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Breathing Limited Air Situational Training Masks (BlastMask) Versus Self-Contained Breathing Apparatus (SCBA) for Firefighters: A Pilot Study

THOMAS L. ANDRE‡1, SILVIO VALLADAO†1, SHANA M. WALSH‡2, and DEREK C. REISBECK‡3

[1]Health, Exercise Science, and Recreation Management, University of Mississippi, Oxford, MS, USA; [2]School of Education, Peru State College, Peru, NE, USA; [3]Northshore Fire Protection District, Lucerne, CA, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 12(6): 941-949, 2019. Despite maintaining high levels of fitness, firefighters' performance may be negatively impacted by the use of a Self-Contained Breathing Apparatus (SCBA), an essential piece of safety equipment worn during structural firefighting. Routine training with SCBAs can be cost-prohibitive and inefficient. The Breathing Limited Air Situational Training Mask (BlastMask) was developed as a training aid used to simulate the SCBA. The purpose of this study was to examine physiological and perceptual responses elicited by firefighters during steady state exercise when using the BlastMask compared to the SCBA. Current staff male firefighters (n = 10; mean age = 29.5 ± 7.7; mean BMI = 26.9 ± 2.7) performed two separate 10-minute steady state treadmill exercise sessions: one using an SCBA and one using a BlastMask. Paired-samples t-tests were conducted to determine differences between mean heart rate (HR), mean pulse oximetry, post-exercise perceived stress, rate of perceived exertion of the session (S-RPE-), and for each minute of breathing (B-RPE) across the two trials. There were no significant differences between SCBA and BlastMask for HR (p = .07), pulse oximetry (p = .67), S-RPE (p = .08), or post-exercise perceived stress (p = .32); though firefighters reported greater B-RPE (p < .001) when using the BlastMask. Mean HR was strongly correlated between both sessions (r = .89). Based on these initial findings, the use of the BlastMask appears to elicit similar physiological and perceptual responses during steady state exercise when compared to the SCBA. The BlastMask may therefore be an appropriate supplemental, cost-effective training aid for firefighters, though more research is recommended.

KEY WORDS: Performance, exercise, fitness

INTRODUCTION

Firefighting is widely accepted as a high-risk occupation. Fire suppression activities are physically demanding, requiring firefighters to perform vigorous muscular efforts including climbing stairs and ladders while carrying heavy loads often in awkward positions. The work can elicit near-maximal heart rates (HR), which can remain elevated for extended periods (2). Difficult rescue operations in hazardous environments are requirements of the job, where firefighters may be exposed to high temperatures, smoke, low visibility, and other chaotic conditions (19). Firefighters are always faced with a sense of urgency, given that the civilians requiring their services are likely in immediate danger. Exacerbating already dangerous situations, the personal protective equipment firefighters wear to perform job tasks is burdensome due to its weight and restrictiveness and therefore negatively impacts firefighter performance (8).

The self-contained breathing apparatus (SCBA) is one such piece of personal protective equipment used by firefighters during structural fire suppression that is essential for firefighter safety but adds significant physiological burden (8). The SCBA device provides breathable air for firefighters and is made up of a mask, tank, and regulator worn as a backpack. The SCBA increases workload both through the weight of the pack and the breathing system (14, 15). Even during short duration fire suppression, the SCBA can negatively affect firefighters' performance while simultaneously increasing cardiac strain (14, 15). The SCBA alters exhalation/inhalation and is associated with a reduction in maximal ventilation and maximal oxygen uptake during strenuous exercise (8). Specifically, it is the regulator utilized with an SCBA that has been shown to decrease VO2max by 14.9%, and also reduce peak power output and oxyhemoglobin saturation (8). Further, the SCBA regulator augments the breathing environment resulting in increased total work (~13%), inspiratory elastic work (26%), and active expiratory resistive work (5). Additionally, the added weight of the SCBA pack results in a reduction of 4.8% in maximal exercise (8).

Subsequently, firefighters are required to maintain rigorous levels of physical fitness and training to meet the demands of the occupation. Previous researchers have suggested an aerobic capacity between 33.6 and 49 mL/kg/min is needed to safely perform fire suppression tasks (10, 13, 16, 20, 21). The International Association of Fire Fighters (IAFF) established a VO2max of 42 mL/kg/min as the criterion threshold (22), and a VO2max lower than 33.6 mL/kg/min is the threshold for firefighters being unable to complete a standard fire suppression protocol (14, 21). Given this, Brown and Stickford (2007) suggest firefighters train regularly within a range of 60-95% of one's maximal capacity to ensure readiness (3). While specific training with the SCBA would be ideal, and some departments do train while wearing SCBA devices in preparation of a fire event (6), this training is typically limited. Having the SCBAs remain "on-air" for physical fitness training is often cost prohibitive. Constant training on an SCBA also leaves a department exposed; should a fire occur during training and their SCBAs need to be refilled, response time to an emergency could be delayed. Unfortunately, many fire departments, both large and small, do not have the funds for routine training on SCBA and the subsequent maintenance it would require.

