

Peer Reviewed

Comparison of Treadmill Exercise Performance Times for Several Types of Respirators

Arthur T. Johnson
Professor

William H. Scott
Faculty Research Assistant

Christopher G. Lausted
Graduate Research Assistant

Karen M. Coyne
Graduate Research Assistant

Biological Resources Engineering
University of Maryland
College Park, MD 20742
USA

Abstract

It was shown in a previous paper that treadmill performance times of subjects wearing respirators decreased linearly with increasing inhalation resistance. To see if loose-fitting respirators with their ultra-low inspiratory resistances would, indeed give longer performance times, an experiment was performed using a Racal Air-Mate 3 Respirator. To contrast these results, a North #76008A, a U.S. Army M17 respirator, and a control condition were included. Average performance times with these respirators were found to be longer for the lower resistances, but standard deviations for the data were too large to allow statistical significance. It was also found that an educational videotape shown during treadmill walking did not statistically significantly affect performance time, as anticipated.

Introduction

Respirators have been shown to impair work performance due to a number of factors (Johnson *et al.*, 1992). Respiratory factors are especially important at intense work rates of about 80–85% VO_2 max, and treadmill performance times have been found to

be linearly related to inspiratory resistance levels at that rate of work (Johnson *et al.*, 1999A).

There are several respirators on the market that have almost no inspiratory resistance. These are the

loose-fitting powered air purifying respirators configured as hoods, helmets, or face shields. According to previous results, these types of respirators would be expected to impair worker

performances much less than would other air purifying respirators with higher inspiratory resistances. It was to test this hypothesis that this experiment was performed.

Methods

Twelve volunteer subjects participated in this test. Subject demographics appear in Table 1. The protocol was approved by the Institutional Review Board of the University of Maryland.

Subjects walked on a motorized treadmill at 80–85% of age-predicted maximal heart rate while one of five treatments were administered. Treadmill speeds were 1.9 ± 0.13 m/sec (mean $\pm$ std dev) and grades were 8.3 ± 1.7 percent, and remained the same for all test sessions with the same subject. The control condition, to which all other treatment results were compared, was a bareheaded (no apparatus) condition. The standard respirator used in our previous studies was a U.S. Army M17 air purifying respirator, and this respirator was used in this test as one of the treatments for comparison purposes.

The Racal AirMate 3 face shield respirator was tested to determine if there was a significant advantage to this configuration. A North model 76008Aa air purifying respirator with #17AO filters was used as the fourth condition to represent standard commercially available full face piece air purifying respirators. The fifth treatment condition was meant to test the effect of distraction on treadmill performance while wearing a respirator, a question raised in a previous paper (Johnson *et al.*, 1992). Subjects wore M17 respirators while an educational videotape was shown to them as they walked. The

videotape chosen to be shown was entitled, "Risk Communication: Overcoming the Barriers," By Peter M. Sandman, and is available from the American Industrial Hygiene Association.

Sessions began with a 60 second warm-up period and continued until the subjects expressed the desire to stop. Before, during, and after exercise the following were measured: heart rate, blood pressure, blood oxygen saturation (pulse oximetry), and Breathing Apparatus Comfort (Johnson *et al.*, 1999B). The first three measurements are standard in our laboratory to assess the physiological health of the subjects; the last measurement was used to assess subject reactions to the respirators. Also measured before the test session was the respiratory resistance of each subject. This measurement was made with the Airflow Perturbation Device (Lausted and Johnson, 1999) developed in our laboratory. This measurement helps to assure that the respiratory condition of each subject is normal. Prior to testing each subject, the Spielberger State-Trait Anxiety Inventory test (STAI) was administered to screen for anxious subjects (Spielberger *et al.*, 1970). All subjects tested were nonanxious.

It would be possible for the subjects to over breathe the Racal blower, requiring higher minute volumes that the blower could supply. If this were to happen in a contaminated atmosphere then the respirator would no longer protect against airborne

Table 1. Subject demographics.

