Chapter 8

The effect of pre-warming on performance during simulated firefighting exercise

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Accepted for publication in Applied Ergonomics
ABSTRACT

Purpose
To examine the effect of active pre-warming on speed and quality of performance during simulated firefighting exercise.

Methods
Twelve male firefighters performed two trials in counterbalanced order. They were either pre-warmed by 20-min cycling at 1.5 Watt·kg$^{-1}$ body mass (WARM) or remained thermoneutral (CON) prior to a simulated firefighting activity.

Results
After the pre-warming, gastrointestinal temperature (P<0.001), skin temperature (P=0.002), and heart rate (P<0.001) were higher in WARM than in CON. During the firefighting activity, RPE, thermal sensation and comfort scores were higher for WARM than for CON. Finish time of the firefighting activity was similar, but the last task of the activity was completed slower in WARM than in CON (P=0.04). In WARM, self-reported performance quality was lower than in CON (P=0.04).

Conclusion
Pre-warming reduces the speed during the last part of simulated firefighting activity and reduces self-reported quality of performance.
INTRODUCTION

Firefighting is an occupation that is characterized by long periods of relatively low intensity work and short periods of moderate-to-high intensity work (Bos et al. 2004). The low intensity work periods usually consist of training and sporting activities in and around the firehouse. The moderate-to-high intensity work periods involve activities that impose high physical demands on firefighters such as extinguishing fires, victim search-and-rescue, stair climbing, and equipment transport (Gledhill and Jamnik 1992). During these activities, performance has to be optimal since the safety the possible victims and the firefighters themselves may be at stake.

One factor that can have a serious impact on physical as well as mental performance during emergency operations is the thermoregulatory strain that firefighters encounter (Hancock et al. 2007). The high metabolic rate associated with firefighting in combination with wearing personal protective equipment (PPE), and the sometimes extreme environmental temperatures impose severe thermoregulatory and cardiovascular strain on firefighters (Rossi 2003; Smith et al. 2001; Fernhall et al. 2011; Cheung et al. 2011; Smith et al. 1997). During firefighting simulations, increases in rectal temperature to values over 38.5°C (Smith et al. 2001; Romet and Frim 1987), and a rise in mean skin temperature to values over 37°C (Romet and Frim 1987; Eglin et al. 2004) have been observed. Although it is generally accepted that at the attainment of a critical core temperature of approximately 40°C exercise performance is seriously compromised and physiological functioning may be hampered (Gonzalez-Alonso et al. 1999), also core temperatures well below this value have been associated with impaired exercise performance (Ely et al. 2010). This is especially relevant when individuals are able to adopt a pacing strategy and can select the intensity at which they are exercising. It is proposed that both anticipation and feedback mechanisms play an important role in the regulation of exercise intensity (Tucker and Noakes 2009). In the heat, the main goal of this regulation appears to be to minimize the heat storage and thereby ensure successful completion of the task. Starting core temperature (Gonzalez-Alonso et al. 1999), skin
temperature (Schlader et al. 2011b), rate of heat storage (Tucker et al. 2004), and thermal perceptions (Schlader et al. 2011a) have all been associated with the anticipation/feedback driven regulation of exercise intensity and appear to be inversely related to self-paced exercise performance.

Because sport activities as well as performing station chores and sitting outside on a warm day can increase firefighters’ body temperature, these activities possibly impair firefighting performance during subsequent emergency operations by causing a fatigue-related reduction in both speed and quality of performance. Starting with a higher core temperature results in a decreased margin for metabolic heat storage, and consequently the time that exercise can be performed at a given intensity is reduced (Mol et al. 2007).

In order to delay or prevent an excessive rise in body temperature, firefighters need to reduce exercise intensity or change pacing strategy to successfully complete the task and ensure that physiological limits are not surpassed (Tucker and Noakes 2009). Not only the increase in body temperature, but also other factors related to the activities (e.g. increased cardiovascular strain, peripheral muscle fatigue) can cause reductions in work efficiency during a subsequent emergency operation (Dennison et al. 2012).

