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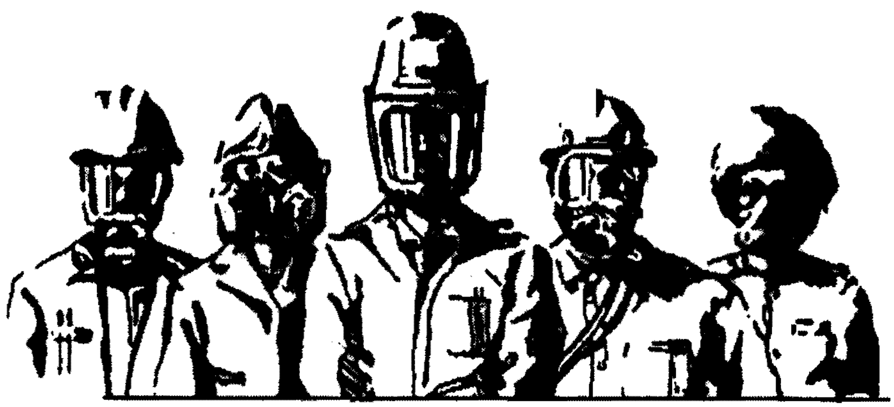

The Effect of Respirator Wear on Blood Lactate During Maximal Exertion

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ABSTRACT

The impact of a filtering half-face respirator and a half-face supplied air respirator use on blood lactate production was assessed during maximal exertion to determine if anaerobic strain increased compared to no respirator use. Twenty-eight participants performed a 30 second cycling Wingate anaerobic test (WAnT) wearing a half-face respirator. Blood lactate production was measured to evaluate if there was an increase in anaerobic strain from wearing a tight fitting half-face respirator compared to wearing no respirator. A supplied air respirator WAnT was then performed using 18 participants from the first experiment to evaluate if supplied air decreased anaerobic strain. Data from both experiments were compared to evaluate differences in the physiological effects due to respirator use during maximal exertion. A survey was administered following the second WAnT experiment to measure the participants' perception of acceptability and impact of supplied air respirator use in workplace.

The blood lactate levels measured directly after the WAnT yielded lower overall mean values during the half-mask respirator trial (12.1 mmol/L) and supplied air respirator trial (12.2 mmol/L) than the no respirator trial (13.1 mmol/L). However, differences in blood lactate levels were not statistically significant ($p = 0.597$).

Participants reported an average acceptability of 92.3% to wearing the supplied air respirator while performing light work. However, the average acceptability decreased as the exertion increased to moderate (78.8%) and heavy (46.6%) workloads.

The supplied air respirator used provided no significant reduction in anaerobic strain within this study group compared to either the filtering half-face respirator or the no respirator condition. However, there were differences in physiological effects of respirators on each gender identified in this study. Further assessment of the anaerobic impact of respirators on each gender should be conducted.

Keywords: Blood lactate, respirator, Wingate, maximal exertion, oxygen saturation, anaerobic strain, half-face, supplied air, ergometer, acceptability

INTRODUCTION

In 2002, the Bureau of Labor Statistics reported that nearly half of private workplaces require non-emergency respirator use. Respirator use has been shown to affect normal respiratory function as well as other physiological responses of the wearer. Determining the impact of respirator wear on anaerobic strain parameters, specifically blood lactate production and percent oxygen saturation, can demonstrate the necessity for respirator wearers working in high intensity jobs to have a work/rest regimen.

Wearing a tight-fitting filtering respirator has been show to increase the wearer's oxygen consumption compared to wearing no respirator. The inspiratory resistance from respirator valves, filters, and canisters contributes to the increase in ventilation rates. This additional breathing effort required to wear a respirator results in cardiorespiratory strain (Louhevaara et al., 1984) and can affect performance (Zimmerman et al., 1991). As the inspiratory resistance increases, the amount of oxygen debt increases (Johnson et al., 2005).

Oxygen debt is the volume of oxygen required to recover from intense exercise and must be made up when the body returns to rest. Insufficient oxygen supply forces the body to convert from aerobic to anaerobic metabolism. The reduction in oxygen forces muscles to rely on anaerobic metabolism for energy and thus blood lactate is produced. Blood lactate accumulates until aerobic metabolism is restored, and then blood lactate begins to revert into pyruvate. Low concentrations of blood lactate may result in soreness while high concentrations can result in heart failure, coma, and even death (Burtis et al., 1994).

