

Effects of Respirator Inhalation Resistance on Low-to-Moderate Intensity Task Performance

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ABSTRACT

This study assessed physical and subjective performance decrements resulting from wearing air-purifying respirators with different levels of inhalation breathing resistances during wear trials of low-to-moderate intensity activities. Twenty-four volunteers completed 4 trials of No Mask and full-facepiece air-purifying respirator (APR) wear involving 3 inhalation resistance (P_{IN}) conditions (1.23 ± 0.16 cm H_2O , 2.61 ± 0.05 cm H_2O , and 4.29 ± 0.43 cm H_2O measured at 85 L·min⁻¹ flow rate). Test sessions comprised 3 hr of continuous APR wear while performing both fine and gross motor physical tasks for various durations; both objective measures of performance and subjective feedback of user comfort were obtained throughout testing. No significant differences were observed among P_{IN} conditions for any of the dependent variables assessed for the hand-tool dexterity task. No interactive effects between P_{IN} and task loads used for the gross motor physical activities were found, but box lift rates decreased linearly as P_{IN} increased for each load task. Independent of task load, a significant linear decrease in lift rate performance rating was found with increased P_{IN} ($R^2 = 0.96$; $p < 0.01$). Physiological and subjective responses indicated that neither the P_{IN} nor the physical tasks invoked significant amounts of physiological stress from the test participants. These findings suggest use of respirators with inhalation resistances equal to or less than those used in this investigation will not significantly impact performance of fine or gross motor activities of low to moderate intensities.

Keywords: APR, respirator, inhalation resistance, physiology, performance

INTRODUCTION

The resistance to breathing inherent to respiratory protective devices is a key determinant that affects human performance. Considerable attention has been paid to this factor in past research investigations and results have helped define quantitative limits on inspiratory and expiratory breathing resistances (Caretti et al., 2006; Caretti et al., 2001; Johnson et al., 1999; Caretti & Whitley, 1998; Johnson et al., 1997; Harber et al., 1991; Louhevaara et al., 1986). This knowledge base indicates that the respiratory encumbrance imposed by the airflow resistance of respirators adversely affects physical performance, particularly under hard work conditions. However, studies that measure work performance as the ability to conduct heavy physical exertion may not be directly applicable to the low-to-moderate exertion typical of most applications (Laird et al., 2002; Louhevaara et al., 1985).

Unfortunately, the impacts of respirator breathing resistance on cognitive performance and physical performance at low and moderate work intensities are not as well defined. While several studies (Flook and Kelman, 1973; Demedts and Anthonisen, 1973; Silverman, et al., 1951; Cerretelli, et al., 1969;

Hermansen et al., 1972) have investigated the impact of respirator wear on physical performance during low and moderate intensity tasks, these efforts focused on the effects of respirator wear on ventilation and did not define task performance per se. Shykoff and Warkander (2011) included an assessment of self-paced load lift and transfer as part of an investigation of the impact of an air purifying respirator (APR) on performance. Subjects lifted a box from the floor, carried it for 2 m, and then placed it on an 88 cm high bench. One 6-min trial required subjects to move three boxes that weighed 20%, 27%, and 33% of the subject's body weight. No difference was found in the number of boxes carried between the APR and no mask conditions.

This study involved a series of activities aimed at identifying physical and subjective performance decrements that might result from wearing APRs with different levels of inhalation breathing resistances. Respirator wear trials included a battery of fine and gross motor tasks of low-to-moderate intensities that simulated workplace activities.