Age (yr)	26 $\pm$ 4
Height (cm)	174 $\pm$
Mass (kg)	69 $\pm$ 13
Max Heart Rate (bpm)	194 $\pm$ 3
Anxiety (STAI)	32 $\pm$ 8.4
Respiratory Resistance (cmH ₂ O·Sec/L)	3.39 $\pm$ 0.74
Sexes	6 males, 6 females

Values are means $\pm$ standard deviations.

hazards. Because of this, minute ventilation was monitored for the Racal condition using a RespiTrace (Ambulatory Monitoring; Ardsley, NY) respiratory monitor. This monitor uses two elastic bands, one around the chest and the other around the abdomen. As the elastic bands expand, voltage signals are obtained that can be converted to volumes and flow

rates. Calibration of these voltages was performed both before and after the test session by monitoring voltage while the subject breathed through a Fleisch #3 pneumotach (OEM Medical; Richmond, VA). By using the RespiTrace, the subject remained unencumbered at the mouth, and the Racal respirator could be tested as it was meant to be used.

Results

Subject data appear in Table 1. Subjects were young and appeared to be normal.

The two most important performance measures for this study were exercise performance times and Breathing Apparatus Comfort Scale (BACS) results. These appear in Table 2.

Wearing the Racal respirator was seen to degrade performance times by about 4 minutes compared to the control; subjects wearing the North respirator performed for a slightly shorter time than for the Racal; the M17 had the greatest effect of all. In terms of performance ratings, defined as the ratio of performance while wearing a respirator compared to the performance of the control, the Racal had a performance rating of 89, the North had an 82, and the M17 had a 76. Comparing performance rating data for the M17 to previous results from our laboratory (Johnson *et al.*, 1999A) shows that the performance rating of the M17 at this work rate is almost identical to previous results.

Paired t-tests for performance times of the various respirators compared to the control were all statistically significant at the $p=0.05$ level. Paired t-tests for performance times for one respirator type compared to any other type (for example, the Racal vs M17) yielded no statistically significant comparisons.

Paired t-test for performance ratings of the various respirators compared to the control were all statistically significant except for the control vs Racal comparison. No statistically significant paired t-tests resulted for comparisons of one respirator to another.

Subjects rated the Breathing Apparatus Comfort Scale for the control condition at 7.64, standing for "very comfortable." This rating was obtained despite the fact that the subjects were not actually wearing any breathing apparatus at the time. Nonetheless, subjects were asked to give a rating anyway.

The BACS score for the Racal was much better than for the other respirators, although lower than for the control. The average Racal BACS score corresponded to "neither comfortable nor uncomfortable." The North respirator (with an inspiratory resistance of $1.58 \text{ cm H}_2\text{O} \cdot \text{sec/L}$, as measured in our lab) was rated more comfortable than the M17 (with an inspiratory resistance of $3.4 \text{ cm H}_2\text{O} \cdot \text{sec/L}$). The 3.46 corresponded to "fairly uncomfortable" while the 2.73 corresponded to "very uncomfortable."

All paired t-tests comparing respirator BACS scores to the control were statistically significant at the $p=0.05$ level. Except for the North vs M17 and t-test comparisons were statistically significant.

Table 2. Performance results for the five treatment conditions.

Treatment	Performance Time (min)	Performance Rating	BACS	Minute Volumes (L/min)
Control	19.1 $\pm$ 10.6	100 $\pm$ 0.00	7.64 $\pm$ 1.96	82 $\pm$ 18
Racal	15.4 $\pm$ 7.85	88.8 $\pm$ 26.3	5.09 $\pm$ 2.07	76 $\pm$ 19
North	14.7 $\pm$ 7.68	82.2 $\pm$ 23.5	3.46 $\pm$ 2.02	75 $\pm$ 18
M17	13.4 $\pm$ 6.18	76.1 $\pm$ 22.4	2.73 $\pm$ 1.85	75 $\pm$ 18
M17 + Video	12.4 $\pm$ 6.60	68.4 $\pm$ 15.1	2.00 $\pm$ 1.55	79 $\pm$ 24

Values are means $\pm$ standard deviations.

Respirace minute volume measurements for the various conditions are found in the last column. There were no significant differences found among the various respirator types. There also was no evidence of the hypoventilation reported previously to result from breathing through an inspiratory resistance (Johnson *et al.*, 1999A). Perhaps this is because the Respirace measurements were too variable to see subtle differences.

