Thermal Strain in Fire Fighters While Wearing Task-Fitted Versus EN 469:2005 Protective Clothing During a Prolonged Rescue Drill

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Fire fighters are normally overprotected during their working hours because of the tendency to keep the personal protection level sufficiently high in case of the worst possible scenarios. This study investigated the effects of task-fitted protective clothing on thermal strain in fire fighters as compared to EN 469:2005 protective clothing during a prolonged (2 1/2 hrs) job-related rescue drill under neutral and hot climates. The subjects were 23 healthy, physically fit professional male fire fighters aged 26–44 years. Measurements included cardiovascular and thermal responses and subjective assessments. Wearing task-fitted clothing during rescue tasks in a neutral climate considerably reduced total thermal and cardiovascular strain in prolonged rescue work. The fire fighters also perceived physical work as significantly harder on average, and reported more intense subjective discomfort while wearing EN 469:2005 as compared to task-fitted clothing.

thermal strain   cardiovascular strain   heart rate variability   vagal recovery   fire fighter
protective clothing   job-related rescue drill

1. INTRODUCTION AND AIMS

Fire fighters are multiskilled rescuers. In Finland, as in many other countries, they are trained to carry out a wide range of tasks from fire fighting to surface rescue and underwater rescue diving. Full-time professional fire fighters also work in fire prevention and other activities, and are responsible for patient transportation and medical care in their area. As the level of protection for fire fighters must be sufficient for the worst possible scenarios, e.g., flames and radiant heat, they are overprotected for most of their working hours. In Finland, the protective clothing system (PCS), which meets the requirements of standard No. EN 469:2005 [1], is used in most fire brigades as multipurpose clothing and is worn during most operations, except during water rescue and incidents with hazardous materials. However, a fire fighter in Finland only needs a multilayer turn-out suit in structural and other fires ~10 times per year and the mean wearing time of the PCS in fire is only ~6% of total working time [2]. The rest of the time, fire fighters are exposed to unnecessary

thermal and cardiovascular strain [3, 4] which also reduces work ability and efficiency [5]. The evaluation of these extra demands should also be included in the health examinations of fire fighters [6].

Small changes to the thermal insulation properties of a water vapour permeable EN 469:2005-type [1] protective clothing have only minimal, if any, effect on heat exchange and do not affect the resulting thermal strain [7]. However, even a microporous water barrier liner may expose a fire fighter to more pronounced heat and cardiovascular strain during prolonged rescue operations as compared to protective clothing without a barrier [8, 9]. To have a truly measurable attenuating effect on thermal strain in fire fighters, a new approach is needed for planning the protection. When the needed protection level is based on the risks of the work tasks it is possible to develop clothing with lower thermal strain.

The purpose of this study, which is part of a more comprehensive project on fire fighters' PCSs, was to compare the degree of thermal strain in fire fighters wearing task-fitted PCSs and PCSs fulfilling EN 469:2005 [1] during a prolonged work simulation, consisting of different rescue tasks in a thermally neutral, and hot and dry climates.

2. METHODS

2.1. Subjects

The voluntary subjects were 23 healthy professional male fire fighters with an average age of 34 (26–44) years, height of 181 (172–196) cm, weight of 85 (69–102) kg, BMI of 26 (21–32), body fat percentage of 16 (7–24)%, and body area of 2.0 (1.8–2.3) m^2. Before the experiments, the subjects underwent a medical check-up including a clinical cardiopulmonary exercise test measured under neutral conditions on a treadmill using a modified Bruce protocol [10]. The average $\dot{V}_{o2max}$ of the study group was 45.1 (35.6–54.0) ml/kg·min^{-1}.

The research protocol was reviewed and approved in advance by the Institutional Research Committee and the Coordinating Ethics Committee of the Hospital District of Helsinki and Uusimaa (Finland). The subjects gave written informed consent before the experimental sessions and received compensation for loss of working hours.
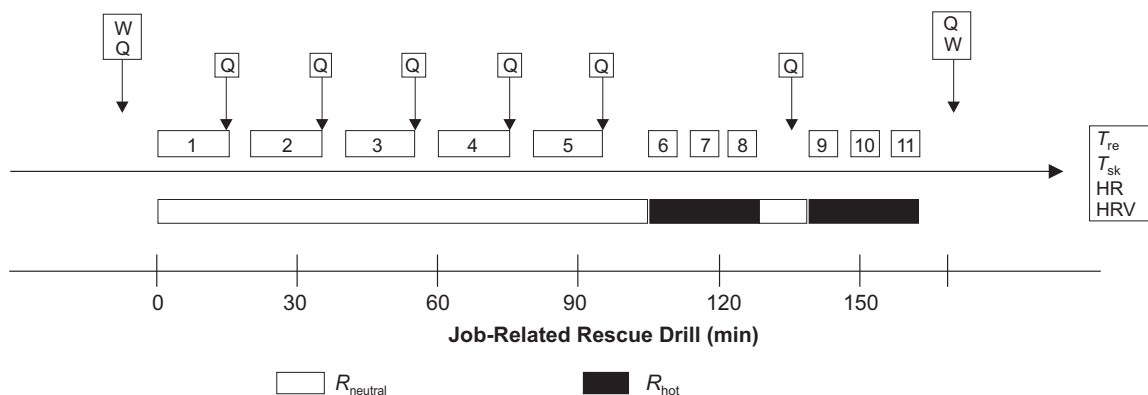

Figure 1. Experimental design of job-related test drill in neutral and hot conditions while task-fitted and EN 469:2005 [1] protective clothing for fire fighters was worn. *Notes.* T_{re}—rectal temperature, T_{sk}—skin temperature, HR—heart rate, HRV—heart rate variability, W—weight, Q—subjective evaluations and questionnaires; $R_{neutral}$—22–25 °C/45–50% RH, R_{hot}—45 °C/35% RH; RH—relative humidity; 1—ascending and descending stairs, 2—working with hydraulic tools, 3—walking and transposing weights in hands, 4—rescuing a 100-kg manikin from a hole, 5—stretchering a 70-kg manikin through a 200-m long passage, 6—walking on a treadmill, 7—transposing weights in hands, 8—stepping, 9—crawling under bars, 10—driving a bicycle ergometer, 11—walking on a treadmill.

