

PSYCHOLOGICAL PROBLEMS ASSOCIATED WITH
THE WEAR OF INDUSTRIAL RESPIRATORS

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The overview of earlier research involving the psychological aspects of respiration was prepared in the author's capacity as a consulting psychologist to the Respirator Division, Los Alamos Scientific Laboratory, Los Alamos, New Mexico. The psychometric and perceptual data presented in this paper were collected in the author's capacity as a consulting psychologist to the Department of Physiology, Texas College of Osteopathic Medicine, Fort Worth, Texas. Details of this research protocol are elaborated upon in the paper by Dr. Peter B. Raven which appears in the Workshop Proceedings.

OVERVIEW

Industrial respirators offer protection for men and women who are required to work in hostile environments such as toxic and oxygen deficient atmospheres. While major advances have been made in recent years with respect to improved face-mask design and modes of protection, there has been little effort directed toward the development of criteria for use in evaluating individual fitness or ability to wear respirators in extreme environments. This has led Cooper (1974) to propose that specific evaluative techniques be developed for use in deciding whether or not a worker can wear a respirator. In other words, the research and development on (1) air purifying respirators, (2) supplied air respirators, and (3) self-contained breathing apparatus (SCBA) has focused on the respirator component of the person-respirator interface. There has been a tendency to view person variables as psychological in nature, and most authors writing in this general area often conclude their discussions with a section involving psychological problems. The psychological variables and problems referred to in these discussions have been addressed in a cursory manner, and there exists very little research directed toward an understanding of the psychological component of the person-respirator interface.

The absence of systematic research involving the psychological problems associated with respirator wear should not be interpreted to mean that authorities in the fields of occupational safety and health have not recognized that psychological problems exist. Indeed, discussion with workers in this field readily points out the important role of "psychological" factors, and these verbalized views are echoed in countless publications (Pritchard, 1976). However, there does not appear to be a single published investigation in a refereed journal dealing with phobic reactions or anxiety attacks of workers under conditions of simulated stress or field observations. Furthermore, if research were presented to support the view that individuals who experience claustrophobia or anxiety when confined to small places should not be given jobs requiring respirator wear, it would then be necessary that some type of diagnostic tool be developed for use by industrial physicians and others responsible for personnel selection.

According to Phillips (1978) scientific studies of human behavior in fires are almost nonexistent, and the majority of accounts available consist of anecdotes on behavior that are not well documented or even documented at all. Phillips (1978) has also emphasized that it is very difficult to distinguish between behavior resulting from stress per se and that due to smoke inhalation. This succinct review of literature dealing with the

effects of smoke on human behavior concludes with a discussion of behavior in fires with special reference to (1) fear, (2) panic, (3) trained and untrained behavior, (4) previous fire experience and (5) the extent to which behavior modification can result from knowledge, intelligence and sense of responsibility. This particular paper implies that workers who possess undesirable traits at the time of entrance to the work force can be identified and trained to overcome these shortcomings. Again, however, it is important to realize that such an approach could only be initiated after valid diagnostic tools were made available.

There seems to be general agreement that "wearer comfort" represents a crucial consideration in the selection of respirators. Douglas et al.

(1976), for example, have pointed out that everyone who wears a respirator experiences some discomfort. The distress associated with work in an extreme environment is accentuated by wearing a respirator according to these authors. The amount of distress is dependent on various factors such as (1) type of facepiece (i.e., full, half, or quarter facepiece devices), (2) powered versus non-powered units, and (3) open versus closed circuit devices. Vision is restricted to some extent with all devices, and this can lead to "tunnel vision" or perceptual narrowing (Landers, 1978). This response can in turn lead to the production of anxiety and hyperventilation, and these responses can be due in part to restriction of the visual field. In other words, perceptual narrowing due to facepiece devices could provoke an anxiety response in certain individuals above and beyond the stress induced by heavy physical work or firefighting. This response generally leads to a decrement in performance, but "tunnel vision" is also known to facilitate physical performance in certain settings (Nideffer, 1978). The process, therefore, is rather complex, and elimination of "tunnel vision" might or might not represent a sound safety measure. A more appropriate approach would seem to involve identification of "responders" or individuals who "overreact" to stress.

It is also recognized that breathing is difficult, ventilation across the face is limited, movement is restricted because of the cumbersome nature of most equipment, and simply wearing a respirator adds to the energy cost of exercise which in turn accentuates the effect of working in a hot environment. It has also been pointed out by Douglas et al. (1976) that improperly fitted masks may create "pain spots" that become intolerable. A malfunctioning or improperly designed valve may restrict breathing or irritate the wearer by flicking and popping. Communication is restricted, and this can become unpleasant and add to existing hazards while working in extreme environments. At least one "person variable" of a non-pathological nature is known to impair respirator performance. Males with excessive facial hair (i.e., facial stubble, sideburns, and beards) cannot obtain the same degrees of respirator performance as clean shaven individuals owing to the interference of facial hair with the respirator seal (Hyatt et al., 1973).

When all the factors described under the rubric of "wearer comfort" are considered collectively, it is easy to understand why the willingness to wear and to make proper use of respirators represents a significant problem. One solution to this problem, of course, is to pay attention to all these factors when selecting equipment. According to Douglas et al. (1976) ". . . most people may be provided with respirators that do not cause undue distress and that will effectively protect the wearer (p. 33)."

It has been emphasized by Davis and Held (1978) that use of breathing apparatus at the scene of fires must be increased in order to protect the firefighter at all times rather than reserving their usage for times "when the smoke is thick." These investigators have also noted that such an approach will reduce the high rates of inhalation injury and mortality at the scene of fires as well as across the firefighter's working career. Phillips (1978) has recently reinforced this viewpoint and goes on to present a convincing argument for the necessity of wearing breathing apparatus when fighting fires where there is invisible smoke (fire gases) as well as visible smoke (particulate matter). Certain invisible gases such as hydrogen chloride gas (HCL) are readily detectable owing to the strangling sensation that is immediately produced. Unfortunately, the victim is usually immobilized and escape is restricted. Other common chemical compounds called ketones cause little lung trouble, but these hypnotic, narcotic and anesthetic gases produce confusion and unconsciousness when they reach the CNS. Also, carbon monoxide, a colorless, odorless, tasteless gas, has been viewed as a major killer of fire victims for many years.

The position advanced by Davis and Held (1978) and Phillips (1978) makes it clear that firefighters must somehow be motivated to wear breathing apparatus when fighting fires. This problem, of course, is not limited to firefighters. It has represented a problem in various industrial settings for many years. Cooper (1962) has commented that,

. . . a man who knows that he will not see his wife and family again unless he wears a respirator will tolerate much more resistance than, say, a miner who is told that if he wears a dust filter on every shift for the next 10 or 20 years, his chances of developing pneumoconiosis will be reduced.

The advantage of wearing protective devices in such settings are well documented, but some workers are simply not willing to tolerate the daily discomfort associated with the wearing of protective devices. In many respects, this problem seems to be somewhat analogous to tobacco usage. Short term damage is not apparent to the smoker, and some smokers do not seem to develop serious health problems despite the casual link between smoking and lung cancer. At any rate, motivating workers to wear protective devices when the apparent acute risk is minimal represents a major research challenge.

Another far more serious issue relates to the problem of firefighters who take pride in being a "smoke-eater." Davis and Held (1978) have recommended that firefighters must be educated concerning the fact that lethal toxic materials are not always detectable by smell. Also, as Phillips (1978) has emphasized, toxic materials can be present even though the smoke is invisible. Furthermore, cellulose, one of the most common materials used in American homes, produces 175 breakdown products, and only about 150 have been identified. The effects of exposure to many of these products, absorbed singly for 5-30 minutes, are not known. Fatalities have occurred in small home fires, in one case involving plastic curtains and another involving a bean bag chair. Davis and Held (1978) have emphasized that home fires are no longer of the "wood and paper" variety. That is, they involve synthetics which decompose to produce toxic products. The need to motivate firefighters to wear protective devices seems to be a significant problem.

There are obviously many reasons why individuals who are placed in potentially toxic atmospheres elect not to wear protective devices. First, as noted by Douglas et al. (1976), these devices are not comfortable. Second, many individuals have learned that they can work in certain environments without wearing a breathing apparatus, and they do not experience immediate effects. An individual who routinely disconnects and connects chlorine cylinders, for example, might elect not to wear a protective mask because he or she has done so on many occasions without being confronted with major leaks. However, once exposed to a serious leak such an individual might be immobilized and unable to escape. The possibility of such an occurrence might be consciously entertained from time to time, but in all likelihood it is repressed. In other words, individuals apparently "decide" at a conscious or pre-conscious level not to tolerate the discomfort and nuisance associated with the wearing of a protective mask in such a setting. The challenge, as noted earlier, seems to be one of motivating individuals to wear protective devices in potentially toxic environments. Prior to constructing motivational strategies it would seem appropriate to first review the factors thought to be responsible for the development of discomfort while wearing masks. Such an approach should ultimately be of value in addressing the motivational issue.

The subjective discomfort associated with respirator wear has not been studied systematically, but it is widely agreed that wearer comfort represents a crucial issue in facilitating use of protective devices. Shephard (1962) has reported that all physiological problems associated with respirator wear were rather minor in comparison to the psychological response. The psychological response in this study referred to a feeling of "claustrophobia" and additional distress arising from accumulation of sweat and pressure on the skin surface.

Research by Bentley et al. (1973) suggests that 90 percent of a given population should not experience discomfort when breathing through a low-resistance system if the pressure across the apparatus does not exceed 17 cm H₂O. This finding provides a possible clue to understanding the breathing problems encountered by some individuals when wearing respirators. First of all, a general observation in psychometric research consistently reveals that at least 10 percent of any given population are found to manifest various psychological problems such as depression or anxiety states that are regarded as clinically significant. Hence, even though 90 percent of a given population would not experience discomfort at a given pressure, it would not be uncommon for certain types of individuals (e.g., anxiety neurotics) to experience anxiety attacks under identical circumstances. The challenge would seem to be one of screening such individuals out of jobs requiring respirators as proposed by Pritchard (1976), or identification and treatment of such individuals prior to exposing them to such jobs. As mentioned earlier, such an approach would require that valid diagnostic tools first be developed. This possibility will be examined in more detail in a later section of the present review.