METHODS

Test Participants and Baseline Data Collection

Twenty-four volunteers (22 males and 2 females) between the ages of 21 and 41 years (27.6 ± 1.3 yr; mean $\pm$ SEM) participated in this study. Subjects weighed 83.7 ± 2.6 Kg and were 176.5 ± 1.7 cm tall. The human use protocol had been reviewed and approved by the Edgewood Chemical Biological Center Human Use Committee prior to soliciting volunteer consent. Signed informed consent was obtained for all subjects upon completion of volunteer agreement paperwork. Each volunteer also completed the Occupational Health and Safety Administration (OSHA) Regulation 29 CFR 1910.134 Respirator Medical Evaluation Questionnaire and was cleared for respirator wear and testing by medical personnel from the Kirk U.S. Army Health Center, Aberdeen Proving Ground, MD. A demographic questionnaire was administered to collect data regarding subjects' general fitness and experience with respirator wear. A baseline measurement of salivary amylase, concentrations of which are predictive of plasma catecholamine levels, was obtained from each volunteer as a noninvasive physiological measure of stress (Chatterton et al., 1996). A salivary amylase sample was obtained from a subject using a small, clean rectangular sponge (2.5 cm x 1.3 cm x 1.3 cm) rolled in the mouth for one minute. After this time, the sponge was expelled from the mouth into a pre-labeled cup that was then covered and refrigerated until the assay procedure was performed. The collection of salivary amylase coincided with completion of the Multiple Affect Adjective Check List - Revised (MAACL-R) in order to gather appropriate diagnostic information necessary for a comprehensive stress assessment (Lubin & Zuckerman, 1999). The MAACL-R with its five subscales of anxiety, depression, hostility, positive affect and negative affect has been particularly suitable for investigations that postulate changes in specific effects in response to stressful situations (Lubin & Zuckerman, 1999).

Trained personnel obtained anthropometric measurements of each research participant's face length (Menton-Sellion) and width (Bizygomatic Breadth) to aid in respirator sizing. Once completed, subjects were fitted for the test respirator. A five exercise respirator fit test routine (normal breathing, deep breathing, rotating the head from side-to-side, nodding the head up and down, and rotating the jaw with the mouth held slightly open) was included as part of the sizing and fitting process to ensure proper sizing for each test participant. Mask fit testing was accomplished using the PortaCount® Plus Respirator Fit Tester Model 8020 (TSI, Incorporated, Shoreview, MN). The pass/fail criterion for an acceptable fit was a minimum fit factor (FF) level of 500. Although low relative to the chemical, biological, radiological and nuclear (CBRN) APR standard of 2000 (NIOSH, 2004), a FF of 500 was considered appropriate because of the pending use of modified versions of the test APR, which may or may not compromise fit, and because the 500 minimum was unattainable without proper donning of the APR. Regardless, fit test

results were not the focus of the investigation. Once all criterion tests were passed, a test administrator instructed volunteers on the proper donning and doffing of a heart rate monitor and the test respirator.

Experimental Procedures

All subjects participated in four separate test iterations requiring three different conditions of respirator wear and one no-mask wear condition. Since the planned series of experiments aimed to identify physical and subjective performance decrements that might result from wearing CBRN protective respirators with significantly different breathing resistances, a full facepiece APR was modified to impose each of the following inhalation resistance conditions: 1.23 ± 0.16 cm H₂O (at 85 L·min⁻¹ flow rate, ATPS) (120.6 ± 15.7 N/m²), 2.61 ± 0.05 cm H₂O (256.0 ± 4.9 N/m²), and 4.29 ± 0.43 cm H₂O (420.7 ± 42.2 N/m²) (Figure 1). The 2.61 cm H₂O condition represented the inhalation pressures of the unmodified test APR. The 1.23 cm H₂O inhalation pressure was accomplished by removing the gas filtration bed of the filter used with the APR, whereas parts of the air-inlet port of the APR's filter were blocked with hot-melt glue to create the 4.29 cm H₂O pressure condition. Presentation of conditions was randomly assigned and volunteers were exposed to only one test condition on any given day. All testing procedures were conducted indoors at room temperature and humidity to minimize environmental influences on the data. Environmental conditions in the laboratory test areas averaged $T_{\text{air}} = 22.2 \pm 0.1$ °C, $\text{RH} = 38.8 \pm 0.9\%$ over all test days. Each subject was instructed to get adequate rest the night before each test, to eat breakfast and/or lunch, and to drink plenty of fluids, excluding alcohol and caffeine, before reporting to the laboratory. Volunteers were clothed in U.S. Army combat uniforms consisting of a T-shirt, long pants, socks, and combat boots, for all trials.

