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Prediction of Respiratory Distress During Maximal Physical Exercise: The Role of Trait Anxiety

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Industrial respirators offer protection for men and women who are required to work in toxic and oxygen-deficient environments. Major advances continue to be made with respect to improved face mask designs and modes of protection, yet only recently have efforts been directed toward the development of criteria for use in evaluating individuals' psychological fitness to wear respirators. The purpose of the present investigation was to confirm (i.e., replicate) an earlier finding, using a simplified protocol, that an individual's tendency to experience respiratory distress during exercise can be predicted. In the present experiment, an independent sample of 38 subjects underwent a maximal exercise test. It was predicted that subjects with elevated trait anxiety scores would experience respiratory distress when required to perform heavy physical exercise using a full-facepiece, air-line supplied, pressure-demand respirator. The prediction of respiratory distress was accurate in 34 of 38 cases (89.5%). It was concluded that an objective measure of trait anxiety can be used to identify those individuals who are most likely to experience distress while performing maximal physical exercise and using a pressure-demand respirator.

Keywords: anxiety, dyspnea, exercise, respirator

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Respiratory protective devices have developed over the years as a means of enabling the worker to perform necessary functions despite the presence of environmental stressors. Yet, to provide protection, the respirator invariably interferes with normal human respiratory function. Depending on the protection required and the intensity of work performed in extreme environments, the interference with respiratory function may become significant. The psychological distress for the wearer, who senses an inability to breathe normally, may become so great as to cause the individual to remove the respirator in the midst of hazardous surroundings. Morgan[1] has indicated that a number of psychological problems are associated with the wearing of industrial respirators. In addition, there is evidence that individuals with a predilection for the hyperventilation syndrome would be more prone to experience respiratory distress associated with the use of industrial respirators.[2]

Major advances in mask design and protection have been made. Numerous studies have indicated the physiological demands respirators place on wearers.[3–6] Little effort, however, has been directed toward developing criteria for use in evaluating an individual's psychological fitness to wear an industrial respirator. In 1974 Cooper[7] proposed that specific techniques be developed to evaluate whether an individual should be expected to perform work in an environment requiring wearing of a respirator. Furthermore, many authors have concluded their discussions involving respirator wear with a section dealing with psychological problems. Unfortunately, the psychological variables and problems of respirator wear have not been addressed in a systematic manner. Little research has been directed toward an understanding of the psychological component of the person-respirator interface, but preliminary research by Morgan and Raven[8] suggests that the wearing of respirators is best viewed within a psychobiological context. To illustrate this point, Pritchard[9] has gone as far as to suggest that workers who experience claustrophobia or anxiety when confined in a small space should not be given jobs that require respirator wear. In addition to the suggestion by Pritchard,

there also have been recommendations presented for the level of physiological fitness required with wear of an industrial respirator.[5,7,10] Furthermore, Johnson et al.[6] studied the influence of anxiety levels on treadmill performance in high- and low-anxiety subjects during exercise performed while wearing a respirator mask. These investigators reported that high anxious subjects experienced more discomfort and had lower performance than subjects with low anxiety.

The influence of respirator wear on physical, psychomotor, and cognitive tasks was studied in 12 males by Zimmerman et al.[11] The individuals were tested while exercising on a bicycle ergometer at a power output estimated to be 25–30% of VO_{2max}. The subjects were tested while wearing disposable dust masks, air-purifying half masks, and full-face air-line masks. When compared with the no-mask control condition, it was found that wearing the respirators did not have a significant effect on performance of the cognitive tasks, whereas performance of psychomotor tasks was impaired. The results of this investigation have important implications since the impaired psychomotor performance was observed at a relatively light work load.