Most studies investigating firefighting have focused on thermoregulatory and physiological strain (Smith et al. 2001; Smith et al. 1996; Eglin et al. 2004; Romet and Frim 1987). However, it is still not clear what the effect of this strain is on firefighting performance. Although the effect of body heat content on general exercise performance has been studied extensively (Gonzalez-Alonso et al. 1999; Galloway and Maughan 1997; Tatterson et al. 2000), the effect of an increased core temperature on quality and speed of specific firefighting activities is still unknown. Therefore, the goal of this study was to determine the effect of active pre-warming on physiological and perceptual responses, speed, and quality of performance during simulated firefighting exercise. We hypothesized that the physiological and perceptual changes induced by pre-warming would reduce the speed as well as the quality of performance during simulated firefighting exercise.
METHODS

Participants

Twelve male firefighters were recruited for this study from fire departments near the testing facility. The characteristics of the participating firefighters were (mean ± SD): age 37 ± 6 years, body mass 85 ± 9 kg, and height 184 ± 5 cm. Each participant gave written informed consent after receiving detailed information about the study, and after being screened for known contraindications to exercise in the heat. The study was approved by the Research and Ethics Committee of TNO, The Netherlands. Each firefighter was tested at the same time of the day to avoid circadian variation in core and skin temperatures. The firefighters were instructed to avoid strenuous physical activity during the 24 hours leading up to a trial. They consumed a standardized meal on the evening preceding the tests, refrained from alcohol and caffeine during the previous 24 hours and consumed a light, standardized meal before coming to the field lab at the Education and Training Centre of the Amsterdam Fire Service at Schiphol Airport (BOCAS). During the simulated firefighting activity, the firefighters wore standard PPE, consisting of rubber boots, bunker pants, cotton undershirt, jacket, heavy-duty gloves, Gallet firefighter’s helmet, and a self-contained breathing apparatus (SCBA).

Overview of the experiment

Each firefighter completed a familiarization trial and two experimental trials; a control trial (CON) and a pre-warming trial (WARM), performed in a counterbalanced order and at least three days apart to ensure adequate recovery. Each trial started with a 30-min passive habituation period in 20°C during which the firefighters received detailed information about the experimental protocol and more specifically about the components of the upcoming simulated firefighting activity. In CON, the habituation period was followed by a 20-min rest period, in which the firefighters remained seated in 20°C. After the rest period, they were given five minutes to change into their PPE and after this the simulated firefighting activity started. In WARM, the habituation period was followed by an active pre-warming protocol consisting of 20-min cycling on a cycle ergometer.
(Ergoselect 200, Ergoline GmbH, Bitz, Germany) at 1.5 W·kg\(^{-1}\) body mass in 20°C. The active pre-warming was followed by five minutes to put on the PPE and the simulated firefighting activity. During the habituation and pre-warming, the firefighters wore underwear, shorts, a cotton shirt, and running shoes. The firefighters were allowed to drink tap water at room temperature ad-libitum during the rest and pre-warming period.

**Simulated firefighting activity**

The simulated firefighting activity was performed in a gas-burned testing facility (burn building) that was a model of a four story house. Within the burn building, live fires and smoke could be applied in a standardized manner by a computer operator in a control room overlooking the facility. Therefore, all the simulated firefighting activities, including the firefighting tasks, temperature inside the testing facility, smoke and fire, were identical for each firefighter during all the trials. The simulated firefighting activity consisted of three combined fire extinguishing and search-and-rescue tasks that had to be completed within the testing facility. The firefighters were instructed to complete these tasks as fast as possible and with the highest quality, applying the standardized operating procedure (SOP). The SOPs for these tasks were uniform across the different departments from which firefighters were recruited. The first task of the firefighters was to extinguish a fire on the third floor. For this task, firefighters had to unroll and carry a fire hose from the ground floor to the third floor. On arrival, a kitchen fire was simulated and the fire would only stop when the temperature of a sensor located within the fire decreased below a threshold value and remained below this threshold for 10 seconds, indicating successful fire extinguishing. After extinguishing the fire, firefighters had to return to the ground floor while carrying the fire hose. The second task was to search-and-rescue a dummy (30 kg) on the fourth floor (attic) while this room was filled with smoke. For this task, firefighters did not have to carry the fire hose because no fire was simulated. On arrival at the attic, the firefighters performed the search-and-rescue task and after finding the dummy, they were instructed to carry this dummy down to the ground floor and bring it to a ‘safe’ location outside the burn building. The third task was to search-and-rescue a baby dummy (5 kg) and extinguish a fire on the second floor. For this task, the firefighters
had to carry the fire hose with them to the second floor, rescue the baby dummy and take it to a ‘safe’ location outside the burn building. After rescuing the baby dummy, they returned to the second floor to extinguish the fire. Again, the fire would only stop when the temperature of a sensor located within the fire decreased below a threshold value and remained below this threshold for 10 s. After extinguishing the fire, the firefighters carried the fire hose down to the ground floor and the simulated firefighting activity was finished. The activity was designed for a duration of approximately 20 min.