A comprehensive volume titled Design and Use of Respirators (Davies, 1962) summarizes the major problems associated with respirator wear. In the introduction to this edited volume Davies (1962) emphasizes that modern filters and absorbers are quite effective, but "the main limitations of a respirator are facepiece leakage, breathing resistance, poor speech and vision, and discomfort." It has also been noted by Davies (1962) that it is much easier to correct the above deficiencies for the operator of a machine than it is for an active laborer. In this context it is easy to understand why a man or woman who is required to work at 200 watts may suddenly remove a face mask as a consequence of breathing discomfort. According to Astrand and Rodahl (1970) ventilation increases in a fairly linear fashion with increasing work loads, but the slope of this function becomes much steeper during heavy work. The basis for this increase in ventilation at higher work loads is not entirely understood. The relatively small changes in P_{O_2} , P_{CO_2} and hydrogen ion concentration in the arterial blood cannot explain the hyperventilation observed in heavy work (Astrand and Rodahl, 1970). At any rate, the psychophysiological consequences of hyperventilation, as described elsewhere in this review, clearly lead to performance decrements and enhanced safety risks. In other words, heavy exercise per se produces hyperventilation, and there is evidence suggesting that wearing a face mask accentuates the hyperventilatory response.

It has been reported by Astrand and Rodahl (1970) that a patient may perceive a pulmonary ventilation of 100 l/min as quite disturbing, whereas an athlete may not be consciously disturbed while exercising at ventilatory minute volumes of 200 l/min. Astrand and Rodahl (1970) have indicated that it is not clear why respiration becomes troublesome, but it is not governed by the magnitude of ventilation per se.

EXERCISE CONDITIONS

There is not a great deal of available information concerning the perception of breathing during exercise, and most of the available evidence is of an indirect nature. Investigators have been primarily concerned with the study of perceived exertion or "effort sense" during exercise, and the contribution of ventilation to the effort percept has been examined.

Individuals who are required to perform hard physical work under both neutral and extreme conditions tend to make decisions about the intensity at which they will work, as well as the decision to continue or cease work, on the basis of various bodily sensations. The sensation of effort has been labeled "perceived exertion," and Borg (1973) has developed a psychophysical category scale for use in quantifying effort sensation or sense. The 15-grade category scale developed by Borg (1973) has verbal anchors associated with the odd numbered items, and it is intended to serve as an indicator of somatic stress.

The original formulation of the perceived exertion model by Borg (1973) proposed that somatic stress, as measured by heart rate (HR), was equal to the rating of perceived exertion times 10. The categories range from 6 through 20, and the odd numbers are followed by verbal anchors (7 = very,

very light; 9 = very light; 11 = fairly light; 13 = somewhat hard; 15 = very hard; and 17 = very, very hard). The model predicts that simply adding a zero to any given rating yields an estimate of cardiac frequency at a given work load. In other words, a person's heart rate should be 120, 140, 160 and 180 bpm when rating work intensity as 12, 14, 16 and 18. This model has been found to be a good approximation in experimental research involving progressive increments in work intensity, but it has not been accurate for evaluations of strain during steady state work. Various physiological measures such as heart rate, blood lactate, ventilation, catecholamine production, and skin temperature have been reported to correlate significantly with perceived exertion in various studies. Respiratory measures have proven to be one of the most consistent predictors of perceived exertion during steady state work. The present section contains a review of research dealing with the ventilatory correlates of perceived exertion. This research has been carried out in laboratory settings with normal individuals cycling ergometers, or running and/or walking on motor driven treadmills. Test subjects have not been required to wear paks in this research, and ventilatory measures have been obtained in a classical manner. That is, exercising subjects have breathed through low resistance valves while wearing nose clips. These findings may, therefore, not be directly generalizable to the case of an individual performing hard physical work while wearing a SCBA, but inferences should not be unduly restricted either. Research is currently underway (P.B. Raven, TCOM) that addresses this issue in a systematic manner.

It has been reported by Pandolf et al. (1972) that perceived exertion ratings obtained during bicycle ergometry were significantly correlated with ventilation ($r = 0.78$) and respiration ($r = 0.60$). In a related investigation by Noble et al. (1973) an attempt was made to evaluate which of several physiological variables accounted for the greatest amount of variance in predicting perceived exertion ratings. By means of a multiple regression analysis it was found that ventilatory minute volume was the strongest predictor at 5 ($r = 0.56$) and 15 ($r = 0.75$) minutes into an exercise bout performed in a neutral environment. Respiration rate, however, was found to be the strongest predictor ($r = 0.65$) of perceived exertion ratings obtained at 30 minutes. Comparable findings were reported by these investigators when their subjects were exercised in the heat, but the correlations were somewhat lower owing to a greater contribution by skin temperature. These findings suggest that subjects seem to cue on volume during the early phase of a 30-minute exercise bout, but their attention seems to shift toward rate later in work.

The results of Pandolf et al. (1972) and Noble et al. (1973) have been supported by Kamon et al. (1974) (1974) who evaluated effort sense and selected physiological variables of subjects performing bicycle ergometer work. These investigators observed correlations of 0.77 and 0.47 for ventilatory minute volume and respiration rate, respectively. Kamon et al. (1974) suggested that sensations arising from receptors in the lungs and chest wall may provide significant input to effort sense. It is quite possible that the role played by ventilation in forming judgements of strain is governed by one's physical fitness. Support for this view is provided by Stamford and Noble (1974) who, unlike earlier investigators, reported that ventilation was not an important cue. Their test subjects, however,

possessed an above average level of aerobic power ($\text{MAP} = 61 \text{ ml/kg-min}$), and the work load of 960 kpm may not have provided a significant ventilatory stimulus to effort sense.

A significant bivariate correlation of 0.52 between ventilatory minute volume and perceived exertion has been reported by Morgan and Pollock (1977). Their test subjects consisted of elite distance runners who were required to run at speeds of 10-12 mph on a motor-driven treadmill. In other words, ventilation becomes a significant cue even for individuals with above average aerobic power when the metabolic cost of work is high.

A number of studies have been conducted in which ventilation has been manipulated during exercise, and the effects of such ventilatory alteration on ventilation has been examined. Pederson and Welch (1977), for example, evaluated test subjects under control and hyperoxic conditions as they performed work on a bicycle ergometer. Perceived exertion was significantly lower for these six male subjects at work loads of 75, 150 and 225 watts while they were breathing a 50 percent oxygen mixture. Ventilation and blood lactate were significantly reduced at each work load. Pederson and Welch (1977) concluded that decrements in perceived exertion may be due in part to reduced ventilation, and these observations offer partial support for the correlational evidence presented earlier.

The results of Pederson and Welch (1977) are contradicted by the report of Allen and Pandolf (1977) who administered 50 percent and 80 percent oxygen mixtures to subjects who ran on a treadmill for 10 minutes at 50 percent and 80 percent of their maximal aerobic power on two separate occasions. Twelve male subjects participated in this study and significant decrements in perceived exertion were observed for both hyperoxic conditions when compared to normoxic runs. These investigators, however, did not observe a reduction in ventilatory minute volume or respiration rate. Pederson and Welch (1977), as well as most investigators studying the effects of hyperoxic mixtures, have noted reduced exercise ventilation during hyperoxia. Hyperoxic mixtures containing 50 percent and 80 percent oxygen were found to reduce blood lactate by both Pederson and Welch (1977) and Allen and Pandolf (1977). Furthermore, Morgan and Pollock (1977) reported a correlation of 0.61 between blood lactate and perceived exertion in their study involving treadmill running. These results suggest that cues arising in the working muscles may be of considerable importance.

Another approach to the study of perceived exertion and ventilation has involved the use of increased carbon dioxide levels in the inspired air. Cafarelli and Noble (1976), for example, administered air containing CO_2 concentrations of 1.75% and 3.50% to subjects who exercised on a bicycle under one condition and a treadmill on another occasion. Ventilatory minute volumes were significantly higher for the increased CO_2 conditions when compared to control values, and the condition involving 3.50 percent CO_2 resulted in higher ventilatory values than the 1.75 percent CO_2 condition. Perception of effort was found to be significantly higher while running under the 3.50 percent CO_2 condition in comparison to the control run, but none of the other differences were significant. These investigators concluded that ventilation does not have a great deal of impact on effort sense when exercise intensity falls below 50 percent of maximal aerobic power, but

ventilation may be an important cue at higher work loads. This study must be regarded cautiously, however, since pulmonary physiologists view altered ventilation following a CO₂ challenge as being substantially different, in a physiological sense, from exercise induced hyperpnea (Dempsey, 1979).

Rather than altering physiological variables in an attempt to study perceived exertion, an alternative strategy would be to alter perception itself and then evaluate physiological changes. This approach was taken by Morgan et al. (1973) and Morgan et al. (1976) who administered hypnotic suggestions of easy and difficult work to test subjects as they exercised at a constant work load of 100 watts. Perceived exertion was systematically increased and decreased in these studies following hypnotic suggestion, and these perceptual changes were consistently associated with changes in ventilatory minute volume. In other words, it appears that ventilatory cues are not limited to conditions of heavy work alone.

SUMMARY

The research reviewed in this section suggests that subjective judgements of perceived exertion or effort sense are based in large measure on ventilatory cues. This evidence is based upon research involving both manipulation of ventilation and perturbation of effort sense itself, as well as correlational data. Correlations ranging from 0.52 to 0.78 have been reported between perceived exertion and various ventilatory measures. This means that approximately 27 percent to 61 percent of the variance in perceptual ratings can be explained on the basis of ventilation alone. Other physiological factors such as blood lactate are known to influence effort sense. Also, it has previously been demonstrated that psychological variables such as extroversion, neuroticism, anxiety, depression and somatic perception are all correlated with perception of effort (Morgan, 1973). In other words, a psychophysiological model accounts for the greatest amount of variance. Nevertheless, ventilation alone represents a crucial variable in the formation of effort perception, and this represents an extremely important consideration for men and women who are required to wear industrial respirators while performing hard physical work. The following section will summarize research dealing with subjective effects of wearing various respirators.