The physiological impact of respirator wear increases as the workload becomes more physically challenging. Holmer (2007) reported that high work rates can only be sustained for several minutes with modern types of filtering respirators as well as with powered air purifying respirators. Previous respirator research evaluated physiological responses at sub-maximal exertion (Louhevaara et al., 1986), exhaustive constant load (Caretti & Whitley, 1998) and simulated circuits (Harvey et al., 2008). These studies focused on oxygen consumption, respiration rate and performance during different workloads and respirators. However, these studies lacked maximal effort workloads and evaluation of the effect on the anaerobic threshold of the wearer.

In a study using a predictive model for oxygen consumption, Chiou (2004) recommended that blood lactate be analyzed when exercising at different intensities. Three studies have previously measured physiological responses at maximal exertion during respirator use and the associated effect on blood lactate. Three types of canisters attached to a Canadian military respirator were evaluated for their respective effects on physiological responses during maximal exertion. The canisters failed to show significant difference in the rate of perceived exertion, maximal lactate and the 2-minute post exercise lactate levels compared to a laboratory valve, therefore it was concluded that each of the three purifying canisters had no detrimental effect on aerobic work at light to moderate workloads (Jette et al., 1990). A separate study reported no significant difference in regards to the lactate threshold and the ventilatory threshold between an M-17 full-face respirator and a mouth mask (Dooley et al., 1996). However, prolonged heavy work would likely impair the level of work performed prior to exhaustion. The last study evaluated the effects of full-face respirator use compared to no respirator use during bicycle exercise at various increments of resistance. The results showed a significant difference in oxygen consumption between the two trials. However, lactate and ventilation thresholds were not affected by the respirator. The study concluded that hypoventilation caused by mask resistance leads to higher amounts of blood lactate (Johnson et al., 1995).

The previous maximal exertion studies have shown no significant impact on anaerobic metabolism due to select respirator wear. However, each of the respirators in these studies requires the wearer to draw air through the protective media and into the face piece, thus creating negative pressure within the mask. A supplied air respirator reduces inspiratory resistance and reduces hypoventilation by providing air into the mask, creating a positive pressure within the mask. This can allow more oxygen to reach the pulmonary airways thus reducing anaerobic metabolism in respirator wearers. It is expected that a person wearing a supplied air respirator will have a lower oxygen debt than someone wearing a filtering respirator performing the same activity. Positive pressure respirators have been shown to be beneficial to physiological responses (Harber et al., 1991) as well as subjective parameters. Supplied air respirators reduce the thermal accumulation of moist warm air inside supplied air respirator facepieces which is a common complaint of filtering respirator wearers. If the temperature and humidity within the respirator are lowered, the wearer is able to breathe in comfort and reduce the rise in facial temperature (Raven et al., 1979). Powered air-purifying respirators (PAPRs) are usually considered most comfortable for this reason (DuBois et al., 1990).

Supplied air respirators could be more beneficial physiologically and psychologically for workers than filtering respirators which may increase the acceptance and effectiveness of a respiratory protection program. Supplied air respirators were evaluated to identify if physiological stress on the wearer was reduced when breathing air was provided to the respirator. Also, the investigation evaluated the respirator wearers' perceptions regarding the cognitive and physiological impacts of the supplied air respirator for acceptability of use. Matching the respirator to the wearer's comfort and usability could result in an increase in willingness to wear a respirator as well as improved workplace morale and productivity.

METHODS

Subjects

Participants were collegiate athletes 18 – 24 years old (**Table I**). They were required to have a physical exam within the previous year and have no respiratory symptoms or diseases that may be exacerbated by maximal exercise or by wearing a half-mask respirator as documented by a Physical Activity Readiness Questionnaire (PAR-Q). All of the participants were familiar with cycling; however, their level of cycling experience was not evaluated. Approval for the study was granted by the University of Montana Institutional Review Board (IRB) prior to the research being conducted.

