THE EFFECTS OF RESPIRATOR WEAR ON HEART RATE AND BLOOD PRESSURE DURING MODERATE STEADY-STATE WORK

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ABSTRACT

Respirator wear is common in work environments where overexposure to airborne contaminants is possible and cannot be controlled by other measures. However, respirator wear can be both physiologically and psychologically stressful for the wearer due to increased breathing resistance, decreased range of vision, anxiety and other factors. This study was undertaken to examine physiological effects of respirator wear during activity.

The purpose of this study was to observe changes in heart rate and blood pressure in subjects performing moderate work while wearing three types of air purifying respirators. Thirty volunteers 21-58 years old, 15 of each gender, performed cycle ergometry trials for each of four treatments. The following treatments were randomly administered: N (no respirator, the control); H (half-face respirator); F (full-face respirator); and P (powered air-purifying respirator). All respirators were 3M models fitted with HEPA filters.

Each treatment began with a no-load warm-up, followed by three to four minutes of pedaling at a 420 kilogram-meters per minute workload until steady state heart rate was attained. After each treatment, subjects pedaled at no workload until their heart rate decreased to near pre-treatment levels. Heart rate was monitored continually with a pulse oximeter, with values recorded each minute. Blood pressure was measured at the end of each treatment with a sphygmomanometer and stethoscope. Pre-and post-treatment levels were measured and recorded to assure normalcy and adequate recovery.

Data analysis using a two-way interactive ANOVA showed no statistically significant effect (p range 0.67-0.95) on heart rate or blood pressure due to respirator wear during moderate exercise. The differences in corresponding heart rate and blood pressure values between genders were significant.

INTRODUCTION

In the workplace, the effects of physical work are exacerbated by other factors such as protective clothing, respirators, heat and anxiety. The additional physiological stress responses can include increased ventilation heart rate and blood pressure. Fatigue and recovery time also increase with physiological stress (Wilson, 1989). In addition, respirator stress or the worry of being in a hazardous environment can elicit physiological reactions to psychological stimuli.

Due to the highly integrated relationship between the cardiovascular and respiratory systems, effects on one system usually also affect the other. The magnitude of response to such stressors and the body's attempt to maintain balance depends upon a multitude of factors regarding the individual, the environment and the activity. By monitoring heart rate and blood pressure reaction to respirator wear while working, critical response trends may be identified. Responses to different types of respirator may reveal important differences which can be applied to the work force.

Respirator wear increases the work of breathing due to the extra effort required to inhale and exhale. Other factors can add to this effort and the resultant physiological stress, including cartridge or filter loading, increased external workload, increased ventilation, and increased dead space which causes an increase in alveolar CO2 concentration and ventilation frequency.

The normal airflow resistance in the human respiratory system (approximately 0.2 mm H2O/cc/sec.) increases with disease or when breathing through mechanical respiratory devices (Zechman, 1957). Breathing against added resistance, as with respirator wear, increases the energy cost of breathing due to the increased activity of the intercostals, diaphragm, and other breathing muscles during both inspiration and expiration (Agostini, 1978). Shephard suggests that increased resistance, or negative pressure, on inspiration increases cardiac work because the decrease in intrathoracic pressure causes the left ventricle to develop a greater tension in order to maintain blood pressure (Raven, 1979). This concept is an interesting alternative, as it discusses an increase in the demands of the heart muscle itself, in contrast to the increased cardiac work due to increased demands of the breathing muscles.

The environmental, physiological, and psychological factors related to respirator wear comprise a dynamic set of variables whose interactions cannot be predicted but must be anticipated. The increases in both the work load (due to breathing muscle and, perhaps, cardiac muscle recruitment) and the rate of work (the breathing rate) increase the energy demands of the body. Elevation in heart rate is a usual response to increased energy demands. However, studies of heart rate response to respirator use have seen varied results.

In a study of the cardiopulmonary and thermal effects of respirators, respirator wear during work caused an increase in the following: breathing rate; heart rate during heavy work; systolic blood pressure during heavy work; diastolic blood pressure (less dramatic, but higher); and heat stress. (Jones, 1991).

Harber, et al (1982) evaluated each individual component of respirator wear (resistance, dead space, and exercise) individually and in combination. Heart rate showed the effects of exercise, but insignificant effects with resistance and dead space, both individually and together. A later study supported these findings, with heart rate and oxygen consumption unaffected by respirator wear at zero load, 200 kg.m/min., 400 kg.m/min., and maximal exercise (Harber, 1984). The researchers contended that any heart rate changes from increased breathing resistance and dead space should be small or nonexistent and that a significant increase in heart rate occurring from respirator wear is an abnormal reaction. Based on these studies, they propose that approval to wear a respirator include an exertion component both with and without respirator wear to evaluate heart rate response (Harber, 1984).

