Applied Ergonomics xxx (2014) 1–6

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

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

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ARTICLE INFO

Article history:
Received 20 September 2013
Accepted 14 April 2014
Available online xxx

Keywords:
Live-fire drill
Heat stress
Pacing

ABSTRACT

This study examined the effect of active pre-warming on speed and quality of performance during simulated firefighting exercise. 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. 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, rating of perceived exertion, thermal sensation and discomfort 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 ($P = 0.04$). It is concluded that pre-warming reduces the speed during the last part of simulated firefighting activity and reduces self-reported quality of performance.

1. 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 of 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 (Cheung et al., 2011; Fernhall et al., 2011; Rossi, 2003; Smith et al., 2001, 1997). During firefighting simulations, increases in rectal temperature to values over 38.5 °C (Romet and Frim, 1987; Smith et al., 2001), and a rise in mean skin temperature to values over 37 °C (Eglin et al., 2004; Romet and Frim, 1987) 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)

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http://dx.doi.org/10.1016/j.apergo.2014.04.011
0003-6870/

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 and 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 (Eglin et al., 2004; Romet and Frim, 1987; Smith et al., 2001, 1996). 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 (Galloway and Maughan, 1997; Gonzalez-Alonso et al., 1999; 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.

2. Materials and methods

2.1. 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 h 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 h 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).

2.2. 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 Watt 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.

2.3. 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 s, 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 entire simulated firefighting activity, two experienced firefighter instructors accompanied the firefighters for safety reasons. Also, they instructed the firefighters about the task to

Please cite this article in press as: Levels, K., et al., The effect of pre-warming on performance during simulated firefighting exercise, Applied Ergonomics (2014), http://dx.doi.org/10.1016/j.apergo.2014.04.011