The blower on the Racal was rated at 300 LPM. The minute volume measurements indicated that our subjects did not approach this flow rate, although, if exhalation is considered to represent approximately 50% of the breathing cycle, then peak flows would have been in the 150-200 LPM range.

Discussion

In tests of this type it is frequently seen that the variations in the data are very large. Such was the case for this study, where standard deviations for performance times were 50% or more of the means. With such large variability, traditional statistical significance is difficult or impossible to achieve. However, we consider tests for statistical significance as just one tool among many, and just as important as statistical significance is the way the data fits with previously established results. Subsequent statements in this discussion are made considering the data means more importantly than otherwise statistically justified because the means are consistent with results from previous studies (Johnson *et al.*, 1999A).

The Racal face shield respirator gave good results. Its performance rating was highest of the three respirator types, and it was deemed the most comfortable. This model is no longer commercially available, but its merits can be seen anyway.

The North respirator was not quite as good as the Racal, but was still not too bad. Wearing this respirator can be expected to give a performance decrement of about 20% compared to the no respirator condition. The M17 was generally comparable to the North, but gave somewhat shorter performance times.

These results indicate that there is more than just resistance that determines performance while wearing a respirator. The extra weight, and perhaps uncomfortable head harnesses decreased performance rating and breathing apparatus comfort for the Racal respirator. It is possible that the face seal and additional resistance contributed to the additional discomfort of the North, and the M17 includes a lot of old technology that adds to its discomfort.

Breathing apparatus comfort and treadmill performance times are highly interrelated. One

would expect the most comfortable respirator to allow wearers to work for longer times. Thus, the longer performance times and higher BACS scores vary consistently. The purely subjective BACS scores were no more inconsistent than were the more objective performance times.

Some might argue that a more correct control condition would be one where such things as weight, at least, were equalized among respirator types. A control condition such as this would not be a bare-headed condition, but, rather, would place a weight on someone's head. This control condition would be good for isolating the effect of breathing resistance and, perhaps, other variables, but would not be a good comparison between the respirator and no respirator conditions.

For similar reasons, results from this experiment cannot be expected to confirm or refute the linear relationship between inspiratory resistance and performance times found previously (Johnson *et al.*, 1999A). Each respirator type differed from the others by many aspects such as weight, configuration, exhalation resistance, dead volume, visual field, and others. Performance time differences among respirators were undoubtedly influenced by at least some of these aspects, so the performance time differences cannot be attributed solely to inhalation resistance levels.

This experiment also partially answered the question about distractions while exercising. Some of the subjects indicated that the videotape chosen to be shown was actually annoying. Performance time with the videotape was essentially the same as without, but the BACS score and performance time both indicated a possibly small negative effect of this particular tape. It is possible, therefore, that a videotape considered more interesting by the subjects could enhance performance measures.

Conclusions

The lower resistance respirators resulted in improved average work performance times for constant rate intense exercise lasting about 15-20 minutes. The loose-fitting powered air purifying respirator gave the best performance of

all the respirators used, with a performance rating of 89. Distractions during the test in the form of educational videos can possibly affect performance times of the subjects.

References

- Johnson, A.T., C.R. Fooly, 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. *Amer. Ind. Hyg. Assoc. J.* 58:345-353(1997).
- Johnson, A.T., R.A. Weiss, and C. Grove: Respirator Performance Rating Table for Mask Design. *Amer. Ind. Hyg. Assoc. J.* 53:193-202(1992).
- Johnson, A.T., W.H. Scott, C. G. Lausted, M.B. Benjamin, K.M. Coyne, M.S. Sahota, and M.M. Johnson: Effect of Respirator Inspiratory Resistance level on Constant Load Treadmill Work Performance. *Amer. Ind. Hyg. Association J.* 60:474-479(1999A).
- 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, *Amer. Ind. Hyg. Assoc. J.* (accepted) (1999B).
- Lausted, C.G., and A.T. Johnson: Respiratory Resistance Measured by Airflow Perturbation Device, *Physiol. Meas.* 20:21-35 (1999).
- Spielberger, C.R. Gorsuch, and R. Lushene: *STAI Manual* Palo Alto; Consulting Psychologist Press. 1970.