

Do Respirators Stress the Cardiovascular System?

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ABSTRACT

Medical surveillance of respirator users includes the need to assess cardiovascular health. There is, however, no scientifically established link between cardiovascular stress and respirator wear. Heart rate data from several studies conducted in three laboratories have been presented to determine if there is evidence of respirator wear-induced stress. The studies included long-term wear, graded exercise, intervals of work and rest, intense exercise, comparisons for individuals, anxious subjects, and commercial air-purifying respirators (powered and non-powered). In only a handful of instances were there any significant differences in heart rate between respirator use and control conditions, and these differences were just as likely to show lower heart rate with respirator wear as the other way around. The most important factor precluding occupational respirator use is still the anxiety level of the wearer.

Keywords: heart rate, anxiety, exercise, work

INTRODUCTION

Use of a respirator may place a physiological burden on a wearer depending on the type of respirator worn, the job and workplace conditions in which the respirator is used, and the medical status of the employee. This statement, paraphrased from 29 CFR 1910.134 (OSHA, 1978), introduces section (e), entitled "Medical Evaluation." Included in the OSHA Respirator Medical Evaluation Questionnaire (RMEQ), Appendix C, are questions about the detailed health status of the worker. Among areas of interest are pulmonary, cardiovascular, and musculoskeletal conditions. This questionnaire is inclusive enough to be of value for a wide range of occupational safety and health issues.

Whereas 29 CFR 1910.134 specifies when medical evaluation must be performed (before and during required respirator use), it avoids guidance on how to interpret health histories obtained from the questionnaire or through other means. Instead, physicians or other licensed health care personnel (PLHCP) are free to make their determinations to the best of their abilities.

Drafts of the new ANSI Z88.6 (2000) standard, intended to provide specific recommendations for physical qualifications for respirator use, disqualify individuals from occupational respirator wear who have symptoms of a number of cardiovascular diseases. Included in these are coronary artery disease, significant arrhythmias, history of myocardial infarctions, abnormal rhythms (tachycardia or bradycardia), hypertension, and obesity.

Little written evidence has been given to the PLHCP that bears on the importance of various health issues in the determination of suitability to wear and work in respiratory protective masks. The inclusion in the RMEQ of many of the health history questions might lead a PLHCP to suppose that

respirator use is an important stressor for the cardiovascular system. We decided to investigate this supposition by reviewing heart rate data from past studies independently performed in three laboratories.

METHODS AND RESULTS

Except for one study (Johnson *et al.*, 1997), heart rate data appearing in this paper have not been published previously in the open literature. Thus, this is not a review of previously-published results. Details of the experimental methods used for each of the tests included herein (except Danisch (1998)) have, however, been described in previously-published material. Thus, for brevity, only a synopsis of test methods is given for each different cited test. For the Danisch (1998) study, a similar brief style is used to give essential details of methods. Except where otherwise noted, all tests were performed in air-conditioned laboratories on young, healthy volunteers who wore light clothes consisting of shorts, tops, and athletic shoes.

1. 10-Hour Respirator Wear

This test was conducted at the University of Maryland (Johnson *et al.*, 1997), and included eleven young, nonanxious, healthy subjects who performed various tasks arranged in 3-hour blocks. Tasks included cognitive, psychomotor, and motor tasks, ranging from rest to heavy work rates. Tests were performed with and without full facepiece air-purifying respirator masks.

Data from different hourly time periods appear in Table I. These data represent heart rates obtained for the entire group of eleven subjects. The data also show that average heart rates with no respirator were often higher than those while wearing a respirator. None of these data are statistically significant using the Student's *t* test at the $p = 0.05$ probability level.

2. Graded Exercise Test

Fourteen subjects underwent an incremental bicycle exercise test at the University of Maryland (Johnson *et al.*, 1995A). Their ages ranged from 18 to 30, all were in good physical condition, and most (although not all) were nonanxious. Two conditions were tested: a full facepiece air-purifying respirator mask and a half mask often used as a control in laboratory testing (not a respirator mask). The half mask had one-third of the inhalation resistance and one-third of the dead volume of the full mask.