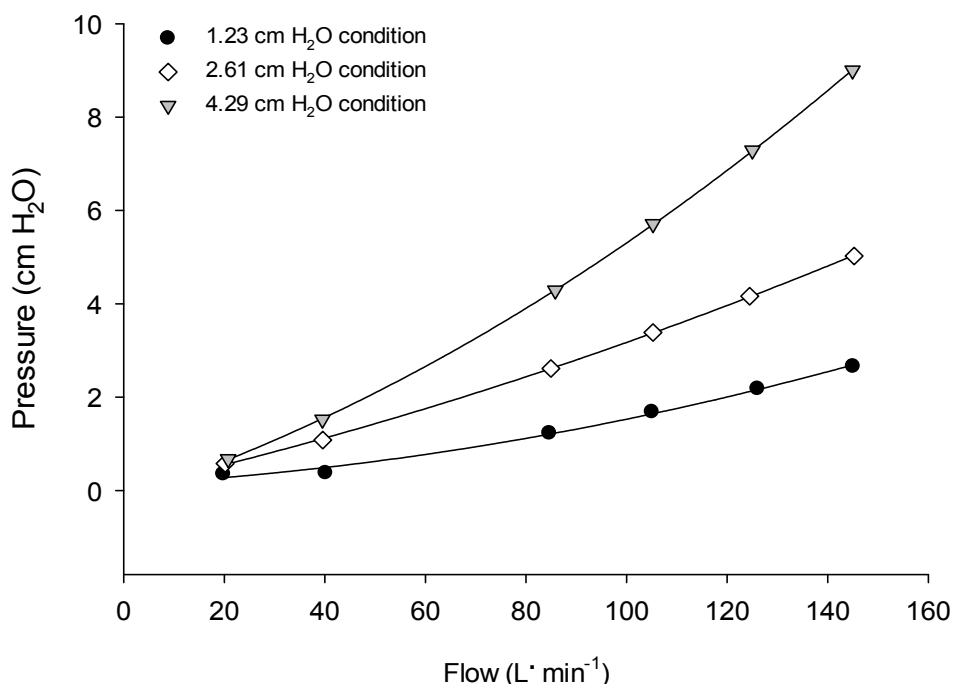


Figure 1. Pressure-flow characteristics for each P_{IN} condition. Conditions were defined by pressures recorded at a constant flow of 85 L·min⁻¹.

Test trials were performed on four consecutive days. Subjects reported to the lab one day prior to commencement of testing to receive instructions concerning the self-report questionnaires used in testing and to practice specific tasks included in this study. The physical tasks selected for this investigation included the Bennett Hand Tool Dexterity Test (Bennett, 1965) and three simulated vehicle-loading tasks. These tasks were chosen to represent light to heavy intensity physical workloads. In brief, the hand tool dexterity test (HTDT) is a widely accepted hand dexterity task for measuring proficiency in the use of ordinary tools. In the test, two open-ended wrenches, one adjustable wrench, and one screwdriver were used to loosen, relocate, and tighten three sizes of nut, bolt, and screw assemblies (12 total fastenings) from one location to another on a wooden form. The dependent measure was task completion time. The HTDT served as a measure of fine motor activity.

The simulated loading tasks assessed gross motor capability under three conditions of exercise consisting of light, moderate and heavy exertion. Volunteers were required to lift and move a series of 35.6 x 35.6 x 35.6 cm cardboard boxes loaded with 10 kg (light load; LL), 15 kg (moderate load; ML), or 20 kg (heavy load; HL) of weight from one bench top to another. These loads weighed approximately 11%, 17%, and 23% of body mass for the light, moderate, and heavy loads, respectively. The height of each bench top from the floor was 94 cm. The distance between locations was 6.1 m for each load condition. Walking between locations was defined for each condition and required volunteers to step on three round 24 cm diameter targets placed on the floor at set intervals. The amount of time allotted for completing box moving tasks was limited to 40 min for LL, 20 min for ML, and 10 min for HL tasks. Performance of each box loading task was measured as lift rate and target accuracy. The number of boxes available for the loading tasks was 50 for the LL, 25 for the ML and 15 for the HL. Volunteers moved only one box at a time; subjects who completed movement of boxes from one location to the other before time transpired were instructed to continue the task by returning boxes to their original location.

Upon reporting for testing subjects donned a portable heart rate monitor (Polar® Vantage XL, Polar CIC, Inc., Port Washington, NY) in preparation for heart rate monitoring. A pre-trial measurement of salivary amylase was obtained from each volunteer as a pre-trial MAACL-R questionnaire was completed. Subjects then self-donned their assigned test respirator and completed the State subscale questionnaire of the State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983) to further document how they felt at that moment. Subjects then completed a fit-test consisting of the same five one-minute activities used previously to ensure an acceptable respirator fit ($FF \geq 500$) was obtained. Upon successful completion of the respirator fit test, subjects sat quietly while wearing the respirator and performed a card sorting task for 15 min. This task was used only to occupy time while acclimating to respirator wear, so no measures of performance were collected at this time.