2.2. Experimental Design

2.2.1. Test protocol

The test protocol provided a series of work tasks simulating typical rescue operations. The prolonged test drill (Figure 1) conducted in the mornings was divided into two consecutive work sessions with a 10-min rest between the sessions for body cooling (removing the jacket for ventilation of underwear), drinking ad libitum and putting on the required fire-protective clothing system (FPCS) including a self-contained breathing apparatus (SCBA). The tasks were as follows:

- One hour and 35 min of work at t_a of 22–25 °C combined with relative humidity of 45–50% ($R_{neutral}$) including typical rescue tasks with a 5-min rest between each task (ascending and descending stairs; work with hydraulic rescue tools; walking and transposing weights, 2×6 kg, in hands; rescuing a 100-kg manikin from a 1.8-m deep hole with rope rescue equipment; and stretchering a 70-kg manikin through a ~200-m long passage with two staircases and 12 doors) performed at own speed and some tasks in pairs.
- A 54-min rescue task with FPCS performed in a climatic chamber at t_a of 45 °C combined with relative humidity of 35% (R_{hot}) and divided into two work bouts of 22 min with 10-min recovery in a neutral climate ($R_{neutral}$) between each work bout, for changing the air container. The rescue simulation involved walking on a treadmill (4 km·hr^{-1}/grade 2°), transposing weights (2×6 kg) in hands, stepping, crawling under 70-cm high bars, driving a bicycle ergometer (100 W/60 rpm), and walking on a treadmill (4 km·hr^{-1}/0°) with a 3-min rest between each task.

2.2.2. PCSs

In random order, the subjects performed both of the test configurations once (~4 weeks between the test days), in the two types of PCSs that were studied (Table 1), i.e.,

- the task-fitted protective clothing system (PCS_{task}) during $R_{neutral}$ and in conjunction with a turnout suit fulfilling the EN 469:2005 requirements [1] and SCBA during R_{hot} ($FPCS_{task}$); and
- the EN 469:2005 protective clothing system (PCS_{EN}) during $R_{neutral}$ and with SCBA during R_{hot} ($FPCS_{EN.}$).

TABLE 1. Items and Materials for Task-Fitted Protective Clothing System (PCS_{task}) and for Protective Clothing System That Meets the Requirements of Standard No. EN 469:2005 [1] (PCS_{EN})

Item	Material, PCS_{task}	Material, PCS_{EN}
underwear	66% PES/34% WO (Sportwool®), 210 g/m², undershirt with long sleeves, knee-length underpants	100% CO shirt with short sleeves, trunks
intermediate layer		uniform trousers, 50% CO/50% PES
outer jacket and trousers	one layer, 75% CO/24% PE/1% antistatic thread, 250 g/m²	3-layer aramid with moisture barrier [1]
safety boots and fire gloves	leather	leather

Notes. PES—polyester, WO—wool, CO—cotton, PE—polyethylene.

The outer garment of PCS_{task} was selected from the market on the grounds that the material met the basic protection requirements of general rescue work. The underwear made of a wool-blend material with good thermal and moisture transfer properties was especially designed for fire fighters.

The total mass of the PCSs averaged 4.0 kg for PCS_{task} and 7.4 kg for PCS_{EN} and, correspondingly, 13.8 kg for SCBA (Dräger, Germany, PSS 100 ET, 6.8 L, 300 bar) and the helmet. The measured [11] thermal insulation, I_{tr}, was 1.07 clo for PCS_{task}, 1.90 clo for $FPCS_{task}$, and 1.97 clo for PCS_{EN} and $FPCS_{EN}$.

2.2.3. Physiological measurements

Heart rate and heart rate variability (HRV) were continuously recorded with a Suunto t6 wriststop computer (Finland) and analyzed using

special software for ambulatory HRV analyses (Firstbeat Technologies Ltd., version 1.4.1, 2006, Finland). RMSSD (square root of the mean of sum of the squares of differences between adjacent RR intervals of QRS complexes in electrocardiogram) was used as an index of HRV [12]. The magnitude of excess post-exercise oxygen consumption (EPOC) was also calculated indirectly from the heart rate and HRV recordings using neural network analysis described elsewhere [13]. EPOC reflects the general disturbance in body's homeostasis and the recovery requirements of the body during and after exercise [15].

Rectal temperature (T_{re}) was continuously measured with a flexible thermistor probe (YSI 401, Yellow Springs Instrument Co., USA) at a depth of 10 cm and, correspondingly, skin temperatures (T_{sk}) were measured at seven sites (YSI 427) and registered once a minute (Veritec Instrument Type 1400, Canada). Mean skin temperature ($\overline{T}_{SK}$) was calculated as an arithmetic mean and, correspondingly, mean body temperature ($\overline{T}_{b}$) using the weighting coefficients 0.65 for T_{re} and 0.35 for $\overline{T}_{SK}$ under $R_{neutral}$ and, respectively, 0.9 and 0.1 under R_{hot}. The change in heat storage for certain exposure times was calculated from changes in $\overline{T}_{b}$ using 0.97 W·hr/kg·ºC for specific heat of the body. Sweat loss was determined through the change in nude weight measured before and after exercise (Sauter EC 240, Type 1200 ± 5 g, Germany), corrected with fluid intake.

2.2.4. Subjective evaluations

The following subjective evaluations were requested at the start and at the end of each work task:

- ratings of perceived exertion (RPE) using the Borg scale [15] from 6 (*no exertion at all*) to 20 (*maximal exertion*);
- thermal sensation modified from the Standard No. ISO 10551:1996 [16] scale from −5 (*bitterly cold*) to +5 (*exhaustive heat*);
- thermal comfort modified from the Standard No. ISO 10551:1996 [16] scale from 1 (*comfortable*) to 5 (*intolerable*); and

- skin wettedness, using a scale from 1 (*dry*) to 5 (*watery wet*).

