Effect of Menthol on Respiratory and Perceptual Responses to Exercise in Firefighter Protective Gear

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ABSTRACT

Impaired respiration reduces firefighters’ work capacity. This study evaluated the effect of menthol lozenge on respiratory and perceptual responses during exercise in a hot environment. Ten participants wearing firefighter protective gear performed two repeated exercise and rest trials in a counter-balanced order. Exercise consisted of two bouts of 20-min treadmill exercise at 60% of maximal oxygen uptake and one bout of 20-min stepping exercise at a wet bulb global temperature of 35°C. Participants either took 10-mg menthol or control lozenges prior to the beginning of each exercise bout. Respiratory gas exchange, heart rate, thermal sensation, and breathing comfort were continuously recorded. Menthol lozenges significantly increased pulmonary ventilation (menthol: 45.0±6.6 L·min⁻¹ vs. control: 41.4±5.8 L·min⁻¹ and menthol: 52.7±9.7 L·min⁻¹ vs. control: 46.5±7.0 L·min⁻¹, for the 1st and 2nd treadmill exercise, respectively) and oxygen consumption (menthol: 26.7±2.0 ml·kg⁻¹·min⁻¹ vs. control: 25.2±2.3 ml·kg⁻¹·min⁻¹ and menthol: 28.8±2.3 ml·kg⁻¹·min⁻¹ vs. control: 26.9±1.9 ml·kg⁻¹·min⁻¹, for the 1st and 2nd treadmill exercise, respectively) (p<0.05). The effect of menthol on respiration disappeared during the stepping exercise (p>0.05). The ventilatory equivalents though were not different throughout the exercise (p>0.05). Ratings of thermal sensation and breathing comfort were not different (p>0.05). It was concluded that menthol could alter breathing pattern and increase respiratory responses during strenuous exercise in the heat. There was no favorable effect of menthol on respiratory or perceptual responses under exercise-heat stress.

Key words: Firefighter, protective clothing, respiration, oxygen consumption.

Introduction

The high metabolic demand of firefighting is a complex result of strenuous muscular work, heavy equipment (Gledhill & Jammik, 1992), impermeable protective clothing ensemble (Romet & Frim, 1987), and challenging environments (Smith, Petruzzello, Kramer, & Misner, 1997). In addition, hazardous work environments require firefighters to wear a self-contained breathing apparatus (SCBA) for respiratory protection. SCBA could result in a sharp decrease in pulmonary ventilation (VE) and oxygen consumption (VO₂) (Eves, Jones, & Petersen, 2005; Louhevaara, Smolander, Tuomi, Korhonen, & Jaakkola, 1985) hence a substantial reduction in maximal work capacity (Eves et al., 2005).

Menthol is of great interest for two practical reasons. First, the oral cavity is a major airway entrance during strenuous exercise and when menthol is administrated orally, it reduces sensation of respiratory discomfort (Eccles, 2003). Menthol ingestion has been shown to induce bronchodilation (Wright, Laude, Grattan, & Morice, 1997), and this mechanistic influence on the airways expansion has been suggested to be via inhibition of sensory afferents and relaxation of airway smooth muscle (Ahijevych & Garrett, 2004; Maher et al., 2014). Previous study (Mundel & Jones, 2010) investigating swilling a menthol solution on exercise capacity in the heat found that fatigue was delayed and VE increased. Considering the impaired respiration greatly reduces firefighters’ maximal exercise performance (Eves et al., 2005; Louhevaara et al., 1985), this may provide a situation where menthol has practical applications. Second, when menthol is applied to the mucosal surfaces it triggers a cool sensation (Eccles, 2003) which is perceived as refreshing and stimulating during exercise (Mundel & Jones, 2010). Menthol might provide relief effect from thermal and/or breathing discomfort during strenuous exercise in the heat. Therefore, menthol ingestion is clearly appealing from both physiological and perceptual point of view.

Accordingly, this study evaluated the effect of menthol on respiratory and perceptual responses to exercise in firefighter protective gear in a hot environment. Reducing stressors could be of great importance for firefighter’s health, safety, and performance.
Methods

Participants

Ten physically active male volunteers for this study. This study was conducted in autumn season and participants were acclimatized to heat during the study period. Heat acclimation could cause adaptation of exercise ventilation during hyperthermia hence may mask potential effects of menthol on respiration (Beaudin, Clegg, Walsh, & White, 2009). A minimum aerobic fitness of 40 ml·kg⁻¹·min⁻¹ was required in order to participate in this study (Bilzon, Scarpello, Smith, Ravenhill, & Rayson, 2001). Mean ± standard deviation (SD) characteristics of the participants were: age 24±4 yr, height 179±6 cm, weight 76.3±15.3 kg, body fat percentage (Pollack, Schmidt, & Jackson, 1980) 8±5%, and VO₂max 52.8±5.3 ml·kg⁻¹·min⁻¹. This study was approved by the university’s Institutional Review Board and all participants provided written consent before participation.