During the complete simulated firefighting activity, two experienced firefighter instructors accompanied the firefighters for safety reasons. Also, they instructed the firefighters about the task to perform and ranked their performance. The two instructors were always the same for each scenario and apart from giving standardized instructions to the firefighters, no assistance was provided. The selected firefighting tasks were realistic representations of real-life firefighting actions and were perceived as such by the firefighters. The temperature within the burn building fluctuated widely from room to room due to the selective presence of fire. The firefighters reported that the conditions inside the burn building were comparable to real-life firefighting conditions.

**Measurements**

At least four hours before arrival at the field lab, participants ingested a disposable core temperature capsule (Jonah, Hidalgo, Cambridge, UK) to measure gastrointestinal temperature \(T_{GI}\). Upon arrival at the field lab, firefighters were equipped with a Hidalgo Equivital™ Physiological Monitor system (Hidalgo, Cambridge, UK) to record \(T_{GI}\) and heart rate (HR) at 15-s intervals. These measurements continued until the end of the trial. To determine mean skin temperature \(\bar{T}_{sk}\) (\(^\circ\)C), four iButtons (DS1922L, Maxim Integrated Products Inc, Sunnyvale, CA, USA) were taped to the skin (neck, right scapula, right shin, left hand) using sweat-proof tape (Fixomull stretch, BSN Medical, Hamburg, Germany). Mean skin temperature was calculated using equation 8.1 (ISO9886 2004).

\[
\bar{T}_{sk} (\circ C) = 0.28 \cdot (T_{neck} + T_{right\ scapula} + T_{right\ Shin}) + 0.16 \cdot T_{left\ hand} \quad \text{(Equation 8.1)}
\]
Mean body temperature ($T_b$) was calculated using equation 8.2 (Burton 1935; Gisolfi and Mora 2000).

$$T_b (°C) = 0.7 \cdot G_I + 0.3 \cdot T_{sk} \text{ (Equation 8.2)}$$

To determine speed of performance and pacing strategy, ten split times were recorded at standardized moments during the simulated firefighting activity. Quality of performance was rated by the firefighting instructors (expert opinion) and the firefighters themselves directly after the simulated firefighting activity. The firefighting instructors were blinded to the experimental condition and were therefore not aware if a firefighter was pre-warmed before the start of the simulated firefighting activity. The quality of performance was assessed with a questionnaire that is commonly used in the evaluation of firefighting performance (NBBE, Capelle aan den IJssel, The Netherlands). The questions concerned preparation, safety, movement technique, dealing with victims, and performance under stress. Ratings were given on a 5-point scale (1 = bad, 2 = unsatisfactory, 3 = poor, 4 = satisfactory, 5 = good). Besides completing the questionnaire, the instructors and firefighters also ranked the performance on a scale from 1 (extremely poor) to 10 (perfect). The final score of the quality of performance was determined by averaging the scores of all the questions and is presented on a scale with a range from 1 (lowest possible score) to 10 (highest possible score).

RPE was recorded at the start of the simulated firefighting activity and after each of the three tasks on a 6-20 scale (Borg 1970). A 9-point scale (ranging from -4: very cold to 4: very hot) was used to determine the firefighters’ thermal sensation (TS) and a 5-point scale was used to determine the perception of thermal comfort (TC) (ISO10551 1993). TS and TC were determined at the same moments as RPE during the exercise.