Commonly attributed to insufficient fitness levels, firefighters face a high on-duty death rate due to sudden cardiac death and or underlying coronary heart disease. Data from 1994 to 2004 indicated that coronary heart disease accounts for 39% of on-duty deaths in firefighters in the United States (12). While the risk factors for cardiovascular disease among firefighters are multiple and varied, the most modifiable of risk factors is physical fitness, a known factor related to coronary outcomes among firefighters. Fit firefighters demonstrate greater efficiency in ventilation while on an SCBA, plausibly extending time on tank while maintaining higher intensities (9). Thus, increased fitness may lead to better air ventilation efficiency and task duration at the same relative workload intensity.

To address the need for specific training for firefighters and the limited and costly access to SCBAs, the Breathing Limited Air Situational Training Mask "BlastMask" was developed (BlastMask, 2015). The BlastMask is specifically marketed as a supplemental training aid designed to simulate the SCBA breathing environment. It connects to a face-piece where the regulator of an SCBA would and creates controllable exhalation and inhalation resistance mimicking the SCBA. This product is significantly less expensive than an SCBA and allows firefighters to simulate the breathing environment experienced while "on air" but can be utilized during routine physical fitness. The company that produces the BlastMask purports that because of the specific training it provides, the device can increase firefighter fitness and thus reduce the in the line of duty deaths among firefighters. Despite these claims, the scientific literature evaluating the BlastMask is extremely limited. Therefore, the purpose of this study was to compare the physiological and perceptual responses of firefighters while using the BlastMask and an SCBA among firefighters during steady state exercise. The results of this study can be used to help determine if the BlastMask is an appropriate, cost-effective training aid for firefighters to mimic SCBA training, and can be used to make recommendations for fire departments across the country.

METHODS

Participants

After obtaining Institutional Review Board Approval from the referent institution, participants were recruited from a California fire station via email and or telephone call and were invited to complete the study. To be eligible for inclusion, participants: a) were current staff firefighters; b) identified their sex as male; c) had a body mass index (BMI) of < 30; and d) based on the guidelines by the American College of Sports Medicine were at a low risk for cardiovascular disease and reported no contraindications to exercise. Participant demographics are reported in Table 1. Using heart rate (HR) as the main variable, an a-priori power calculation indicated 10 participants per group was adequate to detect significant differences between groups in the dependent variable of HR and the independent variable of steady state exercise condition, given a type I error rate of 0.05 and a power of 0.80. Written permission to complete testing at the Northshore Fire Station (Nice, CA) was obtained. After an initial review of eligibility criteria and obtaining informed consent, a total of 10 firefighters were enrolled in the study.

Table 1. Participant demographic information.

Variable	Mean ± SD
Age (years)	29.5 ± 7.7
Height (cm)	176.6 ± 9.3
Bodyweight (kg)	84.4 ± 13.4
BMI	26.9 ± 2.7

Protocol
One study visit was required to complete the study. The visit took place 24 hours after the firefighters' previous shifts had ended. Based on this, start times ranged between 10 am and 4 pm. Firefighters were asked not to exercise or consume alcohol for the 24 hours prior to arrival, and to refrain from caffeine 6 hours prior to participation. Upon arrival, participants first completed a survey that assessed demographic information. Total body mass and height were measured using a calibrated electronic scale and stadiometer with a precision of ± 0.02 (Detecto, Webb City, MO). Participants were then permitted a 2-minute breathing familiarization with the BlastMask. Following these initial assessments and in preparation for the submaximal exercise trial, participants warmed up for 5 minutes on treadmill (Nordictrack X9i, Nordictrack Inc., Logan, UT) at 1.12 m/s and 0% grade without the use of the SCBA or BlastMask. Participants were randomly assigned to either complete the SCBA or BlastMask trial first (i.e., a crossover counter-balanced design), and each trial was separated by 30 minutes of seated recovery. A 30-minute recovery period was selected to ensure that participants adequately recovered between submaximal efforts. During the recovery period, the firefighters remained seated and did not consume any fluids or foods. Participants completed both trials on one day to accommodate their schedule, which is a continuous cycle of two days of work, followed by four days off from work.