Figure 1 shows heart rates for both conditions plotted against each other. The lower left hand corner of the graph represents resting conditions, and exercise becomes progressively intense as heart rate increases to the upper rightmost corner. Heart rates tended to cluster around the line where both conditions are equal (the line of identity), and are evenly distributed on both sides of the line. Except perhaps at rest, where heart rates for the half mask are somewhat higher than heart rates for the full mask, there is no evidence that the full facepiece respirator systematically causes higher heart rates than does the less burdensome half mask. The full mask was found to produce respiratory hypoventilation, but no heart rate effect was seen.

3. Intervals of Work and Rest

Seven subjects ranging in age from 21 to 44 years were tested at the University of Minnesota (Danisch, 1998). Subjects wore two types of commercial air-purifying respirators and a no-mask control condition while they underwent two 15 minute exercise sessions followed by two 10 minute rest periods. Exercise consisted of treadmill walking at a constant rate of speed and grade to give a physiological work rate of 420W (estimated to be an average of 50% $\dot{V}O_2$ max). Subjects wore a cloth jumpsuit without a hood, leather gloves, and leather boots in an environment maintained at 20°C and 70% relative humidity for the set of tests included in this paper.

Table I. Average Heart Rate Data from a 10-Hour Study with Various Rates of Work (Values Are Group Subject Means $\pm$ Standard Deviations)

	Hourly Period	No Respirator	Respirator
Light Work (Walter Reed Performance Assessment Battery)	1	79.5 $\pm$ 11.7	77.6 $\pm$ 9.0
	4	84.9 $\pm$ 14.5	82.3 $\pm$ 10.8
	7	83.5 $\pm$ 13.3	84.3 $\pm$ 10.7
	10	86.6 $\pm$ 14.5	87.3 $\pm$ 11.2
Light Work (AcuVision)	1	94.2 $\pm$ 18.2	84.2 $\pm$ 28.6
	4	95.9 $\pm$ 20.8	92.8 $\pm$ 7.8
	7	96.1 $\pm$ 19.3	96.2 $\pm$ 12.7
	10	98.0 $\pm$ 19.5	97.0 $\pm$ 11.9
Light Work (Assembly)	1	89.9 $\pm$ 22.6	86.4 $\pm$ 15.1
	4	90.0 $\pm$ 24.7	92.8 $\pm$ 8.0
	7	90.6 $\pm$ 24.0	87.3 $\pm$ 13.0
	10	95.3 $\pm$ 17.7	88.7 $\pm$ 12.7
Moderate Work (ergometer)	2	106.9 $\pm$ 10.6	106.9 $\pm$ 11.5
	5	114.2 $\pm$ 17.7	108.1 $\pm$ 14.9
	8	117.7 $\pm$ 16.7	115.8 $\pm$ 11.8
Heavy Work (ski machine)	3	124.1 $\pm$ 42.3	134.5 $\pm$ 12.2
	6	138.6 $\pm$ 14.5	140.8 $\pm$ 15.6
	9	140.9 $\pm$ 12.3	141.1 $\pm$ 14.1

Data from Johnson *et al.* (1997).

Data from these tests appear in Figure 2. The top bar chart shows heart rate in each of the pre-exercise, exercise, and rest conditions for the 20°C environment. There is no significant difference in heart rates among the two respirators and control condition.

The bottom bar chart shows blood pressure for the same set of environmental conditions. Although blood pressures varied from one time period to the next, there are no significant differences among respirator conditions.

4. Intense Exercise

Tests were conducted at the University of Maryland to determine the effects of respirator dead volume (Johnson *et al.*, 2000) and exhalation resistances (Carette *et al.*, 2001) on treadmill walking performance times. Sixteen volunteers (ages 19 through 39) participated in the exhalation resistance study. One treatment was a standard U. S. Army M40 air-purifying full-facepiece respirator. Another was a control condition with either a laboratory-type half-mask (with no air-purifying filter) or no mask at all. The half-mask is used to collect exhaled respiratory gases for subjects who object to a mouthpiece. Subjects walked on a treadmill at 80-85% $\dot{V}O_2$ max.