Table I. Subject Demographics for Experiment I & Experiment II

Experiment I

	Age (years)			Weight (kg)			Workload (N)		
	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall
Min.	19	18	18	68.9	53.3	53.3	61	37	57
Max.	25	22	25	111.1	90.7	89.0	105	80	78
Mean	21.9	20.0	21.0	89.0	67.6	79.0	78.8	57.3	68.8
SD	1.4	1.6	1.8	9.9	13.8	16.3	11.1	13.6	16.4

Experiment II

	Age (years)			Weight (kg)			Workload (N)		
	Male	Female	Overall	Male	Female	Overall	Male	Female	Overall
Min.	20	18	18	68.9	59.0	59.0	61	37	37
Max.	25	22	25	111.1	90.7	111.1	98	80	98
Mean	21.9	20.2	21.1	86.8	68.7	77.7	76.8	58.1	67.4
SD	1.5	1.5	1.7	12.9	10.8	14.8	11.5	12.6	15.1

Instrumentation

Each experiment was performed on a Monark 818E cycle ergometer (Sweden) with adjustable resistance. The ergometer was calibrated according to the manufacturer's specifications prior to each experiment. Each participant was allowed to adjust the seat height and handle bar position during the first experiment, but was required to maintain the same configuration for the all the experiments.

The following calculations for active males and females were used to determine the workload (leg force) for each participant (Inbar et al., 1996).

Active Males
Leg Force (N) = BM (N) * 0.090

Active Females
Leg Force (N) = BM (N) * 0.086

Where: Leg Force (N) = ergometer workload in Newtons
BM (N) = body mass in Newtons = body mass in kilograms * 10

Heart rate and oxygen saturation were continuously monitored using a BCI Digit 3420 finger pulse oximeter (St. Paul, MN) attached to the participants' forefinger. Blood pressure was measured with a wrist blood pressure monitor (Omron, HEM-637, Bannockburn, IL). The wrist cuff was worn throughout the entire testing protocol, but only activated prior to cycling, following the acceleration period, prior to the WAnT and immediately after the 30 second WAnT.

Blood lactate was measured by a Nova Lactate Plus analyzer (Waltham, MA). Blood was drawn from the participants' finger using a retractable Arkray Multi-Lancet II Lancet Device (Edina, MN) and applied to a test strip inserted in the analyzer. The blood lactate values were displayed in millimoles per liter (mmol/L) with a standard deviation of 0.3 mmol/L. Blood lactate levels were measured prior to cycling, immediately after the WAnT and after the participants' heart rate returned to 100 beats per minute (bpm).

Each subject was fit tested using a TSI Portacount® Plus (Shoreview, MN) for the best fitting 3M™ 7500 Series half-face respirator (St. Paul, MN) with a passing fit factor of a 1000 or greater. The half-face respirator was fitted with P100 filters (3M™, St. Paul, MN) for the negative pressure respirator WAnT experiment, and a 3M™ Combination Dual Airline Back-Mounted Adaptor Kit SA-1200 (St. Paul, MN) connected to the inhalation valves in place of the filters for the supplied air experiment. A continuous low-flow pump (Gast, Model 0523, Benton Harbor, MI) supplied air through the mask at a constant rate of 150 L/min

Wingate Anaerobic Test (WAnT)

The Wingate Anaerobic Test (WAnT) was developed by members of the Department of Research and Sport Medicine at the Wingate Institute in Israel during the 1970s. This test was used because it has been established as a standard, repeatable task that can be used to analyze physiologic and cognitive responses to supramaximal exercise. The calculated prescribed force applied on the ergometer during the 30 second WAnT was dependant on the participants' body weight. These calculations set the exact force needed to attain anaerobic activity dependent on the subject's body mass (Inbar et al., 1996).

Each participant performed a WAnT for each of the conditions examined: no respirator, filtering respirator and supplied air respirator. Each trial was separated by at least a week for proper rest to ensure that all levels in the body returned to normal (Epstein et al., 1982).

Participants were instructed to begin cycling at a rate of less than 50 revolutions per minute (rpm) with a low resistance (10-15 N) for five minutes. The warm-up section was performed to prepare the participant for the WAnT and reduce the risk of injury. Following the warm-up, the participants performed a series of accelerations. The resistance for each sprint was calculated as being half of the maximum prescribed force for the 30 second WAnT test for each participant. Four 10 second sprints were performed and separated by a 10-15 second recovery period. During the recovery period, the participants were instructed to cycle at a rate less than 50 rpm and at a low resistance (10-15 N).

