à sortir de la chambre ou que le chercheur fasse sortir le sujet de la chambre. Le port du gilet pare-éclats a fait grimper le stress cardiovasculaire et le stress thermique et a considérablement réduit le temps d'exercice, soit d'environ 30 minutes, le faisant passer de 111,9 ± 33,4 et de 111,1 ± 38,9 minutes pour le gilet tactique et le harnais respectivement, portés sans le gilet pare-éclats, à 84,9 ± 14,4 et à 81,3 ± 18,5 minutes pour les mêmes articles portés avec le gilet pare-éclats. La différence de stress thermique est minime entre le port du harnais, du gilet tactique et du gilet à matériel (122,0 ± 38,1 min) sans le gilet pare-éclats. Cependant, le port du gilet pare-éclats augmente le stress thermique et nuit considérablement à l'efficacité fonctionnelle lorsque le harnais ou le gilet tactique est utilisé.

This page intentionally left blank.

Executive summary

In a military environment, body armour and other types of load bearing outerwear are commonly used when carrying out a task, and are necessary under certain threat and environmental conditions. They provide protection against the physical and/or threat environment, but at a cost. These extra layers impede an individual's ability to maintain a comfortable body temperature by increasing the thermal resistance to heat transfer and by reducing the evaporation of sweat. At the request of the Directorate of Land Requirements, this study evaluated the heat stress associated with wearing in-service webbing (WEB) or the new Clothe the Soldier tactical assault vest (TV) worn alone or in combination with a fragmentation protection vest (FPV). In addition, the heat stress of wearing an interim load-bearing vest (LBV) was assessed. Seven subjects performed a familiarization trial and 5 randomly ordered experimental sessions that involved walking at a speed equivalent to a forced march on a treadmill at 40ºC and 30% relative humidity. Wearing the fragmentation vest increased the cardiovascular and thermal strain and significantly reduced exercise time by approximately 30 min, or 30%, from 110 to 80 minutes regardless of whether the TV or WEB was worn. The 30-minute reduction in exercise time translated into a 3 km shortfall in the distance covered during the forced march. The LBV did not increase the thermal or cardiovascular strain compared with the WEB and TV configurations worn without the FPV. It was concluded that there was little difference in heat stress among the WEB, TV or LBV configurations. However, if fragmentation protection must also be provided, then the additional heat stress of wearing the FPV would significantly impair work performance when either the WEB or TV was used.

McLellan T.M., Sleno N.J., Bossi L.L., Pope J.I., Adam J.J., Thompson J.J., Narlis C. 2003. Heat stress of tactical assault, fragmentation and load-bearing vests worn over combat clothing. DRDC Toronto TR 2003-033. Defence R&D Canada – Toronto.

Sommaire

Dans un environnement militaire, un gilet de protection balistique et d'autres types de vêtements de dessus à matériel sont couramment utilisés pour effectuer les tâches et sont nécessaires face à certaines menaces et dans des conditions environnementales particulières. Dans ces situations, ils offrent une protection, mais non sans prix. Ces couches supplémentaires font obstacle à la capacité d'une personne de maintenir une température corporelle confortable en augmentant la résistance au transfert de chaleur et en diminuant l'évaporation de la sueur. À la demande de la Direction des besoins en ressources terrestres, cette étude a évalué le stress thermique lié au port du harnais actuel ou du nouveau gilet tactique d'assaut du projet Habillez le soldat, seul ou en combinaison avec un gilet pare-éclats, ainsi que le stress thermique lié au port d'un gilet à matériel provisoire. Sept sujets ont été soumis à un essai de familiarisation et, dans un ordre aléatoire, à cinq expériences comprenant une marche à une vitesse de marche forcée sur un tapis roulant à une température de 40 ºC et à une humidité relative de 30 %. Le port du gilet pare-éclats a fait grimper le stress cardiovasculaire et le stress thermique et a considérablement réduit le temps d'exercice, soit d'environ 30 minutes ou de 30 %, le faisant passer de 110 à 80 minutes pour le gilet tactique et le harnais. La réduction de 30 minutes dans le temps d'exercice s'est traduite par une distance de marche forcée raccourcie de 3 km. Comparativement au harnais et au gilet tactique portés sans le gilet pare-éclats, le gilet à matériel n'a pas augmenté le stress thermique ni le stress cardiovasculaire. Il en a été conclu que la différence de stress thermique est minime entre le port du harnais, du gilet tactique et du gilet à matériel. Cependant, le port du gilet pare-éclats augmente le stress thermique et nuit considérablement à l'efficacité fonctionnelle lorsque le harnais ou le gilet tactique est utilisé.

McLellan T.M., Sleno N.J., Bossi L.L., Pope J.I., Adam J.J., Thompson J.J., Narlis C. 2003. Heat stress of tactical assault, fragmentation and load-bearing vests worn over combat clothing. DRDC Toronto TR 2003-033. Defence R&D Canada – Toronto.

Table of contents

List of figures

Acknowledgements

The time and effort of the subjects in this investigation are greatly appreciated. Also, we thank Mr. G.A. Selkirk for his assistance in overseeing the data collection. The authors would also like to express their gratitude to Ms Rayisa Honstcharuk for her technical assistance throughout the study.

This page intentionally left blank.

1. Introduction

In a military environment, body armour and other types of load bearing outerwear are commonly used when carrying out a task, and are necessary under certain threat and environmental conditions. They provide protection against the physical and/or threat environment, but at a cost. These extra layers impede an individual's ability to maintain a comfortable body temperature by increasing the thermal resistance to heat transfer and by reducing the evaporation of sweat. In addition the added weight of the body armour or load bearing outerwear increases the heat production during weight-bearing activity. The heat stress of wearing body armour in hot environments has been described previously (1, 2, 3). Not surprisingly, core and skin temperatures and heart rates were increased to higher levels while wearing body armour and the impact of the body armour on thermal and cardiovascular strain was greatest in hot-wet environments (1).

Presently, the Directorate of Land Requirements (DLR) has asked DRDC Toronto to characterize the thermal stress induced by several items of outerwear. These include the fragmentation protective vest (FPV), an interim load bearing vest (LBV) and the new Clothe the Soldier tactical vest (TV), the latter two in comparison with in-service webbing (WEB). The FPV is currently only worn by Canadian Forces (CF) personnel on deployments, where the ballistic threat is real. DLR wishes to make the FPV part of every operation and training exercise, but the additional physiological strain associated with wearing such a garment across all mission environments is not clear. In a second but related project, the TV was recently developed as part of the fighting order for the new Clothe the Soldier load carriage system for the CF (4). The TV was developed because the in-service webbing was not considered to be compatible with either rucksacks or the FPV. However, there is concern that the move from webbing to the TV, which covers more of the torso, could lead to an increase in thermal load over the in-service option, especially if worn independent of the FPV. During the user trial phase of the TV development, subjects noted that the new design was much warmer to wear than the currently issued web gear. Thermal comfort was rated as a fairly important design acceptance criterion and 71% of subjects reported discomfort particularly in the middle back area when wearing the TV (4). An alternate and interim design for this type of equipment is the LBV. Currently, the LBV is being worn only by those deployed in Afghanistan and Bosnia because the TV has not yet been brought into service. The thermal stress of the LBV has not been characterized and has not been compared to the TV alone.

Thus it was the purpose of the present study to quantify the heat stress associated with wearing the TV, FPV and the LBV. Specific comparisons were made between the current in-service WEB and the TV when they were worn alone or with the FPV. In addition, the LBV was also compared to the WEB and TV configurations when they were worn alone. It was hypothesized that the current webbing would impose the least amount of thermal burden when the FPV was not worn because it provided the least amount of coverage on the torso. Similarly, it was hypothesized that the LBV would impose the greatest additional heat stress when the FPV was not worn because the torso was completely covered when it was worn. Finally, it was hypothesized that wearing the FPV would increase the thermal stress associated with wearing the WEB or TV alone.

