Monten. J. Sports Sci. Med. 4 (2015) 2: 29–34
Original scientific paper
UDC 614.847.7:[615.232:665.582.8

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

Yang Zhang, Gytis Balilionis and Catalina M. Casaru
The University of Alabama, Department of Kinesiology, Tuscaloosa, AL, USA
Randall E. Schumacker
The University of Alabama, Department of Educational Studies in Psychology, Research Methodology, and Counseling, Tuscaloosa, AL, USA
Yasmin H. Neggers
The University of Alabama, Department of Human Nutrition, Tuscaloosa, AL, USA
Matthew D. Curtner-Smith and Mark T. Richardson
The University of Alabama, Department of Kinesiology, Tuscaloosa, AL, USA
James M. Green
The University of North Alabama, Department of Health, Physical Education and Recreation, Florence, AL, USA
Phillip A. Bishop
The University of Alabama, Department of Kinesiology, Tuscaloosa, AL, USA

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 & Jamnik, 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 (VO_2) (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.

Received for publication April 26, 2015

Methods

Participants

Ten physically active male volunteered for this study. This study was conducted in autumn season and participants were unacclimatized 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 VO_{2max} 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' VO_{2max} and maximal heart rate (HR_{max}), 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% VO_{2max} 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.

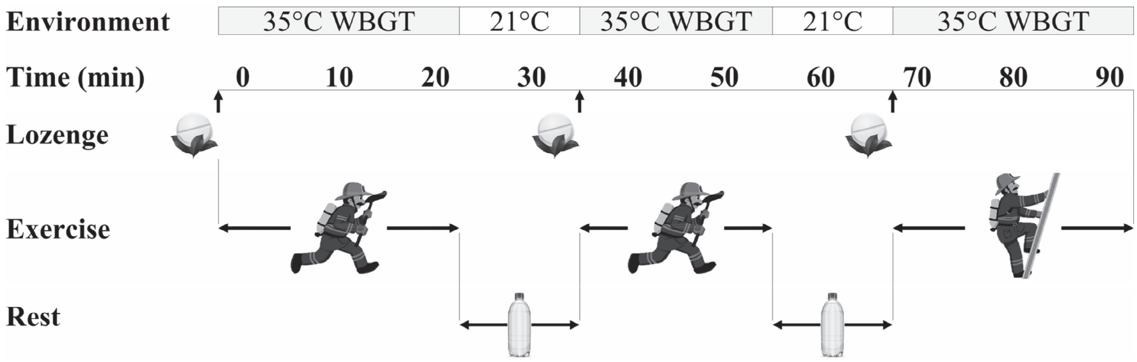

Figure 1. Schematic overview of the experimental protocol (see text for explanation).

Trials were conducted on a weekly basis in a counter-balanced order. Each participant performed their trials at the same time of day and week to avoid any circadian variations' influence. Data were collected in a heat chamber and a laboratory area. Participants exercised in a heat chamber at a wet bulb global temperature of 35°C (wet bulb 31°C, dry bulb 45°C, globe 43°C; 40% relative humidity) and rested in a controlled laboratory with ambient temperature of 21±1°C and relative humidity of 45±3%.

Participants took one menthol or control lozenge prior to each treadmill/stepping exercise. Each menthol lozenge (Chloraseptic Sore Throat Lozenges, Prestige Brands, Irvington, NY) contained 10 mg of menthol and 6 mg of benzocaine. The control lozenge (Cepacol Fizzlers, Combe Inc., White Plains, NY) contained 6 mg of benzocaine. Participants were told to keep menthol lozenge naturally dissolved in the mouth as this would allow the lozenge to last for about 20 min. The control lozenge typically melted in 1 min as reported by participants.