After the acceleration period was performed, each participant cycled at a low intensity (10-15 N) for five minutes similar to the warm up. The five minute recovery period was performed to allow the participant to return to a baseline level prior to performing the WAnT. The 30 second WAnT was administered immediately after the recovery period.

For the 30 second WAnT, each participant was instructed to cycle at the highest rpm possible against his/her prescribed force for 30 seconds. Participants were encouraged by the researchers to maximize the number of revolutions performed throughout the 30 second test. Immediately upon completion of the 30 second WAnT, the participants' heart rate, oxygen saturation, blood pressure and blood lactate were measured. The participants were recommended to continue cycling at a low resistance and rate until he/she felt recovered from the WAnT.

Experiment I

Experiment I had 28 volunteer athletes, fifteen male and thirteen female 18 – 25 years old. A filtering half-face respirator with P100 filters was donned by the participant prior to cycling to allow for acclimation to the respirator. Participants wore the respirator continuously during test preparation and throughout the WAnT protocol until the cool down period. In the baseline trial, participants performed the WAnT without a respirator. Both trials were randomized and participants were fit tested at their first trial with a passing fit factor of 1000 or greater.

Experiment II

In Experiment II, 18 volunteers from Experiment I, nine of each gender, 18 – 24 years old performed the same WAnT test and procedures from Experiment I but with a supplied air respirator. The experiment was replicated with a dual airline adapter which was connected to the inhalation valves of the half-face respirator and to a continuous low-flow pump that supplied air through the mask at a constant rate of 150 L/min.

Participant Survey

During the recovery period following the 30 second WAnT of Experiment II, a survey was administered to assess respirator comfort and usability, discomfort of lungs, legs and face and perceived level of cognitive thought of each participant following the trial with the positive pressure respirator. The survey was given to assess the participants' perception of the respirator's impact and their acceptability to wearing a supplied air respirator during various workloads.

A five-point Likert scale was used to determine the participants' degree of agreement to statements of perceived affect of the supplied air respirator. A 100 millimeter acceptability scale was used to rate how acceptable the supplied air respirator would be for an extended period of time at light, moderate and heavy workloads. The discomfort experienced during the test in the lungs, leg and seal around the face was also measured using a 100 millimeter discomfort scale.

Results from the participant survey were designed to measure applicability of use in the workplace. A survey was not administered after the baseline or the filtering half-face respirator trial, so only the overall means and standard deviations could be determined for the supplied air respirator.

Statistical Method

Statistical analysis (Minitab® 15, State College, PA) was performed using a general linear model for blood lactate and oxygen saturation versus type of respirator worn and activity (resting or exertion) per subject and gender using a significance 95% confidence level. A Tukey test was used for a paired comparison between respirator types and the baseline trials regarding blood lactate and oxygen saturation. Descriptive statistics were provided for heart rate and blood pressure since they were measured to ensure the participants were able to perform maximal exertion tests.

RESULTS

Experiment I

The mean blood lactate value immediately following the WAnT Test was lower during the filtering respirator trial (12.3 mmol/L, SD ± 4.3) than the no respirator trial (13.0 mmol/L, ± 4.7). Blood lactate values following the filtering respirator and non-respirator trial were greater than the resting blood lactate reading, which proved that anaerobic metabolism was initiated due to the WAnT protocol. Although the blood lactate mean was higher in the non-respirator trial, the highest individual value was measured in the filtering respirator (24.0 mmol/L).

Blood lactate values measured after the filtering respirator and no respirator WAnTs were lower in female participants than in male participants. The highest individual blood lactate value recorded was for a male during the filtering respirator trial. Even with differences between genders, the respective mean and median values for males and females were less in the filtering respirator trial than in the no respirator trial.