PSYCHOPHYSIOLOGICAL EFFECTS OF WEARING RESPIRATORS

One of the first psychophysiological investigations involving the influence of respirators on performance and "subjective" factors was reported by Shephard (1962) who found that respirator wear was associated with (1) a decrease of 2-10 percent in psychomotor performance, (2) a reduction in maximal physical capacity of less than 4 percent, and (3) a decrement of 8-9 percent in negotiation of an obstacle course. This led Shephard (1962) to conclude that "prolonged wearing of a respirator is limited mainly by subjective factors (p. 51)." Furthermore, Shephard went on to state,

All of the physiological problems considered are relatively minor under most circumstances in which the respirator is worn for a long period, and the limiting factor is usually not the physiological cost, but the summed psychological response to a feeling of "claustrophobia" and a variety of small but irritating discomforts such as accumulation of sweat and pressure on the skin (p. 60)*

All individuals who wear respirators, however, do not develop a sensation of claustrophobia. In this connection it is of interest to note Senneck's (1962) report that while most subjects find a given external respiratory work to be acceptable, "a few record a noticeable resistance at lower levels." The situation invariably reduces to a matter of individual differences. Shephard's (1962) proposed solution to this overall problem is to increase tolerance for respirator wear through "training" but steps to be followed in "training" are not spelled out. Also, it is conceivable that "training" could become aversive for the large number of subjects who normally do not experience intolerable discomfort. It might be more efficacious to identify the small percentage of individuals who experience problems and attempt to increase their tolerance levels. Shephard's (1962) view that accumulation of sweat and pressures on the skin represent sources of discomfort has been proposed by others. Snook et al. (1966), for example, conducted an experiment in which five different forces were applied to twelve different facial locations. Twelve subjects performed psychophysical judgements, and it was found that facial locations differ in sensitivity to force. The differences in force were not considered to be great enough to warrant changes in facepiece design, however. In other words, it is generally agreed that facepieces serve as a source of irritation for most wearers, but this discomfort is usually tolerable for most people. Shephard's (1962) proposal of "training" subjects to increase tolerance appears viable, but this does not eliminate the need to insure that the person-respirator interface be as comfortable as possible.

The acceptable level for breathing resistance of respiratory apparatus has been studied by Bentley et al. (1973). The tolerance of added external resistance to inspiration was investigated in 158 mine rescue workers during exercise. An attempt was made to determine whether peak inspiratory pressure, minute volume or respiratory work rate was best correlated with subjective tolerance of resistance. It was concluded that excessive pressure exerted during inspiration was the major factor in determining subjective tolerance. Bentley et al. (1973) concluded that 90 percent of the individuals who are required to breathe through an apparatus with low resistance expiratory valves should not experience discomfort if pressure across the apparatus does not exceed 17 cm H₂O. What about the 10 percent of a given population who experience discomfort? Are these the same type of individuals referred to in the paper by Senneck (1962)? Is it appropriate to classify these individuals as "responders"? It is possible that these individuals are also the 10 percent in any given population who suffer from anxiety and depression of clinical significance. Are these individuals hyperventilators? Is this the 10 percent of a given population who cannot accurately perceive exercise intensity? Can these individuals be identified? Is it possible to modify the behavioral style of a "responder" once he or she is identified? These issues are pursued in each of the sections of this review, as well as the final summary section.

There seems to be general agreement that physical endurance is impaired when one is required to wear a respirator. The exact reason(s) for the impairment are not entirely understood. The mere weight of a unit will play a significant role in decreasing performance, but there are clearly other

forces at work. Craig et al. (1970) attempted to identify the basis for an exercising subject's awareness of impending exhaustion. In this investigation 13 men were required to work on a treadmill at grades up to 22 percent and they breathed against inspiratory resistances of 1.5 and 15.5 cm H₂O/liter/second and expiratory resistances of 2.0 and 3.9 cm H₂O/liter/second. The influence of inhaling carbon dioxide mixtures of 3.1-3.9 percent was also examined. Endurance time averaged 11.3 minutes while subjects breathed room air at inspiratory and expiratory resistances of 1.5 and 2.0 cm H₂O/liter/minute, respectively. Endurance time decreased to 6.9 minutes when CO₂ mixtures of 3.1-3.9 percent were added to the inspired air. Increasing the inspiratory resistance to 15.5 cm H₂O, with room air being breathed, reduced endurance time to 5.1 minutes. The increase in resistance from 1.5 to 15.5 cm H₂O/liter/second shortened endurance time more at the easier than the harder grades. The fraction of CO₂ in expired air, oxygen debt, and pressure swings differed widely at the time of exhaustion under various conditions of resistance and inhaled gas. These differences were accompanied by wide differences in the inspiratory phase, but the duration of the expiratory phase remained the same under various conditions. These findings offer additional evidence for the necessity of obtaining subjective judgements in a consistent manner which considers respiratory phase; that is, sensations arising during the inspiratory and expiratory phases seem to differ. Craig et al. (1970) concluded that an individual's awareness of impending exhaustion appears to be influenced by the approach to a minimum time for expiration.

The question of whether or not performance decrements provoked by wearing a mask can be minimized by training has been studied by Martin (1972). In this investigation four male subjects completed 16 tests over a period of five weeks. The subjects cycled on a bicycle ergometer at a rate of 50 revolutions/minute and a resistance of 100 watts until self-imposed exhaustion. A monetary reward was used as an incentive for the subject with the best performance, and each subject completed eight trials while wearing the NBC 56 respirator and another eight trials without the mask. A dry bulb/wet bulb temperature of 35/25°C was employed for all trials. Endurance times increased significantly from 29.8 to 33.4 minutes for the eight trials involving the mask, and performance increased from 33.0 to 41.9 minutes for the trials in which a mask was not worn. In other words, endurance time was significantly lower when wearing a mask, but training produced a significant increase in performance under both the mask and control conditions. Martin (1972) concluded that training will improve exercise performance, but it will not eliminate performance decrements due to wearing a mask. It should be emphasized, however, that training resulted in a mean endurance time of 33.4 minutes for the mask condition which was essentially the same as the pre-training endurance value of 33.0 minutes observed for the subjects without a mask.

The recent report by Raven et al. (1977) probably involves the most comprehensive exercise study completed to date. In this investigation fifteen adult males participated in a maximal treadmill test on four occasions. Maximal exercise was performed (1) while wearing a Scott Air Pak (SAP) in the "demand" breathing mode; (2) while wearing a SAP in the

"pressure-demand" breathing mode; (3) while wearing a SAP with the face mask removed; and (4) without the SAP respirator. A performance decrement of approximately 20 percent was observed for all the conditions involving the SAP respirator. Since condition (3) above did not involve a face mask, it may be concluded that the added weight of the SAP respirator (15.8 kg) was responsible for the performance decrement. However, the summary of subjective responses reported as the reason for terminating exercise revealed different perceptual cues were operating in the four conditions. The reasons given for stopping when subjects did not wear a SAP, or wore the SAP without a face mask, consisted of leg pain and general fatigue. In other words, there were no respiratory symptoms presented for these trials. However, four subjects reported a sensation of claustrophobia as the basis for stopping while wearing the SAP in both the "pressure demand" and "demand" modes. Eight of the subjects reported that "lack of air" was responsible for terminating exercise while wearing the SAP in the "demand" breathing mode. These observations are quite interesting in that they rule out a weight by mask interaction effect; that is, performance decreased while wearing the SAP independently of whether or not a mask was worn. Interestingly, while the performance decrement was comparable under all SAP conditions, the reasons for stopping differed.

Wearing protective masks while fighting fires would protect firefighters against the loss of pulmonary function. Why do firefighters elect not to wear protective breathing devices? A possible clue comes from the work of Raven et al. (1977). These investigators found that performance did not decrease while wearing a SAP respirator but a far greater degree of breathing distress and discomfort was associated with the wearing of a SAP, especially in the "demand" breathing mode. Investigators have often described subjective complaints such as "lack of air," "claustrophobia," and so on as "psychological" problems. Raven et al. (1977) have pointed out that manufacturers generally supply valves capable of delivering 400-500 l/min flow, but "peak respiratory flow rates may exceed 720 l/min." This would mean that the demand valve would be unable to supply the necessary air in a given respiratory cycle. While this could clearly lead to "psychological" problems, the problem would not be psychological, but rather it would be mechanical. In other words, the answer would seem to be development of improved valves rather than training "responders" to cope with an inadequate breathing valve, or screening "responders" out of the work force.

An unpublished report by Myhre (1979) addresses the issue of respirator effects in a different manner. In this experiment: 21 males exercised for 10 minutes on a treadmill at 3.3 mph with inclines altered to require a cost of 50 percent, 65 percent and 80 percent of each subject's maximal aerobic power. These exercise intensities were evaluated on four occasions. A control session was compared with responses obtained when the subjects exercised while wearing a Scott Air-Pak (SAP) (1) with the facepiece absent; (2) in the "demand" breathing mode; and (3) in the "pressure demand" breathing mode. All testing was carried out according to a table of random numbers. Physiological measurements were performed during the exercise and recovery, and the subject completed a series of self-report questionnaires designed to measure various subjective sensations following each ten-minute exercise trial.

Perceived stress ratings were obtained by means of a psychophysical scale ranging from 6 to 22. The work loads of 50, 65 and 80 percent of $\dot{V}O_2$ max yielded mean stress ratings of 9.7, 12.6 and 16.0, respectively, and these differed significantly as expected (P less than .001). However, the mean stress ratings for the "pak alone," "demand mode," and "pressure demand mode" did not differ (i.e., 12.8, 12.8 and 12.7).

Ease of inspiration and expiration was rated on a scale ranging from 1 to 7 (easy to hard). This analysis revealed that the "pressure demand" regulator was perceived as less resistant during inspiration than the "demand" regulator for the 50 percent and 65 percent work loads, but the two modes were rated as comparable at the 80 percent work load. Ratings of resistance did not differ for the expiratory phase.

The results of this unpublished report by Myhre (1979) are in close agreement with those of Raven (1977). Wearing of a SCBA alone resulted in an increased energy cost of 17-20%, but this increase was not due to respiratory stresses imposed by breathing in the "demand" or "pressure demand" modes. That is, the increased energy cost was due to the weight (15 kg) of the SCBA. It should be kept in mind that Myhre (1979) evaluated physiological and subjective responses to relative work loads carried out for a fixed period (i.e., 10 minutes). Results from an experiment of this nature cannot be readily compared to those of one in which test subjects are required to perform until self-imposed exhaustion occurs. Therefore, the observation that physiological responses and subjective ratings generally did not differ as a function of breathing valve, may not apply to situations where work is carried out for longer periods of time.