There is also research by Caretti et al.[12] showing that continuous wear of a full-facepiece respirator for 3.5 hr does not impair cognitive performance as measured by a reaction time task. As a matter of fact, these investigators found that respirator wear was actually associated with improved decision-making speed. This paradoxical, or unanticipated, effect was attributed to the presumed increase in arousal resulting from respirator wear. On the other hand, Johnson et al.[6] reported that elevated anxiety is associated with increased discomfort and decreased performance. It is possible that the results reported by Caretti et al. were influenced in part by ''volunteerism'' or sampling bias.[13] The mean trait anxiety score for the participants in the study reported by Caretti et al. was 26.8 (±5.7), and the individual scores ranged from 19 to 37. The lower end of this range represents an apparent error since a score of 20 is the lowest possible value on this scale. This sample should be viewed as scoring in the low-anxious range, and therefore, the findings cannot be inferred to the general population. These results have little meaning for individuals classified in the high-anxious category. Indeed, the firefighters who were classified as being prone to experience respiratory distress by Morgan and Raven[8] while exercising and wearing a full-face mask respirator in demand and pressure-demand mode scored 39 or above on the same scale used by Caretti et al.[12] The use of Spielberger's model of stress and anxiety would not predict that individuals scoring in the low-anxious range would experience distress when exposed to a stressor. This is a very common problem in stress research since individuals who score in the high-anxious range are often reluctant to expose themselves to various stressors.[13]

There is general agreement that ''wearer comfort'' is a crucial consideration in the selection of respirators. Virtually everyone who wears a respirator experiences some discomfort, the severity depending on the characteristics of the respirator. If vision is restricted or breathing is difficult, an anxiety response can be provoked in certain individuals above and beyond the stress induced by physical work. It has been reported that approximately 90% of any given sample of test subjects can judge accurately the physiological cost of work.[14–16] However, it is also known that approximately 10–15% of any given sample of nonhospitalized individuals manifest psychological problems such as depression and anxiety. This is important since the degree of psychopathology has been observed to correlate inversely with perception of effort, CO_2 sensitivity, and work tolerance.[17,18] Therefore, specific individuals may experience breathing distress while wearing a respirator, even though such equipment is necessitated by a given environment, and these individuals may remove the respirator while working in a dangerous environment. The removal of a respirator in such a setting may result in unconsciousness due to the presence of various gases and particulates, severe injury, or even death. It therefore seems imperative that a method be developed to identify ''responders'' or individuals who ''overreact'' when performing heavy exercise and wearing a respirator in hostile environments.

Psychological inventories are available to measure an individual's propensity to experience distress when confronted with various stressors. In a previous study by two of the present authors[8] it was possible to predict respiratory distress a priori for individuals differing in trait anxiety as measured by the State-Trait Anxiety Inventory (STAI).[19] Individuals scoring high on trait anxiety (i.e., 39 or higher) were more likely to experience respiratory distress when performing submaximal and maximal exercise on a treadmill while wearing an industrial respirator than were individuals who scored low on trait anxiety (i.e., 38 or lower). The accuracy of prediction was 85%, and both predictions and classifications of distress were performed independently within a ''blinded'' context.[8]

The primary purpose of the present study was twofold. First, an effort was made to confirm the initial findings of the effectiveness of using the trait anxiety subscale of the STAI in predicting respiratory distress during maximal treadmill work performed while using a full-facepiece, air-line supplied, pressure-demand respirator. Second, the earlier work of Morgan and Raven[8] was extended to include individuals who were inexperienced in respirator wear, as well as individuals who were experienced firefighters. It was hypothesized that the experience of respiratory distress would be greater in those individuals found to score higher on the trait anxiety scale of the STAI regardless of experience wearing respirators.