Experiment I showed that there was significant difference in activity (rest vs. exertion), as should be expected due to the WAnT protocol, but there was little variation in the oxygen saturation mean for all subjects between the no respirator trial (92.3 %, SD ± 3.3) and the filtering respirator trial (92.4 %, SD ± 4.0). Minimum oxygen saturation values fell within the 80% oxygen saturation region for some participants during the half-face respirator trial, however none of the participants showed any signs of confusion nor did any participant lose consciousness.

In the no respirator trial, the male heart rate (168.7 bpm, SD ± 25.2) was slightly higher than the female heart rate (162.2 bpm, SD ± 16.4) after the WAnT. But after the filtering respirator trial, the female mean heart rate (170.5 bpm, SD ± 15.9) was higher than the male heart rate (167.7 bpm, SD ± 23.5). In addition to these differences, the mean heart rate for all subjects showed a slight increase while wearing the filtering half-face respirator (169.0 bpm, SD ± 20.0) verses no respirator (165.7 bpm, SD ± 21.4). The systolic and diastolic blood pressure values remained consistent throughout Experiment I, as should be expected.

Experiment II

The mean blood lactate value immediately after the WAnT in the supplied air respirator trial was 12.2 mmol/L (SD ± 4.4), which was less than both of the other treatments. The differences among the participants showed significance (p=0.000); however, the differences did not yield statistical significance with regard to the type of respirator worn (p=0.597). This indicates there were significant differences due to individual characteristics of the subjects, possibly due to body type, gender and fitness levels. Even though the mean for all participants was lower during the supplied air trial than the no respirator and filtering respirator trials, mean blood lactate for females was higher following the supplied air respirator trial (12.3, SD ± 4.1) than following the filtering respirator trial (10.2, SD ± 2.8). The difference in male and female participants measured in the no respirator trial and filtering respirator trial for blood lactate was not seen in the supplied air respirator trial (**Figure 1**).

There was no difference in oxygen saturation levels following the filtering respirator trial (92.4 %, SD ± 4.0) and the supplied air respirator (92.8 %, SD ± 4.6). Even though the overall values had little variation, the percent oxygen saturation was higher in male participants during the supplied air respirator trial (93.6 %, SD ± 2.4) compared to the filtering respirator trial (91.9 %, SD ± 4.2) (**Figure 2**).

As seen in Experiment I, there was little variation in heart rate in the three trials. Female participants showed a considerable decline in heart rate following the supplied air respirator trial (154.2 bpm, SD ± 34.0) from the filtering respirator trial (170.5 bmp, SD ± 15.9) while male participants had a slight decrease from 167.6 bpm (SD ± 23.5) to 161.7 bpm (SD ± 10.0). As expected, systolic and diastolic blood pressure was also consistent with the values measured in Experiment I.

Participant Survey

Even with properly fit testing all of the participants, only 15 of the 18 participants (83%) agreed that there was no air leaking through the sides of the supplied air respirator during heavy breathing and maximal exertion. Only eleven (61%) participants felt that they had a sufficient amount of air during the supplied air respirator trial. Most, thirteen (72%) of the participants felt that they did not have any cognitive impairment due to wearing the supplied air respirator. Thirteen (72%) participants disagreed that their clarity of thought was impaired during the WAnT and 11 (61%) disagreed that their speed of mental processing was impaired.