In the SCBA condition, the SCBA was connected to a face-piece (Av-2000 assembly, Scott Health and Safety, Monroe, NC). Participants breathed compressed air through a Scott E-Z Flo positive pressure regulator that was connected to a Scott pressure reducing regulator attached to a Scott 4.5 Air-Pak cylinder (11.91 kg). Participants then completed 10 minutes of steady state treadmill exercise at an intensity in which firefighters routinely train for submaximal efforts (velocity of 1.12 m/s and 15% grade) (3). This amount of time was selected to ensure excess air on 30-minute SCBA bottle. Every minute, HR, pulse oximetry, and rate of perceived exertion (RPE) specifically for breathing (B-RPE) was collected. Oxygen saturation was measured using a fingertip pulse oximeter (MightySat, Maximo Inc., Irvine, CA), and HR was measured utilizing a polar heart rate monitor (Polar USA Inc., Lake Success, NY). Two additional measures, Session RPE (S-RPE) and post-exercise perceived stress were assessed 10 minutes after the completed trial. Session RPE (S-RPE) was assessed using the 10-point category ratings of perceived exertion scale (23), and post-exercise perceived exertion was reported using a 10-cm sliding scale. Prior to exercise, the RPE scale was verbally explained to participants. They were told that a score of "1" corresponds to the same level of exertion felt during seated rest, while a "10" corresponds to a feeling of maximal exertion.

In the BlastMask condition, the BlastMask was connected to a face-piece (Av-2000 assembly, Scott Health and Safety, Monroe, NC), and participants also wore the Scott 4.5 Air-Pak cylinder (11.91 kg). On the BlastMask, there are three valve settings: open, half closed, and closed, with each setting providing increased resistive forces. The closed setting was utilized for the current investigation to best mimic the SCBA, as recommended by the manufacturer. All other measurements and procedures were the same during both trials.

Following both trials, participants remained in the laboratory for 10 minutes. S-RPE and post-exercise perceived stress were collected at the 10-minute mark post-exercise, and that concluded participation in the study.

Statistical Analysis

Paired samples t-tests were used to determine if there were differences in mean session HR, oxygen saturation, mean B-RPE, S-RPE, and post-exercise perceived stress between the SCBA trial and the BlastMask trial. Pearson *r* correlations were computed to compare variables across the two trials. Prior to data analyses, data were screened for normality using the Shapiro-Wilk test. No violations were detected, and analyses were conducted as planned. The effect size was computed using Cohen's *d*. Partial Eta squared effect sizes were determined to be: weak = 0.17, medium = 0.24, strong = 0.51, and very strong = 0.70. Analyses were performed using SPSS 21.0 software (IBM, Chicago, IL), and an alpha of .05 was adopted throughout.

RESULTS

No significant differences were found in mean HR across sessions (p = .07; d = 0.08; r = 0.89); mean pulse oximetry (p = .67; d = 0.07; r = 0.66); S-RPE (p = .08; d = 0.53; r = 0.55); or post-exercise perceived stress (p = .32; d = 0.29; r = 0.71); B-RPE was significantly greater in the BlastMask trial compared to the SCBA trial (p < 0.01; d = 0.73; r = 0.63). Complete findings are reported in Table 2.

Table 2. Comparison of firefighter responses between SCBA and Blastmask trials across physiological and perceptual measures.

Variable	SCBA		Blastmask		*p*	*r*	*d*
	Mean	*SD*	*Mean*	*SD*			
Heart Rate (bpm)	144.1	17.7	142.7	17.4	.07	0.89	.08
Oxygen Saturation (%)	92.9	2.4	93.1	2.9	.67	0.66	.07
Breathing RPE	4.0	1.5	5.1	1.5	< .001	0.63	.73
Session RPE	5.1	0.9	5.6	1.0	.08	0.55	.53
Perceived Stress	5.0	1.7	5.5	1.7	.32	0.71	.29

Note. SCBA = Self Contained Breathing Apparatus; *SD* = standard deviation; RPE = rate of perceived exertion; bpm = beats per minute; *r* = Pearson's correlation; *d* = Cohen's *d* measure of effect size

DISCUSSION

This pilot study was designed to compare the physiological and perceptual responses of firefighters during steady state exercise while utilizing the BlastMask versus an SCBA. The developers of the BlastMask claim their device mimics SCBA training effectively and can therefore improve firefighter training, ultimately reducing the number of in the line of duty deaths due to inadequate fitness levels. The results of this trial indicated most physiological and perceptual responses were similar between the two devices during steady state exercises with the exception of B-RPE. Given the novelty of the BlastMask and the paucity of scientific research available, limited comparisons could be made regarding the present findings to those of previous researchers. Despite this, the results of this preliminary study offer evidence that the

BlastMask may be useful in firefighter training and suggest that researchers continue to explore the device's utility.

The results of this study first showed that similar HRs were elicited between the two trials. The mean difference was approximately 1.4bpm, with the SCBA eliciting the slightly higher HR than the BlastMask in the present sample. Use of an SCBA during maximal aerobic exercise will produce similar heart rate responses compared to free breathing, although a reduction in aerobic power is observed (7, 8). However, at submaximal aerobic intensities, an SCBA will increase heart rate comparatively to free breathing (18). Given the similar HR response during the current investigation's submaximal conditions, it is plausible that the BlastMask produced a comparable breathing environment to the SCBA. The current investigation did not directly compare free breathing submaximal exercise to the BlastMask, but given the previous research demonstrating the SCBA increases heart rate and that the BlastMask should produce a similar response to the SCBA, it would be expected to induce an elevated heart rate response compared to free breathing. This concept may, however, warrant further investigation.