The subjects were also interviewed through questionnaires on PCSs and FPCSs regarding their wear comfort and functioning at work.

2.2.5. Termination criteria

The subject's own desire to terminate the drill or objective signs of exhaustion and exertion dyspnoea or dizziness were the criteria of termination.

2.3. Statistics

Means ± *SD* and ranges were used for describing the data. The normality of the distributions was assessed using the Kolmogorov-Smirnov test. Paired *t* tests were used in physiological strain and subjective perception differences between PCSs. A level of probability of less than .05 was considered statistically significant. Statistical analyses were performed using SPSS for Windows version 12.0.1.

3. RESULTS AND DISCUSSION

All the subjects completed the test drills. However, just at the end of R_{hot} four of them had symptoms (headache, nausea and shivering) reflecting intense thermoregulatory strain. One of the oldest subjects (40 years with $\dot{V}_{o2max}$ of 40 ml/kg·min^{-1}) even reported foreseeable exhaustion after 1–2 min.

3.1. Thermal Strain

3.1.1. Rectal temperature

Figure 2 presents T_{re} responses for a subject wearing both PCSs during rescue tasks. This single example demonstrates very clearly the typical effects of clothing on thermal strain. The mean increase in T_{re} during $R_{neutral}$ was 0.58 ± 0.21 °C for PCS$_{task}$ and 0.69 ± 0.25 °C for PCS$_{EN,}$ and further mean increase during R_{hot} was 0.79 ± 0.25 °C for FPCS$_{task}$ and 0.87 ± 0.25 °C for FPCS$_{EN}$ (Figure 3). The difference over time
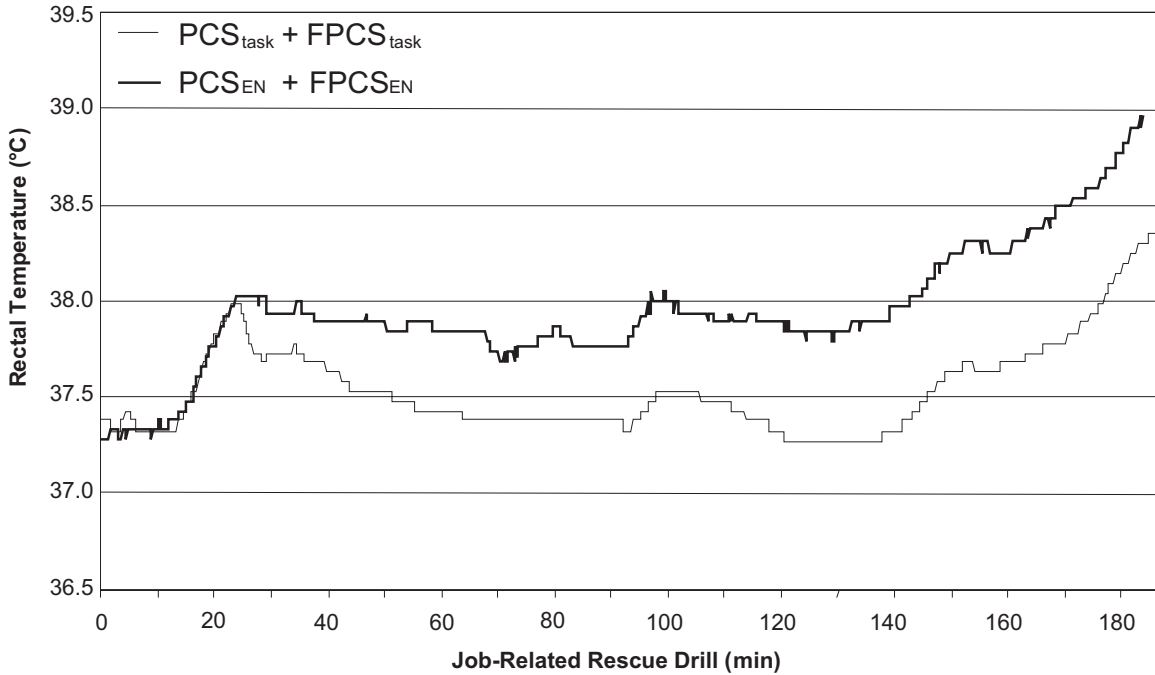
Figure 2. Rectal temperature responses over time for a subject while task-fitted (PCS$_{task}$ and FPCS$_{task}$) and EN 469:2005-based [1] (PCS$_{EN}$ and FPCS$_{EN}$) protective clothing systems for fire fighters during job-related rescue drill in neutral ($R_{neutral}$) and hot (R_{hot}) climates were worn. *Notes. $R_{neutral}$—22–25 °C/45–50% RH, R_{hot}—45 °C/35% RH; RH—relative humidity.*
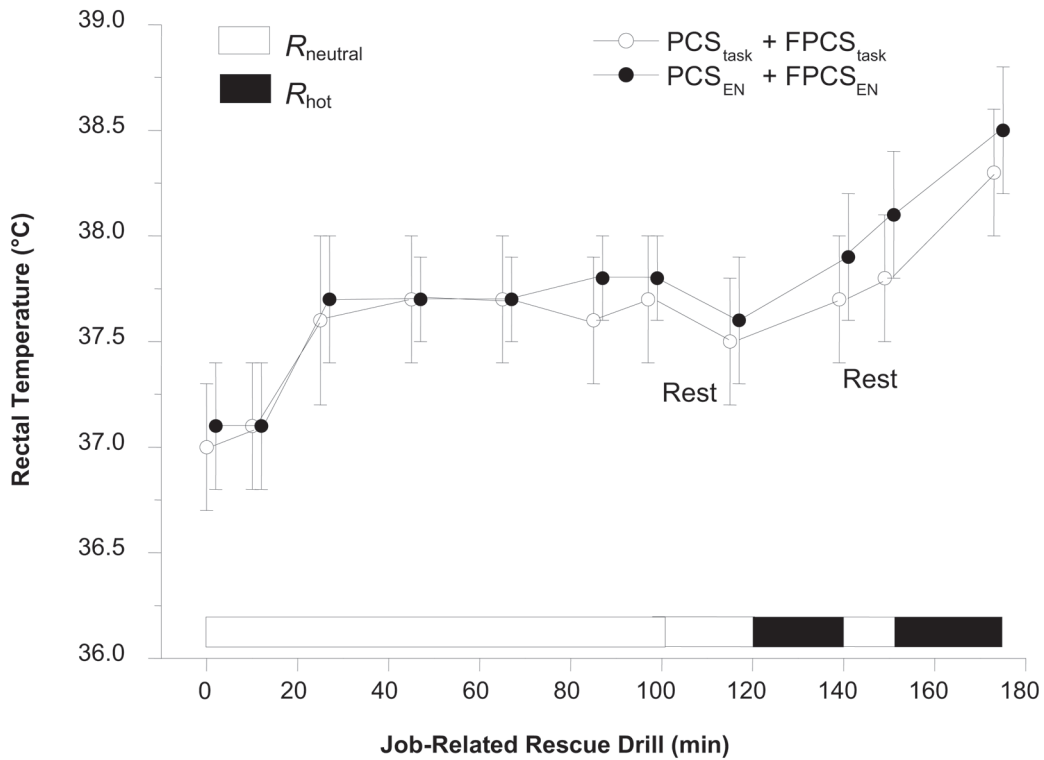