It will be recalled that Raven et al. (1977) reported that eight of their 15 test subjects reported that "lack of air" was the reason they stopped exercise while wearing the SAP in the demand" breathing mode, whereas none of the subjects reported this as the basis for terminating exercise while in the "pressure demand" mode. In this context it is of interest to note that Myhre (1979) found the "pressure demand" mode was perceived as significantly less resistant than the "demand" mode for the inspiratory phase of work performed at 50 percent and 65 percent of $\dot{V}O_2$ max. It is conceivable, therefore, that subjects in Myrhe's (1979) study may have experienced performance decrements while wearing the SAP in the "demand" mode had the exercise protocol involved long-term work to exhaustion. Firefighters are, of course, often required to work for periods of time much longer than 10 minutes. On the other hand, the subjects in the experiment by Raven et al. worked to self-imposed exhaustion, and while the "demand" mode was characterized by greater breathing difficulties, mean performance times were not influenced by type of breathing valve.

SUMMARY

Research involving the psychophysiological effects of wearing respirators while exercising is in agreement on several points, but disagreement appears to exist in several areas. It is extremely difficult to evaluate the points of disagreement, however, since (1) different types of respirators have been involved, (2) differing exercise protocols have been utilized, (3) various environmental conditions have been employed, and (4) different samples of subjects have been studied.

There is substantial agreement on a number of points, however, and these will now be reviewed. First of all, there is unanimous agreement that wearing of self-contained breathing apparatus (SCBA) during exercise produces a variety of subjective sensations associated with breathing. Second, SCBA employed in the "demand" breathing mode appear to create a greater number of breathing difficulties than does the "pressure demand" mode. Earlier investigations revealed that physical work capacity was reduced between 4 percent and 20 percent while wearing a SCBA, but more recent work reveals that performance decrements are caused by the weight of SCBA per se, not the discomfort associated with resistance produced by breathing valves. Third, while endurance performance is not apparently influenced adversely by modern day respirators, it appears that psychomotor performance and the commission of "errors" may be significantly influenced; that is, information processing and decision making seem to be impaired. This needs to be studied in greater depth. Fourth, there is evidence that physical performance can increase significantly when subjects are retrained to wear SCBA while exercising. Fifth, it appears that approximately 10 percent in any given sample of test subjects experience considerable difficulty while wearing respirators during exercise. This figure is undoubtedly attenuated due to volunteerism. That is, the actual percentage is probably higher in the "non-volunteer" sector. At any rate, the nature or "traits" that characterize the 10 percent who experience serious breathing difficulties are not understood at this time. Information presented in later sections permits one to speculate that factors such as anxiety, depression, extroversion, CO₂ sensitivity, hyperventilation syndrome, training, learning and so on may influence the perceptual response to wearing SCBA during exercise. Sixth, there is some evidence that responses during the inspiratory and expiratory phases of the respiratory cycle may be characterized by different perceptual exponents, and this should be studied in greater detail. Seventh, there is some evidence suggesting that physical performance of smokers is significantly less than that of non-smokers who are required to exercise at maximal levels with and without a SCBA. It should be kept in mind, however, that firefighters in general have reduced pulmonary function in contrast to the general population, and this decreased pulmonary function has been reported to be directly proportional to the frequency of exposure to fire, not age or smoking habits. This observation emphasizes the necessity of developing educational and motivational programs designed to facilitate respirator wear during firefighting activities. Eighth, there is some evidence that respirators generally have supply valves capable of delivering 400-450 l/min flow, but peak flow may exceed 720 l/min. Hence, anecdotal information obtained in firefighting events which have been labelled as "psychological" reactions or problems, may well have been due to the very real sensation of suffocation. Hence, the decision of an experienced firefighter to suddenly remove a mask while fighting a fire may stem from the problem of restricted flow. Ninth, and perhaps the most important observation of all, is the stark realization that all existing data are based upon laboratory experiments involving healthy, young adult males, who volunteer to participate. There has been no attempt made to demonstrate the extent to which the findings can actually be generalized to the population of individuals to whom the generalizations are invariably inferred. This problem of ecological validity should be addressed in a systematic fashion.

The remainder of this review consists of experimental and theoretical literature dealing with the "psychological" aspects of respiration. While much of this material does not deal directly with the problem of wearing respirators, it does deal with published information dealing with the "psychology of respiration." It is hoped that this material will provide the basis for further work in the study of ways in which the wearing of self contained breathing apparatus (SCBA) can be made safer for the men and women who are required to wear a SCBA under extreme conditions such as those provoked in many firefighting situations. The following section deals with the psychometric correlates of respiration. While this literature does not deal directly with the problems associated with respirator wear, it does suggest that certain "types" of individuals are more likely to experience problems than others when subjected to stress.

PSYCHOMETRIC CORRELATES OF RESPIRATION

It is well documented that alterations in respiration can be readily provoked by means of exercise, elevated oxygen concentration of inspired air, increased carbon dioxide levels, high altitude, exposure to high temperatures, and changes in the hydrogen ion concentration of the blood. Alteration in respiratory patterns as a consequence of such changes in the internal and external environments are viewed as being appropriate from a physiological standpoint. However, there are substantial individual differences associated with the ventilatory response to exercise, oxygen, carbon dioxide, heat and altitude. Indeed, for any given stimulus, some individuals appear to be essentially non-responsive whereas others are observed to hyperventilate. The individual variability in responsiveness to a given extreme environment suggests that certain "types" of individuals exist. In any given group of individuals who are rapidly translocated to high altitude, for example, some are observed to develop "acute mountain sickness" whereas others are found to adjust to the new altitude with a minor degree of discomfort (Evans, 1969).

A recent investigation by Forester et al. (in press) illustrates the point very well. These investigators conducted an experiment in which test subjects were exposed to varying levels of carbon dioxide in the inspired air. This study was unique in that the subjects were not required to wear a face mask, nose clip, or insert a mouthpiece but, rather, they simply rested in a small chamber as the level of carbon dioxide was changed. In other words, the common problems of discomfort associated with the wearing of respiratory equipment was eliminated. This is very important since the use of a mouthpiece and noseclip, or a breathing mask, is known to create considerable discomfort for some individuals. Hence, these individuals would theoretically have an increase in ventilation due to the psychologic stress as well as the physiological challenge of increased carbon dioxide. Forester et al. (in press), however, observed substantial individual differences in the response to elevations in carbon dioxide, even though their subjects were not encumbered with respiratory equipment. Ventilatory minute volume was observed to increase in a linear fashion with increases in carbon dioxide concentration, but variability increased in a progressive manner as well. In other words, some individuals experienced a substantial increase in ventilatory minute volume while breathing a 6 percent CO₂ mixture, whereas others had very little change in ventilation. It is also noteworthy that these "responders" and "non-responders" were remarkably similar under control conditions.

The findings of Forster et al. (in press) simply reinforce an important point that has been recognized by environmental physiologists and psychologists for many years. The reasons for such individual variability, however, are not well understood. It is important to recognize that individuals who are "sensitive" to certain stressors such as elevated carbon dioxide, heat, altitude, and so on, would presumably be at greater "risk" than non-responders. It would seem important, therefore, from both a performance and health standpoint, to identify those types of individuals who are at risk. If this could be done, it would be possible to either (1) exclude high risk individuals or "responders" from given stress settings or (2) train "responders" to bring their responsiveness under control. It may not be possible to effectively carry out either approach. At any rate, a logical first step would seem to be characterization of responsive individuals, and the present section is therefore directed toward a review of the literature involving psychometric correlates of respiration. This approach in no way is intended to imply that variables of a physiologic nature are not equally or more important. Research dealing with hyperventilation as a clinical syndrome is often viewed as a psychiatric or psychologic condition, but it is not reviewed here, as a separate section has been devoted to this problem. Sighing respiration as a symptom was described by Baker (1934) many years ago. This paper emphasizes that the symptom of sighing may vary in severity from an occasional sigh to attacks lasting for hours or days. This respiratory pattern was not known to have an organic basis at the time, but it was often resistant to treatment. The symptom was thought to result from nervous stress or ill health. Baker (1934) felt that all evidence pointed to this disorder of sighing as a nervous one, and it was not associated with a cardiovascular disease.

The actual incidence of respiratory neurosis was not known at this time, but Christie (1935) reported that it occurred much more frequently than generally believed. Also, Christie (1935) presented evidence to support the view that respiratory tracings obtained with a standard spirometer could be used in the diagnosis and differentiation of different types of respiratory neurosis. In a subsequent study by Hamilton and Shock (1936) it was reported that respiratory irregularity, usually "sub-breathing," was correlated with neuroticism or the unstable personality structure. The reported correlations were small but consistent.

These early investigations (Baker, 1934; Christie, 1935; Hamilton and Shock, 1934) all indicated that disturbances in respiratory patterns were associated with neuroticism or nervous states. In other words, it has been known for at least 50 years that certain types of individuals are more likely to experience respiratory discomfort, and such alterations were observed more frequently under stress.

In more recent years Dudley et al. (1968) reported that dyspnea was associated with both hyperventilation and hyperpnea which in turn were both associated with anger and anxiety. Also, dyspnea was associated with hypoventilation which in turn was associated with depression. These investigators concluded that dyspnea is perpetuated through a feedback loop mediated by anxiety. They also proposed that such conditions might be responsive to desensitization techniques.