Volunteers completed a battery of five computer administered cognitive tasks following the acclimation period and prior to performance of the previously described physical activities. The procedures and results pertaining to the cognitive assessment portion of the investigation are not reported herein. The importance of this portion of the investigation towards subsequent performance of the physical tasks includes the following: 1. the complete battery of cognitive tasks was 60 min in duration; 2. volunteers were seated for the duration of the cognitive tests and the respirator remained donned; and 3. volunteers were permitted to obtain water ad libitum via the respirator's drink tube at the conclusion of the cognitive test battery.

At the conclusion of the cognitive tasks, subjects provided feedback regarding comfort and thermal sensation associated with the respirator based upon the Breathing Apparatus Comfort Scale (BACS), the Comfort Affect Labeled Magnitude Scale (CALM), the Numerical Discomfort Rating Scale (NDRS), and the American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) Thermal Sensation Scale. The BACS (Abadie and Carroll, 1993) measured subjective comfort on an eleven-point Likert scale with descriptors ranging from "Very, very uncomfortable" to "Very, very comfortable." The CALM (Cardello et al., 2003) measured subjective comfort using a continuous, ratio-level scale ranging from "Greatest imaginable comfort" to "Greatest imaginable discomfort." The NDRS

measured the intensity of discomfort with numbers ranging from zero ("No discomfort") to 10 ("Worst possible discomfort") (Childs et al., 2005). The ASHRAE scale (1993) measured thermal sensation on a seven-point Likert scale with descriptors ranging from "Hot" to "Cold."

After finishing the cognitive test battery subjects completed the four physical work tasks in random order. Heart rate and ratings of perceived exertion (RPE; Borg, 1982) were obtained at the beginning and end of each physical task. Volunteers also provided feedback concerning respirator thermal sensation and comfort at the end of each physical task using the same scales that were used at the conclusion of the cognitive performance tests. Subjects were encouraged to drink water after each task. Upon completion of all four physical tasks, subjects doffed the test respirator and provided an immediate salivary amylase sample while completing post-trial iterations of the MACCL-R and State subscale of the STAI. The duration of continuous respirator wear averaged 181.7 ± 0.5 min per test trial independent of inhalation resistance condition.

Data Analysis

Physiological work rates for the box moving tasks were estimated from the following equation modified to account for movement on a level grade and a terrain factor of 1 (Pandolf et al., 1977):

$$M \text{ (Nm}\cdot\text{s}^{-1}\text{)} = 0.15W_b + 0.2(W_b + W_L)(W_L/W_b)^2 + 0.102(W_b + W_L)(1.5s^2) \quad (1)$$

where M = metabolic work rate, W_b = body weight (N), W_L = load carry weight (N), and s = speed ($\text{m}\cdot\text{s}^{-1}$). Dependent variables assessed for box moving tasks included heart rate (HR), work rate, lift rate, accuracy, and task performance rating. The variables assessed for the Bennett HTDT were task completion time, HR, and task performance rating.

Statistical analyses were performed using Multivariate Analysis of Variance (MANOVA) with main effects of inhalation pressure (P_{IN} ; zero (i.e., No Mask), 1.23, 2.61, and 4.29 cm H_2O) and task (HTDT, LL, ML, and HL) for each dependent variable. All pairwise multiple comparison procedures were performed using the Holm-Sidak method (1979). Respirator performance ratings were calculated based upon the ratio of performance with the respirator to performance without the respirator when possible. Appropriate *post-hoc* analyses were applied to identify between condition differences if warranted. Statistical significance was accepted at the $p < 0.05$ level.

