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Cognitive Performance and Mood During Respirator Wear and Exercise

The combined effects of respirator wear and low-intensity work on decision making and mood were assessed in eight subjects during 60 min of low-intensity treadmill walking with and without a respirator to determine whether the stresses of respirator wear negatively impact decision making. Subjects completed walks during no mask wear, wear of a respirator with high inspiratory resistance, and wear of a respirator with low resistance. Cognitive tasks included choice reaction (CHO), serial addition/subtraction (ADD), logical reasoning (LOG), and serial reaction (SER). Mood was measured using a questionnaire with 36 adjectives representing the factors of activity, anger, depression, fear, happiness, and fatigue. Data were obtained preexercise, after 20 and 40 min of walking, and postexercise. Combined respirator wear and low-intensity exercise did not affect accuracy, speed, or throughput in any of the cognitive tasks. Likewise, no significant effects of condition on the six mood factor scores were observed. These results show that the combination of respirator wear and low-level activity does not adversely alter cognitive performance or mood.

Keywords: cognitive performance, mood, respirators

Decision making of workers performing low-intensity work may be compromised due to changes in cognitive performance and mood. Kamimori et al.⁽¹⁾ found that while exercising at 40% of peak oxygen consumption, subject cognitive task performance was negatively impacted compared with preexercise scores during each stage of a 90-minute discontinuous exercise study. In addition, these researchers found that subject mood states were significantly altered during the last period of exercise. Based on these findings, Kamimori et al.⁽¹⁾ suggested that decision making may be compromised for individuals exposed to similar physical stresses as part of their normal workday. If a respirator is required to be worn to protect a worker from airborne health hazards, additional respirator-induced stresses such as breathing resistance and comfort may further impact decision making. However, specific research that addresses this possibility has not been found.

Several reports have been published concerning the effects of various levels of protective ensembles on cognitive performances of subjects which suggest that, in general, wearing protective clothing degrades speed of cognitive tasks.⁽²⁻⁵⁾

Work by others that involved respirator wear alone suggests that the respirator does not negatively influence cognitive function.⁽⁶⁻¹⁰⁾ However, for these tests, cognitive function was assessed either in the absence of exercise or during rest phases of an extended mask wear and exercise experiment. Caretti⁽⁶⁾ performed a 10-hour respirator wear study during which subjects remained seated before a computer terminal and performed a variety of computer-generated tasks to simulate long-term monitoring operations. Johnson et al.⁽⁸⁾ also assessed respirator wear and cognitive task performance over a 10-hour wear trial and cognitive tasks were performed under sedentary conditions. However, cognitive assessment periods were interspersed with periods of moderate and heavy exercise as an attempt to better simulate working conditions that may be encountered over a 10-hour work day. Under these respective conditions, both Caretti⁽⁶⁾ and Johnson et al.⁽⁸⁾ found that respirator wear had little affect on decision making and cognitive performance. However, the results of these investigations do not address whether the combination of respirator wear and low-intensity work impacts operator decision making efficiency.

Therefore, this article reports on the results of a study that assessed decision making capacity by measuring cognitive ability and mood factors in subjects during 60 minutes of low-intensity treadmill walking with and without a respirator. Two conditions of respirator inspiratory resistance were tested as a part of this study to determine whether cognitive abilities and mood factors were also affected by different respirator breathing resistances.

METHODS

Eight subjects (seven male and one female) aged 30–42 years (mean age 35 years) were recruited to participate in this study. Volunteers were obtained from the civilian personnel employed at Aberdeen Proving Ground, Edgewood Area, M.D. Volunteers were thoroughly briefed on the nature and purpose of the study and informed consent was obtained from each volunteer upon completion of a volunteer agreement affidavit.