Experimental design

An outline of the study design is shown in Figure 1. The first laboratory visit entailed assessment of participants’ VO₂max and maximal heart rate (HRmax), as well as establishing the individualized workload by spirometry (Parvo 2400, ParvoMedics, Sandy, UT). Briefly, the treadmill exercise consisted of 4 bouts of 4 min of walking on a motor-driven treadmill (Model 18-60 Treadmill; Quinton Instrument Co., Seattle, WA) to elicit a metabolic rate of 60% VO₂max followed by 1 min of 10 arm curls (bar weighing 4.5 kg). The stepping exercise consisted of 4 bouts of constant-cadence stepping exercise; each bout consisted of 4-min stepping at a rate of 25 steps·min⁻¹ on a 40-cm high platform, followed by 1-min of 10 arm curls. The stepping exercise was intended to simulate stair climbing, a common activity for firefighters.

Results

There were one menthol trial and one control trial stopped near the end of the stepping exercise (5 min earlier) due to par-
Participants’ volition. No difference of fluid intake was found: menthol 1535±909 ml vs. control 1394±546 ml (p>0.05). Heart rate responses are presented in Figure 2. At the end of the 20-min stepping exercise, mean heart rates corresponded to 94±6% and 95±5% of HRmax for menthol and control, respectively. There were no significant differences between the two conditions (p>0.05).

![Figure 2](image)

**Figure 2.** Mean (± standard deviation) heart rate responses.

Respiratory responses are presented in Table 1. VE and VO2 were significantly higher for menthol compared to control during the 1st and 2nd treadmill exercise (p<0.05). Menthol significantly increased \( f_b \) by a mean of 5 breaths·min\(^{-1}\) compared to control during the 2nd treadmill exercise (p<0.05). VE/VO2 was not different (p>0.05) throughout the trials.

**Table 1.** Pulmonary Ventilation (VE), Oxygen Consumption (VO2), Breathing Frequency (\( f_b \)), and Ventilatory Equivalent (VE/VO2)

<table>
<thead>
<tr>
<th>Respiration</th>
<th>1st treadmill exercise</th>
<th>2nd treadmill exercise</th>
<th>Stepping exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Menthol</td>
<td>Control</td>
<td>Menthol</td>
</tr>
<tr>
<td>VE (L·min(^{-1}))</td>
<td>45.0±6.6*</td>
<td>41.4±5.8</td>
<td>52.7±9.7*</td>
</tr>
<tr>
<td>VO2 (ml·kg(^{-1})·min(^{-1}))</td>
<td>26.7±2.0*</td>
<td>25.2±2.3</td>
<td>28.8±2.3*</td>
</tr>
<tr>
<td>( f_b ) (breaths·min(^{-1}))</td>
<td>29±7</td>
<td>27±4</td>
<td>34±9*</td>
</tr>
<tr>
<td>VE/VO2</td>
<td>27.3±4.2</td>
<td>26.4±2.5</td>
<td>29.4±4.2</td>
</tr>
</tbody>
</table>

*Significantly different from control, p<0.05.

Analysis of individual data (Figure 3) revealed that seven of the ten participants responded to the menthol treatment during the 1st treadmill exercise, five responded during the 2nd treadmill exercise, and three responded during the stepping exercise. There was no treatment effect on perceptual responses (Figure 4) (p>0.05).

![Figure 3](image)

**Figure 3.** Individual responses to the menthol treatment on pulmonary ventilation. The solid line represents responder, and the dotted line represents non-responder.
Discussion

In this study, repeated exercise-heat stress resulted in comparable cardiovascular and respiratory strains to previous reports of field firefighting activities (Holmer & Gavhed, 2007; Smith, Manning, & Petruzzello, 2001). Previous study reported an increase in VE by 8 L·min⁻¹ following menthol swilling whereas no change in VO₂ (Mundel & Jones, 2010). Though we found VE increased by 3.6 L·min⁻¹ (+8%) and 6.2 L·min⁻¹ (+13%) during the 1st and 2nd treadmill exercise, VO₂ correspondently increased by 1.5 ml·kg⁻¹·min⁻¹ (+5.6%) and 1.9 ml·kg⁻¹·min⁻¹ (+7.1%) and the ventilatory equivalences were not different, suggesting the metabolic cost increased following the menthol treatment. In addition, oral administration of menthol has been suggested to reduce the effort of breathing (Mundel & Jones, 2010) and induce subjective sensation of improved airflow (Eccles, Jawad, & Morris, 1990) whereas our participants did not show better breathing comfort. These findings suggest that there is no physiological or perceptual advantage in our test condition.