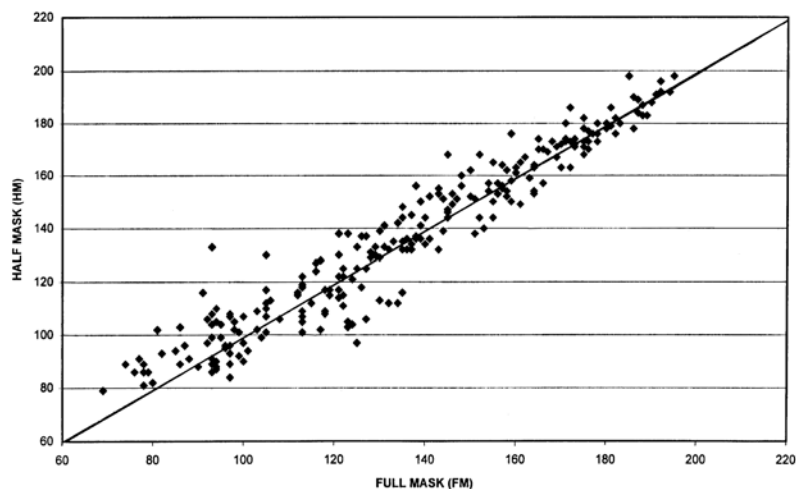


Figure 1. Heart rates for subjects wearing full facepiece air-purifying respirators plotted against heart rates for subjects wearing half masks during a graded exercise test. The line drawn is the line where both values are equal (from Johnson *et al.*, 1995A).

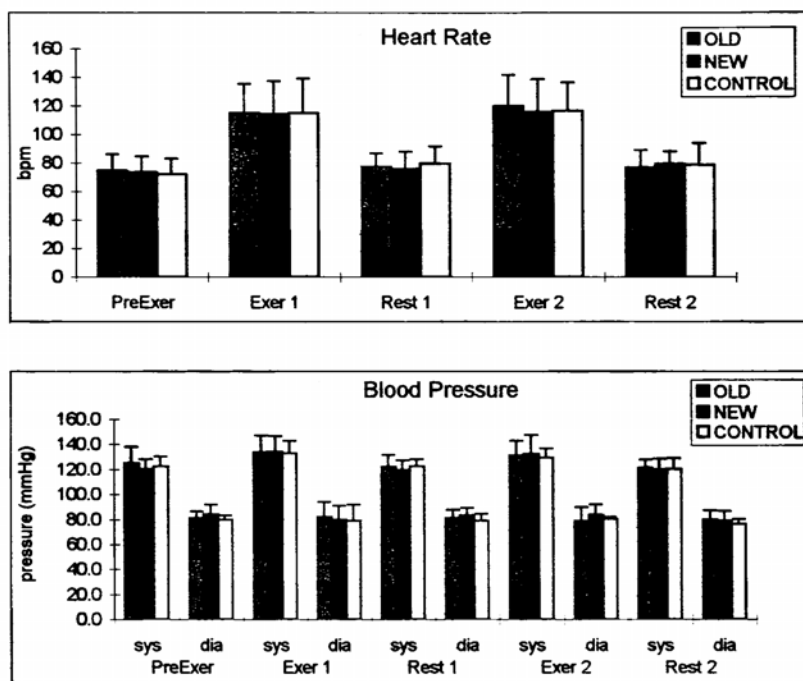


Figure 2. Heart rates and blood pressures for two respirator conditions and control for periods of work and rest (from Danisch, 1998). The “old” condition is the leftmost bar in each set.

Heart rate data appears in Table II. Data were treated as unpaired observations with unequal numbers of samples with equal sample variances. No statistical differences between treatments were

found at the $p=0.05$ level for heart rate taken at the same time using a Student's-t test. Even with statistically non-significant results, however, it can be seen that the mean heart rate for the masked condition is always larger than the corresponding heart rate for the control condition (up to 6.6 % greater). A truly random distribution of the means would likely have shown some mean heart rates for the respirator condition lower than for the control condition.