Figure 3. Time courses for mean rectal temperature ($N = 23$) during a job-related rescue drill while PCS$_{task}$ and PCS$_{EN}$ in $R_{neutral}$ and FPCS$_{task}$ and FPCS$_{EN}$ in R_{hot} were worn. *Notes. $R_{neutral}$—22–25 °C/ 45–50% RH, R_{hot}—45 °C/35% RH; RH—relative humidity; ○—task-fitted protective clothing system, PCS$_{task}$, and task-fitted fire-protective clothing system, FPCS$_{task}$; ●—protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], PCS$_{EN}$, and fire-protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], FPCS$_{EN}$.*

for the rescue drill was significant. The highest T_{re} values for all the subjects were registered at the start of the recovery period, on average at 38.5 (38.1–39.1) °C for FPCS$_{task}$ and correspondingly, at 38.8 (38.2–39.4) °C for FPCS$_{EN}$. $T_{re} \geq 39.0$ °C was measured only for 2 subjects wearing FPCS$_{task}$ and for 8 subjects wearing FPCS$_{EN}$.
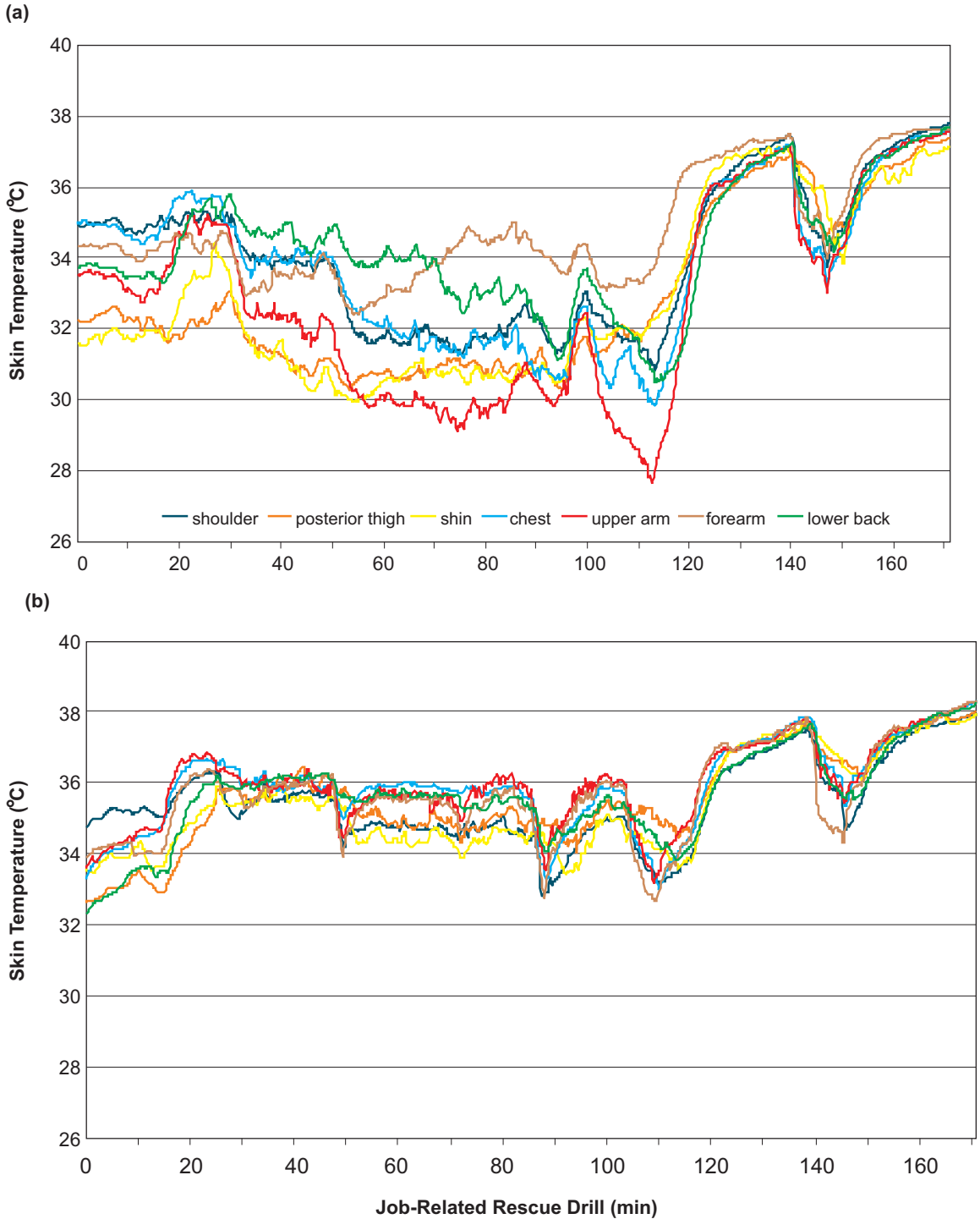
(a)