In a study of submaximal and maximal exertion with and without a respirator, while O2 uptake was significantly greater with the respirator, maximum heart rate and perceived exertion at max were not significantly different. Work performance time to max decreased 24.1 seconds with the respirator (Wilson, 1989). A related study with subjects working at 70% of their predetermined maximum showed no significant difference in the average heart rates of respirator and non-respirator wear. However, their O2 consumption increased and their work performance to exhaustion time decreased. Further, their perceptual breathing work ratings increased 30 minutes into the test, even though the work remained constant (Wilson, 1989). This implies that respirator wear over time causes an additive fatigue which results in earlier exhaustion.

When heart rate, perceived exertion, and postural stability ("sway") were measured with and without respirators, higher perceived exertion ratings, a significantly higher (5.6 bpm) heart rate, and increased sway due to the respirator were seen. The sway factor is important because diminished balance poses a safety risks in many work situations. Spioch, et al, also saw a heart rate increase (7 bpm) and a 24% increase in systolic blood pressure (from 151-188 mm Hg) in Harvard step test results with respirator wear.

One study saw no significant differences in heart rate or maximum work load with or without a respirator and concluded no significant effect on aerobic exercise with industrial respirators (Verstappen, 1986). In contrast, others found maximum exercise intensity and duration significantly reduced due to resistance breathing (Deno, 1981), a reduction (21-27%) of work capacity performance time (Craig, 1970), a decrease in VO2 max (Townsend, 1991) and increase in the oxygen debt (Thompson, 1966).

Varied and often contradictory results, along with under representation of females in study populations should be considered in design of further studies. This study was designed to identify the effects on blood pressure and heart rate due to wearing three types of respirators during moderate steady-state work. Blood pressure and heart rate are astute indicators of circulatory health and physiological and psychological stress. Thus, their measurements under given conditions are indices of the magnitude of effect of said conditions. Significant differences between the control treatment (no respirator) and respirator-mediated levels of heart rate and systolic and diastolic blood pressure would indicate a respirator effect.

METHODS

Participants

Thirty low risk volunteers (15 men and 15 women), 21-58 years old, participated in this project. ACSM defines ‘low risk’ as having no symptoms of disease and one or no coronary risk factor. The broad cross section of volunteers was chosen to represent the wide range of physical characteristics and fitness levels typical of the average work force. Equal numbers of men and women afforded the opportunity to assess gender-related changes and differences. Table 1 reports gender-specific and overall mean values of participant characteristics.

Table 1. Participant Characteristics Ranges and Means

Gender	N =	Age (years)		Height (inches)		Weight (kilograms)	
		Mean	Range	Mean	Range	Mean	Range
Female	*15*	*33*	*21-44*	*64*	*60-68*	*66*	*50-96*
Male	15	39	24-58	71	68-75	91	77-118
All	*30*	*36*	*21-58*	*68*	*60-75*	*78*	*50-118*

Participant Pre-Screening. The pre-assessment information packet provided to each person included general information, test day requirements and restrictions, a Health History/Par-Q form, a Description of the Procedure, and an Informed Consent. Each was asked to review the packet, complete the Health History/Par-Q and bring the packet to their assessment. The Health History was reviewed and the Informed Consent reviewed and signed before the test.

No attempt was made to screen participants for any parameters other than self-reported general health (Health History, PAR-Q), resting blood pressure (<140/90 mm Hg) and resting pulse (<90 bpm) as recorded just before the assessment. Anyone with current blood pressure, heart, respiratory, or other problems that would preclude them from a safe assessment would have been excluded. All volunteers successfully passed the prescreening.

Instrumentation

Cycle Ergometer. A calibrated Bodyguard Model 990 bicycle ergometer provided the workload. This instrument is intended for fitness testing, thus allows for precise workload quantification using ergometer resistance adjustment, pedaling pace and flywheel circumference. The flywheel circumference of the Bodyguard ergometer is six meters per revolution.

Sphygmomanometer and Stethoscope. A Marshall certified sphygmomanometer (blood pressure cuff) with attached stethoscope was placed on the participant's left arm for blood pressure measurement in millimeters of mercury (mm Hg). Proper stethoscope sensor placement at the antecubital space of the arm was assured for each measurement.

Pulse Oximeter. An Ohmeda 3740 Pulse Oximeter continuously monitored heart rate. A finger sleeve containing a laser sensor was placed over the index finger of the participant's right hand. This sensor generated constant visual heart rate readings and pulse waves on the monitor, accompanied by an audible pulse beep.

Metronome. A Franz Model LM-FB-5 electric metronome provided both audible (ticking) and visual (blinking light) cues for cycling pace maintenance. The metronome was set at 140 beats per minute, which set the 70 revolution per minute cycling pace at two pedal down strokes per flywheel revolution.