Table II. Heart Rate Data for Exhalation Resistance Study (Values Are Means $\pm$ Standard Deviations with Number of Subjects in Parentheses)

Time	2 min	4 min	6 min	8 min	10 min
Control	152.07 ± 13.94 (n = 14)	164.79 ± 13.96 (n=14)	169.80 ± 13.16 (n=15)	173.13 ± 10.07 (n = 15)	172.77 ± 11.00 (n = 13)
Standard M40 Respirator	162.00 ± 13.48 (n=16)	169.69 ± 12.31 (n=16)	175.40 ± 12.40 (n=15)	178.69 ± 11.97 (n=13)	178.18 ± 13.44 (n=11)
Significance	NS	NS	NS	NS	NS

Data from study in Caretti *et al.* (2001). NS denotes no significant statistical difference.

The dead volume study was conducted with thirteen young volunteers (24 ± 4 years) who were given six different levels of dead volume and walked on a treadmill at 80-85% $\dot{V}O_2$ max. One treatment was a standard U. S. Army M17 air-purifying full-facepiece respirator and another was a half-mask control with no air-purifying filter. Heart rate data were taken every minute of the test, and these data appear in Table III. Data were treated as unpaired observations with unequal numbers of samples with equal sample variances. As indicated in Table III, none of the differences achieved statistical significance at the $p=0.05$ level using a Student's-t test. As with the exhalation resistance data, all average heart rates for the respirator condition were greater than those for the control condition (up to 2%).

Table III. Heart Rate Data for Dead Volume Study (Values Are Means $\pm$ Standard Deviations with Numbers of Subjects in Parentheses)

Time	1 min	2 min	3 min	4 min	5 min	6 min
Control	151.85 ± 10.22 (n=11)	159.40 ± 11.26 (n=10)	161.60 ± 11.22 (n=10)	165.22 ± 14.10 (n=10)	167.80 ± 14.37 (n=8)	168.67 ± 15.03 (n=8)
Standard Half Mask	154.82 ± 14.29 (n=11)	159.63 ± 14.25 (n=8)	165.67 ± 15.33 (n=9)	167.10 ± 15.45 (n=10)	170.10 ± 16.21 (n=10)	172.56 ± 16.73 (n=10)
Significance	NS	NS	NS	NS	NS	NS

Data from study in Johnson *et al.* (2000). NS denotes no significant statistical difference.

Table IV. Heart Rate Data for Walking and Running for Several Subjects (Values Are Means $\pm$ Standard Deviations with Number of Data Points in Parentheses)

Subject	Condition	Pre	Walk1	Run1	Walk 2	Run 2	Walk 3	Run 3	Post
1	Control	82 (1)	86.3 ± 3.4 (10)	162.2 ± 12.6 (30)	125.1 ± 17.1 (10)	173.8 ± 9.2 (30)	136.1 ± 16.7 (10)	173.5 ± 12.9 (17)	148.5 ± 16.1 (4)
	Mask	72 (1)	77.4 ± 2.6 (10)	151.8 ± 10.1 (30)	116.2 ± 13.8 (10)	165.6 ± 10.3 (30)	126.3 ± 13.1 (10)	170.0 ± 11.8 (12)	148.5 ± 21.9 (2)
	significance		S	S	NS	S	NS	NS	
4	Control	107 (1)	96.2 ± 4.1 (10)	154.3 ± 12.4 (30)	130.6 ± 9.1 (10)	163.1 ± 7.3 (30)	136.4 ± 10.7 (9)	168.9 ± 7.1 (30)	169 (1)
	Mask	82 (1)	93.6 ± 2.2 (10)	160.9 ± 9.4 (30)	132.0 ± 13.0 (10)	166.4 ± 7.3 (30)	135.6 ± 18.0 (10)	171.1 ± 8.1 (30)	173 (1)
	significance		NS	S	NS	NS	NS	NS	
5	Control	71 (1)	85.1 ± 5.0 (10)	143.8 ± 21.2 (25)	98.7 ± 10.2 (9)	148.2 ± 9.1 (30)	118.3 ± 10.8 (7)	136.1 ± 11.6 (30)	121 (1)
	Mask	66 (1)	79.1 ± 3.6 (10)	140.4 ± 9.4 (30)	116.1 ± 13.5 (8)	152.5 ± 5.7 (30)	123.2 ± 16.7 (8)	154.3 ± 5.2 (30)	
	significance		S	NS	NS	S	NS	S	
6	Control	73 (1)	92.0 ± 6.2 (10)	151.5 ± 10.7 (26)	119.1 ± 6.4 (8)	157.0 ± 11.8 (29)	122.2 ± 10.6 (8)	162.2 ± 6.2 (30)	155 (1)
	Mask	73 (1)	89.5 ± 1.9 (10)	146.7 ± 19.3 (20)	116.8 ± 2.2 (5)	167.0 ± 7.8 (28)	134.0 ± 15.7 (7)	170.3 ± 15.5 (15)	170 (1)
	significance		NS	NS	NS	S	S	NS	