(b)

Figure 4. Individual skin temperatures for a subject during job-related rescue drill in neutral and hot climate while (a) PCS$_{task}$ and FPCS$_{task}$ and (b) PCS$_{EN}$ and FPCS$_{EN}$ were worn. *Notes.* PCS$_{task}$—task-fitted protective clothing system, FPCS$_{task}$—task-fitted fire-protective clothing system, PCS$_{EN}$—protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], FPCS$_{EN}$—fire-protective clothing system that meets the requirements of Standard No. EN 469:2005 [1].

3.1.2. Skin temperature

Figure 4 demonstrates a typical example of individual skin temperatures for a subject over time for both suit systems, showing clear differences in individual skin temperature distribution over the skin during $R_{neutral}$. On average, the skin temperature distribution was considerably larger for PCS_{task} (~4–6 °C), a clear contrast to average temperature distribution for PCS_{EN} (~1–2 °C), indicating the effects of high thermal insulation of standard-based clothing. The differences in individual skin temperature distribution were minimal during R_{hot} and there was no significant difference between FPCSs.

The difference in $\overline{T}_{sk}$ between PCSs was significant over time during $R_{neutral}$ (Figure 5). $\overline{T}_{sk}$ for $FPCS_{task}$ and $FPCS_{EN}$ did not differ significantly during R_{hot} and was in both FPCSs at about the same level of 38 °C as T_{re}.

3.1.3. Heat storage

Body heat accumulation resulted in significantly higher mean body temperatures for PCS_{EN} and

$FPES_{EN}$ throughout the whole rescue drill. At the beginning of $R_{neutral}$ the considerable increase in metabolic rate during stair-climbing resulted in very rapid heat accumulation in the body when both PCSs were worn. However, this was significantly greater for PCS_{EN} (148 ± 29.4 W/m^2) than for PCS_{task} (88.3 ± 41.8 W/m^2). At the end of $R_{neutral}$ heat storage was still significantly greater in PCS_{EN} than in PCS_{task}. During the first R_{hot} work bout the increase in heat storage was 157 ± 34.7 W/m^2 for $FPCS_{EN}$ and 171 ± 26.0 W/m^2 for $FPCS_{task}$, and a further increase during the second R_{hot} was 64.4 ± 13.7 for $FPCS_{EN}$ and 73.1 ± 17.1 for $FPCS_{task}$. The difference in changes was not significant.

3.1.4. Body fluid balance

Sweat production for the whole test drill varied greatly between individuals, ranging from 1.2 to 3.7 L for PCS_{task} + $FPCS_{task}$ and from 1.5 to 4.3 L for PCS_{EN} + $FPCS_{EN}$. On average, sweat production was 2.4 ± 0.6 L for PCS_{task} + $FPCS_{task}$, and 2.8 ± 0.7 L for PCS_{EN} + $FPCS_{EN}$. The
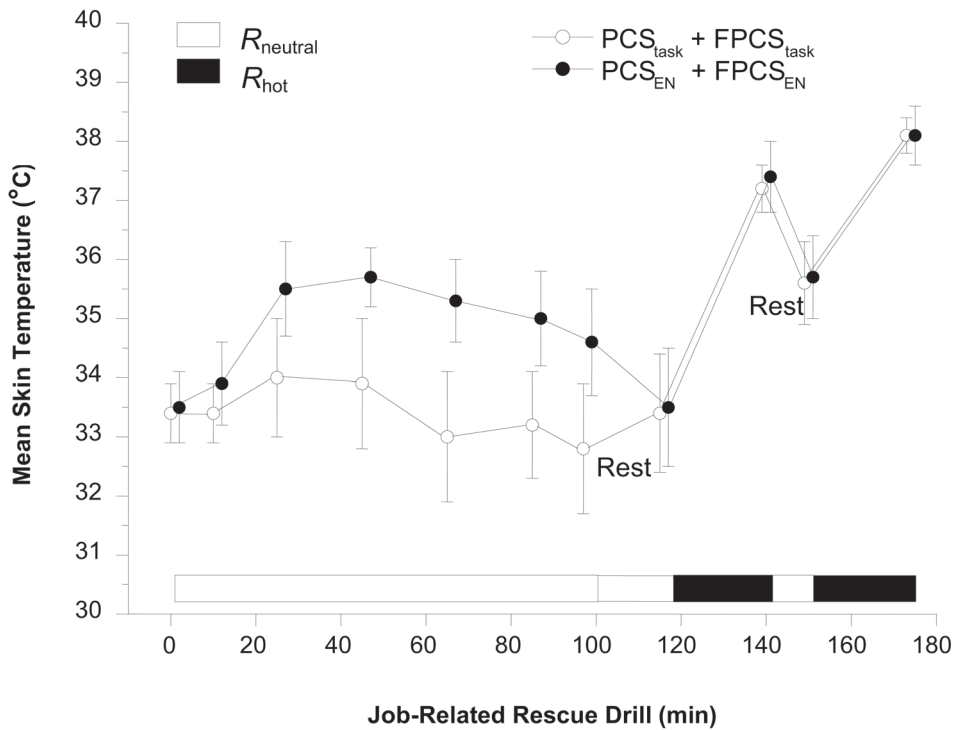

Figure 5. Average time courses for mean skin temperature (_N_ = 23) during a job-related rescue drill while PCS_task_ and PCS_EN_ in _R_neutral_ and FPCS_task_ and FPCS_EN_ in _R_hot_ were worn. _Notes. R_neutral_—22–25 °C/45–50% RH, R_hot_—45 °C/35% RH; RH—relative humidity; ○—task-fitted protective clothing system, PCS_task_, and task-fitted fire-protective clothing system, FPCS_task_; ●—protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], PCS_EN_, and fire-protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], FPCS_EN_.

difference was significant. Water replacement was adequate in most cases and the average water deficit was only $0.8 \pm 0.8\%$ for PCS_{task} + $FPCS_{task}$ and $1.0 \pm 1.1\%$ for PCS_{EN} + $FPCS_{EN}$. However, in some subjects, a net deficiency in fluid intake of even 2–2.7 L was recorded, resulting in a 2.9–3.6% water deficit.