2. Methods

2.1 Subjects

Following approval from the institute's Human Research Ethics Committee, seven non heat-acclimatized males volunteered to participate in the study. Mean values (± S.D.) for age, weight, height, Dubois body surface area, body fatness and $\dot{V}O_{2peak}$ were 25.6 ± 4.2 y, 82.8 ± 10.2 kg, 1.79 ± 0.08 m, 1.90 ± 0.29 m^2, 15.4 ± 3.9 % and 4.15 ± 0.64 $l \cdot min^{-1}$ or 50.2 ± 6.0 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively. They 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 subject gave informed consent prior to the first day of data collection.

2.2 Determination of peak aerobic power ($\dot{V}O_{2peak}$)

$\dot{V}O_{2peak}$ was determined on a motor-driven treadmill using open-circuit spirometry (5) before the series of experiments in the climatic chamber. Following two minutes of running at a self-selected pace, the treadmill grade was increased $1\% \cdot min^{-1}$ until subjects were running at a 10% grade. If necessary increases in treadmill speed of 0.22 $m \cdot s^{-1}$ and grade of 1% were alternated each minute until the subject could no longer continue. $\dot{V}O_{2peak}$ was defined as the highest oxygen consumption ($\dot{V}O_2$) observed during the incremental test. Heart rate (HR) was monitored throughout the incremental test from a telemetry unit (Polar Electro PE3000, Stamford, CT). The heart rate value recorded at the end of the exercise test was defined as the individual's peak value (HR_{peak}).

2.3 Experimental Design

All subjects performed five experimental sessions in random order separated by a minimum of 4 days with the majority of trials being performed on a weekly basis for a given subject. Sessions were performed early in the morning beginning around 0800 hours for all subjects during May through July. The following items were worn during each trial; underwear, T-shirt, shorts, socks, lightweight cotton combat jacket and pants, jogging shoes and helmet. In addition, as shown in Figures 1-5, subjects wore either WEB or the TV alone or in combination with the FPV or the LBV alone over the combat shirt. Subjects also carried approximately 9 kg consisting of lead weight and 2 filled canteens to simulate the additional weight of ammunition, water and other essential items carried in the WEB or TV. This added weight was constant across all trials and is shown in the front and rear views depicted in Figures 1 through 5. Ceramic plates were not inserted in the FPV or LBV since these vests are worn presently without the plates for the majority of time during field operations.

All sessions involved exposure to 40ºC and 30% relative humidity with no wind while walking at 5.9 $km \cdot h^{-1}$ on a treadmill with a 2% elevation. This exercise continued for a maximum of 3 hours or until rectal temperature (T_{re}) reached 40.0°C, heart rate remained at or above 95% of HR_{peak} for 3 min, nausea or dizziness precluded further exercise, the subject asked to be removed from the chamber, or the investigator removed the subject from the chamber. Subjects consumed 5 $ml \cdot kg^{-1}$ of cool water immediately prior to beginning the exercise session and every 30 minutes during the heat stress exposure. Subjects also performed a familiarization session approximately 1 week prior to beginning the experimental sessions that involved the same exercise procedures in the heat while wearing the combat clothing and the helmet.

Figure 1. Front and Rear View of the Webbing Worn over the Combat Clothing

2.4 Dressing and Weighing Procedures

Subject preparation, including the measurement of pre-exposure nude and dressed weights, insertion of the rectal thermistor and placement of skin thermistors have been detailed previously (5, 6). Upon entering the chamber, the subject's thermistors and rectal thermistor monitoring cables were connected to a computerized data acquisition system (Hewlett-Packard 3497A control unit, 236-9000 computer and 2934A printer) and the exercise 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 ($\bar{T}_{sk}$) (7) was subsequently calculated. HR was recorded every 5 min from the display on the telemetry receiver (Polar® CE0537). After the completion of each trial, dressed weight was recorded within 1 min after exit from the chamber and nude weight was recorded following a subsequent short undressing procedure.

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 exercise time that was defined as the difference in time between removal from and entry into the environmental chamber. Evaporative sweat loss was calculated from the differences in pre- and post-trial corrected dressed weights. Although the dripping of sweat from the clothing, face and hands was minimal, our calculation of evaporative sweat loss does not account for any of this lost sweat.

Figure 2. Front and Rear View of the Tactical Vest Worn over the Combat Clothing

2.5 Gas Exchange Analyses

During each session, open-circuit spirometry was used to determine expired minute ventilation and oxygen consumption ($\dot{V}O_2$) using a 2-min average obtained every 15 min. Respiratory water loss was calculated using the $\dot{V}O_2$ measured during the trial and the equation presented by Mitchell et al. (8). Metabolic weight loss was calculated from $\dot{V}O_2$ and the respiratory exchange ratio using the equation described by Snellen (9).

2.6 Ratings of Perceived Exertion and Thermal Comfort

Following the gas exchange measurement, subjects were asked to provide a rating of perceived exertion (RPE) between 6 and 20 for the whole body (10) 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 (11).

Figure 3. *Front and Rear View of the Load-Bearing Vest Worn over the Combat Clothing*

Figure 4. *Front and Rear View of the Webbing Worn over the Fragmentation Protective Vest and the Combat Clothing*

Figure 5. *Front and Rear View of the Tactical Vest Worn over the Fragmentation Protective Vest and the Combat Clothing*

2.7 Statistical Analyses

Data are presented as mean values and standard deviations. A one factor (vest configuration) repeated measures ANOVA was used to evaluate differences in the dependant measures such as exercise time and sweat rate whereas a two factor (vest configuration and time) ANOVA was used to compare the responses for dependant measures such as T_{re}, HR, $\overline{T}_{sk}$, $\dot{V}O_2$, RPE and RTC recorded over time. The Huynh-Feldt correction factor was applied to adjust for any violations in the assumption of sphericity with the repeated factor of time. Two separate sets of comparisons were made among the exercise sessions. Comparisons were made initially among the sessions that involved wearing the WEB, TV or LBV since these configurations would be used to carry ammunition and supplies. To demonstrate the added heat stress of wearing the FPV, comparisons were then made between the webbing and TV alone or in combination with the FPV. 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 Webbing, Tactical Assault Vest and Load-Bearing Vest

3.1.1 Heart Rate

Figure 6 shows that the HR response throughout the heat-stress trial was similar for the WEB, TV and LBV sessions. HR at the end of the heat stress also was similar for the WEB ($165 \pm 13\ \text{b} \cdot \text{min}^{-1}$), TV ($164 \pm 12\ \text{b} \cdot \text{min}^{-1}$) and LBV ($168 \pm 15\ \text{b} \cdot \text{min}^{-1}$) sessions.