Cognitive performance and mood were measured using the Walter Reed Performance Assessment Battery (PAB), a computerized psychological test battery designed for examining the effects of various state-variables on a sample of normal psychomotor, perceptual, and cognitive tasks.⁽¹¹⁾ The battery has been used for studying the cognitive effects of sleep deprivation, sustained performance, jet lag, heat stress, and fatigue, among other things. The tests comprising the PAB were adopted from established and validated paper-and-pencil tests. A comprehensive review that details validity and reliability of each of the tasks selected for inclusion in the PAB can be found in a report published by Perez et al.⁽¹²⁾

For this study, the PAB was configured to include mood scale, serial addition/subtraction, logical reasoning, four-choice serial reaction time, and 10-choice reaction time tasks. All tasks were presented via a computer (Unisys 816 PC, VGA color monitor, Unisys Corp., North Flemington, N.J.) configured with a timer board (Instacal CIO-CTR5, Computer Boards, Inc., Mansfield, Mass.). The mood scale task consisted of a three-point scale (1–3) with the word anchors of “not at all,” “somewhat or slightly,” and “mostly or generally.” Thirty-six adjectives that describe different mood states were presented in random order to the subject. Examples of these include “calm” and “energetic.” Subjects responded by depressing the number that best described the degree to which they currently felt in relation to the presented adjective. Responses to the 36 adjectives were grouped into 6 mood factor scores representing anger, happiness, fear, depression, activity, and fatigue. The factor scales of this mood questionnaire have been shown to have moderate to high validities in a number of situations and moderately high Spearman-Brown interitem reliabilities.⁽¹³⁾

The serial addition/subtraction task was a mental arithmetic task requiring sustained attention. This task has been used extensively in research addressing the effects of sleep deprivation and work-sleep schedules on cognitive performance and has proven to be a reliable and valid measure of sustained attention.⁽¹⁴⁾ For this task, two randomly selected digits and either a plus or minus sign were displayed sequentially in the same screen location, followed by a prompt symbol. The subject performed the indicated mathematical operation and entered the least significant digit of the result (e.g., “7, 5, +” equals 12, so enter 2). Scores were provided for the number of correct and incorrect responses (i.e., response accuracy), speed of response, and throughput (correct responses per minute).

Logical reasoning involved an exercise in transformational

grammar. Sustained subject attention was an aptitude also needed for this task. The letter pair “AB” or “BA” was presented along with a statement describing the order of the letter pair (e.g., “B follows A” or “A is not preceded by B”). The subject had to decide whether the statement was the “same” or “different” from the presented letter pair and responded by pressing the “S” or “D” key. If no valid response occurred within 30 sec, a beep was sounded, the screen went blank, and the next trial was presented. Summary data included scores for response accuracy, speed of response, and throughput. Test-retest reliability tests of the logical reasoning task have shown high ($R^2 \geq 0.80$) intertrial correlations over time.⁽¹²⁾ In addition, tests of task reliability suggest that the task serves as a reliable measure of logical reasoning ability.⁽¹²⁾

For the four-choice serial reaction time task, a red square appeared in one of four boxes positioned in the center of the computer screen and the subject pressed a corresponding button on the numeric key pad of the keyboard as quickly and as accurately as possible. Again, scores were provided for accuracy, speed of responses, and throughput. According to Krause and Bittner,⁽¹⁵⁾ the four-choice reaction time task is characterized by sufficient internal reliability. Likewise, research has shown the task to be characterized by considerable internal validity.⁽¹²⁾ Therefore, performance decrements associated with the four-choice reaction time task can be attributed to the experimental manipulations being evaluated with a high degree of certainty.

The 10-choice reaction time task was a simple reaction time task that served as a control task for the serial addition/subtraction, and as a practice doubler to hasten stability on the keypad. A single number from zero to nine was presented in the center of the screen and subjects responded by pressing the corresponding number on the numeric key pad as quickly as possible.