RESULTS

No significant differences were observed among P_{IN} conditions for any of the dependent variables assessed for the Bennett HTDT. Task performance time averaged 358 ± 9 s without respirator wear and 358 ± 8 s, 362 ± 10 s, and 362 ± 9 s for the 1.23 cm H_2O , 2.61 cm H_2O , and 4.29 cm H_2O P_{IN} conditions, respectively. Results from the box moving tasks are presented in Table I. No interactive effects between P_{IN} and task load were found. Independent of task load, HR differed statistically between the 1.23 cm H_2O and 4.29 cm H_2O P_{IN} conditions and both work rate and lift rate were statistically lower for the 4.29 cm H_2O condition compared to No Mask wear. However, the practical differences in average HR ($\sim 5 \text{ b}\cdot\text{min}^{-1}$) and average lift rate ($\sim 0.3 \text{ boxes}\cdot\text{min}^{-1}$) between these conditions were considered to be negligible. A significant main effect of task load was evident for work rate, lift rate, and accuracy but not for HR. Independent of inhalation resistance condition, calculated work rates differed significantly among all load moving tasks (LL = $2.74 \pm 0.04 \text{ kcal}\cdot\text{min}^{-1}$ ($191.2 \pm 2.8 \text{ W}$), ML = $2.96 \pm 0.03 \text{ kcal}\cdot\text{min}^{-1}$ ($206.5 \pm 2.1 \text{ W}$), and HL = $3.68 \pm 0.03 \text{ kcal}\cdot\text{min}^{-1}$ ($256.8 \pm 2.1 \text{ W}$)). Mean lift rate for the ML task ($4.18 \pm 0.05 \text{ boxes}\cdot\text{min}^{-1}$) was significantly less compared to both the LL ($4.70 \pm 0.05 \text{ boxes}\cdot\text{min}^{-1}$) and HL ($4.58 \pm 0.05 \text{ boxes}\cdot\text{min}^{-1}$) tasks independent of respirator P_{IN} test condition.

Table I. Mean ($\pm$ SEM) Results Obtained during Box Moving Tasks by Mask Wear Condition

Test Condition	Task Load	Heart Rate ($\text{b}\cdot\text{min}^{-1}$)	Work Rate ($\text{kgm}\cdot\text{min}^{-1}$)	Lift Rate ($\text{boxes}\cdot\text{min}^{-1}$)	Accuracy (%)
No Mask	LL (n=23)	131 $\pm$ 5	1196 $\pm$ 38	4.81 $\pm$ 0.18	100.0 $\pm$ 0
	ML (n=23)	130 $\pm$ 5	1290 $\pm$ 30	4.30 $\pm$ 0.18	99.8 $\pm$ 0.1
	HL (n=23)	134 $\pm$ 5	1601 $\pm$ 31	4.73 $\pm$ 0.18	99.8 $\pm$ 0.2
	All (n=69)	132 $\pm$ 3	1362 $\pm$ 28	4.61 $\pm$ 0.18	99.9 $\pm$ 0.1
1.23 cm H ₂ O	LL (n=24)	135 $\pm$ 4	1184 $\pm$ 33	4.76 $\pm$ 0.16	100.0 $\pm$ 0
	ML (n=24)	135 $\pm$ 4	1274 $\pm$ 26	4.26 $\pm$ 0.14	99.8 $\pm$ 0.1
	HL (n=24)	139 $\pm$ 4	1585 $\pm$ 30	4.67 $\pm$ 0.16	98.8 $\pm$ 0.7
	All (n=72)	136 $\pm$ 2	1350 $\pm$ 27	4.56 $\pm$ 0.09	99.5 $\pm$ 0.2
2.61 cm H ₂ O	LL (n=23)	136 $\pm$ 6	1170 $\pm$ 41	4.70 $\pm$ 0.18	99.9 $\pm$ 0
	ML (n=23)	131 $\pm$ 6	1266 $\pm$ 27	4.19 $\pm$ 0.14	99.5 $\pm$ 0.2
	HL (n=24)	137 $\pm$ 4	1571 $\pm$ 28	4.58 $\pm$ 0.15	98.5 $\pm$ 0.7
	All (n=70)	135 $\pm$ 3	1338 $\pm$ 27	4.49 $\pm$ 0.09	99.3 $\pm$ 0.2
4.29 cm H ₂ O	LL (n=24)	128 $\pm$ 5	1147 $\pm$ 34	4.51 $\pm$ 0.17	100.0 $\pm$ 0
	ML (n=24)	124 $\pm$ 5	1236 $\pm$ 25	3.96 $\pm$ 0.14	99.7 $\pm$ 0.2
	HL (n=24)	127 $\pm$ 4	1532 $\pm$ 22	4.34 $\pm$ 0.13	99.3 $\pm$ 0.5
	All (n=72)	127 $\pm$ 3 ^b	1305 $\pm$ 25 ^a	4.27 $\pm$ 0.09 ^a	99.7 $\pm$ 0.2