Respirators. The 3M air purifying respirators used were equipped with 7255 high efficiency particulate air (HEPA) filters and 7288 retainers. The models used were the 7000 series half face, the 7800 series full face and a 7800 series full face adapted to a powered air purifying respirator (PAPR) unit.

Pilot Studies

Before the formal study began, five pilot tests were conducted to assess heart rate response and evaluate participant feedback. This information was used to define workload parameters equivalent to a moderate workload with the desired magnitude of heart rate response and a pedaling pace comfortable for the participant.

Moderate Workload Definition. Definition and determination of workload intensity vary with individual characteristics and with defining agency. The term 'moderate workload' can be defined variously. For purposes of this study, a moderate workload was considered to be an energy expenditure of 200-350 kilocalories per hour. The workload parameters were chosen based on attaining this level of energy expenditure.

Workload Determination. The resistance and pedaling pace were selected in consideration of pilot studies participants' feedback and physiological response and of the goal of attaining a moderate workload. Equation 1 allows workload quantification with regard to resistance, pace and ergometer flywheel circumference.

$$\text{Workload}_{\text{kg-m / min.}} = \text{Resistance}_{\text{kg}} * \text{Wheel}_{\text{m / }\cancel{\text{rev.}}} * \text{Pace}_{\cancel{\text{rev}}\text{./ min.}} \qquad (1)$$

Where:			
	Workload	=	RDf = resistance * distance * frequency (kilogram-meters per minute)
	Resistance	=	Ergometer resistance setting (kilograms)
	Wheel	=	Flywheel circumference; distance (meters per revolution)
	Pace	=	Pedaling pace; frequency (revolutions per minute)

For this study, the ergometer resistance setting of one kilogram, the pedaling pace of 70 revolutions per minute and the ergometer flywheel circumference of six meters resulted in the 420 kg-m/min workload used for all treatments.

Energy Expenditure Determination. The individual energy expenditures for the study participants ranged from 305-355 kilocalories per hour, with individual variations due to differences in body weight—heavier individuals expend more kilocalories. American College of Sports Medicine (ACSM) leg ergometery metabolic calculations and work-oxygen consumption conversions were used to equate ergometry workload to caloric expenditure. Equation 2, the ACSM leg ergometry equation, was used to estimate gross VO2 (oxygen consumption) at a given workload

$$\text{VO2}_{\text{mL / kg / min.}} = (1.8 * \text{Power}_{\text{kg-m / min}} / \text{Weight}_{\text{kg}}) + 7_{\text{mL / kg / min.}} \qquad (2)$$

Where:			
	VO2	=	Volume of O2 used (milliliters of O2 per kilogram of body weight per minute)
	Power	=	Work rate (kilogram-meters per minute)
	Weight	=	Body weight (kilograms)

Caloric expenditure per kilogram of body weight per hour was then determined from gross VO2 using the oxygen consumption-kilocalorie conversion, with one liter (1000 milliliters) of oxygen consumed equal to approximately five kilocalories of energy expended (1 L O2 = 1000 mL O2 = 5 kcal). Equation 3 computes kilocalories expended per unit time using actual or estimated VO2 and body weight.

$$E_{kcal/hour} = VO2_{\not{mL\,O2}\,/\,\not{kg}\,/\,\not{min.}} * Weight_{\not{kg}} * {}^{60\,\not{min.}}/_{1\,hour} * {}^{5\,kcal\,O2}/_{1000\,\not{mL\,O2}} \quad (3)$$

Where:	E	=	Energy expenditure for a given activity (kilocalories per hour)
	VO2	=	Volume of O2 used (milliliters of O2 per kilogram of body weight per minute)
	Weight=		Body weight (kilograms)

Testing and Data Collection

Prior to testing, the necessary paperwork was reviewed and resting blood pressure and pulse were recorded for reference and to insure safe levels before continuing. Proper ergometer seat height was set and the best-fitting respirators were selected. Treatment sequence bias was minimized by randomizing the order of administration using the Latin square method. The following four treatments were administered at the same workload: N (no respirator, the control); H (half face respirator); F (full face respirator) and P (Powered air purifying respirator or PAPR). For comparison to the treatments, R (resting) was also considered.

The participant warmed up by pedaling at no workload and random pace for three minutes. The pace was then introduced on the metronome and the participant was asked match the pace at one pedal down stroke per beat (140 bpm = 70 pedal cycles or wheel revolutions per minute). Participants were instructed to maintain the pace while the resistance was gradually increased to the assessment resistance of one kilogram.