METHODS

Subjects

Thirty-eight individuals (7 women and 31 men) possessing a mean age of 31.8 years of age (24 through 51 years) volunteered to participate in this investigation. The mean trait anxiety scores for the men and women were 31.0 (SD = 6.1) and 32.4 (SD = 7.7), respectively. The mean difference in trait anxiety was not statistically significant ($t = 0.54$, $df = 36$, $P = 0.60$), and the computed effect size was low (i.e., 0.20). Since there were no gender differences in anxiety, the two groups were combined for statistical purposes. Nineteen subjects were firefighters recruited from various city fire departments in the Dallas-Ft. Worth, Tex., area and 19 subjects were controls with no experience wearing respirators. Each subject read and signed an informed consent statement previously approved by institutional review boards at both institutions represented by the authors. It was made clear in this consent form that participants would be free to discontinue their involvement at any point in the experiment. The STAI[19] was completed at this time, and it was scored in a blind fashion by one of the investigators. The exercise testing and data collection were performed in Fort Worth by the other investigators (JRW & PBR) without the involvement of WPM. The STAI questionnaires were shipped to Wisconsin and scored by WPM without the knowledge of how the subjects had responded to the maximal treadmill test. This procedure eliminated behavioral artifacts such as the Halo effect,

experimenter expectancies, and demand characteristics.[13] The three investigators met following the experiment in Fort Worth to compare the psychological predictions of respiratory distress with the actual results observed during and following the exercise tests. The general prediction and testing procedure was identical with that described earlier by Morgan and Raven.[8]

Treadmill Test

Following the baseline testing described above, each subject performed a maximal exercise test to voluntary exhaustion while walking on a motor-driven treadmill. This test was designed to simulate a short, intense burst of physical exertion. This test utilized a ramping protocol that raised the percentage grade 0.5% every 12 seconds or 2.5% per minute. The speed was held constant at 3.4 miles per hour, and the workload was approximately 60 watts per minute. The subjects wore full-face masks that supplied air through a pressure-demand regulator. The air was supplied from an air tank resting on the floor and delivering compressed air at a final stage regulator pressure of 100 psig. The static pressure in the mask was maintained at no more than 3.5 cm of water in accordance with the guidelines for industrial respiratory protection presented by Pritchard.[20] At the conclusion of each exercise test, the investigators recorded the principal reason given by the subject for stopping. Various explanations were offered as to the reason an individual could not continue and these were classified as respiratory or nonrespiratory (see below).

Respiratory Distress

Respiratory distress served as the primary independent variable, and this classification was nominal (i.e., yes or no). Individuals with respirator experience (N = 19) were compared with a sample (N = 19) lacking experience with respirator wear. However, the two groups did not differ on respiratory distress or trait anxiety, and therefore, the two groups were combined for statistical purposes. The mean trait anxiety scores for the experienced and inexperienced groups was 30.7 (SD = 6.1) and 32.2 (SD = 6.7), respectively. A t test for independent samples revealed that the two groups did not differ significantly ($t = 0.71$, $df = 36$, $P = 0.48$), and the effect size was low (i.e., 0.23). Furthermore, the incidence of respiratory distress was similar in the experienced (2 of 19) and inexperienced (i.e., 3 of 19) groups.

A breathing scale has been used previously to quantify respiratory distress on a seven-point psychophysical category scale.[8] The breathing scale was positioned before the subject and ratings were obtained every 2 minutes throughout the maximal exercise test, including recovery. These ratings, along with the subjects' stated reasons for stopping, were employed by the investigators in arriving at a nominal classification of yes or no for respiratory distress. Some subjects reported that they stopped for reasons such as: "stiff legs," "mask tightness," and "legs fatigued." These types of explanations were classified as nonrespiratory. Other subjects reported that it was necessary to discontinue for reasons such as: "hard to breathe," "breathing hard," "not getting enough air," "no air," and "couldn't exhale." It was decided a priori that "respiratory distress" would be defined as those cases where the subject stated that he or she was not getting enough air, or could not breathe, and also had a rating in the 5 to 7 range on the breathing scale. Those individuals who feel that they are "not getting enough air" or "cannot breathe" may represent a subgroup of individuals most likely to remove the mask of a self-contained breathing apparatus (SCBA) when stressed. But if a subject indicated that termination of exercise resulted from leg fatigue or merely breathing hard, this was classified as nonrespiratory distress. The investigators and the technicians were unaware of the test subjects' trait anxiety scores in an effort to minimize the occurrence of behavioral artifacts due to intended or unintended bias.