**Statistical Analysis**

Statistical analysis was performed using SPSS statistical software (SPSS 17.0, SPSS Inc., Chicago, IL, USA). Experimental condition (CON, WARM) was the independent variable, whereas duration of the simulated firefighting activity, duration of the specific tasks within
the simulated firefighting activity, $T_{Gi}$, $T_{sk}$, $T_{b}$, HR, RPE, TS, and TC were the dependent variables. The significance of effects of experimental condition on the dependent variables over time (parts of the simulated firefighting activity) was determined using two-way ANOVAs for repeated measurements. Paired-sample t-tests were used to determine the significance of the effect of experimental condition on total duration of the simulated firefighting activity, duration of the specific tasks within the activity, and quality of performance. Moreover, paired-sample t-tests were used to evaluate the effect of experimental condition on $T_{Gi}$, $T_{sk}$, $T_{b}$, and HR at distinct moments during the trial (start of pre-warming, end of pre-warming, start of simulated firefighting activity, and the end of activity). Statistical significance was set at the 5% level for each analysis. Values are reported as mean ± SD.

RESULTS

Temperature patterns

After the passive habituation period, $T_{Gi}$ was similar in CON (37.1 ± 0.3°C) and WARM (37.1 ± 0.4°C; $P=0.74$). During the active pre-warming period, $T_{Gi}$ increased by 0.6 ± 0.2°C ($P=0.004$) in WARM, whereas in CON, $T_{Gi}$ remained similar. This resulted in a $T_{Gi}$ of 37.1 ± 0.3°C in CON and 37.7 ± 0.3°C in WARM at the end of the active pre-warming period ($P<0.001$). During the simulated firefighting activity, $T_{Gi}$ increased similarly for WARM and CON (interaction effect of condition * time: $P=0.23$). $T_{Gi}$ at the end of the simulated firefighting activity was higher for WARM (38.4 ± 0.4°C) than for CON (37.8 ± 0.4°C; $P<0.001$). $T_{Gi}$ during the active pre-warming and the simulated firefighting activity is presented in Figure 8.1a.
Figure 8.1 GI temperature (a) and mean skin temperature (b) during the experimental trials. * Higher T\textsubscript{GI} for WARM than for CON (P<0.001). \# Higher T\textsubscript{GI} for WARM than for CON during the simulated firefighting activity (P<0.001). † Higher T\textsubscript{sk} for WARM than for CON (P<0.05).

\textbf{Tsk} at the start of the pre-warming period was not different between CON (31.4 ± 1.1°C) and WARM (32.2 ± 0.9°C; P=0.09; Figure 8.1b), but after the active pre-warming \textbar{Tsk} was higher in WARM (34.0 ± 0.5°C) than in CON (32.5 ± 0.8°C; P=0.002). During the simulated firefighting activity, skin temperature was not different between CON (\textbar{Tsk}: 32.2 ± 0.7°C) and WARM (\textbar{Tsk}: 32.8 ± 0.7°C; P=0.14). Also \textbar{Tsk} at the end of the simulated firefighting activity was similar (CON: 32.7 ± 1.4°C, WARM: 33.3 ± 0.9°C; P=0.11).

In line with \textsubscript{TGI} and \textbar{Tsk}, T\textsubscript{b} was higher after the active pre-warming period in WARM (36.6 ± 0.3°C) than in CON (35.8 ± 0.4°C; P=0.002) and this difference was maintained until the
end of the simulated firefighting activity (WARM: 37.0 ± 0.5°C and CON: 36.3 ± 0.7°C; P=0.03).

**Speed and quality of performance**

Time to completion of the simulated firefighting activity showed a trend to be shorter for CON (16:28 ± 1:30 min) than for WARM (19:08 ± 4:19; P=0.08). No difference in time to completion was observed for the first task of the simulated firefighting activity, whereas the second task showed a trend to be shorter in CON than in WARM (P=0.21 and P=0.08, respectively). The third task was completed faster in CON (6:15 ± 0:44) than in WARM (6:58 ± 0:57; P=0.04). Time to completion of the complete simulated firefighting activity and its three tasks is presented in Figure 8.2.