3.2. Cardiovascular and Metabolic Strain

3.2.1. Heart Rate and HRV analyses

Heart rate was significantly higher for PCS_{EN} during $R_{neutral}$ and for $FPCS_{EN}$ during R_{hot} than for PCS_{task} and for $FPCS_{task}$. (Figure 6, Table 2). Absolute RMSSD values decreased while both types of protective clothing were worn (Table 2). Mean RMSSD decreased from the supine pre-test value of 42 to 13 ms during $R_{neutral}$ in both PCSs. A further decrease in RMSSD during R_{hot} was more pronounced ($p < .05$) for $FPCS_{EN}$ than for $FPCS_{task}$.

TABLE 2. Circulatory and Metabolic Strain in Fire Fighters During Intermittent Rescue Work Simulations While Wearing PCS$_{task}$ and PCS$_{EN}$ Under Neutral ($R_{neutral}$) Climate Conditions and, Correspondingly, FPCS$_{task}$ and FPCS$_{EN}$ Under Hot (R_{hot}) Climate Conditions. Values are Means and Ranges ($N = 21$)

Variable	PCS$_{task}$ FPCS$_{task}$	PCS$_{EN}$ FPCS$_{EN}$
HR (min^{-1})		
$R_{neutral}$	105 (85–120)	117 (91–145)
R_{hot}	127 (100–146)	137 (110–174)
RMSSD (ms)		
$R_{neutral}$	13 (10–48)	13 (5–27)
R_{hot}	11 (4–45)	6 (3–24)
EPOC $_{peak}$ (ml/kg)		
$R_{neutral}$	28 (10–48)	44 (3–70)
R_{hot}	91 (16–176)	125 (21–270)

Notes. PCS_{task}—task-fitted protective clothing system, $FPCS_{task}$— task-fitted fire-protective clothing system, PCS_{EN}—protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], $FPCS_{EN}$—fire-protective clothing system that meets the requirements of Standard No. EN 469:2005 [1]; HR—heart rate, RMSSD—
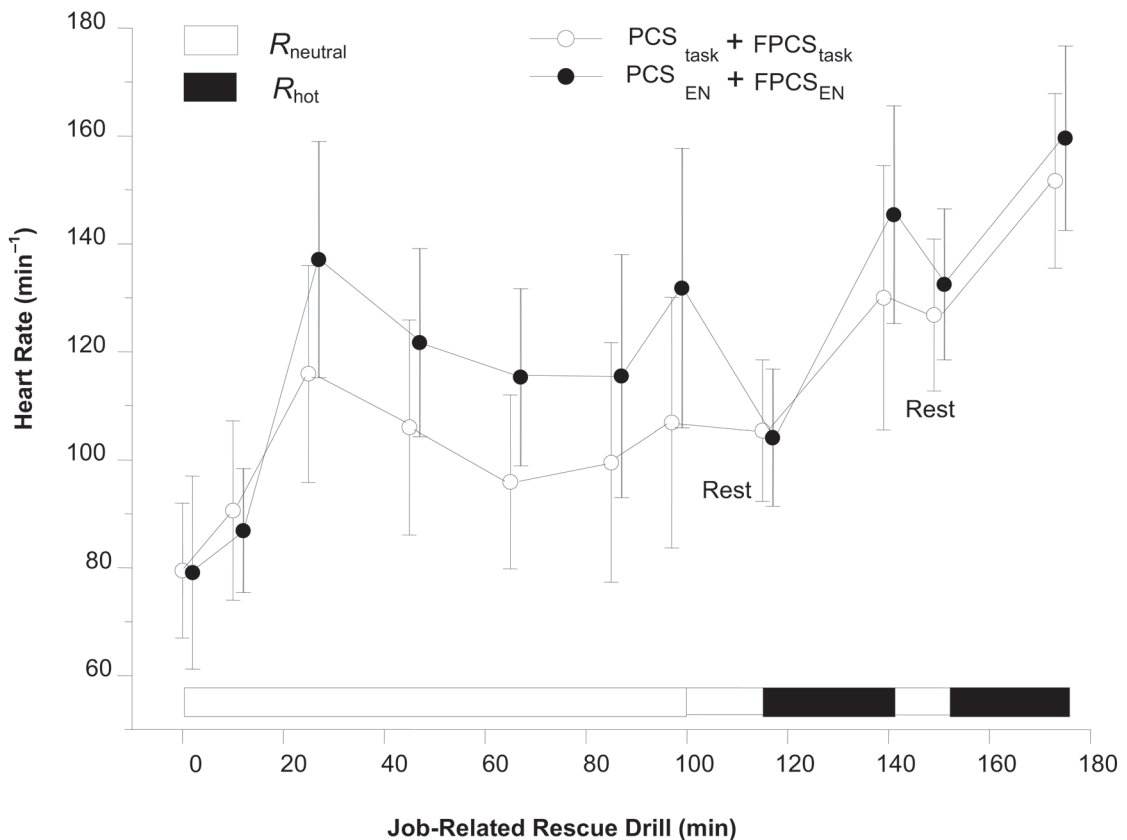

Figure 6. Time courses for mean heart rate ($N = 23$) during a job-related rescue drill while PCS$_{task}$ and PCS$_{EN}$ in $R_{neutral}$ and FPCS$_{task}$ and FPCS$_{EN}$ in R_{hot} were worn. *Notes.* $R_{neutral}$—22–25 °C/45–50% RH, R_{hot}—45 °C/35% RH; RH—relative humidity; ○—task-fitted protective clothing system, PCS$_{task}$, and task-fitted fire-protective clothing system, FPCS$_{task}$; ●—protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], PCS$_{EN}$, and fire-protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], FPCS$_{EN}$.

square root of the mean of sum of the squares of differences between adjacent RR intervals of QRS complexes in electrocardiogram, $EPOC_{peak}$—peak value of excess post-exercise oxygen consumption; $R_{neutral}$—22–25 °C/45–50% RH, R_{hot}—45 °C/35% RH; RH—relative humidity.