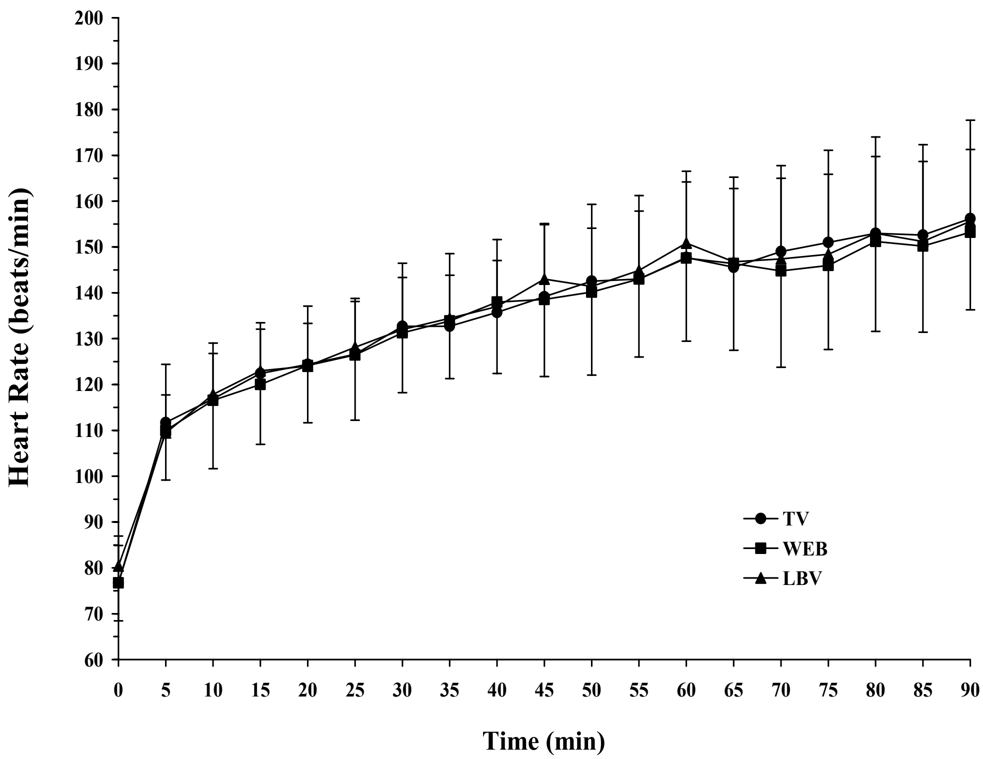

Figure 6. *Heart rate response during the heat stress while wearing the tactical vest (TV), webbing (WEB) or load-bearing vest (LBV) over the combats. Values are mean ± SD for n = 7 to 60 min and n = 5 from 65 to 90 min.*

3.1.2 Rectal Temperature

There was no difference in the T_{re} response throughout the heat stress between the WEB and TV configurations (Figure 7). However, T_{re} was significantly reduced during the LBV session after 50 min of heat stress compared with the other two configurations. Final T_{re} reached at the end of the heat-stress exposure was not different among the sessions (39.2 ± 0.6ºC, 39.2 ± 0.5ºC and 39.1 ± 0.5ºC for the WEB, TV and LBV sessions, respectively).

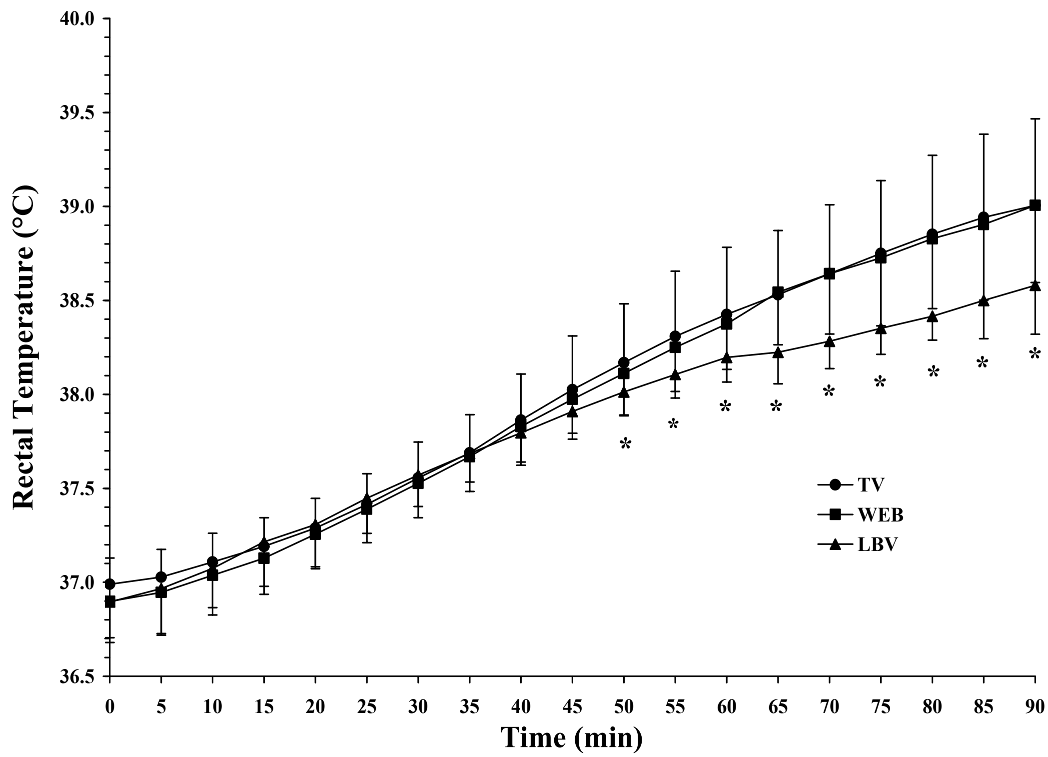

Figure 7. *Rectal temperature response during the heat stress while wearing the tactical vest (TV), webbing (WEB) or load-bearing vest (LBV) over the combats. Values are mean ± SD for n = 7 to 60 min and n = 5 from 65 to 90 min. The asterisk indicates a significant difference between the LBV session and the other two sessions.*

3.1.3 Skin Temperature

Figure 8 presents the response for $\overline{T}_{sk}$. There were no statistical differences among the clothing configurations in $\overline{T}_{sk}$ although mean values appeared lower for the LBV configuration towards the end of the heat stress.

3.1.4 Oxygen Consumption

$\dot{V}O_2$ was not different for the three configurations after 15 min of heat stress ($1.70 \pm 0.25\ L \cdot min^{-1}$, $1.75 \pm 0.32\ L \cdot min^{-1}$ and $1.66 \pm 0.16\ L \cdot min^{-1}$ for the WEB, TV and LBV sessions, respectively). There was a main effect of time indicating that values increased throughout the heat stress exposure but this increase was similar for all three of the clothing configurations.

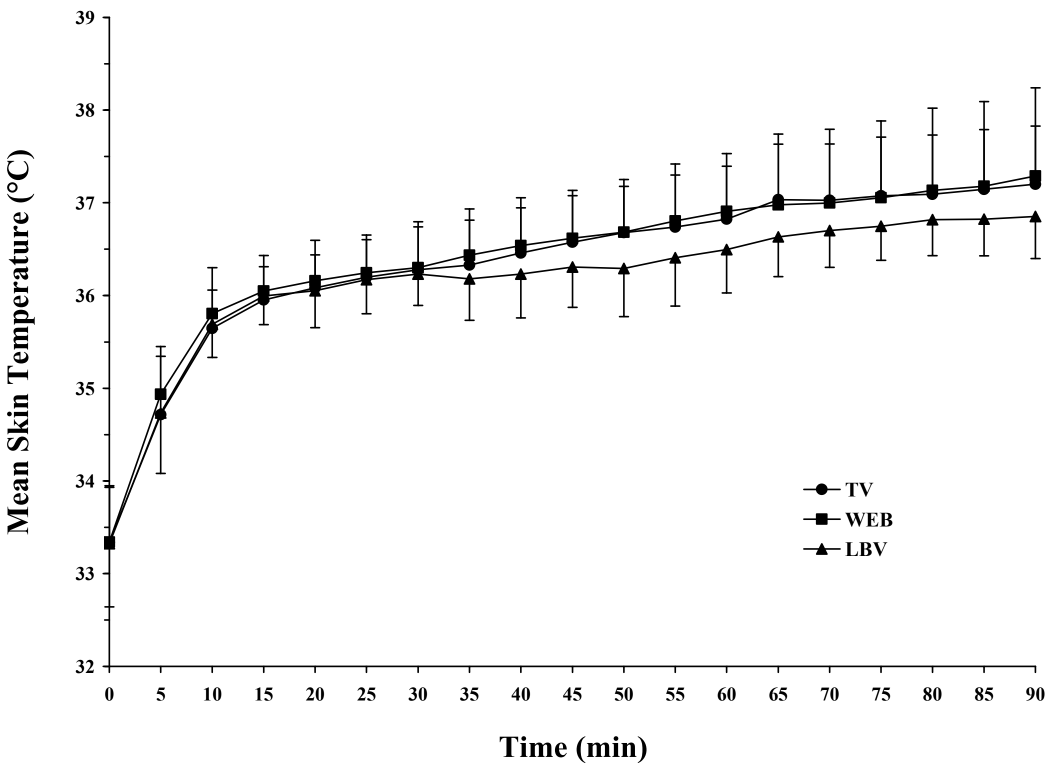

Figure 8. *Mean skin temperature response during the heat stress while wearing the tactical vest (TV), webbing (WEB) or load-bearing vest (LBV) over the combats. Values are mean ± SD for n = 7 to 60 min and n = 5 from 65 to 90 min.*