Trait Anxiety

The operational definition of "trait anxiety" employed in this investigation represented the score on the Y-2 version of the STAI developed by Spielberger et al.[19] Trait anxiety is conceptualized as a fixed or enduring feature of personality, whereas state anxiety is viewed as a transitory form of anxiety that is situation dependent. This model predicts that persons with high levels of trait anxiety will be more likely to have a large increase in state anxiety compared with others who have lower levels of trait anxiety. Hence, for any given stressor, a firefighter with high levels of trait anxiety would be more likely to experience stress responses. This might involve distress in the form of elevated state anxiety, it could escalate into a panic attack, and the individual might become involved in life-threatening behaviors (e.g., removal of the SCBA mask). In the present investigation the individual's score on the trait anxiety measure was employed in an effort to predict the development or absence of respiratory distress. It was hypothesized that trait anxiety would be effective in predicting respiratory distress resulting from maximal physical work performed on a motor-driven treadmill.

The STAI was administered to all the subjects and was carried out in advance of the maximal treadmill test. The trait anxiety scores were used in predicting whether an individual would experience respiratory distress during this maximal physical effort. A raw score of 39 or greater on the trait scale of the STAI was employed as the cut-off point for predicting respiratory distress. This criterion was previously found to possess a prediction accuracy of 83% by Morgan and Raven.[8] The investigator (WPM) responsible for the scoring and analysis of the anxiety data, as well as prediction of respiratory distress, was unaware of the reasons individuals gave for stopping. The assessment of trait anxiety and the treadmill test were conducted independent of one another, and the results were placed in sealed envelopes. There was no discussion of individual or group data until completion of the investigation. The sealed envelopes were exchanged between investigators following the experiment to evaluate the concordance between predicted and actual respiratory distress. This blind paradigm ensured that experimenter bias or behavioral artifacts such as expectancy, demand characteristics, and the Halo effect[13] did not influence test results.

RESULTS

The principal results of this study are summarized in Tables I and II. These results indicate that 5 of the 38 (13.2%) subjects experienced respiratory distress, and this figure can be used as the "distress base-rate" for analysis purposes. Also, since three of the five individuals were identified a priori, the prediction rate was 60%. In other words, there was a prediction-rate/base-rate gain of 46.8%, and this gain rate is statistically significant ($z = 2.93$; $p < 0.005$) according to the procedure described by Ferguson.[21] Another way of interpreting these results, and a method that is more common, is to examine the overall hit rate for negative and positive results (i.e., 31 + 3 = 34), and this yields an overall prediction accuracy of 89.5% (i.e., 34 of 38). A summary of this prediction effort for each subject is presented in Table I.

TABLE I. Summary of the Prediction Efforts for the Entire Sample (N = 38)

Subject Number	Experienced With SCBA	Trait Anxiety Score (STAI)	Prediction Decision	Prediction Evaluation
1	yes	22	no	true negative
2	yes	35	no	true negative
3	yes	27	no	true negative
4	yes	42	yes	true positive
5	yes	30	no	true negative
6	yes	36	no	true negative
7	yes	23	no	true negative
8	yes	33	no	true negative
9	yes	34	no	true negative
10	yes	26	no	true negative
11	yes	22	no	true negative
12	yes	31	no	true negative
13	yes	34	no	true negative
14	yes	27	no	true negative
15	yes	31	no	true negative
16	yes	36	no	true negative
17	yes	42	yes	false positive
18	yes	28	no	false negative
19	yes	24	no	true negative
20	no	39	yes	true positive
21	no	35	no	true negative
22	no	35	no	true negative
23	no	34	no	true negative
24	no	36	no	true negative
25	no	31	no	true negative
26	no	28	no	true negative
27	no	27	no	true negative
28	no	29	no	true negative
29	no	34	no	true negative
30	no	44	yes	false positive
31	no	23	no	true negative
32	no	23	no	true negative
33	no	29*	no	false negative
34	no	29	no	true negative
35	no	49	yes	true positive
36	no	27	no	true negative
37	no	31	no	true negative
38	no	28	no	true negative