3.2.2. EPOC

Mean EPOC increased to 125 ml/kg for $FPCS_{EN}$ and to 91 ml/kg for $FPCS_{task}$ during R_{hot} (Table 2). EPOC values increased significantly less during $R_{neutral}$ than during R_{hot}. However, the levels were higher while PCS_{EN} rather than PCS_{task} was worn.

The difference was not statistically significant because of the great individual variation. In some cases, however, the difference in the EPOC load between the two PCSs was highly significant as shown in Figure 7. Time courses for heart rate, EPOC and the peak value of EPOC ($EPOC_{peak}$) show the intensity of the rescue drill when the two clothing systems are worn. It can be expressed as training levels from 1 to 5. These levels were originally developed for training purposes. In the assessments of work strain, it can be roughly estimated that a training (intensity)
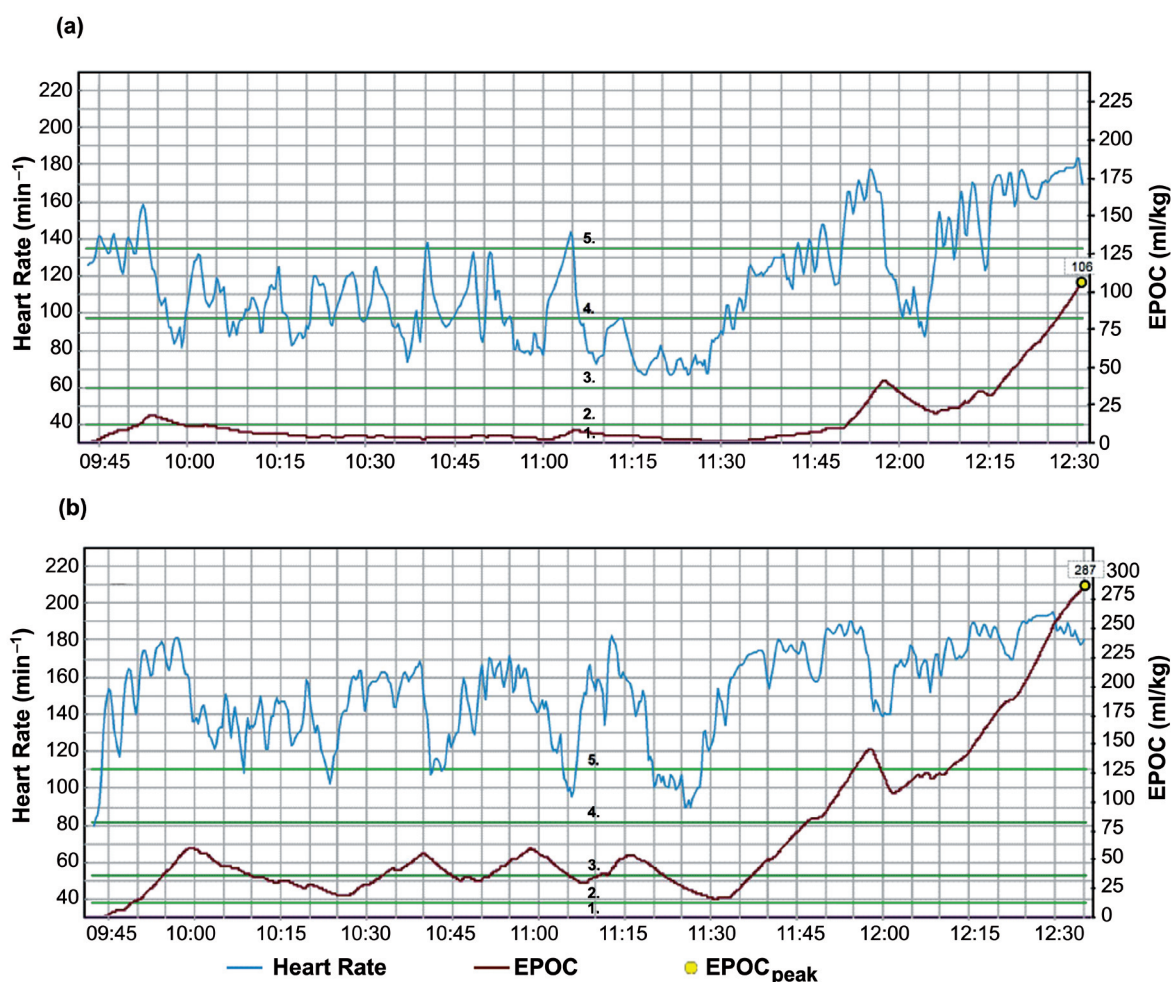
(a)

(b)

Figure 7. Heart rate and metabolic load of a 30-year-old fire fighter with $\dot{V}_{O2max}$ of 40 ml/kg·min^{-1} during intermittent rescue work simulations while (a) PCS_{task} and $FPCS_{task}$ and, correspondingly, (b) PCS_{EN} and $FPCS_{EN}$ in $R_{neutral}$ and in R_{hot} were worn. *Notes.* $R_{neutral}$—22–25 °C/45–50% RH, R_{hot}—45 °C/35% RH; RH—relative humidity; PCS_{task}—task-fitted protective clothing system, $FPCS_{task}$—task-fitted fire-protective clothing system, PCS_{EN}—protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], $FPCS_{EN}$—fire-protective clothing system that meets the requirements of Standard No. EN 469:2005 [1]; EPOC—excess post-exercise oxygen consumption (ml/kg); $EPOC_{peak}$—peak value of EPOC; ▬ training effect: 1—*minor*, 2—*maintaining*, 3—*improving*, 4—*greatly improving*, 5—*overreaching*.

level of 4 should be found only occasionally and only for short periods during normal physical work, and that level 5 indicates overstrain. In fire fighting and other rescue activities, high levels of strain cannot, however, be totally avoided. Nevertheless, peaks of 200 ml/kg or more require good physical performance capacity and those markedly increase the need for recovery, even among physically fit fire fighters.