All subjects completed three random test iterations. One test involved no respirator wear and served as the control condition for each subject. Both respirator wear tests required wear of the U.S. Army M40 respirator. For one respirator trial, inspiratory airflow resistance of the M40 was measured to be 46 mm H₂O at a constant flow rate of 1.4 L/sec (high resistance condition). The second respirator wear trial required wear of the M40 with an inspiratory airflow resistance of 22.3 mm H₂O (low condition), or approximately half the resistance of the first respirator condition.

Before data collection procedures were initiated, subjects reported to the laboratory to complete several practice trials of the PAB test battery chosen for this study. Subjects completed at least three practice trials of the customized PAB battery to become familiar with the various tasks, the position of the computer keyboard, and with use of the numeric key pad of the keyboard. A test administrator went through the instructions with each subject to provide further explanation if necessary. Since subjects would be required to complete the PAB while walking on a treadmill, at least one practice trial was conducted during treadmill walking. Volunteers were given the option to complete additional practice trials if they felt it would increase their familiarity with the PAB tasks and the numeric key pad.

Subjects were prepped for heart rate monitoring upon arrival at the laboratory for testing. Heart rate was monitored continuously during and following exercise by recording a bipolar three-lead ECG (Quinton Q3000 ECG monitor, Quinton Instrument Co., Seattle, Wash.) to ensure that subject work load was maintained at approximately 50% of predicted maximum heart rate (220 minus age) throughout each exercise iteration. Heart rate was recorded at 10-minute intervals during exercise. If a subject

TABLE I. Response Accuracy (% Correct) of PAB Tasks

Task	Time	No Mask	High	PR High	Low	PR Low
Serial \pm	Pre	95.8 \pm 3.6	96.3 \pm 2.3	100	94.0 \pm 4.0	98
	20 min	94.8 \pm 6.0	94.5 \pm 6.6	100	97.0 \pm 1.5	102
	40 min	97.8 \pm 2.5	95.7 \pm 5.0	98	95.8 \pm 3.5	98
	Post	96.3 \pm 2.9	95.0 \pm 8.9	99	93.8 \pm 5.4	97
Logical reasoning	Pre	88.3 \pm 15.5	87.5 \pm 13.9	100	83.9 \pm 14.7	96
	20 min	89.4 \pm 11.9	88.6 \pm 17.8	98	86.3 \pm 14.2	97
	40 min	90.6 \pm 13.8	90.2 \pm 15.3	99	90.6 \pm 12.0	103
	Post	89.1 \pm 16.1	87.9 \pm 17.3	98	90.8 \pm 8.4	105
4-Choice RT	Pre	99.8 \pm 0.7	99.8 \pm 0.7	100	99.5 \pm 0.9	100
	20 min	98.3 \pm 2.3	99.5 \pm 0.9	99	97.3 \pm 3.7	101
	40 min	99.3 \pm 1.0	99.3 \pm 1.5	99	98.5 \pm 2.8	100
	Post	99.8 \pm 0.7	99.8 \pm 0.7	100	99.8 \pm 0.7	100

Notes: Serial \pm = serial addition/subtraction; 4-Choice RT = four choice reaction time; High = high resistance condition; Low = low resistance condition; and PR = performance rating.

was scheduled to complete a respirator wear iteration, M40 respirator fitting was completed following heart rate monitoring preparations.

Before testing commenced, subjects completed the State-Trait Anxiety Inventories.⁽¹⁶⁾ The trait anxiety inventory evaluated how respondents felt in general and served as a measure of subject anxiety proneness. This questionnaire was administered to each subject only at the beginning of their initial test iteration. The state anxiety inventory assessed how subjects felt at a particular moment and served as measure of anxiety at the particular time of administration. Thus, state anxiety scores were obtained to assess anxiety levels at specific instances during each respirator wear trial. Subjects then completed one practice session of the PAB to reacquaint themselves with what was to be displayed on the computer screen, which keys would be used, and what the rules were for each task. Once subjects completed the practice trial, testing commenced with subjects performing the tasks of a preexercise PAB battery.