As mentioned earlier, it has been known for many years that marked interindividual differences exist in the ventilatory response to carbon dioxide. While the aforementioned studies suggest that ventilatory response to carbon dioxide might be related to personality, this particular possibility was not evaluated empirically until the early 1970s. Saunders et al. (1972) tested 50 normal volunteers consisting of 25 males and 25 females. The subjects completed Forms A and B of the Eysenck Personality Inventory (EPI), and those subjects with cumulative distortion scores equal to or greater than 10 lies were excluded. A 6-liter bag containing 7 percent CO₂, 50 percent O₂, and 43 percent N₂ was used for rebreathing, and minute ventilation was calculated from a Godart spirometer. There was no history of respiratory or psychiatric disease for any of the subjects. The slope of the line of ventilatory response for increasing CO₂ tensions (CO₂) was calculated for each subject. The mean slope for the men was 2.43 compared with 1.92 for the women, and this difference was statistically significant (P less than .025). The two groups did not differ on the extroversion, neuroticism, or distortion scales of the EPI. The slope of the ventilatory response to CO₂ and extroversion was significantly (P less than .05) correlated (r = 0.29) for the total group (N = 50). However, these variables were highly correlated (r = 0.61, P less than .005) for the female sample (N = 25), but they were not significantly (P greater than .05) correlated (r = 0.01) for the male sample (N = 25). The ventilatory response was not correlated with neuroticism for the total group or the individual samples. The authors do not offer an explanation for the differences observed between the males and females in this study, and the ventilatory response of men and women to CO₂ needs to be studied further. The results indicate that sensitivity of the central respiratory chemoreceptors is positively correlated with extroversion in healthy young women. In other words, the greater the ventilatory response to CO₂ the higher the extroversion score.

A similar study was subsequently reported by Shershow et al. (1973). These investigators administered three to four trials of a rebreathing test for CO sensitivity to 33 test subjects, and the Minnesota Multiphasic Personality Inventory (MMPI) was employed as the personality measure. The mean ventilation values for individual subjects ranged from a low of 6.7 l/min to a high of 37.1 l/min, with a group mean of 20.8 l/min. Subjects scoring above the group mean were classified as "high responders" (N = 18). It should be pointed out that the initial trial correlated .89 with the third and fourth trials. In other words, individuals were quite consistent in their responses, but substantial interindividual differences existed. This suggests that CO₂ sensitivity represents a trait and, therefore, it would be predicted that the two groups would differ on the MMPI. The "low responders" were found to have elevations on nearly all of the MMPI scales. The "low responders" scored significantly higher on the depression, psychopathic, psychastenic, social introversion, and Welsh Factor A scales. The general elevation of MMPI scores in the group of low responders to CO₂ supports the view that respiratory response to inspired CO₂ is influenced in part by personality. Shershow et al. (1973) indicated that "... variation in respiratory response to CO₂ between subjects reflects differences in central nervous system control of respiration (p. 158)." These investigators have presented a rationale to support the view that response to CO₂ is determined by the sensitivity of the medullary receptors. It appears that a subject's ventilatory response to CO₂ differs for individuals possessing different personality structures. Specifically, the ventilatory response to CO₂ is inversely correlated with psychopathology.

There are numerous methodological problems that must be considered when evaluating research involving the ventilatory response to inhaled CO_2 , but Saunders et al. (1972) and Shershow et al. (1973) fail to emphasize this matter in their papers. A summary of existing research dealing with four interrelated aspects of the ventilatory response to inhaled CO_2 has been presented by Dempsey (1976), and this review suggests that numerous problems of a methodologic nature must be considered in evaluating the ventilatory response to inhaled CO_2 . A major problem in this type of research relates to the definition of slope, and Dempsey (1976) has described three potential sources of discrepancy.

Evidence suggesting that ventilatory patterns are governed in part by personality structure should not be viewed as excluding pathophysiology. Burns (1971), for example, studied 66 patients with breathlessness as a prominent symptom. Thirty-three of these patients had advanced obstructive lung disease, and the remaining 33 had a depressive illness. Most of this latter group had chronic bronchitis and a mild degree of airway obstruction. Of relevance to the present discussion was Burns' report that the two groups differed distinctly in their experience of breathlessness. The depressed patients experienced breathlessness at rest, and their main difficulty was associated with inspiration. Their breathlessness fluctuated rapidly and it was frequently associated with hyperventilation and sighing. From a psychodynamic standpoint these patients experienced depressive delusions of imminent death, and these delusions were associated with fear of heart failure and lung cancer. It is of considerable importance to note that these somatic symptoms disappeared with psychiatric treatment and recovery from depression. The patients with advanced obstructive airway disease were found to differ in several ways. First, their breathlessness was associated with expiration and it was exertional. Furthermore, recurring attacks of hyperventilation was only observed in one of the 33 patients. The breathlessness in this group was relieved by rest, expectoration, and cessation of smoking. It is tempting to interpret these results as suggesting that breathlessness is largely of a somatic or psychic nature. At any rate, there appear to be different types of breathlessness.

The report by Burns (1971) has since been supported in part by the work of Mora et al. (1976) who studied the PCO_2 in end-tidal air and the breathing rate of controls and patients with endogenous depression, neurotic depression, and schizophrenia. Increased breathing rate with a fall in PCO_2 was observed in the depressed patients, but results for the schizophrenic patients were more anomalous. Since depression of clinical significance is not at all uncommon in the non-hospitalized population, these reports suggest that a certain portion of any given sample of workers would experience ventilatory distress in association with their depression.

It is possible that problems of depression may simply represent a source for the ventilatory discomfort experienced by depressed individuals, but this state may not necessarily place the man or woman at risk when they find themselves in an extreme environment. On the other hand, individuals who suffer from anxiety attacks periodically, or those individuals characterized by chronic anxiety, may very well be at greater risk than "normals" when exposed to an extreme environment. Therefore, research involving anxiety states will now be reviewed.

It has been known for many years that patients with neurocirculatory asthenia (NCA) have a low physical work capacity and tolerance for hard muscular work. Individuals with this diagnosis would not be expected to perform well in a stressful environment while wearing protective breathing equipment. First of all, their work capacity is typically far below the average for men and women of their age. Second, their ventilatory response to exercise, even in a neutral environment, is usually characterized by hyperventilation. An elevated stress response coupled with hyperventilation during exercise would presumably place such individuals at greater risk than "normals" in the same setting.

In a report by Kellerman et al. (1969), for example, it was noted that 60 healthy adults and 41 NCA patients did not differ in their resting minute ventilation. However, the mean ventilatory response to five minutes of work at 50 watts on a bicycle ergometer was found to be 21.0 l/min for the normals and 40.0 l/min for the group of NCA patients. Increases of work load to 75 and 100 watts resulted in ventilatory responses of 34.8 l/min and 44.4 l/min in the normals versus 45.9 l/min and 62.8 l/min for the NCA patients. In other words, NCA patients had minute ventilations that averaged about 20 l/min higher than the normal individuals, and this characteristic hyperventilation took place at light and moderate work loads (50-100 watts). These individuals would presumably have even greater distress if required to perform heavy exercise under stressful conditions.

It has also been reported by Kent and Smith (1977) that patients with lung disease have some special psychological problems. They have emphasized that pulmonary patients often (1) express fear of rooms closing in on them, (2) they experience a sense of claustrophobia, and (3) a crushing sensation in the chest. Also, these patients often express severe dyspnea out of all proportion to actual physiological changes. Reactions of this nature while fighting a fire, for example, would presumably lead to a performance decrement and potential injury.

The relationship between self-reported respiratory symptoms and measured pulmonary function has been studied by Wright et al. (1977). The pulmonary function test consisted of FEV and FVC, and these were administered to 1110 smelter and mine workers who also completed a set of self-report questionnaires. The relationship between self-report data and actual pulmonary function was found to be mediated by three psychosocial factors: (1) a lack of hypochondriasis, (2) high job satisfaction, and (3) low life stress. It was found that 96 percent of all workers who did not have agreement between their self-report and pulmonary data were found to overreport symptoms of impairment. Also, overreporting of symptoms was significantly correlated with low job satisfaction. Self report data on medical or psychological questionnaires can be extremely useful, but the validity of such reports can be seriously compromised by psychosocial factors of the type described in this study. The findings of Wright et al. (1977) emphasize the importance of using both physiologic and psychologic data of a self-report nature in clinical practice as well as research settings.

Further support for the view that personality structure plays a role in response to stress has been presented by Rohles et al. (1967). During the course of evaluating responses to heat stress, these investigators observed that anxious individuals did not seem to perform well under conditions of

thermal stress. They hypothesized that thermal stress tolerance is governed by the individual's general or trait anxiety. In order to test this hypothesis they administered the Taylor Manifest Anxiety Scale (TMAS) to a large number of subjects, and this resulted in the identification of 35 high-anxiety subjects and 35 low-anxiety subjects. Their plan was to next evaluate the thermal stress tolerance of the two groups, and they proceeded to invite the 70 subjects to volunteer for participation in a thermal stress study. All the low-anxiety subjects volunteered! This particular finding is provocative for a number of reasons. Most stress research of the type considered in this review is based upon experiments with volunteers, and investigators typically proceed to advance generalizations with little attention given to possible problems of volunteerism. Is it possible that all or most of our existing research involving heat stress can only be generalized to individuals with low anxiety? This potential problem of volunteerism, at least from a psychological standpoint, has implications for each of the sections of this review.

SUMMARY

It appears that substantial differences exist in the ventilatory response of individuals to various stressors such as exercise and high levels of CO₂ in the inspired air. Both of these stresses are commonly experienced by workers in various settings, and both hyperventilation and hypoventilation are capable of provoking a chain of events that conceivably could have catastrophic results for the man or woman working in extreme environments. A portion of the exaggerated responsiveness of some individuals to exercise and CO₂ is associated with psychopathology. Anxiety neurosis, or neurocirculatory asthenia, depression and extroversion all have been demonstrated to be associated with ventilatory abnormalities. All of these psychometric variables have been found to be significantly correlated with perception of effort and, therefore, it is conceivable that ventilatory response to exercise and CO₂ are mediated by perception. Furthermore, the psychometric variables examined in this section are primarily of a trait or enduring nature rather than a state or situational response. It is concluded that ventilatory responses to exercise and CO₂ is influenced in part by psychopathology, and ventilatory disturbances can be consistently provoked in certain "types" of individuals in both neutral and extreme environments. It appears that individuals who are classified as "hyperventilators" may represent a clinical subgroup of the general population who might be especially susceptible to problems associated with respirator wear. The following section deals with the hyperventilation syndrome.