![Figure 8.2 Duration of the total simulated firefighting activity and of the three different tasks. * Shorter duration of the task for CON than for WARM (P<0.05).](image)

The firefighting instructors ranked the quality of the performance during the simulated firefighting activity similarly for CON and WARM (6.6 ± 1.4 and 7.1 ± 1.6 on a 10-point scale, respectively; P=0.47). This is in contrast with the firefighters’ own judgment of their
performance. They ranked the quality of their performance higher for CON than for WARM (7.0 ± 0.5 vs. 6.5 ± 0.7, respectively; P=0.04).

**Heart rate**

Heart rate increased during the active pre-warming period in WARM (from 82 ± 8 beats·min⁻¹ to 144 ± 24 beats·min⁻¹; P<0.001; Figure 8.3) and HR at the end of the pre-warming period was higher in WARM than in CON (83 ± 12 beats·min⁻¹, respectively; P<0.001). HR during the simulated firefighting activity was not different between CON (147 ± 21 beats·min⁻¹) and WARM (158 ± 24 beats·min⁻¹; P=0.11) and also HR at the end of the activity was similar (CON: 159 ± 21 beats·min⁻¹, WARM: 162 ± 31 beats·min⁻¹; P=0.81).

![Figure 8.3](image)

*Figure 8.3* Heart rate during the pre-warming and simulated firefighting activity. * Higher HR for WARM than for CON during the active pre-warming (P<0.001).

**Psychophysiological parameters**

RPE during the simulated firefighting activity was higher from the start onwards with mean values of 14.4 ± 1.4 in WARM and 12.2 ± 1.1 in CON (P<0.001), corresponding to ‘heavy’ and ‘somewhat heavy’. Also TS and TC were higher for WARM (TS: 1.7 ± 0.5; TC:
2.4 ± 0.7) than for CON (TS: 1.2 ± 0.3, P=0.02; TC: 1.8 ± 0.4, P=0.03) during the entire simulated firefighting activity, indicating that the firefighters felt warmer and more uncomfortable in WARM than in CON.

**DISCUSSION**

The goal of this study was to evaluate the effect of active pre-warming on physiological and perceptual responses, speed, and quality of performance during a simulated firefighting activity. The main finding is that active pre-warming increases GI temperature, mean skin temperature and HR, reduces speed during the last part of a simulated firefighting activity and reduces self-reported quality of performance. Because our hypothesis was that physiological and perceptual changes induced by the active pre-warming would reduce the speed as well as the quality of firefighting performance, we can only partly accept the hypothesis.

To increase body temperature we pre-warmed firefighters by 20 minutes of low-intensity (1.5 W·kg⁻¹ body mass) cycling exercise. This intensity was selected as it is a realistic representation of the (low) intensity of the activities that firefighters generally perform in the firehouse (e.g., working out, training, cleaning) (Bos et al. 2004). A difference between this warm-up protocol and exercise generally performed in the firehouse is the relatively large contribution of strain to the lower extremities. The pre-warming resulted in a substantial increase in mean body temperature, calculated from core and skin temperature. Also, heart rate after this active pre-warming period was significantly higher than in the control condition. The higher thermoregulatory and cardiovascular strain after the pre-warming period was only partly extended into the simulated firefighting activity. Although mean skin temperature and heart rate were similar during the activity, gastrointestinal temperature remained higher during the entire simulated firefighting activity. Moreover, thermal sensation and thermal comfort scores were higher during the entire simulated firefighting activity for WARM than for CON. The values that we found for gastrointestinal temperature, skin temperature, and heart rate during the activity are
similar (Romet and Frim 1987; Eglin et al. 2004), or slightly lower (Smith et al. 2001; Smith et al. 1997) than found in previous studies using live-fire exercise protocols.