During each treatment, participants pedaled at workload for three to four minutes, until steady-state heart rate was attained. Heart rate was recorded each minute. Blood pressure was recorded at the end of each treatment, after which the next treatment was initiated, until all four phases were completed. When the treatments were completed, participants cooled down by freewheeling at a random pace for at least three minutes or until their heart rate was less than 100 beats per minute. Recovery blood pressure was then recorded to assure return to normal levels and the end of the assessment.

Statistical Analysis

Data were analyzed using a two-way ANOVA with interaction to assess significance at the 95% confidence level ($p < 0.05$) with respect to treatment and gender for heart rate and systolic and diastolic blood pressure.

RESULTS

Though small differences were seen, no statistically significant effects were found among treatment means for heart rate and blood pressure. Differences in heart rate, systolic blood pressure and diastolic blood pressure were statistically significant (p = 0.000) between genders. P values and treatment means per gender and overall are reported in Table 2.

Table 2. P-values and Mean HR and BP Values Per Treatment for Gender and Overall

Treatment	HEART RATE bpm			SYSTOLIC BP mm Hg			DIASTOLIC BP mm Hg		
	Female	Male	*Overall*	Female	Male	*Overall*	Female	Male	*Overall*
R	68	60	*65*	105	122	*113*	71	78	*74*
N	137	100	*118*	124	136	*129*	64	79	*71*
H	139	102	*120*	127	141	*134*	68	79	*73*
F	139	101	*120*	127	140	*133*	68	77	*73*
P	138	101	*119*	124	140	*132*	66	77	*72*
P value	0.000		*0.7080*	0.000		*0.6709*	0.000		*0.7080*

Figure 1 illustrates and compares gender-sorted resting and treatment means for heart rate, systolic blood pressure and diastolic blood pressure.

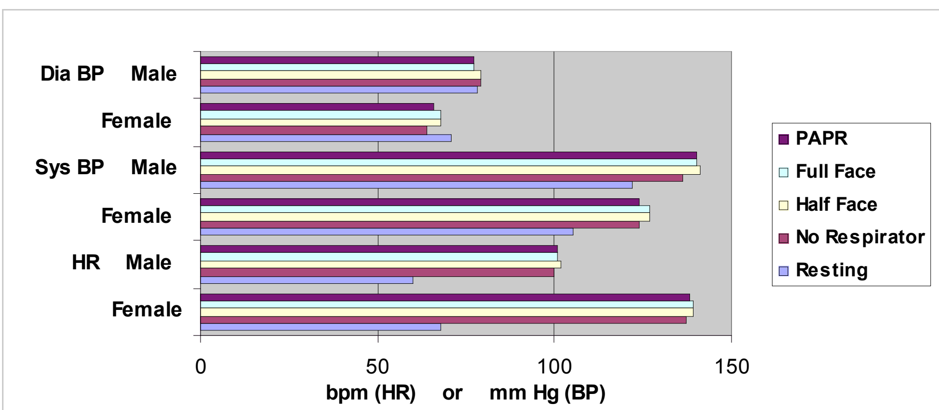

Figure 1. Comparison of HR and BF Means for Treatment and Gender

DISCUSSION

The prevalence of respirator use in industry necessitates accurate knowledge not only of the protection and limitations of the given respirator, but also of the effects a respirator has on the wearer. When donning a respirator, the wearer must accept any discomforts and side effects in exchange for protection from a hazardous atmosphere. This necessary tradeoff is acceptable when the discomforts are reasonable and do not cause physiological or psychological responses that could potentially be harmful. However, this 'critical effect threshold' varies with each individual and according to the environment, the work intensity, and various other factors.

Some workers, depending upon their individual characteristics, have greater capacity for work and adaptation and more reserves for adjusting to both physiological and psychological changes and challenges. For such workers, the added stress of respirator wear may be easily assimilated, while others with limited or no reserves or capacity for adaptation may be pushed beyond safe physiological limits. What may trigger minimal or no discernable response in one person may instigate a critical incident such as a heart attack in another.

Statistical significance is a valuable mathematical construct for data evaluation. However, any effect, whether statistically significant or not, deserves consideration and discernment. The results of this study regarding overall response to respirator wear—small increases in heart rate and systolic blood pressure with little change in diastolic blood pressure—while statistically insignificant are consistent with several other studies. The varying and often contradictory results of other research suggest that the mechanisms for the body's adaptation to respirator wear during work are not always evident. It has been suggested that the body adapts to stress by compensating and making adjustments from system to system (Wilson, 1989). Therefore, the expected outward response may not occur because the stimulus is buffered, or outwardly equalized, by another system.

The statistically significant gender-related differences in effects are evident in this study. Inter-gender mechanisms for adaptation and compensation to any physiological stressors should be identified. Future research in all areas should include male and female participants, both to eliminate gender bias and to define important gender-specific responses and effects.

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