HYPERVENTILATION SYNDROME

The nature of the hyperventilation syndrome as observed in clinical or applied real-life settings may not be entirely the same as that observed in the laboratory, and there is a problem associated with nomenclature. Pitts and McClure (1967) have emphasized, for example, that anxiety reaction is not symptomatically distinguishable from the clinical syndrome known as anxiety neurosis, and these terms are not distinguishable from other disorders such as neurocirculatory asthenia, vasoregulatory asthenia, nervous tachycardia, effort syndrome, neurasthenia, Da Costa's syndrome, vasomotor neurosis, nervous exhaustion, soldier's heart, and irritable heart. Also, Pitts and McClure (1967) listed the following symptoms for anxiety neurosis: headache,

dizziness, blurred vision, chest pain, palpitations, dyspnea or breathlessness, sighing, tiredness-fatigue, parasthesias, depressed mood, trembling, shakiness, weakness, smothering, choking and nausea. Many of these symptoms can be readily provoked with voluntary hyperventilation. Lum (1975) presented the symptoms observed in 270 cases of hyperventilation syndrome and these consisted of: (1) cardiovascular (e.g., palpitations, tachycardia, precordial pain, and Raynauds phenomenon); (2) neurological (e.g., dizziness, disturbance of consciousness and vision, parasthesiae, and tetany); (3) respiratory (e.g., shortness of breath, "asthma," chest pain); (4) gastrointestinal (e.g., globus, dysphagia, epigastric pain, aerophagy); (5) musculoskeletal (e.g., muscle pains, tremors, tetany); (6) psychic (tension, anxiety) and general (e.g., fatiguability, weakness, exhaustion, sleep disturbance, nightmares). The symptoms presented by Lum (1975) to characterize the hyperventilation syndrome appear to be quite similar to those presented by Pitts and McClure (1967) to describe anxiety neurosis. Lum (1975), however, argues that anxiety state and hyperventilation should not be viewed as the same.

Lum (1975) has described 700 cases of hyperventilation syndrome studied in a single respiratory physiology unit over a ten-year period, and 82 percent of this group had no detectable pathology. Lum points out that the commonest diagnosis under which hyperventilation is mislabeled is anxiety state, and this is particularly unfortunate because of the treatment that typically follows. That is, tranquillizer therapy is usually initiated to control the anxiety when the individual's body ". . . is merely protesting against an unbalanced diet deficient in carbon dioxide, oxygen and calcium and calcium ions: to name but a few of the well-known biochemical disturbances which may accompany acute hypocapnia (Lum, 1975) ."

In Lum's (1975) view the diagnosis of hyperventilation syndrome rests on (1) the ability to rule out significant pathology and (2) reproduction of the patient's symptoms by voluntary hyperventilation. Many authors have reported that symptoms can be reproduced within a few minutes through voluntary overbreathing. Overbreathing can rapidly blow off large amounts of CO_2 and this provokes a precipitous fall in PCO_2 levels (i.e., respiratory alkalosis). Bicarbonate and carbonic acid are quantitatively the most important buffer systems. Overbreathing results in the offloading of CO_2 with an excess of bicarbonate and a deficiency of hydrogen ion. The result is that a pH shift and hypocapnia are almost immediate.

The immediate effects of hypocapnia are reflected in the cerebral circulation. "Carbon dioxide is the most important regulator of cerebral vascular tone (Lum, 1975)", and hypocapnia produces an immediate vasoconstriction which leads to cerebral hypoxia. The hemoglobin dissociation curve is shifted to the left as a result of the alkalosis which potentiates the hypoxic effects. The hypocapnia decreases the amount of oxygen available from the hemoglobin, and its release is slowed down as well. In other words, the brain receives less blood, the blood contains less oxygen, and its delivery is slowed. These effects are almost immediate and the most common results are faintness, dizziness and visual disturbances ranging from mere clouding of vision to tunnel vision or a total lack of vision (i.e., "hysterical" blindness). Blackouts are quite common at this point, and disturbances of consciousness are often confused with petit mal* Further, grand mal can be provoked with hyperventilation, and the consequences of these responses for men and women working in extreme environments are readily apparent.

The ionic shifts occurring with hyperventilation involve an attempt to restore hydrogen ion balance, and this quest for balance involves a complex series of events. Bicarbonate is offloaded via the kidney and pH is returned to normal with a lowering of bicarbonate in the plasma. Lum (1975) has reported that deficient bicarbonate buffer is a constant feature of "effort syndrome," and low plasma bicarbonate is seen as the hallmark of chronic hypocapnia. Lactic acid production is also associated with this state (Huckabee, 1958), and the acid-base balance is governed by many factors such as acute clinical fever (Koehler, 1923). In view of the fact that acid-base balance can be altered with the development of fever, it is quite possible that febrile states might serve as the stimulus for initiation of hyperventilatory attacks. This is an important point since hard physical work is often performed while wearing respirators in hot environments. It is believed that availability of calcium ion is required for normal muscle function, and reduced calcium ion level can lead to parathesiase and tetany (Pitts and McClure, 1967). Lum (1975), however, regards this as uncertain and suggests that tetany is probably brought about by the "direct action of alkalosis on the peripheral nerves."

Much of the preceding discussion has borrowed heavily from Lum's lucid discussion of the hyperventilation syndrome. The position outlined by Lum (1975) is compatible with that of other writers for the most part. Subsequent review papers by Missri (1978), Pfeiffer (1978), and Pincus (1978) suggests that little has changed since the appearance of Lum's review. Missri (1978), however, reinforces the point that inaccurate diagnosis often occurs because physicians simply are not aware of the syndrome or because very few patients

present the classic textbook symptoms" . . . of obvious overbreathing, parathesia, and tetany." In this context, Lum (1975) reported that spontaneous tetany is a rare manifestation of hyperventilation, occurring in only one percent of all cases, and this has led Lum (1975) to state that tetany ". . . is merely the top of the iceberg." Missri (1978) has emphasized that symptoms are far more subtle, and often mimic those of other organic and functional conditions, and many of these patients are eventually "dismissed" as being anxious or neurotic.

It has been noted by Pincus (1978) that hyperventilation is often the result of anxiety, and the hyperventilation in turn produces physiological changes that become the basis for subsequent fear. The symptoms include,

. . . faintness, visual disturbances, inability to concentrate, nausea, vertiginous instability, headache, fullness in the head, chest, and epigastrium, breathlessness, palpitations, hot flushes, cold sweats, parasthesiae and occasionally vomiting.

It is little wonder that a patient with the above symptoms, upon being told to "get hold of yourself" or "it's all in your nerves," may develop a chronic anxiety state.

It has been noted by Pfeffer (1978) that a great deal of research has been carried out over the past 50 years dealing with respiration in psychiatric disorders, but very little of this research has been concerned with the hyperventilation syndrome. Exceptions to this generalization are papers by (1) Kerr et al. (1937) involving the relationship of anxiety states to hyperventilation; (2) Fraser and Sargant's (1978) paper on hyperventilation attacks in hysteria; (3) Goldberg's (1958) review on the psychiatric aspects of hyperventilation; and (4) Lazarus and Kostan's (1969) discussion of "psychogenic" hyperventilation and death anxiety. Some contemporary writers, however, argue that hyperventilation should be viewed as a response to anxiety, and others argue that it merely represents a bad breathing habit (Dalessio, 1978; Lum, 1975); Missri, 1978; Pfeffer, 1978; Pincus, 1978). At any rate, whichever view is correct, it is clear that hyperventilation provokes considerable distress, the resulting symptoms could easily produce anxiety, and a vicious cycle would be established (Pfeffer, 1978). The development of such attacks in men and women working in hostile environments would place them at obvious risk as noted earlier.

It has been proposed by Lum (1975) that hyperventilation is essentially nothing more than a "bad breathing habit" that results in a relatively low PCO₂ on a day-to-day basis. Further, any stressor (physical or emotional), according to Lum (1975), is capable of triggering a chain reaction consisting of: (1) increased ventilation, (2) production of hypocapnic symptoms, (3) alarm, (4) sympathetic arousal, (5) increased ventilation and (6) increased symptoms.

It has been reported by many investigators that hyperventilation is most common in young women, and this view is partly supported by Lum (1975). However, while Lum (1975) found the incidence of hyperventilation to be much higher in women aged 20-29 years than in men of the same age, it was reported that the incidence was almost identical in the middle years (30-59) for men and women. These differences relating to sex and age may be significant when one considers the age at which men and women are likely to enter stressful occupations where hyperventilation could pose problems.

There is at least one major point surrounding the diagnosis and treatment of hyperventilation on which there exists some confusion. First of all, it is generally agreed that symptoms of hyperventilation can be readily reproduced in "hyperventilators" within several minutes by simply having them overbreathe, or following intravenous epinephrine (Yu et al., 1952). Second, these symptoms can be prevented by inhalation of CO₂, injection of potassium, or rebreathing in a paper bag. Third, many clinicians believe that hyperventilators can learn to detect these symptoms and prevent full-blown attacks from occurring, and there is some evidence that physical training is effective in treatment of the hyperventilation syndrome (Ferguson, et al., 1969). Disagreement arises with respect to the importance of ruling out organic pathology. Lum (1975) and Goff and Caensler (1969) believe that an accurate diagnosis of hyperventilation syndrome includes the systematic exclusion of organic disease. This represents a difficult matter, however, since hyperventilation is known to alter the electroencephalogram (Engel et al., 1947) and the electrocardiogram (Yu et al., 1952), and the state is usually characterized by symptoms that simulate organic disease (Lewis, 1954).

SUMMARY

This section has dealt with the psychophysiological phenomenon known as "hyperventilation syndrome." Published research on this syndrome dates back at least a century to Da Costa's classic investigation involving "soldier's heart." Various labels such as "effort syndrome," "anxiety neurosis," "neurocirculatory asthenia," "vasoregulatory asthenia," and "irritable heart," have been employed over the past century to describe this syndrome. The use of different labels to describe this syndrome seems to be inappropriate for at least two reasons. First of all, the symptoms associated with these diagnostic labels appear to be remarkably similar; but, second, the treatment for the syndrome often differs as a function of the diagnostic label. Symptoms include breathlessness or dyspnea with effort, parathesia, trembling, tachycardia, tetany, carpopedal spasms, and convulsions in the case of a full-blown attack. Hyperventilation, a normal consequence of vigorous exercise and/or high temperatures, can often occur in some individuals for no apparent reason. Hyperventilation, and the resulting physiological changes noted above are often associated with decrements in psychomotor performance along with increased error rates.