Data from study in Caretti (1999). S denotes a statistically-significant difference. NS denotes no significant statistical difference.

5. Individual Comparisons

Five healthy male volunteers (34 ± 3 yr) participated in a study of respiratory muscle fatigue conducted at the U.S. Army Edgewood Chemical Biological Center (Caretti, 1999). Subjects completed an exercise regimen of three cycles beginning with 10 minutes of treadmill walking followed by 30 minutes of treadmill running at about 55% of maximal minute ventilation. Three test conditions were tested: a control condition using a laboratory half mask with very low inspiratory resistance of 0.66 cmH₂O-sec/L, a U.S. Army M40 full facepiece air-purifying respirator with standard C2 cartridge (resistance of 3.25 cmH₂O-sec/L), and the same U.S. Army M40 respirator with modified cartridge (1.57 cmH₂O-sec/L).

Comparisons shown in Table IV are for the control and standard cartridge conditions, and for four of the five subjects that performed the test with the intended exercise regimen. Missing heart rate data caused some of the numbers of data points to vary. Average heart rates during the different time periods were tested for statistical significance of the difference between two means. A Student's *t* test was used, with corrections for unequal sample sizes and unequal variances, where appropriate.

Results are shown in Table IV, and are largely inconclusive. Most comparisons between the control condition and the masked condition show no statistically significant differences ($p = 0.05$) between average heart rates. Of the three statistically significant differences for subject 1, all indicate lower heart rates for the masked condition. The one statistically significant difference for subject 4 indicated a higher heart rate for the masked condition. Of the three significant differences for subject 5, two showed higher heart rates for the masked condition, and one for the control condition. Both statistically significant differences for subject 6 indicated higher heart rates for the masked condition.

6. Anxious Subjects

If heart rate differences between masked and unmasked subjects were to appear, one might suspect that they would happen for those who are highly anxious. A study such as this was published (Johnson *et al.*, 1995B). Unfortunately, heart rate for this study was purposely held constant for all conditions by manipulating treadmill speed and grade.

In an unpublished study conducted at the University of Maryland a group of 22 subjects participated in a treadmill exercise test, walking until they reached their voluntary end-points. Treadmill speed and grade were set to elicit 80-85% of each subject's age-predicted maximum, and no adjustments were made during the test session or between different treatments. Subjects for all tests wore standard U.S. Army battle dress uniform (fatigues) and either a standard U.S. Army M17 full facepiece air-purifying respirator or a no-respirator control assigned in random order. When they wore the respirator, subjects were required to wear an impermeable hood and rubber gloves. Subjects without respirators were required to wear a backpack weighing 1 kg to compensate for the weight of the respirator. Test conditions were identical to the published study (Johnson *et al.*, 1995B) except that treadmill speed and grade were maintained at constant values for each subject.

The Spielberger State-Trait Anxiety Inventory (STAI) was administered to all subjects before testing began (Spielberger *et al.*, 1970), and subject data were treated as two groups. Data from all subjects with STAI scores below 42 were considered to be low anxious (17 subjects); those with scores higher than 42 (range 42-55 for this study) were considered to be highly anxious (5 subjects). All subjects were young (ages 18-35) and healthy.