A simulated road march involving continuous walking for 60 minutes at a work load of 50% of predicted maximum heart rate was then completed by each subject. Speed and grade of the treadmill (Quinton model Q65) were adjusted as needed to elicit and maintain the target work intensity. Subjects repeated the tasks of the PAB after 20 and 40 minutes of exercise. Subjects continued to walk while completing these PAB iterations. All testing was

conducted in an air-conditioned laboratory with a temperature of approximately 23°C.

Subjects provided subjective self-ratings of respirator comfort after initial donning, every 10 min of exercise, and immediately postexercise through the use of the Breathing Apparatus Comfort Scale (BAC).⁽¹⁷⁾ The BAC is an 11-point scale with word descriptive anchors where 10 = most comfortable and 0 = most uncomfortable.

Following the treadmill walk, subjects completed a final iteration of the PAB. Subjects remained masked while completing the final PAB trial during respirator wear trials. The state anxiety questionnaire was repeated following exercise after subjects removed their respirators.

RESULTS

Performance results for the PAB serial addition/subtraction, logical reasoning, and four-choice serial reaction time task are presented in Tables I through III. Data are presented for the different experimental conditions (control, high, and low) over time. Calculated respirator performance ratings represent the ratios of performance measures during respirator wear for each of the different inspiratory resistance configurations compared with the no respirator condition.

TABLE II. Speed (responses/min) of Response for PAB Tasks

Task	Time	No Mask	High	PR High	Low	PR Low
Serial \pm	preexercise	64.5 \pm 9.3	63.8 \pm 13.3	100	58.9 \pm 10.0	93
	20 min	67.6 \pm 10.7	70.8 \pm 11.4	106	60.4 \pm 14.4	89
	40 min	70.6 \pm 10.0	76.3 \pm 14.5	112	69.6 \pm 16.3	101
	postexercise	70.0 \pm 9.3	70.3 \pm 11.1	102	61.0 \pm 12.8	88
Logical reasoning	preexercise	18.2 \pm 5.1	17.2 \pm 4.6	96	16.8 \pm 6.2	92
	20 min	18.0 \pm 5.1	18.7 \pm 5.1	105	18.3 \pm 4.7	105
	40 min	20.2 \pm 5.2	19.0 \pm 4.1	97	17.2 \pm 5.7	86
	postexercise	20.4 \pm 4.6	18.3 \pm 5.0	91	16.8 \pm 5.2	82
4-Choice RT	Preexercise	139.5 \pm 19.2	140.6 \pm 15.2	102	145.0 \pm 8.7	105
	20 min	145.8 \pm 17.4	147.9 \pm 15.6	102	139.8 \pm 23.4	96
	40 min	153.0 \pm 19.7	150.2 \pm 21.6	99	146.4 \pm 21.3	96
	postexercise	149.4 \pm 15.8	155.1 \pm 17.0	103	144.8 \pm 22.1	97

Notes: Serial \pm = serial addition/subtraction; 4-Choice RT = four choice reaction time; High = high resistance condition; Low = low resistance condition; and PR = performance rating.

TABLE III. Throughput (hits/min) for PAB Tasks

Task	Time	No Mask	High	PR High	Low	PR Low
Serial ±	preexercise	61.7 ± 9.0	61.4 ± 13.1	100	55.5 ± 10.5	91
	20 min	63.9 ± 10.6	67.1 ± 13.2	106	58.6 ± 13.8	91
	40 min	69.2 ± 10.9	73.3 ± 16.0	110	70.0 ± 17.4	99
	postexercise	67.1 ± 10.0	66.6 ± 11.9	100	57.5 ± 14.0	86
Logical reasoning	preexercise	16.3 ± 6.2	15.4 ± 5.8	96	14.8 ± 7.6	90
	20 min	16.1 ± 5.3	16.7 ± 6.2	103	16.0 ± 5.4	103
	40 min	18.4 ± 6.0	17.3 ± 5.3	97	16.0 ± 6.5	89
	postexercise	17.9 ± 4.6	16.3 ± 6.4	88	15.5 ± 5.6	85
4-Choice RT	preexercise	139.1 ± 18.8	140.2 ± 14.7	102	144.3 ± 18.8	105
	20 min	143.2 ± 16.8	147.1 ± 15.4	103	136.1 ± 24.4	96
	40 min	151.8 ± 19.5	149.1 ± 22.2	99	144.0 ± 20.1	95
	postexercise	149.1 ± 16.1	154.7 ± 16.8	103	144.4 ± 21.7	97