3.1.5 Sweat Production and Evaporation Rate

Sweat rates were similar for the WEB ($1.32 \pm 0.25\ kg \cdot h^{-1}$), TV ($1.28 \pm 0.25\ kg \cdot h^{-1}$) and LBV ($1.33 \pm 0.27\ kg \cdot h^{-1}$) sessions. Similarly, evaporation rates were not significantly different for the three configurations being 0.88 ± 0.16, 0.80 ± 0.16 and $0.83 \pm 0.14\ kg \cdot h^{-1}$ for the WEB, TV and LBV sessions, respectively. Dressed weights prior to entry into the climatic chamber were also not different among the clothing configurations indicating that subjects carried the same total mass while walking on the treadmill.

3.1.6 Ratings of Perceived Exertion and Thermal Comfort

RPE was not different throughout the heat stress for the three configurations but did increase from 10.8 ± 1.5 after 15 minutes of exercise in the heat to 13.2 ± 1.8 after 60 minutes. RTC also was not different among the configurations but increased significantly from 7.9 ± 0.8 at 15 min to 9.5 ± 1.4 after 60 minutes of exercise and heat stress.

3.1.7 Exercise Time and Reasons for Termination

Although mean exercise times were the longest during the LBV session the value of 122.0 ± 38.2 min was not significantly different than the values of 111.1 ± 38.9 or 111.9 ± 33.4 min for the WEB and TV sessions, respectively. Five of the seven subjects ended all of their sessions due to exhaustion and stating that they were unable to continue. One subject reached the three-hour limit for all sessions and the other subject reached the T_{re} or HR ceiling during all of the heat stress exposures.

3.2 Webbing, Tactical Vest and Fragmentation Protective Vest

3.2.1 Heart Rate

The HR response throughout the heat-stress exposure for the WEB and TV configurations worn with or without the FPV is shown in Figure 9. Wearing the FPV under the WEB or TV significantly increased the HR approximately 10 $b \cdot min^{-1}$ following 60 minutes of heat-stress but this increase was not influenced by the choice of WEB or TV. Final HR also was not different for those trials that involved wearing the FPV (168 ± 15 $b \cdot min^{-1}$) or not wearing the FPV (165 ± 12 $b \cdot min^{-1}$).

3.2.2 Rectal Temperature

The T_{re} response was not significantly increased with the donning of the FPV in combination with either the TV or WEB ($p < 0.1$, Figure 10) despite the fact that values were higher by about 0.2ºC after 60 min of exposure. Final T_{re} at the end of the heat-stress also was not different ($p < 0.08$) between those sessions that either did (39.0 ± 0.1ºC) or did not (39.2 ± 0.2ºC) involve wearing the FPV.

3.2.3 Skin Temperature

Figure 11 shows that the $\overline{T}_{sk}$ response was significantly higher when the FPV was worn following 30 minutes of heat stress regardless of whether it was worn in combination with the WEB or TV.

3.2.4 Oxygen Consumption

Despite the additional 3 kg mass of the FPV, $\dot{V}O_2$ after 15 min of exercise during the heat stress was not different among these four configurations (1.75 ± 0.15 $L \cdot min^{-1}$ and 1.73 ± 0.13 $L \cdot min^{-1}$ for the FPV + WEB and FPV + TV configurations, respectively) compared with the WEB (1.70 ± 0.25 $L \cdot min^{-1}$) and TV (1.75 ± 0.32 $L \cdot min^{-1}$) sessions that did not involve wearing the FPV. There was a main effect of time indicating that values increased throughout the heat stress exposure but this increase was similar for all four of the clothing configurations.

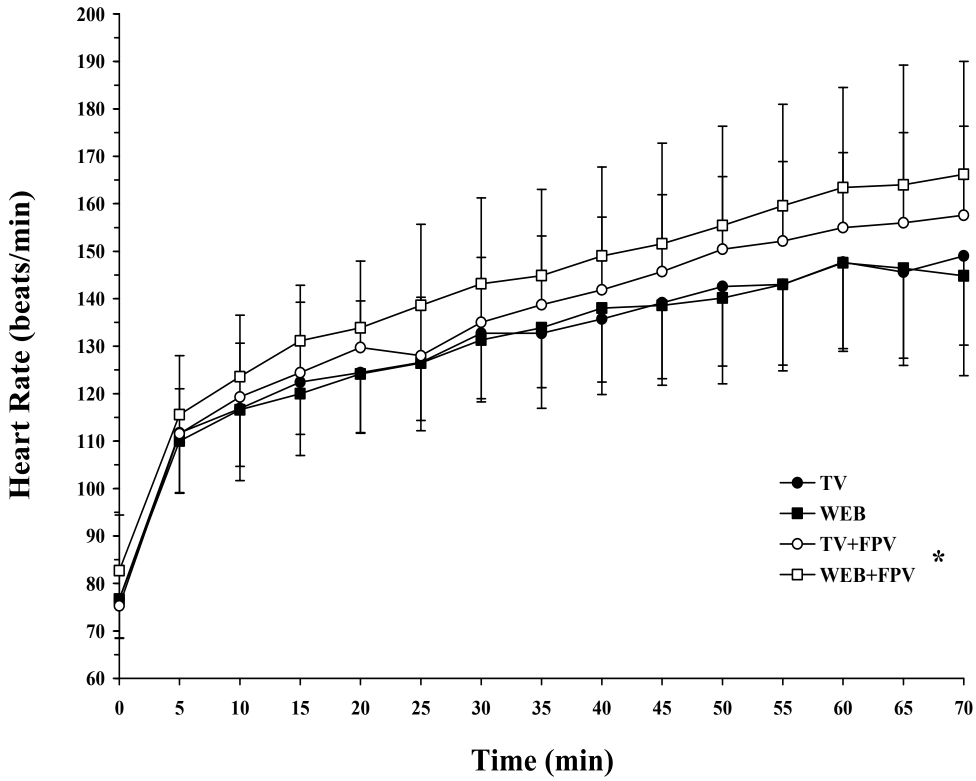

Figure 9. *Heart rate response during the heat stress while wearing the tactical vest (TV) or webbing (WEB) alone or in combination with the fragmentation protection vest (FPV) over the combats. Values are mean ± SD for n = 7 to 60 min and n = 5 from 65 to 70 min. The asterisk indicates that the FPV significantly increased the heart rate response throughout the trial regardless of whether the WEB or TV was worn.*

3.2.5 Sweat Production and Evaporation Rate

Dressed weights were increased approximately 3 kg during the FPV sessions reflecting the additional mass of this vest. Sweat production was significantly increased while wearing the FPV (1.45 ± 0.33 $kg \cdot h^{-1}$) compared with those sessions that did not include the use of this vest (1.30 ± 0.24 $kg \cdot h^{-1}$). Evaporation rates although similar among the four configurations at 0.82 ± 0.16 $kg \cdot h^{-1}$ reflected a lower percentage of the higher sweat production during the FPV sessions (56.4 ± 3.9% vs 64.9 ± 8.9% for the FPV and non-FPV sessions, respectively).