The symptoms which characterize the hyperventilation syndrome can be readily produced in certain "types" of individuals within minutes by requiring them to overbreathe or through introduction of a CO₂ challenge. The symptoms, once produced, can be quickly reversed by placing a paper sack over the subject's head and requiring him to rebreathe expired air. Overbreathing and CO₂ challenges do not, however, produce full-blown hyperventilatory attacks in most individuals. That is, some individuals or "types" appear to be especially sensitive to the effects of overbreathing or a CO₂ challenge. It seems reasonable to propose that individuals who experience hyperventilatory attacks could be identified during routine office evaluations. Individuals who experience the hyperventilation syndrome would presumably be at greater risk when required to wear respirators and exercise vigorously in a stressful setting. Future research and practice could be directed toward identification of "hyperventilators" with an aim toward (1) correcting this problem, or (2) not permitting them to become involved in stressful work settings requiring the use of respirators.

PILOT STUDY

The research reviewed in this paper demonstrates that respiration is influenced to a substantial degree by various psychological traits. It has also been reported that some men terminate hard physical work while wearing respirators because of a sensation they describe as "suffocation", "inability to breathe", "claustrophobia", and so on. Other individuals who are wearing the identical respirator, possess comparable levels of physical fitness, and are required to work at the same metabolic demand, do not experience such sensations. The possibility that certain "types" of individuals are more likely to experience respiratory distress than other individuals seems to be a distinct possibility.

Methodological details relating to the present investigation are described in Dr. Raven's paper which appears in this volume. The overall study design involved the psychological and physiological evaluation of volunteer test subjects who were diagnosed as normal (N = 25), impaired (N = 16), or badly impaired (N = 11) from the standpoint of pulmonary function. These individuals were evaluated at rest, and during exercise on a motor driven treadmill test performed at increasing workloads. The exercise was performed with and without a SCBA in order to evaluate the physiological and performance consequences of respiratory resistance and external load due to wear of the SCBA. Again, the details of this study are reported elsewhere in the present volume by Dr. Raven.

The psychological characteristics of the three groups are summarized in Table 1. Anxiety was assessed with the State-Trait Anxiety Inventory (STAI) and mood was evaluated by means of the Profile of Mood States (POMS).

TABLE 1. Psychological characteristics of normal, impaired, and badly impaired adult volunteers.

Variable	Normal Group N = 25		Impaired Group N = 16		Badly Impaired Group N = 11	
	Mean	SD	Mean	SD	Mean	SD
<u>STAI</u>						
State Anxiety	32.4	7.6	32.7	9.5	35.1	7.7
Trait Anxiety	33.3	9.2	32.4	7.6	38.5	6.4
4-Item State	6.9	2.3	5.3	1.1	6.1	2.1
<u>POMS</u>						
Tension	8.0	5.6	7.6	5.1	14.9	7.2
Depression	6.4	9.9	3.8	4.4	7.4	6.8
Anger	6.5	5.9	5.3	4.1	7.1	4.9
Vigor	20.5	5.4	20.3	7.4	14.4	5.7
Fatigue	5.2	4.9	7.7	4.2	13.3	6.2
Confusion	5.4	3.3	3.9	2.7	6.9	5.7

Details concerning the STAI and POMS are presented in manuals developed by Spielberger et al. (1969) and McNair et al. (1971). The data presented in Table 1 reveals that the normal and impaired groups were quite similar on all psychological variables measured, but both of these groups differed substantially from the badly impaired group on (1) trait anxiety, (2) tension, (3) fatigue, and (4) vigor. These results are illustrated in Figures 1, 2, and 3. It will be noted in Figure 1 that the badly impaired group scored significantly higher than the normal or impaired groups on trait anxiety. These individuals would be expected to have respiratory distress during exercise because of their impaired lung function as well as their elevated anxiety. Indeed, these individuals would be expected to respond to a variety of stressors at a greater intensity than individuals in the other groups.

It is possible to compute a composite score of mood disturbance from the POMS, and this involves summing the scores on tension, depression, anger, fatigue, and confusion, and subtracting vigor, the positive measure (McNair et al., 1971). The results of this analysis are illustrated in Figure 2. Again, the badly impaired group is observed to score substantially higher than the normal or impaired groups on this composite measure of mood disturbance. The mood state measure reflects how the individual is feeling at the present time, while the trait anxiety measure depicted in Figure 1 summarizes how the individual generally feels. Three mood states accounting for most of the elevation in the badly impaired group were tension, fatigue, and vigor. The results for these three mood states are illustrated in Figure 3. The badly impaired individuals scored significantly higher than the other two groups on tension and fatigue, and significantly lower on vigor. These results make sense at an intuitive level, and they imply that badly impaired individuals would experience more difficulty while exercising with or without a SCBA. The results also predict, however, that the normal (N = 25) and impaired (N = 16) would not differ.

These hypotheses were evaluated by asking the test subjects to rate their breathing on a dyspnea scale consisting of seven categories. The odd numbers were anchored with verbal descriptions, and the scale appears below.

Breathing Scale

1. My breathing is okay right now.
- 2.
3. I am starting to breathe harder.
- 4.
5. I am not getting enough air.
- 6.
7. I can't breathe.

A summary of responses appears in Figure 4 for the control and mask conditions during exercise at Stage 1 on the treadmill. Breathing discomfort was significantly greater for the badly impaired group in comparison to the normal and impaired groups for both the control and mask conditions. The normal and impaired groups, as predicted from the baseline psychometric data, did not differ in their rating of breathing discomfort. While all groups experience an increase in respiration distress during the mask condition, the increase was far greater for the badly impaired group. The impaired and normal groups

were only found to differ on the dyspnea scale at the third stage of exercise, and this only occurred for the mask condition. That is, the normal and impaired groups did not differ at any exercise stage under control conditions. Also, the difference at stage 3 for the mask condition was not remarkably different in that the impaired group rated breathing to be 4.1 (+ .2) and the normal group rated their breathing to be 3.5 (+ .2). The badly impaired group was unable to exercise with or without a mask at stage 2 or 3.

The test subjects were also asked to rate their perception of effort with the psychophysical category scale designed by Borg (1973) and described earlier in the present paper. The results of this analysis are presented in Figure 5. It will be noted that the impaired group rated their perception of effort to be higher at each stage of exercise for both the control and mask conditions, and the differences between the two groups were greatest for the mask condition. This finding is somewhat unexpected since the two groups did not differ a great deal for the breathing rating. At any rate, the breathing and perceived exertion findings suggest that individuals with lung impairment have comparable sensations of "exercise cost" while performing physical work without a SCBA. However, the individual with impaired pulmonary function perceives work to be more demanding, both breathing and general perceived exertion, when wearing a SCBA. The badly impaired group's mean perceived exertion ratings are illustrated in the upper left hand corner of Figure 5. These individuals scored substantially above the normal and impaired groups at stage 1 of exercise.

One additional analysis of a clinical nature was performed. The previous review suggests that 10% of any given sample of "normal" individuals are found to have elevated scores on anxiety. The population mean for trait anxiety has been reported to vary between 34 and 36. Three of the 25 test subjects, or 12% of this sample of "normals," were observed to have elevated trait anxiety scores of 46, 46, and 63. Four of the twenty-five subjects in the normal group experienced dizziness, claustrophobia, or anxiety attacks during exercise at stage 3 while wearing the SCBA. Each of the three subjects with elevated scores were among the four who experienced anxiety attacks, and the fourth subject who experienced an attack had scored 27 on trait anxiety. In other words, it was possible to predict 75% of the anxiety attacks a priori in the sample of "normals" studied in this investigation.

It is concluded that exercise stress is perceived as being more difficult by individuals classified as impaired or badly impaired in comparison to normals, and this elevated perceptual cost is most dramatic for conditions requiring the wear of a SCBA. It is also concluded that 10% of any given sample of "normal" individuals will be characterized by elevated anxiety, and these individuals are likely to experience anxiety attacks while wearing a SCBA and performing heavy physical work.

SUMMARY

This review has dealt with the psychological problems associated with the use of industrial respirators. The need for men and women to wear various self-contained breathing apparatus (SCBA) while working in hostile environments such as toxic and oxygen-deficient atmospheres is well documented. Extensive research has been carried out in an attempt to improve

the design of respirators, and major advances have resulted in the manufacture of SCBA that insure health, safety and performance. Indeed, recent research reveals that performance decrements associated with the wear of respirators are due entirely to pack weight; that is, breathing resistance no longer appears to be a significant problem in most cases. Despite the fact that major advances have taken place in the design of respirators, it is still widely recognized that "psychological" problems continue to exist. Unfortunately, very little research has been directed toward an understanding of the "person" component of the respirator-person interface; that is, research has focused on respirator variables with little attention paid to person variables. While it has been proposed that certain "types" of individuals be eliminated from work tasks requiring the wear of SCBA, there has not been a concise diagnostic statement presented to enable such a screening approach to be adopted.

This review indicates that firefighters are characterized by impaired pulmonary function, and the impairment is significantly correlated with the amount of exposure to fires. This impaired pulmonary function in firefighters also has been reported to be independent of age and smoking habits. When this finding is considered in concert with the observation that many firefighters elect not to wear respirators unless smoke is visible, and some individuals (e.g., "smoke-eaters") opt not to wear SCBA even in the presence of smoke, it is clear that future work must be directed toward the identification of methods that will enhance respirator wear. There, of course, are many lethal materials that one cannot smell or see, and these toxic atmospheres present immediate or acute risks for the firefighter. In addition, there are many substances that do not present detectable effects at an acute or daily level, but workers exposed to such irritants for many years are likely to experience impaired pulmonary function at a chronic level. These acute and chronic issues represent rather different motivational problems, and they must be addressed independently. That is, a worker might be warned that he or she could easily die today while fighting a "smokeless" fire unless a SCBA is worn. They could also be warned that the likelihood of developing impaired pulmonary function 20 years hence would be minimized if SCBA were worn routinely in given situations. The motivational forces underlying the decision to wear, or not to wear, a respirator in these situations appear to be quite different.

Why do individuals elect not to wear protective devices while working in extreme environments? There are obviously many explanations or answers to this question. First of all, SCBA are known to produce discomfort, and the degree of discomfort varies with the type of SCBA being worn, as well as with the wearer himself or herself. Most respirators restrict vision to some extent, and all are associated with decrements in endurance performance and psychomotor behavior. Therefore, it is quite understandable why many individuals elect not to wear respirators, especially when there is no perceptual information (e.g., sight, smell or taste) available which encourages the wear of respirators.