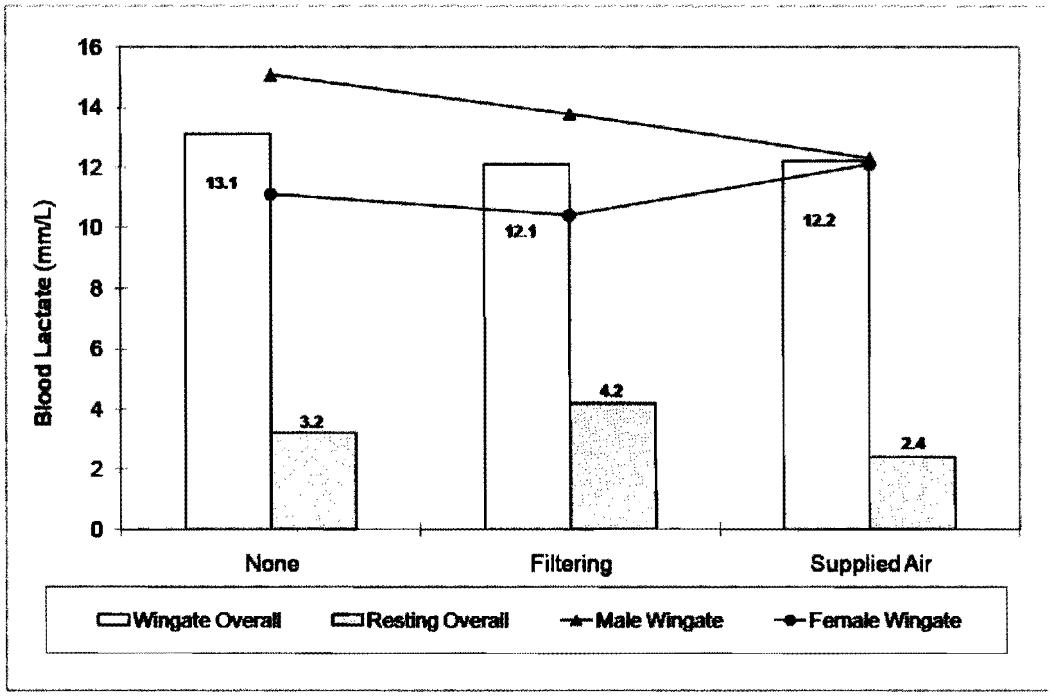

Figure 1. Mean Blood Lactate Levels Per Treatment.

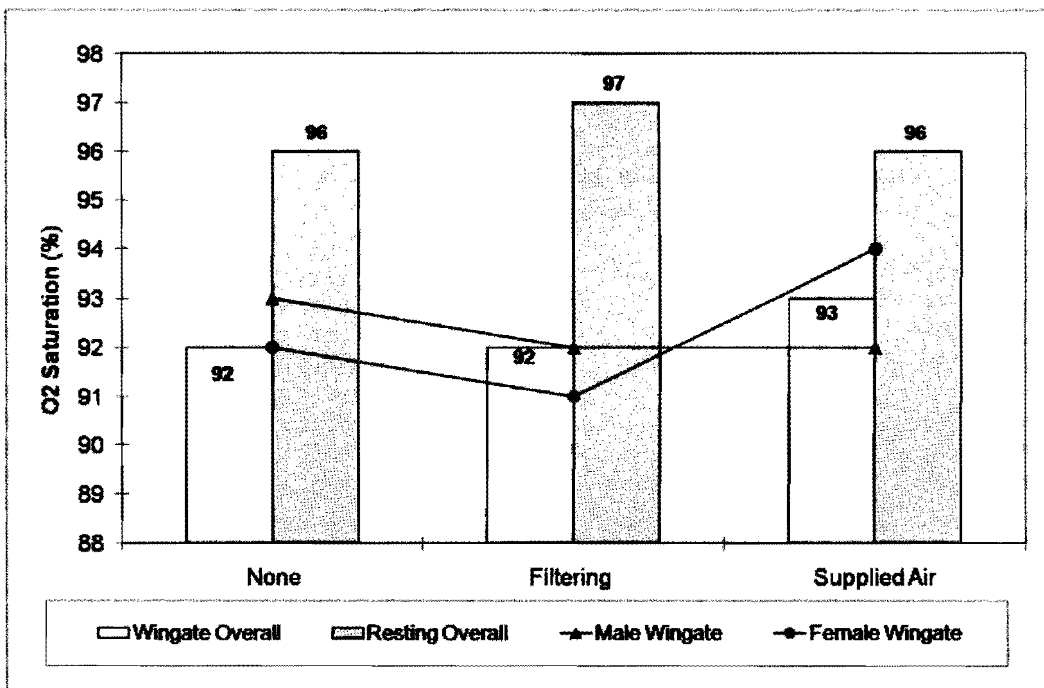

Figure 2. Mean Oxygen Saturation Per Treatment.

Using a 100 millimeter scale, the participants responded with an average of 92.3% acceptability to wearing the supplied air respirator for an extended period of time while performing light work. However, the average acceptability decreased as the exertion increased to moderate (78.8%) and heavy (46.6%) workloads (**Figure 3**). Lastly the participants reported that the most discomfort occurred with his/her breathing during the Wingate test. The participants' legs were the second most described area of discomfort and the participants reported little discomfort around the sealing area of the respirator (**Figure 4**).