In Table V appear values for heart rates for both groups of subjects taken during the first six minutes of testing. The data for the low anxious group is separated from the data for the high anxious group as a comparison. All heart rates of masked subjects are lower than those for unmasked subjects except for the 1-minute value for the low anxious group. Data were tested using the student's *t*-test for unpaired means, testing first for equal variances with an *F*-test. No set of heart rate observations was found to exhibit statistical significance at the $p = 0.05$ level.

Table V. Heart Rates (Average $\pm$ STD Deviation) for Low and Highly Anxious Subjects while Walking on a Treadmill at 80-85% of Maximum Heart Rate

Condition	Time (min)					
	1	2	3	4	5	6
Low Anxious Group (STAI < 42)						
Mask	155 $\pm$ 16 (n = 17)	165 $\pm$ 7 (n = 16)	167 $\pm$ 10 (n = 17)	169 $\pm$ 10 (n = 16)	170 $\pm$ 10 (n = 15)	171 $\pm$ 10 (n = 15)
Control	159 $\pm$ 10 (n = 17)	161 $\pm$ 10 (n = 17)	164 $\pm$ 9 (n = 17)	165 $\pm$ 8 (n = 17)	168 $\pm$ 8 (n = 17)	170 $\pm$ 8 (n = 16)
Significance	NS	NS	NS	NS	NS	NS
Highly Anxious Group (STAI $\geq$ 42)						
Mask	159 $\pm$ 8 (n = 5)	162 $\pm$ 8 (n = 5)	164 $\pm$ 10 (n = 5)	170 $\pm$ 11 (n = 5)	172 $\pm$ 16 (n = 5)	176 $\pm$ 16 (n = 5)
Control	155 $\pm$ 4 (n = 5)	157 $\pm$ 3 (n = 5)	160 $\pm$ 2 (n = 5)	163 $\pm$ 4 (n = 5)	164 $\pm$ 8 (n = 5)	168 $\pm$ 5 (n = 5)
Significance	NS	NS	NS	NS	NS	NS

Data from an unpublished study similar to Johnson *et al.* (1995B). NS denotes no significant statistical difference.

To further investigate the responses by anxious subjects to respirator wear, data from two subjects with high STAI scores (>42) who participated in the dead volume study previously described (Johnson *et al.*, 2000) were isolated for study. This test was an intense ($\dot{V}O_2 \geq 80\% \dot{V}O_{2\text{ max}}$) treadmill walking study. Heart rates for these two subjects appear in Table VI. As given in Johnson *et al.* (2000), two standard respirator conditions were used, a standard medium size U.S. Army M17 full facepiece air-purifying respirator (condition A), and a small size U.S. Army M17 respirator (condition C). The control condition was a Hans-Rudolph half-mask normally used to collect respiratory gases.

There appear to be no clear-cut trends in these data comparisons. Heart rates for mask C were all above heart rates for mask A, but comparisons between either mask and the control condition did not show any consistent heart rate differences.

7. Commercial Respirators

Twelve volunteer subjects participated in a test of treadmill walking performance time at the University of Maryland (Johnson *et al.*, 1999). Subjects walked at a rate of 80-85% of age-predicted heart rate while one of five treatments was administered. Treadmill speed and grade remained constant for each subject.

Four of the five treatments were: U.S. Army M 17 full facepiece air-purifying respirator, Racal AirMate 3 loose-fitting powered air-purifying respirator, North model 76008A air-purifying respirator, and a bare-headed control condition. Treatments were applied in balanced order.

In Table VII appear heart rate data for all subjects for each of these treatments. Using a Student's-t test, there were no statistically significant differences for each respirator compared with the control.

Table VI. Heart Rates (Means $\pm$ STD Deviation) for Two Highly Anxious Subjects who Participated in an Intense Exercise Test

Condition	Time (min)					
	1	2	3	4	5	6
Mask A	162 $\pm$ 3 (n = 2)	-	173 $\pm$ 0 (n = 1)	173 $\pm$ 0 (n = 1)	180 $\pm$ 0 (n = 1)	179 $\pm$ 0 (n = 1)
Mask C	164 $\pm$ 4 (n = 2)	172 $\pm$ 6 (n = 2)	178 $\pm$ 8 (n = 2)	180 $\pm$ 6 (n = 2)	191 $\pm$ 0 (n = 1)	195 $\pm$ 0 (n = 1)
Control	166 $\pm$ 3 (n = 2)	170 $\pm$ 8 (n = 2)	174 $\pm$ 6 (n = 2)	176 $\pm$ 14 (n = 2)	182 $\pm$ 4 (n = 2)	195 $\pm$ 0 (n = 1)

Data from study in Johnson *et al.* (2000B).