Participants donned a heart rate (HR) monitor (Polar Electro Inc., Lake Success, NY), wore an air cushioned gas measuring face mask and firefighter protective clothing (coat, pants, gloves) and a SCBA tank (Survivair Respirators Inc., USA). A cotton t-shirt and shorts were worn under the clothing ensemble. Running shoes were worn instead of firefighting boots to avoid unnecessary discomfort. After dressing, participants took one lozenge and entered the heat chamber performing the 1st 20-min treadmill exercise; thereafter, participants exited the heat chamber and undertook a 15-min rest period in a seated position. Room temperature tap water was provided *ad libitum* during rest periods. A second lozenge was provided, then participants repeated the 2nd treadmill exercise and rest period. Thereafter, participants took a third lozenge on the same protocol schedule and performed the stepping exercise.

Measurements

Respiratory gas exchange (Parvo 2400, ParvoMedics, Sandy, UT) and HR were continuously collected throughout the exercise periods. VE, VO_2, and breathing frequency (f_b) were calculated for an average 20-min sample. Fluid intake was recorded. Ratings of thermal sensation (TS) (Young, Sawka, Epstein, Decristofano, & Pandolf, 1987) and breathing comfort (BC) (Abadie & Carroll, 1993) were recorded every 10 min throughout the exercise periods. These scales were each presented on large charts, and participants pointed to indicate their current rating.

Statistical analysis

A two-way repeated-measures ANOVA was used to compare menthol and control for respiratory variables, HR, TS, and BC, with Tukey's *LSD* post-hoc test. Fluid intake was compared with the Student's *t*-test. To determine the responders and non-responders to the menthol treatment, individual VE data were also compared by computing the least mean difference yielding a $p<0.05$ at a power of 80% using the mean observed standard deviation. All values were reported as mean (±SD). Alpha level was set at 0.05.

Results

There were one menthol trial and one control trial stopped near the end of the stepping exercise (5 min earlier) due to 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 HR_{max}, for menthol and control, respectively. There were no significant differences between the two conditions ($p>0.05$).

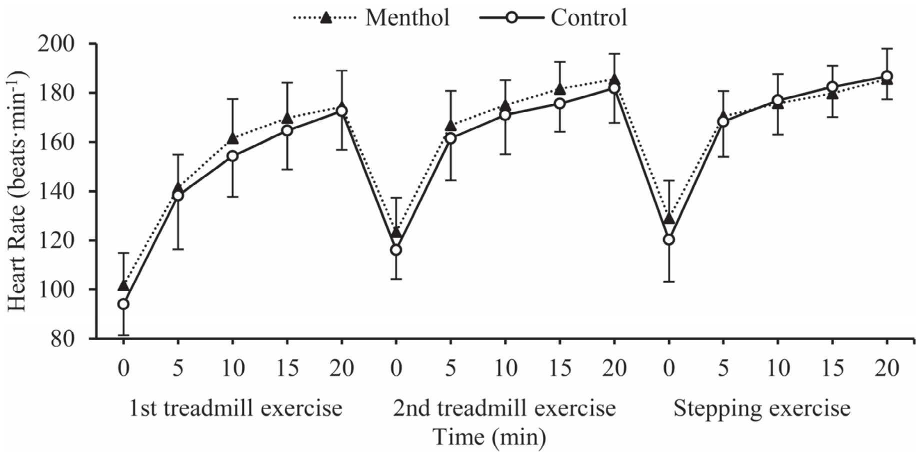

Figure 2. Mean (± standard deviation) heart rate responses.

Respiratory responses are presented in Table 1. VE and VO_2 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/VO_2 was not different ($p>0.05$) throughout the trials.

Table 1. Pulmonary Ventilation (VE), Oxygen Consumption (VO_2), Breathing Frequency (f_b), and Ventilatory Equivalent (VE/VO_2)

Respiration	1st treadmill exercise		2nd treadmill exercise		Stepping exercise	
	Menthol	Control	Menthol	Control	Menthol	Control
VE (L·min^{-1})	45.0±6.6*	41.4±5.8	52.7±9.7*	46.5±7.0	46.8±6.9	43.6±4.4
VO_2 (ml·kg^{-1}·min^{-1})	26.7±2.0*	25.2±2.3	28.8±2.3*	26.9±1.9	25.0±3.6	24.2±3.4
f_b (breaths·min^{-1})	29±7	27±4	34±9*	29±4	32±6	30±6
VE/VO_2	27.3±4.2	26.4±2.5	29.4±4.2	27.8±2.8	30.5±4.5	29.4±3.7

*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) ($p>0.05$).