Notes: Serial ± = serial addition/subtraction; 4-Choice RT = four choice reaction time; High = high resistance condition; Low = low resistance condition; and PR = performance rating.

Individual three-way analyses of variance for the factors of subject, respirator condition, and time of measurement were performed on results obtained for the serial addition/subtraction, logical reasoning, and four-choice serial reaction time tasks. For each analysis a significant main effect of subject on response accuracy scores, measured as the percentage of correct responses, was found independent of respirator wear condition and time of measurement. However, no significant interactions were observed for the subject factor. Likewise, no differences were found within subjects between respirator conditions or over time.

Average response accuracy scores were similar between the three respirator wear conditions within each task and for each measurement period (Table I). In addition, no significant differences were found between time periods within each condition. Performance ratings were also similar for the different inspiratory resistance test conditions. In general, performance rating scores showed that response accuracy for the three tasks was not influenced by respirator wear.

Separate analyses of variance performed on the speed and throughput data resulted in findings similar to accuracy results. No statistical differences were found between experimental conditions within each task, and time of measurement did not alter responses within each condition (Table II). Speed and throughput performance ratings for the low resistance condition for the serial addition/subtraction task were less than high resistance condition ratings at all times, but no significant differences were found. Speed and throughput performance decrements during respirator wear ranged from 0 to 15% and varied over time.

Independent of time of measurement, a significant ($F=3.4$, $df=2,94$, $p=0.03$) main effect of respirator wear condition was found for speed of response for the serial addition/subtraction task. Post-hoc analysis using Duncan's multiple range test showed that average response speed was significantly less for the low resistance condition compared with the other conditions (Table IV).

A separate one-way analysis of variance for the throughput variable showed a significant main effect of respirator condition with a p -value equal to 0.05. Subsequent analysis with the Duncan's multiple range test again indicated that average subject throughput was lower during the low resistance respirator wear trials (Table IV). No other main effects of respirator experimental condition were observed.

Analysis of mood scale responses was performed using multivariate analysis of variance with unique sums of squares for the variables of condition and time of measurement. Results of this

analysis found no significant interactive effects of condition and time on the six mood factor scores of anger, happiness, fear, depression, activity, and fatigue. In addition, no significant main effects of time or condition were observed.

No differences in state anxiety were observed before and after exercise within test conditions. Likewise, similar state anxiety scores were found between respirator wear conditions. Self-reported BAC scores did not differ between the masked conditions.

DISCUSSION

The results of this study showed that respirator wear over time had little effect on performance of cognitive tasks during moderate intensity physical work. Previous research suggests that such a finding should not be unexpected. Caretti et al.⁽⁶⁾ found that reaction time and decision making speed were not significantly altered during 10 hours of continuous respirator wear under nonexercising conditions. Likewise, others have reported that respirator wear did not influence cognitive performance during completion of a variety of physical and psychomotor tasks over time.^(8,10) In contrast, Kamimori et al.⁽¹⁾ found that, in the absence of respirator wear, cognitive performance decreased during low-intensity exercise. However, the present authors found no significant effects of exercise on task performance during the unmasked trials of this study. Therefore, results of this investigation contradict the findings of Kamimori et al.