3.2.6 Ratings of Perceived Exertion and Thermal Comfort

After 15 minutes of exercise and heat stress there was no difference in RPE between those trials that involved wearing the FPV (10.8 ± 1.5) and those that did not (10.9 ± 1.5). RPE increased over time for all trials but the increase was significantly greater for those sessions that involved wearing the FPV. For example, following 60 minutes of exercise RPE had significantly increased to 13.4 ± 1.8 during those sessions that did not involved wearing the vest but during the FPV sessions RPE had increased to 14.5 ± 2.0. RTC also increased over time for all sessions but again the increase was significantly greater during the FPV exposures. Without wearing the vest RTC increased from 7.9 ± 0.9 after 15 minute of heat stress to 9.5 ± 1.5 after 60 minutes. In contrast, for the FPV sessions RTC increased from 8.1 ± 0.8 after 15 minutes to 10.2 ± 1.3 after 60 minutes of heat-stress and exercise.

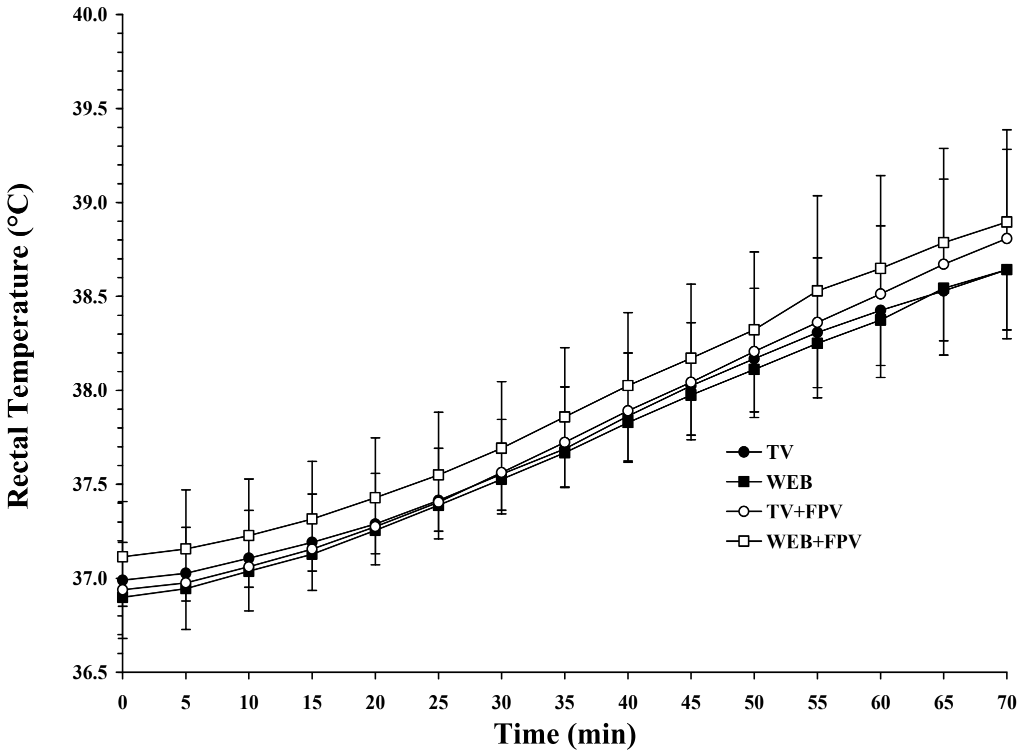

Figure 10. *Rectal temperature response during the heat stress while wearing the tactical vest (TV) or webbing (WEB) alone or in combination with the fragmentation protection vest (FPV) over the combats. Values are mean ± SD for n = 7 to 60 min and n = 5 from 65 to 70 min.*

3.2.7 Exercise Time and Reasons for Termination

Wearing the FPV significantly reduced exercise time by approximately 30 min from 111.9 ± 33.4 and 111.1 ± 38.9 min for the TV and WEB configurations, respectively, worn without the FPV to 84.9 ± 14.4 and 81.3 ± 18.5 min for the same respective configurations worn with the FPV. Four of the seven subjects ended all of their sessions due to exhaustion and stating that they were unable to continue. One subject who reached the three-hour time limit when the FPV was not worn ended his trials while wearing the FPV because of exhaustion. Another subject who ended the sessions without the FPV due to reaching the T_{re} ceiling of 40.0ºC ended the sessions with the

FPV because of the additional cardiovascular strain that elevated his HR to greater than 95% of their maximum value. The last subject ended three of these four sessions because of exhaustion and one session with the FPV because of HR exceeding 95% of maximum.

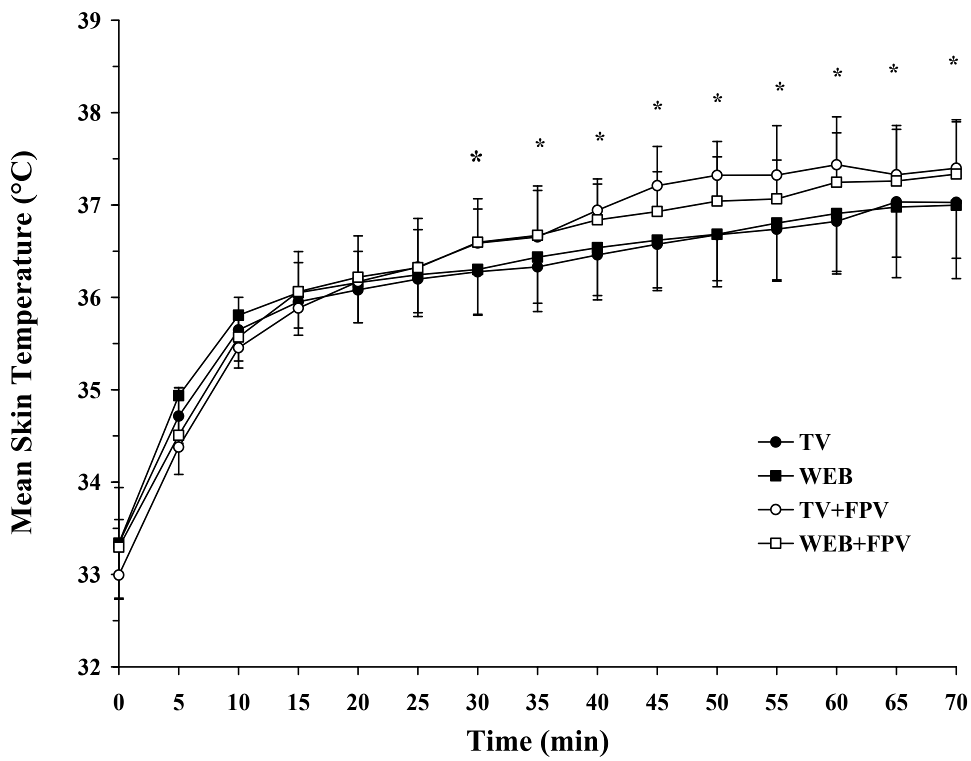

Figure 11. *Mean skin temperature response during the heat stress while wearing the tactical vest (TV) or webbing (WEB) alone or in combination with the fragmentation protection vest (FPV) over the combats. Values are mean ± SD for n = 7 to 60 min and n = 5 from 65 to 70 min. The asterisk indicates a significant difference while wearing the FPV regardless of whether the WEB or TV was worn.*

4. Discussion

The purposes of this study were to characterise the heat stress associated with wearing different vest configurations either currently in-service or being considered for use by our forces. Thus, two separate sets of comparisons were extracted from the heat-stress sessions that were completed. For example, the TV was designed as part of Clothe the Soldier to replace the current WEB because the latter configuration is considered not to be compatible with the current rucksacks and FPV. However, because the TV covers more of the torso than the WEB there was concern that the heat stress would be greater with this new vest. In addition, the LBV is currently being used in operational commitments overseas and the vest is designed in the interim to replace both the WEB and provide FPV compatability. Thus, the first set of comparisons from the current data set involved the WEB, TV and LBV. The second set of comparisons was extracted solely to demonstrate the added heat stress burden associated with wearing the FPV and to note whether this added burden was any different when the FPV was worn in combination with either the WEB or TV. As a result the heat stress of wearing the WEB or TV alone or in combination with the FPV were compared.