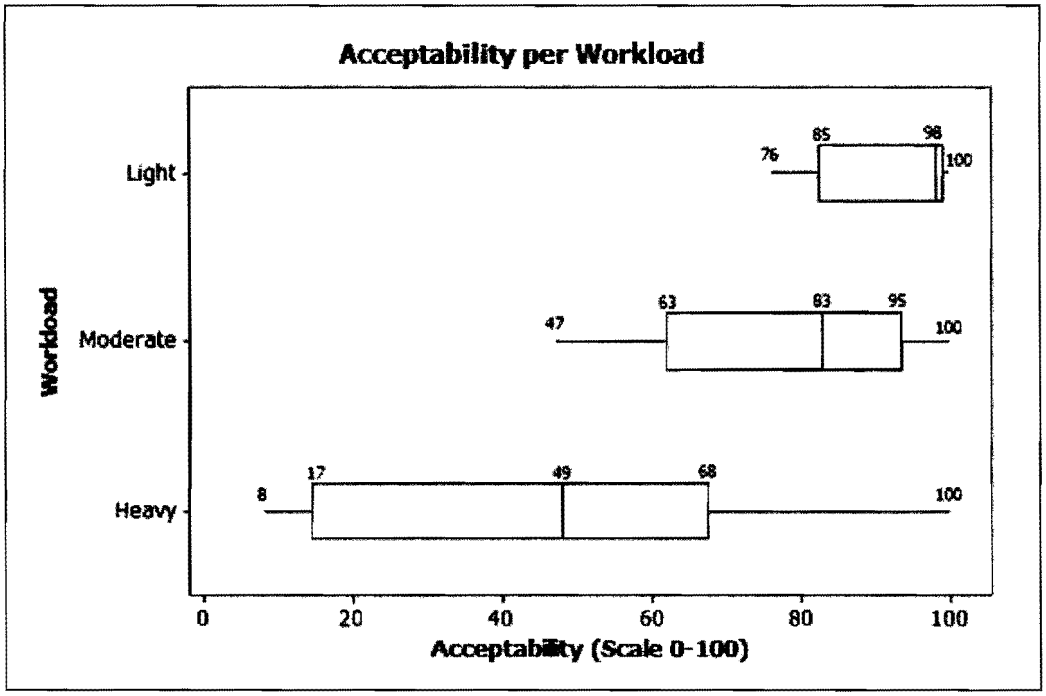

Figure 3. Participants' acceptability to wearing a supplied air respirator at various work intensities. Complete acceptability being a value of 100.

DISCUSSION

There were no significant statistical differences between the respirators analyzed in this study regarding the physiological markers used, but the differences measured provided an indication of the effects of respirators. The physiological responses related to the filtering respirator agree with previous findings for blood lactate production in respirator wearers. The decrease in oxygen saturation was consistent in each of the trials which would indicate there should be no difference in blood lactate levels. However, there were observed increases in adverse physiological responses in the filtering respirator trial compared to no respirator, and the supplied air respirator values were either similar or less than the no respirator trial. This suggests that supplied air respirator use may yield the least amount of anaerobic strain during maximal exertion.

The small differences could have been attributed to the study population being young and physically fit. The general work populations are more diverse regarding age, health and overall physical fitness. Physiological changes may be more pronounced in individuals who are representative of the work force instead of collegiate athletes. However, this test is designed for individuals to reach maximal exertion which had the potential to put less physically fit individuals at risk.