It should also be noted that this prediction effort resulted in two false positives and two false negatives. In other words, it was predicted that two of these subjects would have respiratory distress but they did not (i.e., false positives), and two individuals experienced respiratory distress even though the model predicted this would not occur (i.e., false negatives). Each of the individuals classified as having respiratory distress reported symptoms involving dyspnea during the postexercise debriefing. Two of these individuals actually removed their masks at or near the end of the exercise bout owing to an inability to move air, and one of the individuals accused members of the testing team of cutting off his air supply. However, there was no evidence of equipment malfunction in this case. One of the false negatives (Subject 33) may represent an erroneous classification since the individual experienced respiratory distress during the changeover from one gas cylinder to another. It is possible that this individual's air supply was inadvertently shut off during this process. This is important since Raven et al.[5] previously demonstrated that individuals with a large body mass can reach peak ventilatory volumes that exceed the delivery capacity of industrial respirators. It is possible that a brief, albeit fleeting, interruption in air supply could easily lead to the sensation of suffocation or claustrophobia that has been reported by some firefighters during heavy physical work.[1] This is no longer a problem since National Fire Protection Association regulator standards now require higher peak flows for SCBAs. In retrospect, the authors believe that this subject should probably have been retested to confirm the presence or absence of true respiratory distress. Another option would have been to delete the subject from the analysis, but the authors prefer to err in the conservative direction.

TABLE II. Comparison of Predicted Respiratory Distress with Actual Respiratory Distress During Maximal Treadmill Exercise Performed at a Breathing Resistance of 3.5 cm of Water

	Predicted Distress		
Actual Distress	Yes	No	Total
Yes	3	2	5
No	2	31	33
Total	5	33	38

DISCUSSION

There are examples in most areas of inquiry where efforts to replicate initial findings not only fail, but initial observations are sometimes refuted. It is also not uncommon for findings reported from one laboratory to lack cross-validation by investigators working in other laboratories. While replication between laboratories is more compelling than replication within the same laboratory, the authors elected to proceed with efforts to replicate our initial findings[8] for several reasons. First, it was felt this was necessary to ensure the believability of the general finding since there have not been direct attempts to confirm or refute this observation by other investigators. Second, there seems to be a general lack of awareness regarding this problem within the industrial, military, and firefighting forces in general. Third, the study of respirator usage has tended to focus on the machine side of the person-machine interface. It seems clear that technological advances in the development of more effective respirators have been significant, and such efforts should continue, but there is also a need to emphasize the role of individual differences (person factors) in screening firefighters and others who are required to wear industrial respirators while performing hard physical work under stressful circumstances.

The results of the present investigation serve to replicate the earlier findings in a general sense. That is to say, individuals with elevated levels of trait anxiety were more likely to experience respiratory distress while performing maximal exercise than individuals with lower levels of trait anxiety. This observation is predicted on the basis of Spielberger's model of stress and anxiety.[19] In the earlier study it was reported that 6 of 45 individuals (13.3%) experienced respiratory distress during treadmill exercise while wearing a pressure-demand (N = 25) or a demand (N = 20) SCBA. In the present study respiratory distress was observed in 5 of 38 cases (13.2%), and this value is remarkably similar to the earlier report.[8] While the treadmill protocol employed in the report by Johnson et al.[6] differed from the one used in the present study, it is noteworthy that the reason for terminating exercise was due to subjective respiratory sensations in 3 of 20 (15%) subjects in their study. This proportion of 15% is quite similar to the values observed in the present study and the authors' earlier report. It is

the view of the authors that an individual who experiences respiratory distress while performing vigorous physical exercise in an extreme environment would be at greater risk than someone who does not have this sensation. While the authors recognize that their results must be restricted to this theoretical view, the results suggest that it is possible to predict who will experience respiratory distress in advance of performing maximal physical exercise in a controlled, laboratory environment. It would seem reasonable to speculate that such responses would be amplified in an extreme environment characterized by multiple stressors (e.g., firefighting).