From the first set of comparisons a reduced heat strain was observed as indicated by the significant reduction in T_{re} for the LBV configuration. These findings were unexpected since this vest configuration provided an additional complete layer of coverage over the torso (see Figure 3) whereas the coverage of the torso by the WEB and TV was not as extensive (compare figures 1 and 2). Thus we are left to try to explain these discrepant findings. All three vests weighed approximately the same and the subjects' dressed weight was not different prior to entry into the chamber indicating that the total carried mass was similar for the three sessions. As a result, the rate of heat production, as indicated by $\dot{V}O_2$, was not different. Thus the lower T_{re} response for the LBV session had to reflect greater heat loss despite greater coverage of the torso with the vest. The fact that sweat rates were similar to the WEB and TV sessions despite the lower T_{re} response suggests that subjects were showing signs of greater heat acclimation during the LBV session (12-14, 15). Additional signs of heat acclimation were the lower initial T_{re} values at the start of the LBV exposure (16, 17). Although testing order was randomised, several of the subjects performed the LBV session after the WEB and TV sessions. In addition, Toronto had an exceptionally warm summer and subjects that performed some of their sessions in July would have been more heat acclimatized than for those sessions performed in June or early July. This issue is demonstrated in the figures below that show the T_{re} responses for the three sessions for 2 subjects who performed the LBV exposure either before (Figure 12) or after the WEB and TV sessions (Figure 13). It is apparent that the T_{re} response for the LBV configuration is dependant on the order of testing. In fact, when the order of testing was analysed for these three sessions, the T_{re} response was significantly reduced during the third exposure regardless of the vest configuration (Figure 14). One approach to partially counter this confounding effect of heat acclimation is to adjust any change in the initial T_{re} value over successive heat-stress exposure to the value observed during each subject's first session. However, despite this adjustment the T_{re} response during the LBV session was still significantly lower during the later stages of the heat stress exposure compared with the WEB and TV sessions (Figure 15). Thus the confounding effect of heat acclimation was still evident during the LBV session reflecting the altered relationship between sweat rate and core temperature.

Nevertheless, we feel confident to state that there would be no difference in the heat strain among the three vest configurations if subjects were either not heat acclimated or completely heat acclimated for all test sessions. Typically heat stress experimentation is conducted from September through May but because of other commitments by technical support staff, testing could not be scheduled during these months. Additional delays would have meant that the testing would not have been completed during the current fiscal year and the testing had already been delayed one year because of personnel short falls in the past.

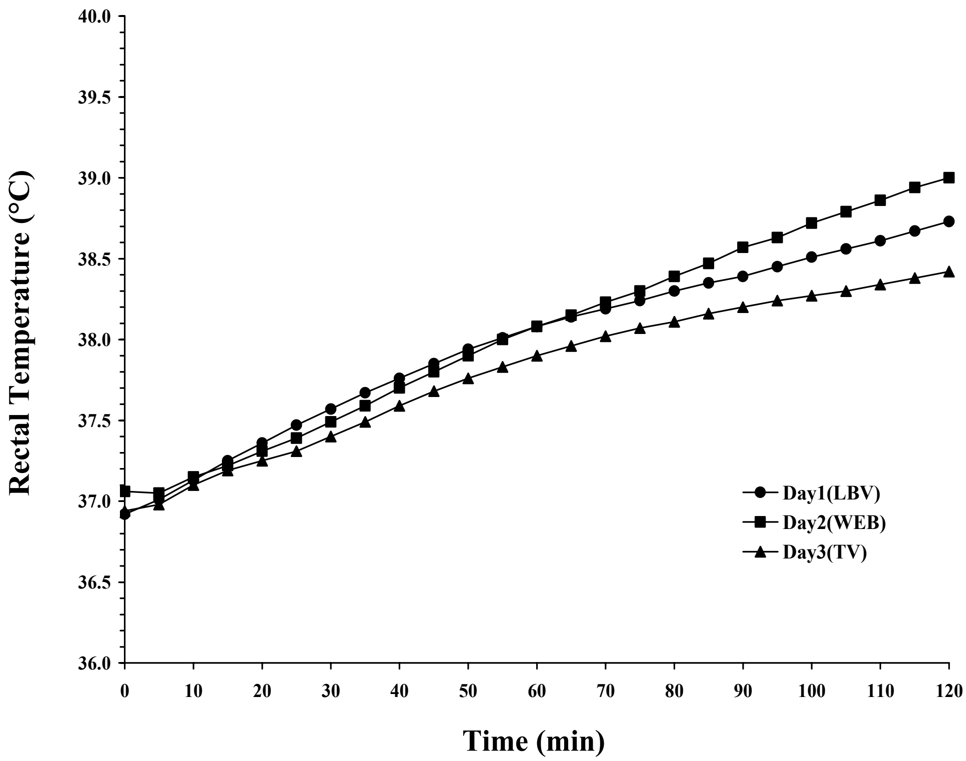

Figure 12. *Rectal temperature response during the heat stress for one subject who perfomed the load-bearing vest (LBV) session first followed by the webbing (WEB) and then the tactical vest (TV) session.*

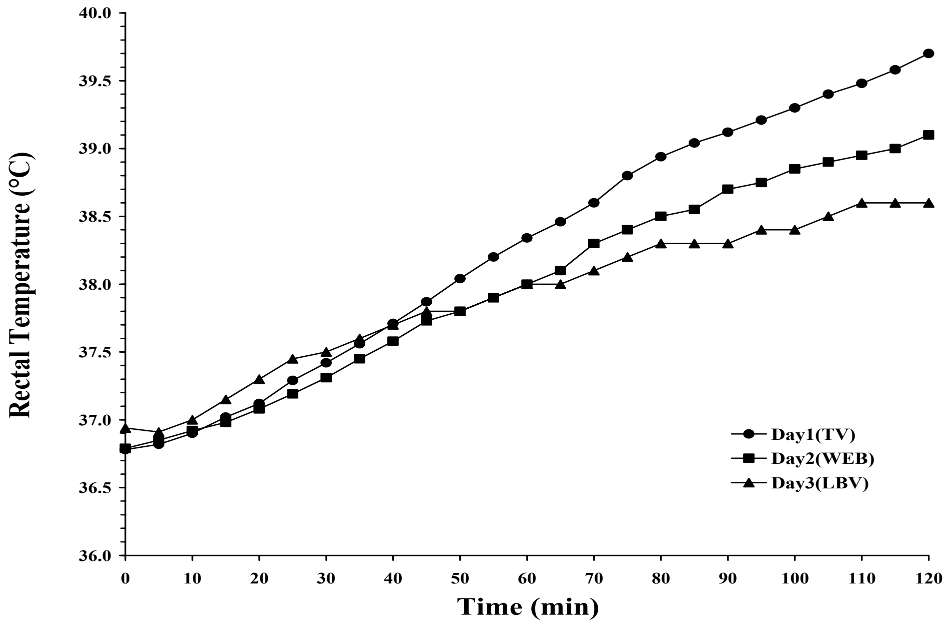

Figure 13. *Rectal temperature response during the heat stress for one subject who performed the load-bearing vest (LBV) session last after the tactical vest (TV)and webbing (WEB) sessions.*