^a = significantly different from No Mask

^b = significantly different from 1.23 cm H₂O condition

Box lift rates decreased linearly as P_{IN} increased for each load task (Figure 2). Comparisons of the regression lines (McCuen, 1993) indicated that decreases in lift rate with increasing inhalation resistance occurred at the same rate for all lift tasks. In addition, the differences between lift rate for the ML boxes and both the LL and HL conditions were consistent across all inhalation pressures, but no significant differences among task loads were found. Lift rate performance ratings for each load lift task also decreased linearly for all P_{IN} conditions and no differences among load lift tasks were found. Independent of task load, a significant linear decrease in lift rate performance rating was found with increased P_{IN} ($R^2 = 0.96$; $p < 0.01$) defined by the equation:

$$\text{Lift Rate Performance Rating (\%)} = -1.74 (P_{\text{IN}}) + 102.4 \quad (2)$$

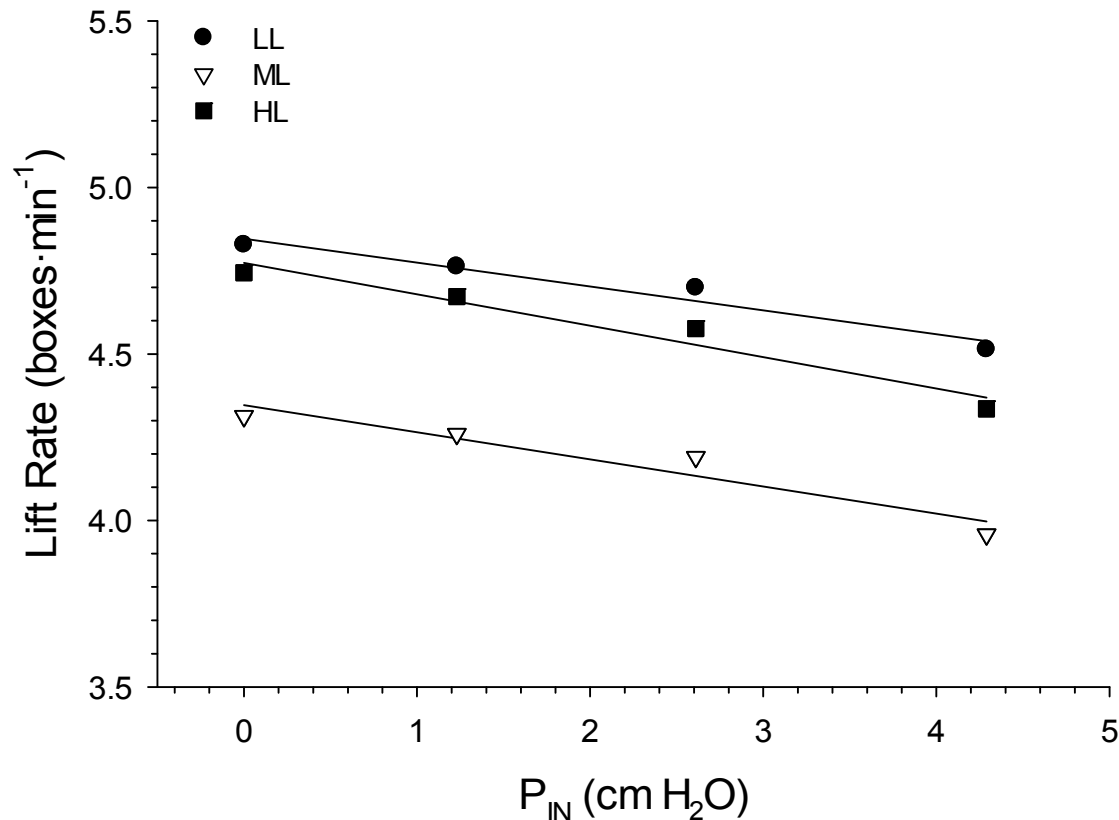


Figure 2. Mean lift rate with increased P_{IN} for each box moving task.