The participants in the earlier study were all experienced with SCBA use, but half of the individuals in the present study were not. Of the five individuals in the present study with respiratory distress, two were from the experienced group and three were from the inexperienced group. These differences in proportions were not statistically significant ($P > 0.05$). Furthermore, 16 of the 19 predictions (84.2%) were correct for the experienced group compared with 17 of 19 (89.5%) for the inexperienced group, and this difference of 5.3% was not statistically significant ($Z = 0.49$; $P > 0.05$). Since the incidence of respiratory distress did not differ in the experienced and inexperienced subjects (i.e., 13.3 versus 13.2%) in this study, and since the prediction of respiratory distress (i.e., 84.2 versus 89.%) did not differ, the two groups were combined for statistical purposes. It should also be noted that the frequency of false positives and false negatives were identical in the two groups as well. The overall results of the present study revealed that 34 of 38 (89.5%) predictions were correct, and this does not differ significantly from the earlier study[8] in which 43 of 45 (95.5%) predictions were correct ($Z = 1.07$; $P > 0.05$). Therefore, while there were a number of differences in the experimental designs in the current and the former study, there is a general replication of the principal finding. That is, elevated scores on the trait anxiety subscale of the STAI[19] is an accurate predictor of respiratory distress during heavy physical exercise.

The perception of a stressor is quite important, because this influences the outcome, which might take the form of elevated state anxiety, and possibly even an anxiety or panic attack. Training and educational programs might be designed in an effort to modify such responses. Rather than screening individuals out of the work force, an effort could be made to identify those who might benefit from training programs designed to create coping strategies that could moderate the perception of a stressor, and in turn influence the outcome. It is certainly possible, however, that respirator wear is simply contraindicated for some individuals.

The scientific question is simply one of whether individuals who are prone to experience respiratory distress while performing maximal physical exercise and breathing against a given resistance can be identified in advance of such an incident. This question was first answered in the affirmative by Morgan and Raven,[8] and the present investigation serves to replicate and extend this earlier finding. Furthermore, the results of the present study apply to individuals who possess prior experience with respirator wear, as well as those who do not.

There is one implicit point that should also be addressed or made explicit. The decision to employ a self-report measure of trait anxiety in the present investigation should not be interpreted to mean that the authors view respiratory distress as simply a psychological problem or issue. The decision to employ Spielberger's model of stress in this investigation is based on the tacit assumption that stress should be conceptualized as a psychobiological process. It is clear, for example, that respiratory distress is correlated with both physiological and psychological parameters. Hyperventilation, as well as hypoventilation, along with the individual's sensitivity to CO_2 all play a role in the dyspneic state. For the time being, however, it has been demonstrated that a self-report measure of trait anxiety is effective in predicting the development of respiratory distress. The explanation for this outcome may ultimately be shown to possess neurochemical correlates, and it is not the authors' intention to suggest that respiratory distress should be viewed simply as a psychological problem.

CONCLUSION

The results of this investigation support the conclusion that elevated levels of trait anxiety are associated with respiratory distress in individuals performing maximal physical exercise. Nevertheless, caution should be exercised in attempting to apply these findings in selection efforts. Caution is urged because of the model's recognized limitations. Prediction efforts of this nature are always associated with false positives and false negatives, and the earlier research by Morgan and Raven[8] resulted in a comparable ($Z = 0.86$; $P > .05$) incidence of false negatives and positives of 2.2%, and the incidence of false positives (2 of 38) and false negatives (2 of 38) was 5.3% in the present study. The overall accuracy of prediction in the present investigation was 89.5%, and while these findings are encouraging, there is a need to focus subsequent research on efforts to reduce the incidence of false positives and false negatives. Nevertheless, elevated trait anxiety is clearly effective in predicting the development of respiratory distress during maximal exercise. However, any prediction or selection efforts should be carried out with the realization that false positives and negatives occur about 2–5% of the time.

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