It is unclear of the mechanism accounting the unexpectedly increase in the energy cost of breathing. A possible explanation for this result would be the pattern of menthol delivery. Previous study (Mundel & Jones, 2010) had their participants swilling menthol solution for a short time and cool fluid (19°C) was available, and menthol swilling was repeated every 10 min during the exercise period. Whereas in our study, menthol was delivered via lozenge and no fluid was available during the exercise periods. As exercise ensued, participants reported that the menthol lozenge became unpleasant due to its sweetness. This became obvious after the 2nd treadmill exercise, when participants were already sweating profusely and reported being thirsty. Repeated menthol swilling accompanied with cool fluid consumption may favor respiratory responses during exercise-heat stress.

Repeated workouts are a common scenario for firefighters to change the SCBA gas tank. Individual data offer additional insight on the treatment effect during repeated exercise. Menthol appears to exert its effect on VE initially and tended to be not effective after a short period of time. When the responders and non-responders were added together across the three exercise bouts (10 participants in 3 exercise bouts = 30 exercise occasions) the total number of responders was 15/30, suggesting a null effect. It is unclear to why the physiological action of menthol diminished as exercise ensued. It is possible that menthol induces earlier onset bronchodilation (Wright et al., 1997), as exercise ensues and the airways open up, this effect dissipates thereby reducing the effect of menthol over time. Because the inhibitory effect of menthol on the airway smooth muscle contraction is highly dependent on temperature, with higher temperature suppressing its effect (Ito et al., 2008), it is also possible that the thermal burden resulting from strenuous exercise, protective clothing, and the environment caused menthol’s effect to transiently diminish during the course of exercise. While it is disadvantageous to observe an increase in VO₂ under constant workload, menthol initially stimulated VE in several individuals. Considering firefighter protective clothing
and SCBA induce impaired respiration and negatively impact on maximal aerobic performance (Eves et al., 2005), the stimulative effect of menthol on respiration still warrants further investigation. In short, current results could not clearly explain whether such responses were due to the pharmacological effect of menthol or the specific pattern of delivery.

Occupational workers frequently report breathing discomfort whilst performing physical activity with respirator, which can be attributed to buildup of facial heat within respirator, specifically due to elevations in facial skin temperature (Roberge, Kim, & Coca, 2012). Improving breathing comfort provides practical work stress relief. Further, strenuous exercise in the heat is also related to deterioration in positive moods such as calmness and alertness (Zhang et al., 2014). Comfort is therefore an important consideration while addressing the physiological strain. Menthol can induce a sensation of coolness (Eccles, 2003) and oral administration of menthol reduced the breathing discomfort during loaded breathing (Nishino, Tagaito, & Sakurai, 1997). However, neither ratings of thermal sensation nor breathing comfort supported those notions. It is plausible that the high heat content of air in our enclosed chamber area (a load of 35°C WBGT) coupling with the prolonged exercise may have overwhelmed any cool and/or refreshing effect of menthol. During the experimental time, heated room air was breathed throughout the 60-min exercise, and participants reported the air cushioned mask as wet and uncomfortable. The combination of heat and humidity was suggested as primary factors for mask and breathing’s acceptability (Nielsen, Gwosdow, Berglund, & DuBois, 1987; Roberge et al., 2012). Specifically, a heat energy content of 70-80 Kj·kg⁻¹ air or more could impact on the breathing effort and a warm and humid air of 33°C considerably decreased the mask acceptance (Nielsen et al., 1987). It has been reported that the expired respiratory air temperature was 35.6±0.7°C under a dry-heat condition (45°C ambient temperature and 20% relative humidity) (Livingstone, Nolan, Cain, & Keefe, 1994). Under a humid-heat condition (45°C ambient temperature and 100% relative humidity), the expired respiratory air temperature reached critically high value of 41.8±0.8°C (Livingstone et al., 1994). In our test environment, the dry bulb temperature was 45°C and the relative humidity was 40%. Within the tight fit gas collection mask, it is logical to assume very higher micro-environment temperature and humidity within the respirator. The expired air temperature in our participants are plausibly well above the suggested critical air heat content hence severely impacted on the breathing comfort.

In conclusion, current results did not find physiological advantages of menthol during repeated exercise with firefighter protective gear in the heat. The increase in VO₂ together with the lack of a positive perceptual responses would not be useful for firefighters. While it is unclear about the causes of the unexpected increase in VO₂, it might be worthwhile to further explore menthol’s stimulative effect on respiration. Impaired respiration is a detrimental factor for firefighters’ health and performance. A modest improvement in respiration may be of practical importance in emergency situations. It is necessary for industry and exercise physiologists to continue exploring solutions to alleviate this occupational stressor.

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