Subjective Self-Report Data

Initial exploratory analysis of subjective responses showed that these data types were non-Gaussian; therefore, all data were rank-transformed and then analyzed. Significant main effects of P_{IN} and physical task were found for all dependent variables, but no interactive effects were evident. In general, differences in subjective feedback scores were found between No Mask and each of the P_{IN} conditions independent of physical task. Within P_{IN} conditions, RPE scores for the HTDT task were significantly less compared to LL, ML, and HL box moving tasks but no RPE differences among the three load moving tasks were found. Average BACS scores reflected a subjective comfort rating of "Fairly comfortable" across all P_{IN} conditions (1.23 cm H₂O = 6.4 ± 0.2 ; 2.61 cm H₂O = 6.1 ± 0.2 ; 4.29 cm H₂O = 5.8 ± 0.2) and average scores for each P_{IN} condition were significantly different from the No Mask rating of 8.7 ± 0.2 or "Very comfortable." Average CALM scores also differed significantly between No Mask and each P_{IN} condition. Comfort ratings based upon average CALM scores indicated that participants were "Slightly comfortable" to "Moderately comfortable" for all respirator conditions and "Extremely comfortable" without the mask. Average NDRS scores were significantly higher for P_{IN} conditions (1.23 cm H₂O = 2.4 ± 0.2 ; 2.61 cm H₂O = 2.6 ± 0.2 ; 4.29 cm H₂O = 3.1 ± 0.2) compared to No Mask (0.6 ± 0.1). The fact that all average NDRS values were along the lower one-third of the Likert scale suggests that little to no discomfort was experienced by test participants. Ratings of thermal sensation were statistically

different between No Mask and each P_{IN} condition, but average values for all conditions were between “Slightly warm” to “Warm” for all conditions.

Assessment of Psychological and Physiological Stress Indicators

The evaluation of the psychological stress experienced with the different P_{IN} restrictions based upon MAACL-R showed a significant main effect of P_{IN} ; however, no interaction between P_{IN} and session (pre and post) was found. Based on these results, session data (pre and post) were pooled into one variable per MAACL-R subscale and a paired t-test between MAACL-R baseline and test scores by P_{IN} was performed. For the No Mask, 1.23 cm H_2O , 2.61 cm H_2O , and 4.29 cm H_2O conditions, participants reported significantly higher levels of depression compared to baseline levels ($t(23) = -2.09$, $p = 0.047$; $t(24) = -3.02$, $p = 0.006$; $t(23) = -3.32$, $p = 0.003$; $t(23) = -2.78$, $p = 0.011$, respectively). In addition to depression, the 2.61 cm H_2O P_{IN} caused hostility and dysphoria scores to increase compared to baseline levels ($t(23) = -2.87$, $p = 0.009$; $t(23) = -2.51$, $p = 0.02$).

Average salivary amylase results obtained before and after each test trial did not differ among or within test conditions. Separate comparisons of post-test amylase values with baseline group samples using a paired t-test also found no differences between any test condition (No Mask = $241 \pm 27 \text{ U}\cdot\text{ml}^{-1}$; 1.23 cm H_2O = $239 \pm 32 \text{ U}\cdot\text{ml}^{-1}$; 2.61 cm H_2O = $208 \pm 26 \text{ U}\cdot\text{ml}^{-1}$; 4.29 cm H_2O = $225 \pm 27 \text{ U}\cdot\text{ml}^{-1}$) and baseline ($220 \pm 27 \text{ U}\cdot\text{ml}^{-1}$) values. Although no main effects emerged for either the MAACL-R or salivary amylase data alone, a significant correlation between the MAACL-R anxiety subscale and amylase samples was evident for pre-trial samples ($R^2 = 0.25$) independent of P_{IN} condition. A significant association between the MAACL-R hostility subscale and post-trial amylase sample ($R^2 = 0.29$) was also found.

State anxiety scores did not differ among or within test conditions for either pre or post trial measurements and no significant differences in State anxiety were found between pre and post scores within test conditions. Because pre and post MAACL-R anxiety and State anxiety pre and post scores showed no significant differences, a paired correlation between the pooled State anxiety and the pooled MAACL-R anxiety data by P_{IN} was performed. A significant correlation between pooled data sets was found for the 4.29 cm H_2O P_{IN} condition ($r = 0.416$, $p = .048$), but no other correlations emerged.