No significant differences between oxygen saturation were found between the SCBA and BlastMask trials (i.e., only a 0.2% mean difference). A concern with using the BlastMask was the possible rebreathing of CO_2 while wearing the mask during exercise. Previous research measuring oxygen saturation using restrictive training masks indicated a mild hypoxic response during 20 minutes of steady state exercise (~90 S_pO^2 %) (11). The authors postulated this was due to the rebreathing of CO_2 from the 100ml of deadspace in the mask, although, additional investigations failed to observe a hypoxic environment in 10 minutes of steady state exercise (17) or resistance training (1). While the BlastMask and restrictive breathing masks are different, there was the potential for the rebreathing of CO_2 while using the BlastMask due to the resistance exhalation and inhalation. Similar oxygen saturation levels between the SCBA and the BlastMask indicate the BlastMask may not induce a physiological hypoxic response, though additional research directly measuring CO_2 and breathing rates under these conditions is needed to confirm this.

There were also no significant differences reported between S-RPE and post-exercise perceived stress, suggesting each 10-minute bout of steady state exercise was perceived to be of a similar intensity following the trials. However, the reported mean B-RPE was higher during the BlastMask condition (SCBA: 4.0 ± 1.5; BlastMask: 5.1 ± 1.5). This indicates that participants perceived breathing as more strenuous while wearing the BlastMask compared to the SCBA. Although not directly measured in this study, the BlastMask may have induced a greater workload on the respiratory muscles because of the breathing resistance comparatively to using an SCBA, which is positive pressure. If this did occur, it is possible routine training with the BlastMask could produce a training effect on the respiratory muscles.

This difference in B-RPE may also be plausibly explained by firefighters being trained to modify their breathing pattern when using an SCBA (14, 15, 24), but potentially did not alter their breathing pattern during the BlastMask condition. Although this concept would require additional investigation to determine if increased familiarity with the product results in altered breathing patterns, it may have contributed to the findings among this sample. There is an increase in expiratory resistive work while wearing an SCBA because of the regulator (8) and this increased workload of breathing could potentially generate competition for blood supply between working muscles and respiratory muscles. Thusly, there is a justification for firefighters to simulate physiological conditions experienced during fire suppression activities. If routinely training with the BlastMask could provide the respiratory resistance, it could be an appropriate supplemental method for training on air. Provided more cardiovascularly fit firefighters produce superior efficiency in ventilation on an SCBA (improved tank efficiency) at the relative intensity (9), the BlastMask could potentially be utilized as a supplemental method for training to improve or maintain firefighter cardiovascular fitness levels and extend time on the tank.

There are several limitations to the present study that should be noted. First, the total sample size for this pilot test was only 10 firefighters. Although this is small, an a priori power analysis indicated it would be appropriate to detect differences between the two conditions. Second, oxygen intake was not directly measured, which could provide a more thorough picture of the differences in physiological responses elicited by firefighters when training with the BlastMask versus an SCBA. Third, a baseline measure of physical fitness without either the SCBA or BlastMask was not included in this study. While comparing both conditions to a baseline may have aided in the interpretations of some results, the purpose of this pilot study was to compare the two conditions to each other, and not to a baseline fitness level. Researchers however should consider including a baseline level of fitness in future studies, especially in studies comparing staff firefighters to volunteer firefighters, where there may be a wider range of fitness levels that could impact results. The present study also only examined responses to the BlastMask versus SCBA in steady state exercise. It is possible that different results could arise in different types of training, such as higher intensity interval training. Future researchers should consider comparing the BlastMask and SCBA using different training protocols. Lastly, women were not included in the sample. Although the results of this study cannot therefore be generalized to women, recent reports indicate that women make up less than 5% of firefighters in the U.S. (4). While researchers may consider conducting a similar study among a sample of women, at present the applicability to the field is far more relevant to samples of males.

Despite these limitations, the results of this study add to the current body of scientific literature by beginning to explore the utility of the BlastMask in firefighter training. While more research is needed, the similar physiological and perceptual responses elicited by firefighters in steady state exercise trials, one with the BlastMask and one with an SCBA, indicate that the BlastMask may be an effective and cost-efficient training tool for firefighters to use. Researchers should continue to explore the BlastMask as a component of the training used by firefighters. This can help ensure that firefighters achieve and maintain adequate levels physical fitness required of the profession, not only benefitting the health and safety of the firefighters themselves, but also benefitting those they serve.

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