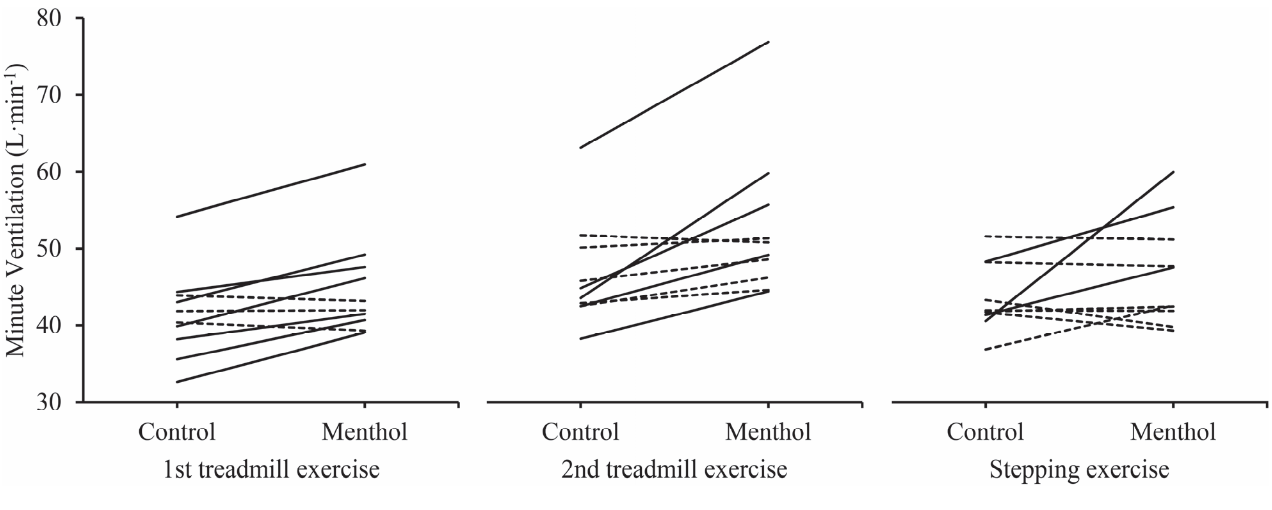

Figure 3. Individual responses to the menthol treatment on pulmonary ventilation.
The solid line represents responder, and the dotted line represents non-responder.