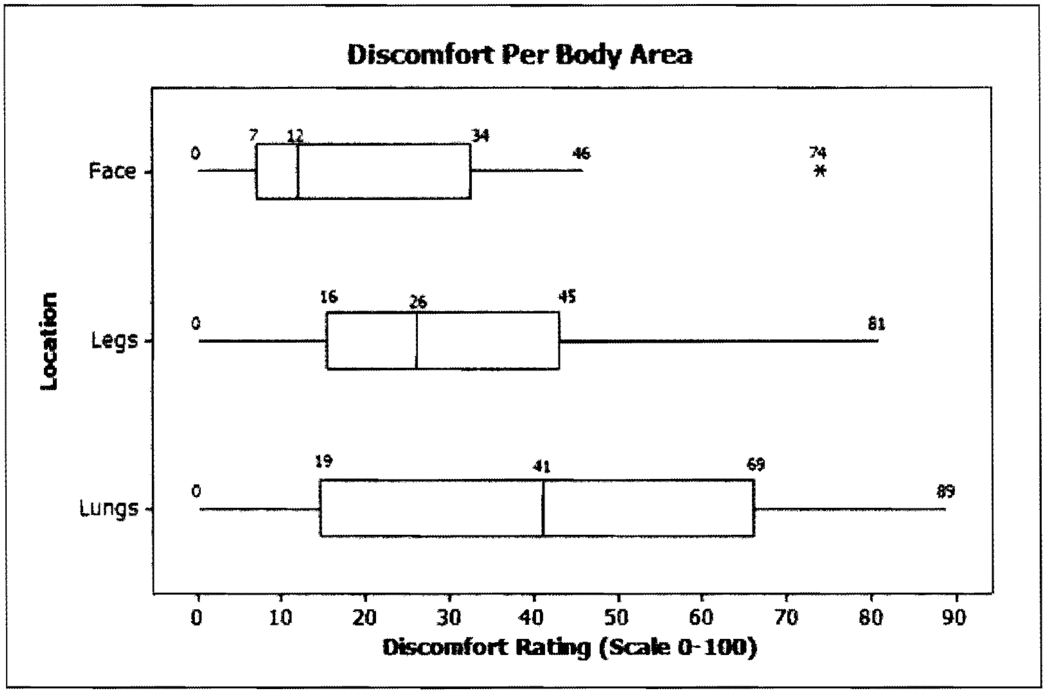

Figure 4. Perceived discomfort in legs, lung and face during supplied air treatment. No discomfort being a value of 0.

Although the physiological differences regarding gender were not hypothesized, there were differences identified through the experiments. Characteristics of women such as relatively inefficient skeletal configuration for certain physical demands as well as their higher percentage of adipose tissue and lower fat-free muscle mass results in their lower peak blood lactic acid levels following maximal exertion (Inbar, 1996). Lactate production during the no respirator and filtering respirator trials was higher in males. However, during the supplied air respirator trial, the blood lactate values were the same for both genders. It should be noted that gender has been shown to not be a factor in blood lactate response for competitive sprint runners (Korhonen et al., 2005).

An additional difference between male and female participants was that the oxygen saturation levels were higher in males for the baseline and filtering respirator test, but the values were less in the supplied air respirator trial. OSHA requires that continuous supplied air to a tight-fitting respirator must be at least 115 L/min (OSHA, 1994). While the rate of air supplied through the respirator in these trials was 150 L/min, it appeared this rate may be insufficient for males performing heavy work.

Participant fitness was a concern in this study due to the exertion required to perform the test. A uniform test population in regards to physical fitness could decrease the likelihood of additional factors that affect the true differences of respirator use. Study groups could be categorized according to level of fitness and body mass index (BMI) to analyze the effect of respirators on different populations. This could produce a model to predict how respirators would affect the working population given their fitness levels. In addition, the participants in this study were screened and selected according to their physical capabilities, which does not represent most of the working population. A study that could help bridge the gap between laboratory experiments of this type with real world conditions could reveal more significant data by exposing higher risk individuals or real work populations. Recovery blood lactate levels should also be evaluated to assess the impact of accumulation and the associated rest required to return these levels to normal.

CONCLUSIONS

Supplied air respirator use yielded no significant reduction in anaerobic strain in respirator wearers within this study group when compared to filtering respirator use. Subjective results show that supplied air respirators are highly acceptable at light and moderate workloads but are less acceptable at heavy workloads. Future research should evaluate various rates of supplied air to identify acceptable ranges based on the anaerobic threshold. The results of this study also identified the need to assess the physiological effects of respirators on each gender to evaluate if the differences were due to varying participant body structure and metabolism. Continuous research analyzing physiological responses for "real world" workers may also demonstrate the necessity for people working in high intensity jobs that require respirator use to have a work/rest regimen.

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