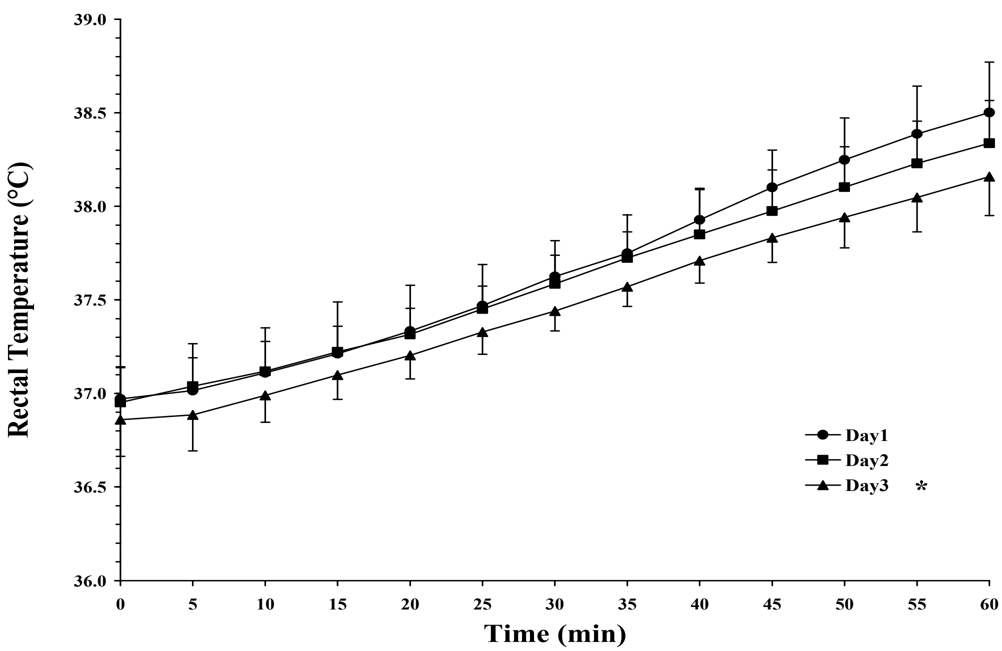

Figure 14. *Rectal temperature response during the heat showing the order effect of the sessions performed over three sessions. The asterisk indicates a significant difference for day 3 compared with the other days.*

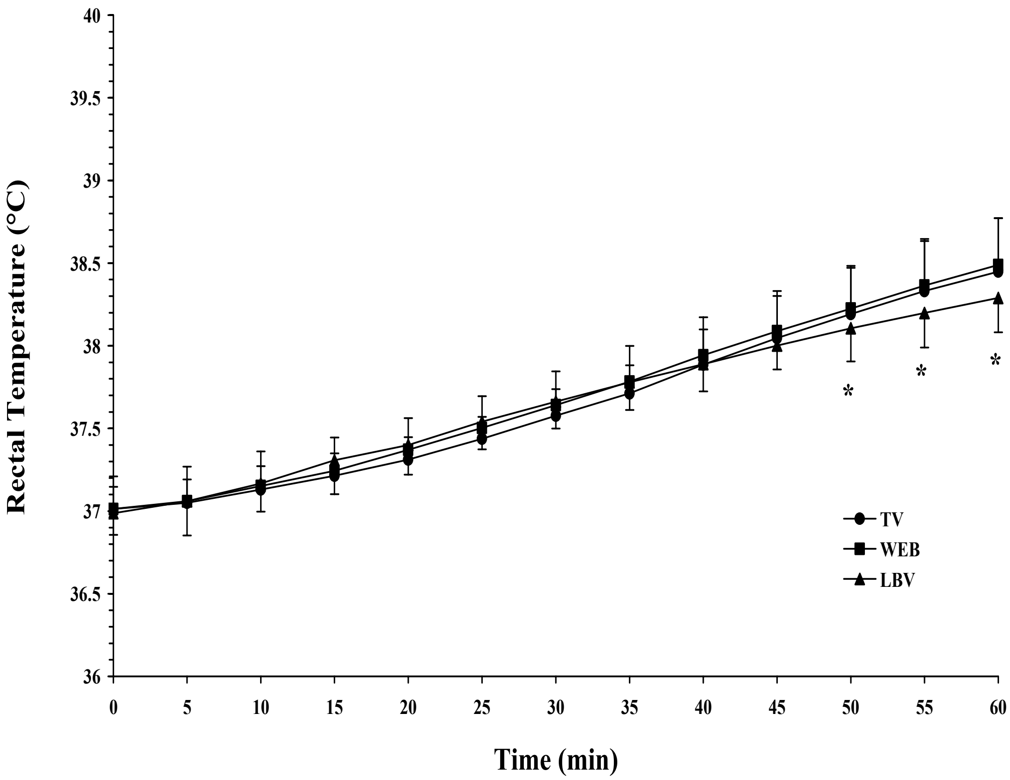

Figure 15. *Rectal temperature response corrected for the order effect of the starting core temperature for the webbing (WEB), tactical vest (TV) and load-bearing vest (LBV) sessions. The asterisk indicates a significant difference between the LBV session and the other two sessions.*

The second set of comparisons revealed the added heat stress associated with the use of the FPV as indicated by the higher cardiovascular (see Figure 9) and thermal strain (see Figures 10 and 11), higher ratings of perceived exertion and thermal comfort and the almost 30% reduction in exercise time when the vest was worn. Thus, there is not only a physiological penalty associated with donning the FPV but Commanders should be aware of the decrements in work output that would be expected. For example, the 30 min reduction in exercise time that was noted while wearing the FPV translates into a 3 km shortfall in the distance that would be covered with the forced march that was employed in the present study. It should also be remembered that these comparisons were made without the insertion of the ceramic plates on the front and rear of the torso. The use of these plates would increase heat production during all soldier weight-bearing activities thereby decreasing work performance (1, 2, 3).

5. Conclusions

There are three main conclusions that evolved from the conduct of this study and these are listed below;

1. The use of the load-bearing vest is not associated with any additional cardiovascular or thermal penalty compared with the use of webbing or the tactical vest.

2. The decision to use either the webbing or tactical vest will have no bearing on the resultant cardiovascular or thermal strain during exercise in the heat.

3. The fragmentation protection vest creates additional cardiovascular and thermal strain that ultimately reduces exercise time by as much as 30% in a hot environment.

6. Recommendations

The following recommendations are consistent with the findings from the current study;

1. The Commander should not be concerned about differences in cardiovascular or thermal strain when making a decision to use either the load-bearing vest, webbing or tactical vest.

2. The Commander should be aware that the decision to use the fragmentation protection vest together with webbing or the tactical vest will dramatically reduce soldier performance in the heat. Implementation of more frequent work and rest periods would be necessary to allow the completion of the mission. For example, allowing 20 min of rest every hour would be an effective means to extend soldiers' exposure time in this hot environment while wearing the FPV. However, this rest schedule would effectively extend the time to complete a mission by one-third or alternatively require 33% more personnel to complete the same task. Higher sweat rates by soldiers wearing the vest would also necessitate a greater need for fluid replacement than when either the webbing or tactical vest is worn alone.

7. References

1. Haisman, M. F., and Goldman, R. F. 1974. Physiological evaluations of armoured vests in hot-wet and hot-dry climates. *Ergonomics* 17, 1-12.

2. Yarger, W. E., Cronau, L. H., and Goldman, R. F. 1968. Body armor in a hot humid environment. Part i. Studies in unacclimatized men. *Res. Rep. US Nav. Med. Field Res. Lab.* 18, 1-12.

3. Yarger, W. E., Litt, B. D., and Goldman, R. F. 1969. Body armor in a hot humid environment. Ii. Studies in heat acclimatized men. *Res. Rep. US Nav. Med. Field Res. Lab.* 19, 1-42.

4. Bossi, L. L., and Tack, D. W. 2000. Human factors engineering in the development of a new load carriage system for the Canadian Forces. In *NATO RTO Specialists' Meeting on Soldier Mobility: Innovations in Load Carriage System Design and Evaluation*, 18A-1 - 18A-22. Kingston, Ontario, Canada: NATO RTO MP-056.