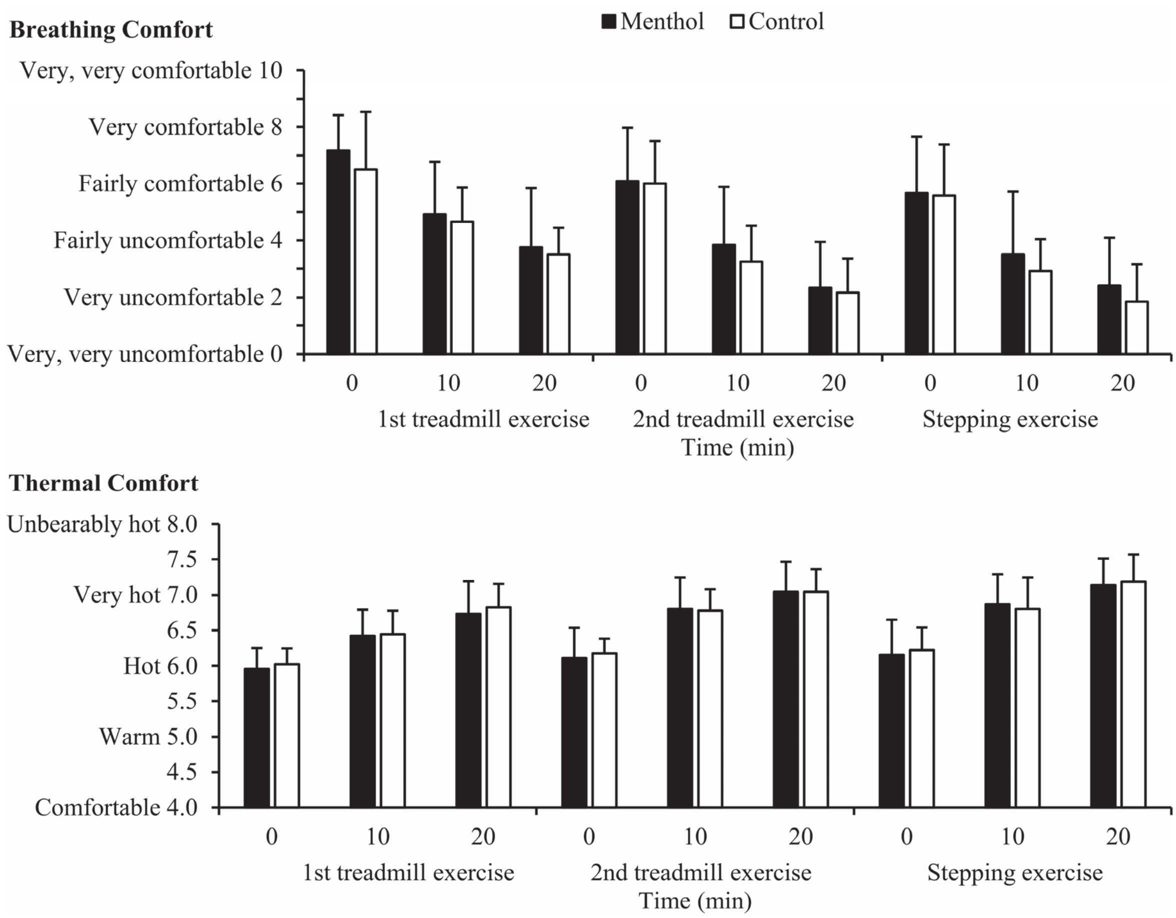

Figure 4. Mean (± standard deviation) ratings of breathing comfort and thermal sensation.

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 VO_2 (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, VO_2 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 VO_2 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 $Kj \cdot kg^{-1}$ 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.

The study is not without limitations. First, the major design weakness is not utilizing SCBA respirator for the respiratory evaluation. The increased respiratory loads whist firefighting are attributed to a variety of factors, including SCBA regulator as its resistance induces the breathlessness (Eves et al., 2005; Louhevaara et al., 1985). The current respiratory evaluation was conducted at ambient barometric pressure with no flow resistance during breathing and it may lead to underestimation of breathing stress. Second, the breathing air content from actual SCBA tank is usually cool and dry, hence, it is unclear how the perceptual responses with the menthol treatment might be altered in field environments. Third, while there is no major difference in the breathing pattern between firefighters and civilians (Donovan & McConnell, 1999), the current experiment was conducted on fit, young, and unacclimatized participants. It is possible however, older firefighters would experience greater cardiorespiratory strain (Choi, Shin, Lee, & Chung, 2014; Prieto, Gonzalez, Del Valle, & Nistal, 2013; Walker, Driller, Argus, Cooke, & Rattray, 2014). The opposite may be found in acclimatized firefighters who are familiar with the clothing ensemble and joint upper-lower body work regime. Fourth, this study used a menthol lozenge containing additional benzocaine, hence, may have impacted on respiration.

In conclusion, current results did not find physiological advantages of menthol during repeated exercise with firefighter protective gear in the heat. The increase in VO_2 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 VO_2, 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.

Acknowledgements

We thank the Tuscaloosa Fire & Rescue Services Department for assisting the firefighter turnout gear.

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Y. Zhang
The University of Alabama, Department of Kinesiology, Moore Hall, Tuscaloosa, AL 35401, USA
e-mail: dr.zhang.yang@qq.com