Table VII. Heart Rates (Means $\pm$ STD Deviations) for Subjects Wearing Several Commercial Respirators

Condition	Time (min)				
	2	3	4	5	6
Control	155.9 $\pm$ 10.7 (n = 10)	-	162.8 $\pm$ 10.8 (n = 12)	-	169.1 $\pm$ 12.6 (n = 11)
M17	160.7 $\pm$ 8.9 (n = 11) NS	-	167.7 $\pm$ 10.0 (n = 11) NS	-	170.6 $\pm$ 9.1 (n = 11) NS
Racal	156.0 $\pm$ 9.2 (n = 11) NS	160.3 $\pm$ 10.0 (n = 11)	164.6 $\pm$ 10.5 (n = 12) NS	167.9 $\pm$ 11.2 (n = 10)	168.1 $\pm$ 10.6 (n = 10) NS
North	158.9 $\pm$ 10.7 (n = 11) NS	161.1 $\pm$ 11.0 (n = 12)	165.5 $\pm$ 12.64 (n = 12) NS	167.4 $\pm$ 13.4 (n = 11)	168.4 $\pm$ 15.3 (n = 12) NS

Data from study in Johnson *et al.* (1999). NS denotes no significant statistical difference.

DISCUSSION

It is always difficult, if nearly impossible, to prove the negative. Demonstrating that respirator use does not stress the cardiovascular system cannot be conclusive. What we have shown, however, is that for subjects who are generally young and fit, there is generally no effect of air-purifying respirator use on heart rate for the population of subjects, and, where possible, for individual subjects within the population. In the only instances where statistically significant differences were found for heart rates for individual

subjects comparing respirator wear against control, the heart rates were as likely to be higher for the control condition as the other way around. We have not shown that abnormalities in the electrocardiogram (ECG) either are or are not affected by respirator wear, because these anomalies (such as S-T depression, premature ventricular contractions, atrial fibrillation, and others that might indicate cardiac malfunction) were not observed in either case. The heart rate alone, however, is often taken to be an index of cardiac stress. The fact that no air-purifying respirator-related statistically-significant heart rate increases were observed can be interpreted to mean that air-purifying respirator use under a variety of work conditions does not stress the cardiovascular system. This conclusion is strengthened by the intentional inclusion of data from studies independently conducted in three different laboratories: at the Edgewood Chemical Biological Center, University of Minnesota, and the University of Maryland. This conclusion is also strengthened by the inclusion of data from a wide range of test and work conditions, from resting to maximal exercise.

There could be a question about the use of Hans-Rudolph half-masks as suitable controls for respirator studies. In order to collect respiratory gases for further analysis, there is no choice other than to use the half-mask or mouthpiece. Some subjects are more disturbed by the uncomfortable mouthpiece, others by the half-mask. There is no known published data indicating whether the half-mask affects heart rate for normal or anxious subjects. The physiological burden imposed by the half-mask is very small, and we suspect there is no measurable heart rate difference when wearing it.

Louhevaara *et al.* (1984) published a report in which they found statistically-significant increases in heart rate for subjects wearing respirators and working at levels of 40% and 55% of $\dot{V}O_2$ max. Subjects wore half-facepiece filtering respirators, air-line apparatus, and SCBA. Perhaps because of the added weight of the SCBA, heart rate differences were greatest with this device. We have no explanation about why the results by Louhevaara differ so dramatically from the ones reported here. The range of test conditions in this report, the number of subjects, and the amount of data are greater than in the Louhevaara study. We also purposely included data from several laboratories and from tests conducted independently from one another.