3.3. Subjective Evaluations

Rescue work while wearing PCS_{EN} and $FPCS_{EN}$ was, on average, perceived as significantly harder compared to that while PCS_{task} and $FPCS_{task}$ were worn (Table 3). Correspondingly, on average, the subjects reported significantly more intense feelings of heat, skin wettedness and thermal discomfort.

The outer garment of PCS_{task} was not designed according to the functional or image needs of fire fighters, and the fire fighters themselves gave a good deal of negative feedback concerning the design and colour combination of the garments. On the other hand, underwear designed especially for fire fighters was evaluated as pleasant and functional compared to traditional cotton underwear. Fire fighters reported that moisture-absorbing cotton underwear exposed them to steam burns, whereas wool-blend equivalents, with better thermal and moisture transfer properties, were more effective in protecting them against these types of burns.

4. CONCLUSIONS AND RECOMMENDATIONS

The results show that thermal and circulatory strain was significantly greater and that, correspondingly, there was more intense perceived exertion and subjective discomfort in fire fighters when they wore PCS_{EN} and $FPCS_{EN}$, rather than PCS_{task} and $FPCS_{task}$. The use of PCS_{EN} increases the metabolic load by ~1 MET (metabolic equivalent) during typical rescue work tasks compared to when PCS_{task} is worn. The use of PCS_{task} during work under neutral conditions raises the fire fighters' capacity to recover during physically demanding intermittent work bouts and maintains the body's capacity to adapt to other stressors, such as mental and heavy heat load.

EPOC reflects the disturbance of the body's homeostasis during exercise. It takes into account the individual's cardiorespiratory fitness, the intensity and the duration of the work load and the duration and effectiveness of the recovery periods during intermittent work [17]. It can be used as an index of cumulative metabolic load. In this study, EPOC was significantly lower in the group with task-fitted clothing. The results show that in some individual cases, the EPOC values of the fire fighters wearing traditional protective clothing throughout the work period reached the values of athletes during an endurance competition, e.g., nearly 300 ml/kg, showing significant overstrain.

TABLE 3. Ratings of Perceived Exertion (RPE) and Subjective Thermal Evaluations at the Beginning of the Test Drill and at the End of Neutral ($R_{neutral}$) and Hot (R_{hot}) Climates. Values are Means and Ranges ($N = 23$)

Test Drill	RPE		Thermal Sensations		Thermal Comfort		Skin Wettedness	
	PCS_{task} $FPCS_{task}$	PCS_{EN} $FPCS_{EN}$	PCS_{task} $FPCS_{task}$	PCS_{EN} $FPCS_{EN}$	PCS_{task} $FPCS_{task}$	PCS_{EN} $FPCS_{EN}$	PCS_{task} $FPCS_{task}$	PCS_{EN} $FPCS_{EN}$
Beginning	7.7 (6–11)	7.9 (7–10)	0.1 (−2.0–1.5)	0.3 (0.0–1.0)	1.2 (1.0–2.0)	1.3 (1.0–2.0)	1.1 (1.0–2.0)	1.2 (1.0–2.5)
End of $R_{neutral}$	12.7 (10–14)	14.0* (12–16)	1.9 (0.5–3.0)	2.6* (0.5–4.0)	1.9 (1.2–5.0)	2.3* (1.5–5.0)	3.1 (2.0–5.0)	3.9* (2.5–5.0)
End of R_{hot}	16.1 (13–19)	17.2* (14–19)	3.6 (2.5–4.5)	4.2* (2.5–5.0)	3.3 (1.5–5.0)	3.9* (1.5–5.0)	4.5 (4.0–5.0)	4.6* (4.0–5.0)

Notes. *—a significant difference between protective clothing systems; PCS_{task}—task-fitted protective clothing system, $FPCS_{task}$—task-fitted fire-protective clothing system, PCS_{EN}—protective clothing system that meets the requirements of Standard No. EN 469:2005 [1], $FPCS_{EN}$—fire-protective clothing system that meets the requirements of Standard No. EN 469:2005 [1]; $R_{neutral}$—22–25 °C/45–50% RH, R_{hot}—45 °C/35% RH; RH—relative humidity.

The low RMSSD values reflect the attenuation in parasympathetic drive, e.g., increased stress. In this study the use of traditional protective clothing during work in a thermoneutral environment increased autonomic nervous system (ANS) stress during hot work. Vagal cardiovascular regulation plays an important role in circulatory recovery after physical work. Vagal capacity decreases with age [18], and environmental factors with a negative influence on the autonomic nervous system may increase the risk of exhaustion. Thus, especially among aging fire fighters, PCS_{task} may protect the ANS balance during dynamic variable work stress situations. Effective thermoregulatory recovery requires an interplay between many physiological control mechanisms [19], and inappropriate protective clothing may inhibit the maintenance of thermal balance.

The present results emphasise the need to write new international standards for clothing systems for fire fighters. In order to prevent daily overprotection causing overstrain in fire fighters and to promote work ability it is highly recommended that fire fighters be issued new layered PCSs with a base layer that includes functional underwear (keeping skin as dry as possible) onto which it is possible to attach intermediate and external protection layers quickly and easily, according to the required level of current hazard. The same applies to situations in which a fire fighter is in a moving vehicle.

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