After the pre-warming period, the simulated firefighting activity was completed approximately 3 minutes slower in WARM than in CON. Although this difference was not statistically significant, it can be of great practical relevance, especially when human lives depend on efficient emergency responding. Of special interest is the significant slowing during the final task of the simulated firefighting activity. This reduction in work rate is a commonly observed phenomenon in studies on the effect of heat stress on self-paced sport performance (Tatterson et al. 2000; Tucker et al. 2004), but has not yet been reported in firefighting exercise. Lowering the work rate modulates the rise in core temperature and it thereby delays or prevents the attainment of a core temperature at which homeostasis could become compromised (Marino 2004; Tucker et al. 2006). Apart from the higher mean body temperature, also the possible lower extremity fatigue caused by the cycling protocol may have caused the slowing down towards the end of the simulated firefighting activity. The absence of statistical significant differences in time to completion of the first two tasks of the simulated firefighting activity in CON and WARM may be explained by the large variation between firefighters. It appears that the starting strategy in the early parts of the simulated firefighting activity differs greatly between firefighters, possibly because of uncertainty about the remaining exercise duration and its effect on their quality of performance.

The RPE is proposed as the integrator of relevant physiological and environmental signals within the anticipatory/feedback model of performance regulation (Tucker 2009). When the rate of rise in RPE is unacceptable, the work rate is decreased as a compensatory mechanism. The higher RPE we observed for WARM compared to CON is most likely a result of the physiological changes induced by the pre-warming. This resulted in down-regulation of the work rate in the final part of the simulated firefighting activity by adjusting the recruitment of skeletal muscle recruitment in order to slow the endogenous heat production and prevent failing to successfully complete the activity (Tucker and Noakes 2009). As suggested by Schlader et al. (2011a), not only physiological signals, but
also less favorable thermal perceptions (TS and TC) may play a role in the down-regulation of exercise intensity in WARM.

A novel aspect of this study is the evaluation of the quality of performance of the specific firefighting tasks by both experts and the firefighters themselves. So far, we are not aware of studies that used expert opinion and self-judgment to evaluate the performance of firefighters in a life-fire simulation. Our main finding was that expert opinion revealed no differences between WARM and CON. Apparently, maintaining quality and reducing speed was preferred over lowering quality and maintaining speed. This observation complies with firefighting training and education in which firefighters are instructed to always execute tasks according to strict procedures, even in stressful settings. Interestingly, firefighters themselves perceived their performance to be of a lower quality after pre-warming, suggesting that either physiological changes, perceptual changes, or a combination of these two, induced by pre-warming, resulted in a blurred perception of own performance quality. This finding is in line with Daanen et al. (2013), who observed a lower self-judgment of jumping performance in the heat by trained athletes. These findings indicate that self-reported quality of performance in the heat may not be a good representation of the actual performance quality.

One of the unique aspects of this study is the completion of realistic firefighting activity in a burn building. Although several studies investigated the physiological strain associated with exercise performed in personal protective equipment (Bakri et al. 2012; Smith et al. 2012) and with firefighters performing specific firefighting exercise in challenging environments (Smith et al. 1997; Holmer and Gavhed 2007; Rossi 2003; Rodriguez-Marroyo et al. 2011; Petruzzello et al. 2009), no studies looked at the effect of this physiological strain on speed and quality of performance. The simulated firefighting activity in this study was composed in close collaboration with experienced firefighters and firefighting instructors. This resulted in three distinct firefighting actions that resembled the major strenuous activities of firefighting in real life; extinguishing fires, stair climbing, and victim search-and-rescue.
Based on the results of this study, it can be concluded that the intensity of activities in the firehouse should be low enough to prevent a considerable rise in core temperature and heart rate, especially because the speed of firefighting exercise is already reduced in the final part of one 20-min activity. Since physical exercise has been shown to reduce the chance of non-exercise injuries in firefighters (Jahnke et al. 2013), and reduces obesity-related work absenteeism (Poston et al. 2011), we would not advise firefighters to stop exercising in the barracks, but to reduce the intensity and think carefully about the timing of the work-outs and other activities that increase body temperature.

Since in real life, firefighters frequently have to perform several consecutive firefighting activities during an emergency operation, the negative effect of increased body heat content on firefighting performance is expected to be even greater during actual-life firefighting. One way to improve firefighters’ performance during emergency operations could be starting at a slower pace. The slower initial pace reduces endogenous heat production resulting in a lower rate of heat storage. By applying this strategy, the occurrence of fatigue can be prevented or delayed, leading to improved performance.

**CONCLUSION**

Active pre-warming increases gastrointestinal temperature, mean skin temperature and HR, leading to a reduced speed during the last part of a simulated firefighting activity and reduced self-reported quality of performance.