5. McLellan, T. M., Jacobs, I., and Bain, J. B. 1993. Influence of temperature and metabolic rate on work performance with Canadian Forces NBC clothing. *Aviat. Space Environ. Med.* 64, 587-594.

6. Aoyagi, Y., McLellan, T. M., and Shephard, R. J. 1994. Effects of training and acclimation on heat tolerance in exercising men wearing protective clothing. *Eur. J. Appl. Physiol.* 68, 234-245.

7. Hardy, J. D., and DuBois, E. F. 1938. The technic of measuring radiation and convection. *J. Nutr.* 15, 461-475.

8. Mitchell, J. W., Nadel, E. R., and Stolwijk, J. A. 1972. Respiratory weight losses during exercise. *J. Appl. Physiol.* 32, 474-476.

9. Snellen, J. W. 1966. Mean body temperature and the control of thermal sweating. *Acta Physiol. Pharmacol. Nederl.* 14, 99-174.

10. Borg, G. A. V. 1972. Psychophysical bases of perceived exertion. *Med. Sci. Sports Exerc.* 14, 377-381.

11. Fanger, P. O. 1970. Thermal comfort: Analysis and applications in environmental engineering. Copenhagen, Denmark: Danish Technical Press,

12. Horvath, S. M. and Shelley, W. B. 1946. Acclimatization to extreme heat and its effect on the ability to work in less severe environments. *Amer. J. Physiol.* 146, 336-343.

13. Nadel, E. R., Pandolf, K. B., Roberts, M. F., and Stolwijk, J. A. J. 1974. Mechanisms of thermal acclimation to exercise and heat. *J. Appl. Physiol.* 37, 515-520.

14. Eichna, L. W., Park, C. S., Nelson, N., Horvath, S. M., and Palmes, E. D. 1950. Thermal regulation during acclimatization in a hot, dry (desert type) environment. *Amer. J. Physiol.* 163, 585-597.

15. Robinson, S., Turrell, E. S., Belding, H. S., and Horvath, S. M. 1943. Rapid acclimatization to work in hot climates. *Amer. J. Physiol.* 140, 168-176.

16. Aoyagi, Y., McLellan, T. M., and Shepard, R. J. 1995. Effects of 6 versus 12 days of heat acclimation on heat tolerance in lightly exercising men wearing protective clothing. *Eur. J. Appl. Physiol.* 71, 187-196.

17. Buono, M., Heaney, J., and Canine, K. 1998. Acclimation to humid heat lowers resting core temperature. *Amer. J. Physiol.* 274, R1295-R1299.

List of symbols/abbreviations/acronyms/initialisms

ANOVA	Analysis of Variance
CF	Canadian Forces
DLR	Directorate of Land Requirements
DRDC	Defence R&D Canada
FPV	Fragmentation Protection Vest
HR	Heart Rate
HR_{peak}	Peak Heart Rate
LBV	Load-Bearing Vest
RPE	Rating of Perceived Exertion
RTC	Rating of Thermal Comfort
S.D.	Standard Deviation
T_{re}	Rectal Temperature
$\overline{T}_{sk}$	Mean Skin Temperature
TV	Tactical Vest
$\dot{V}O_2$	Oxygen Consumption
$\dot{V}O_{2peak}$	Peak Oxygen Consumption
WEB	Webbing

Distribution list

Maj M. Bodner, Directorate of Land Requirements 5-6, MGen George R. Pearkes Bldg, National Defence Headquarters, 101 Colonel By Drive, Ottawa, ON K1A 0K2

DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY DRDC Toronto	2. SECURITY CLASSIFICATION UNCLASSIFIED Unlimited distribution -
1b. PUBLISHING AGENCY DRDC Toronto	

3. TITLE

(U) Heat stress of tactical assault, fragmentation and load-bearing vests worn over combat clothing

4. AUTHORS

Tom M. McLellan, Natalie J. Sleno, Linda L. Bossi, Jan I. Pope, Jameel J. Adam, John J. Thompson and Christina Narlis

5. DATE OF PUBLICATION June 18 , 2003	6. NO. OF PAGES 41

7. DESCRIPTIVE NOTES

8. SPONSORING/MONITORING/CONTRACTING/TASKING AGENCY
Sponsoring Agency:
Monitoring Agency:
Contracting Agency :
Tasking Agency: Directorate of Land Requirements, NDHQ, Ottawa, K1A 0K2

9. ORIGINATORS DOCUMENT NO. Technical Report TR 2003-033	10. CONTRACT GRANT AND/OR PROJECT NO. 12cb11	11. OTHER DOCUMENT NOS.

12. DOCUMENT RELEASABILITY

Unlimited distribution

13. DOCUMENT ANNOUNCEMENT

Unlimited announcement

14. ABSTRACT

(U) This study evaluated the heat stress associated with wearing webbing (WEB) or a new tactical assault vest (TV) worn alone or in combination with a fragmentation protection vest (FPV). In addition, the heat stress of wearing a new load-bearing vest (LBV) was assessed. Seven subjects (25.6 ± 4.2 years, 82.8 ± 10.2 kg) performed a familiarization trial and 5 randomly ordered experimental sessions that involved walking at 6 km/h on a treadmill at 40ºC and 30% relative humidity. This exercise continued for a maximum of 3 hours or until rectal temperature ( ) reached 40.0°C, heart rate remained at or above 95% of for 3 min, nausea or dizziness precluded further exercise, the subject asked to be removed from the chamber, or the investigator removed the subject from the chamber. Wearing the fragmentation vest increased the cardiovascular and thermal strain and significantly reduced exercise time approximately 30 min from 111.9 ± 33.4 and 111.1 ± 38.9 min for the TV and WEB configurations, respectively, worn without the FPV to 84.9 ± 14.4 and 81.3 ± 18.5 min for the same respective configurations worn with the FPV. There was little difference in heat stress among the WEB, TV or LBV (122.0 ± 38.1 min) configurations worn without the FPV. However, if fragmentation protection must also be provided then the additional heat stress of wearing the FPV would significantly impair work performance when either the WEB or TV was used.

(U) L’étude en question a évalué le stress thermique lié au port d’un harnais ou d’un nouveau gilet tactique d’assaut, seul ou en combinaison avec un gilet pare-éclats, ainsi que le stress thermique lié au port d’un nouveau gilet à matériel. Sept sujets (25,6 ± 4,2 ans, 82,8 ± 10,2 kg) ont été soumis à un essai de familiarisation et, dans un ordre aléatoire, à cinq expériences comprenant une marche à 6 km/h sur un tapis roulant à une température de 40 ºC et à une humidité relative de 30 %. Cet exercice a duré un maximum de trois heures ou jusqu’à ce que la température rectale ( ) atteigne 40 ºC, que la fréquence cardiaque demeure à 95 % ou plus de la fréquence cardiaque maximale pendant 3 minutes, que la nausée ou des étourdissements empêchent la poursuite de l’exercice, que le sujet demande à sortir de la chambre ou que le chercheur fasse sortir le sujet de la chambre. Le port du gilet pare-éclats a fait grimper le stress cardiovasculaire et le stress thermique et a considérablement réduit le temps d’exercice, soit d’environ 30 minutes, le faisant passer de 111,9 ± 33,4 et de 111,1 ± 38,9 minutes pour le gilet tactique et le harnais respectivement, portés sans le gilet pare-éclats, à 84,9 ± 14,4 et à 81,3 ± 18,5 minutes pour les mêmes articles portés avec le gilet pare-éclats. La différence de stress thermique est minime entre le port du harnais, du gilet tactique et du gilet à matériel (122,0 ± 38,1 min) sans le gilet pare?éclats. Cependant, le port du gilet pare-éclats augmente le stress thermique et nuit considérablement à l’efficacité fonctionnelle lorsque le harnais ou le gilet tactique est utilisé.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) protective clothing; thermal strain; heat acclimation; exercise