DISCUSSION

This experiment examined the impacts of respirator inhalation airflow resistance on performance of fine and gross motor tasks of submaximal intensities comparable to those in many work situations requiring respirator usage (Bureau of Labor Statistics, 2002; Louhevaara et al., 1985). Based upon the estimated work rates derived from Equation 1, the load moving tasks would be categorized as light to moderate physical activities for the subject population. Predicted ventilation rates associated with these work rates ranged between roughly $21 \text{ L}\cdot\text{min}^{-1}$ and $26 \text{ L}\cdot\text{min}^{-1}$ (Carette and Coyne, 2006). According to the pressure-flow relationships presented in Figure 1, the levels of inhalation resistances imposed by each P_{IN} condition at such ventilation rates would have been relatively low and the differences among conditions would have been small. As such, the chances of finding quantifiable differences in task performance based upon the different levels of imposed inhalation resistance may have been hampered by the limited intensities of the physical tasks used in the study. Nevertheless, linear decreases in lift rate due to increased respirator inhalation resistances were observed for each load carrying task. These findings suggest use of respirators with inhalation resistances equal to or less than those used in this investigation, all of which were below the 6.5 cm H_2O limit defined for CBRN APR standards (NIOSH, 2004), will not adversely impact performance of fine motor activities and should not degrade performance of moderate intensity gross motor tasks by more than 5% compared to not wearing a respirator at all. In

fact, Shykoﬀ and Warkander (2011) found no difference in the number of boxes moved during a load lift and transfer activity due to APR wear. The boxes they used were heavier than those used here, but were carried for a shorter time interval.

Subjective responses provided by test participants showed little to no discomfort associated with the P_{IN} conditions. Additionally, average perceived exertion scores did not exceed ratings of "Somewhat hard" for any of the physical tasks. Since the test subject population was composed of active duty soldiers, these findings were not surprising due to the soldiers' experience wearing respirators and because the tasks performed were not perceived as physically challenging. Even so, analysis of combined pre and post trial MAACL-R subscales found that subject depression scores rose significantly above those of baseline data. The MAACL-R depression subscale measures one's perception of self failure or inability to perform up to expectations. In general, trained soldiers perform their duties well and have very high self expectations. These findings indicate that the test participants expected to perform better than they actually did regardless of P_{IN} condition and reflects the high level of motivation observed among the volunteers.

Of the three P_{IN} conditions used in this investigation the 2.61 cm H₂O P_{IN} condition was the only one that caused significant increases in the MAACL-R dysphoria subscale scores compared to baseline values. This increased feeling of dysphoria resulted from the higher than average baseline values for each of the MAACL-R subscales that comprise dysphoria (i.e., anxiety, depression and hostility). This finding suggests that the 2.61 cm H₂O P_{IN} condition imparted a greater degree of frustration or agitation on the test participants compared to the other respirator conditions. Why this was the case for the 2.61 cm H₂O P_{IN} condition and not the highest P_{IN} condition is unknown. It is plausible that the similarity among P_{IN} levels at the work rates imposed by the physical tasks limited the ability to observe differences in dysphoria among conditions.

The salivary amylase data revealed that neither the P_{IN} nor the physical tasks invoked significant amounts of physiological stress from the test participants. There is substantial evidence that alpha-amylase levels increase in response to physical stressors (Nexo et al., 1988; Chatterton et al., 1996; Steerenberg et al., 1997), as well as psychological stressors (Bosch et al., 1998; Skosnik et al., 2000). Contradictory findings (Bosch et al., 2003) suggest that infrequent sampling of alpha-amylase for recording short-term responses to a stressor will hinder observations of increased alpha-amylase levels in response to stress. The present study required approximately three hours of continuous respirator wear per test session limiting the opportunities for salivary amylase sampling to times when a respirator was not being worn. Because samples could only be obtained prior to donning and after doﬀing the respirator the ability to adequately evaluate alpha-amylase responses to the various P_{IN} conditions was limited. An experimental design that permits frequent sampling before and after individual tasks could potentially show an accurate reaction pattern of alpha-amylase to respirator wear in a distinct stress-related time frame.

CONCLUSIONS

While the three respirator inhalation resistances in this study did not generate detectable differences in performance of the low to moderate intensity tasks, a meaningful linear decrease in lift rate performance rating was found with increased P_{IN} independent of task load ($R^2 = 0.96$; $p < 0.01$). This despite similarities among P_{IN} conditions due to the relatively low ventilation rates believed to be experienced by the test participants. Differences among low to moderate work rates that elicit discernible differences in ventilation rates may identify significant differences among respirator resistance conditions in future efforts. However, assessment of resistance impacts on tasks comparable to those in many work situations need to keep work intensities below maximal efforts to fill data gaps related to these conditions.

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