The finding of a significantly slower response speed and lower response throughput for the serial addition/subtraction task independent of exercise for the low resistance respirator condition compared with the high resistance and control conditions was not expected. This finding suggests that decreasing respirator inspiratory resistance detrimentally influences some cognitive abilities. Previous studies have reported no change or improved cognitive

TABLE IV. Serial Addition/Subtraction Data Independent of Time of Measurement

Measure	No Mask (n = 32)	High (n = 31)	Low (n = 32)
Speed (responses/min)	68.2 ± 9.7	70.1 ± 12.7	62.5 ± 13.6 ^A
Throughput (hits/min)	65.5 ± 10.1	66.9 ± 13.5	59.6 ± 14.2 ^A

^ASignificantly different versus No Mask and High

functioning during wear of the M40 respirator with an identical resistance level, a result that was attributed to a filtering effect of the respirator that serves to help masked subjects to focus better on completion of the tasks compared with unmasked subjects.^(6,7) However, filtering of peripheral distractions would seem to be equivalent for the two resistance conditions in this study because the hardware items of the respirator were identical for each condition. A possible explanation is that the reduced respiratory burden served to lower the overall stress of wearing the respirator. This in turn may have acted to decrease subject arousal. Increased arousal caused by the stress of respirator wear has been suggested to improve subject concentration and stimulate performance.⁽⁷⁾ Therefore, the level of arousal of subjects wearing the low resistance respirator may have been too low to stimulate performance on the serial addition/subtraction task. In any case, the overall effect of respirator wear with a lower inspiratory resistance on overall cognitive performance would be considered to be minimal based on the finding that only one of the three cognitive abilities tested was influenced by this wear condition.

Failure to see differences in mood between no respirator wear, wear of the M40 with a high resistance, and wear of the M40 with a low resistance was unexpected since it has been reported that most individuals can accurately detect changes in breathing resistance.⁽¹⁸⁾ Certainly, before testing commenced, it was anticipated that subjects would be more comfortable during low resistance trials, which would result in a better overall mood state during testing. Mood, state anxiety, and BAC scores, however, were identical between conditions, indicating that subjects were unable to detect a difference in the resistance levels of the two masked trials. In fact, one subject was adamant in his perception that the low resistance respirator was the high resistance condition and vice versa. This inability to notice a difference in breathing resistances most likely limited the chances of seeing significant differences in mood scores. Larger differences in breathing resistances for the masked conditions may have resulted in significant differences in subject mood states between conditions.

Another factor to consider is that of the exercise intensity chosen for testing differences in breathing resistance. It has been suggested that in order to assess the effects of respirator breathing resistance on performance, testing must be done at an intensity that causes the respiratory system to be the limiting factor in exercise performance.⁽¹⁹⁾ Current data suggests that this intensity falls between 85–90% of maximal oxygen consumption, or 75–85% maximal heart rate.⁽²⁰⁾ Since exercise intensity averaged 52% of predicted subject maximal heart rates, stress on the respiratory system was not significant. Results from the PAB test scores could be different between test conditions if testing was conducted to impose a greater stress on the respiratory system, but completion of the computerized tasks would be more difficult during continuous exercise and would likely result in more errors in keyboard use due to greater arm, hand, and head movement due to increased treadmill speeds and grades. However, discontinuous high intensity exercise could serve as a means to assess the effects of breathing resistance on PAB scores.

CONCLUSIONS

The results of this study suggest that decision making ability and mood are not detrimentally influenced under conditions of respirator wear and low-intensity exercise. It should be noted that the relatively small sample size of this experiment may limit

the impact of these findings. Obviously, a larger sample population would serve to improve the sensitivity of the statistical analyses. However, since previous research has found no cognitive effects of respirator wear under varying conditions,^(6–10) the findings of this study should not be dismissed on the condition of sample size alone. Therefore, based on the experimental conditions and the results of this study, respirator wear should not severely impact operator decision making during light physical activity occurring at room temperature. Further research is needed to determine whether respirator wear alters worker decision making under more severe workloads or environmental conditions.

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