White *et al.* (1989) reported that there was a statistically non-significant 8 beats/min difference at the end of exercise while wearing a low-resistance control mask and an SCBA. The heart rate difference was probably largely due to a 10kg difference in mass between the two. Two other respiratory conditions, an air-purifying respirator with HEPA filter and an air-supplied respirator, showed smaller, but still non-significant, differences in heart rate. Our results are consistent with the results from the White *et al.* study.

It seems to be reasonable that if a heart rate difference occurs between respirator wear and no respirator wear, the difference would occur as a result of working with the added respirator weight rather than because of the act of breathing with the additional resistance and dead space of the respirator. Modern respirators may impose some respiratory burden, but the affect on heart rate (and, by implication, cardiac stress) seems to be minimal.

Does this mean that cardiovascular factors should be discounted when evaluating workers for suitability for occupational respirator use? The answer is clearly "no." Most of these tests were conducted on subjects who were younger than 35 years of age or who had no known heart conditions. Thus, a large segment of the working population was not represented in the subject pool for these tests. Also, the full range of respirator types was not tested in these experiments.

Nonetheless, we believe that this analysis has value for the PLHCP. We have shown that, for a large segment of the working population, respirator use is unlikely to be the cause of life-threatening cardiac stress. Data from our laboratories suggests that the most important factor precluding occupational respirator use is still the anxiety level of the wearer (Johnson *et al.*, 1995B).

REFERENCES

ANSI, American National Standard for Respiratory Protection – Respirator Use – Physical Qualifications for Personnel, American National Standards Institute, Z88.6 (draft). (2000).

Caretti, D. M., Effect of Respirator Inspiratory Resistances on Respiratory Muscle Performance Following Long-Term Exercise, J. Int. Soc. Resp. Prot. 17:24-32 (1999).

Caretti, D. M., W. H. Scott, A.T. Johnson, K. M. Coyne, and F. Koh. Work Performance When Breathing Through Different Respirator Exhalation Resistances, Am. Indus. Hyg. Assoc. J. 62:411-415 (2001).

Danisch, S. G., Report of Respirator Trials, 3M Technical Report (1998).

Johnson, A. T., C. R. Dooly, C. A. Blanchard, and E. Y. Brown, Influence of Anxiety Level on Work Performance With and Without a Respirator Mask, Am. Indus. Hyg. Assoc. J. 56: 858-865 (1995B).

Johnson, A.T., C. R. Dooly, D. M. Caretti, M. Green, W. H. Scott, K. M. Coyne, M. S. Sahota, and B. Benjamin, Individual Work Performance During a 10-Hour Period of Respirator Wear, Am. Indus. Hyg. Assoc. J. 58: 345-353 (1997).

Johnson, A.T., C. R. Dooly, and C. O. Dotson, Respirator Mask Effects on Exercise Metabolic Measures, Am. Indus. Hyg. Assoc. J. 56: 467-473 (1995A).

Johnson, A. T., W. H. Scott, C. G. Lausted, K. M. Coyne, M. S. Sahota, and M. M. Johnson, Effect of External Dead Volume on Performance While Wearing a Respirator, Am. Indus. Hyg. Assoc. J. 61: 678-684 (2000).

Johnson, A. T., W. H. Scott, C. G. Lausted, and K. M. Coyne, Comparison of Treadmill Exercise Performance Times for Several Types of Respirators, J. Int. Soc. Resp. Prot. 17(1): 19-23 (1999).

Louhevaara, V., T. Tuomi, O. Korhonen, and J. Jaakkola, Cardiorespiratory Effects of Respiratory Protective Devices During Exercise in Well-Trained Men, Eur. J. Appl. Physiol. Occup. Physiol. 52:340-345 (1984).

OSHA, "Respiratory Protection", Code of Federal Regulations. 2002 ed. Title 29, Pt. 1910.134, 421-446 (1978).

Spielberger, C., R. Gorsuch, and R. Lushene, STAI Manual, Palo Alto, Consulting Psychologist Press (1970).

White, M. K., T. K. Hodous, and J. B. Hudnall, Physiological and Subjective Responses to Working in Disposable Protective Coveralls and Respirators Commonly Used by the Asbestos Abatement Industry, Am. Indus. Hyg. Assoc. J. 50:313-319 (1989).