The review reveals that most individuals are capable of perceiving changes in breathing brought about in a number of ways. It is also apparent that most individuals possess the ability to accurately judge induced changes in breathing. Furthermore, most individuals are able to make very accurate judgements of exercise intensity, and it appears that perception of exercise

intensity is governed in large measure by respiratory cues. Unfortunately, about 10 percent of the subjects in any given experiment are not able to perceive changes in breathing, nor are they capable of accurately judging exercise intensity. It is also of interest that approximately 10 percent of any given group of test subjects experience an excessive amount of discomfort while wearing respirators. It should also be emphasized that 10 percent may represent a conservative estimate of the proportion of individuals who experience discomfort while wearing respirators, since the results of research in this field are undoubtedly attenuated due to volunteerism. Indeed, most of the experiments reviewed in this field have used healthy, male volunteers for test subjects. The findings cannot be generalized to individuals with mild or major problems of a physiological nature. Furthermore, these results should not be generalized to females or older individuals, nor should they be inferred to the "non-volunteer" sector of any given population, at least not until the non-volunteer sector has been characterized.

The reduction in work capacity associated with the wear of respirators can be minimized in part by means of training. The limitations arising from factors of a psychological nature should be particularly responsive to training. The greatest benefit of training would undoubtedly occur for those individuals who experience dyspnea, sensations of claustrophobia or suffocation with physical effort. In view of the fact that psychological correlates of respiration and perceived exertion have been identified, and since perception of stress is known to influence the degree of responsivity to a given stressor, it appears imperative that procedures for the diagnosis and treatment, or exclusion, of "responders" be undertaken. The available literature does not permit application in this area at present*. In other words, it is recognized that certain individuals are more prone to experience distress while wearing respirators, and it is agreed that they should not be subjected to conditions in which they are required to wear SCBA. Results of the pilot study described in this paper reveal that individuals who have elevated scores on the trait anxiety scale (STAI) developed by Spielberger et al. (1969) are far more likely to experience anxiety attacks while performing hard, physical work and wearing a SCBA than are individuals who score in the normal range. Indeed, 75% of those individuals who experienced anxiety attacks in this study were predicted to do so a priori. These results lead to the conclusion that certain "types" of individuals are more likely to experience anxiety attacks while wearing a SCBA than others, and furthermore, these individuals can be identified in advance with an acceptable degree of precision.

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FIGURE 1

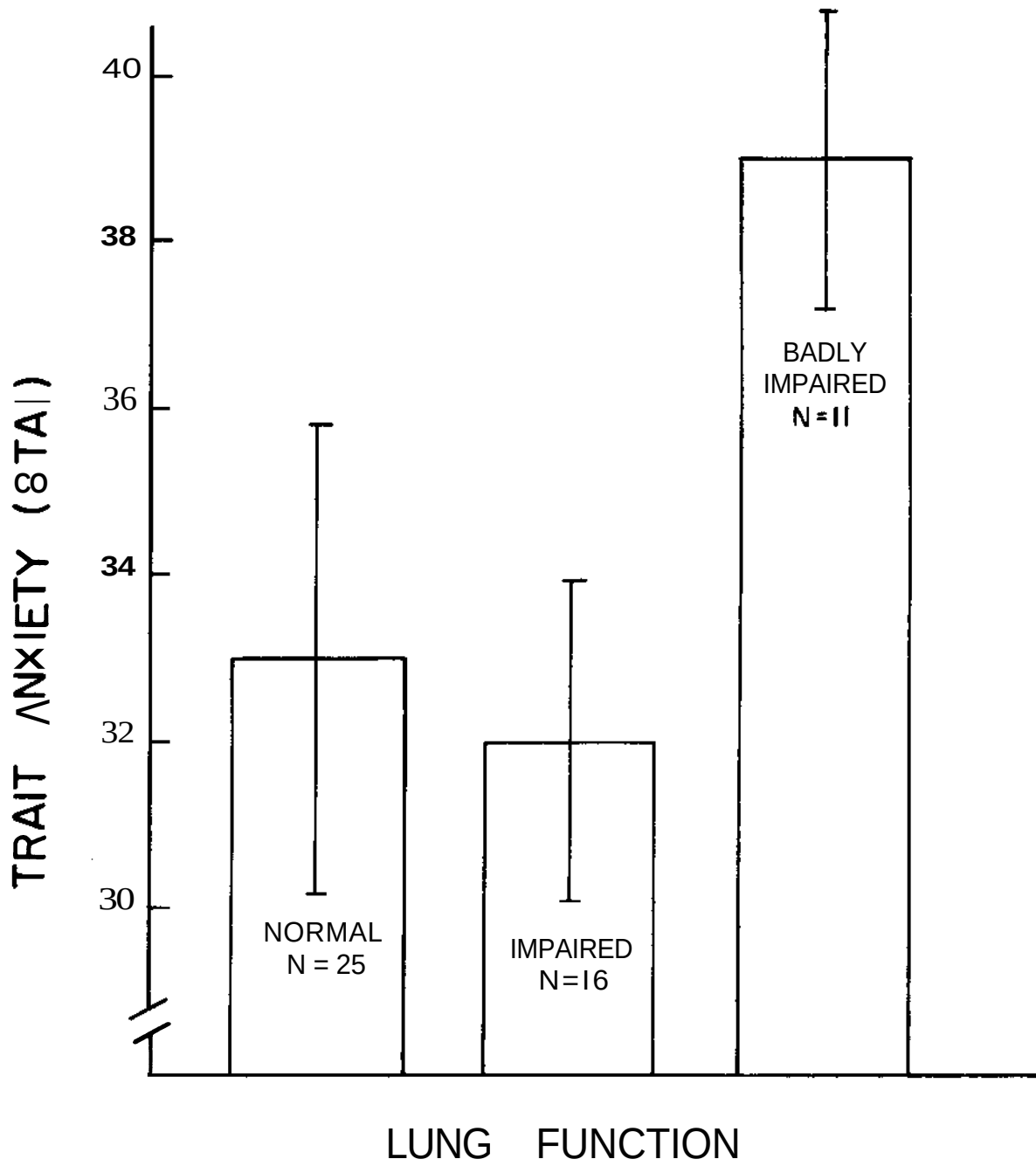


FIGURE 2

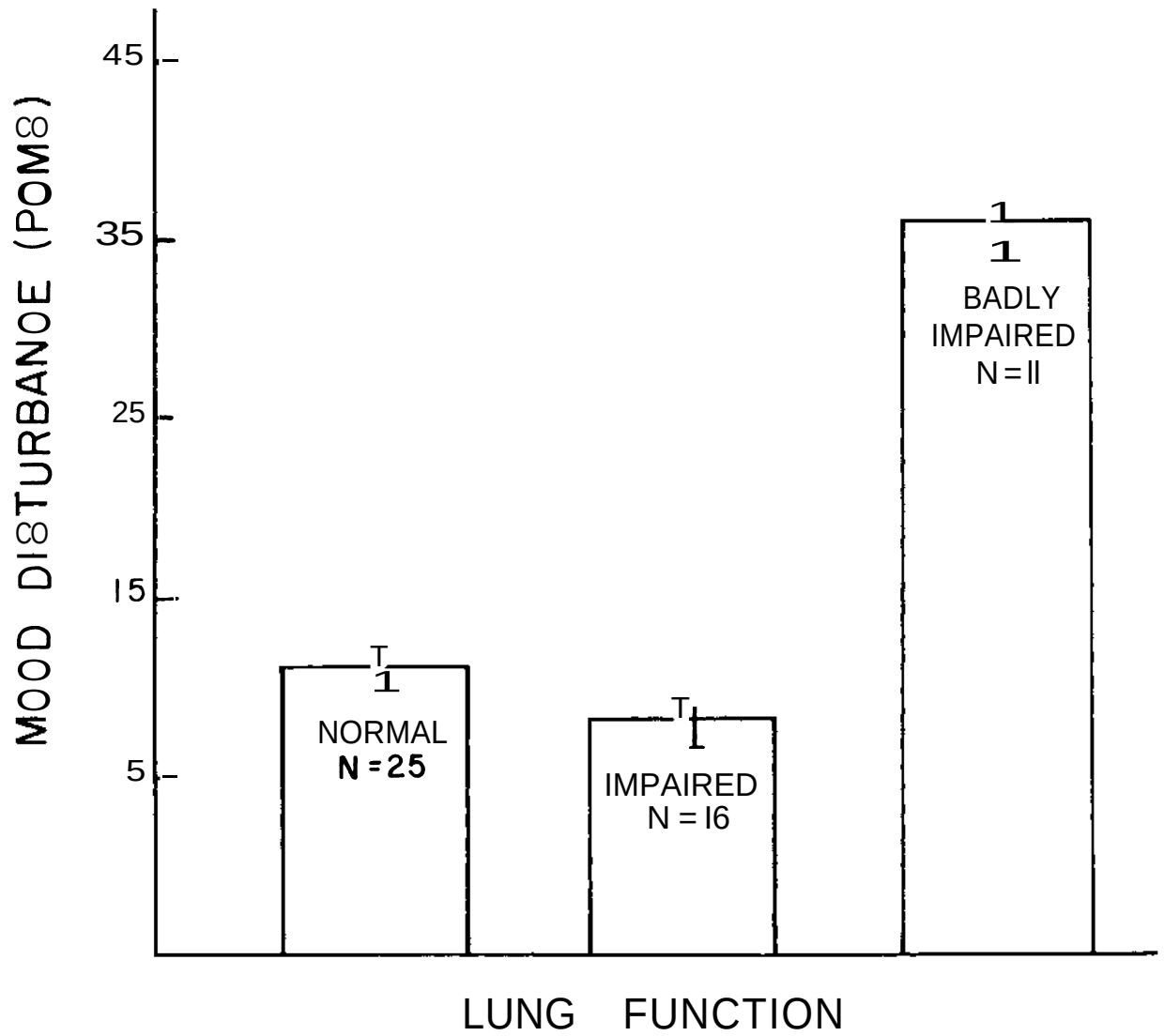


FIGURE 3

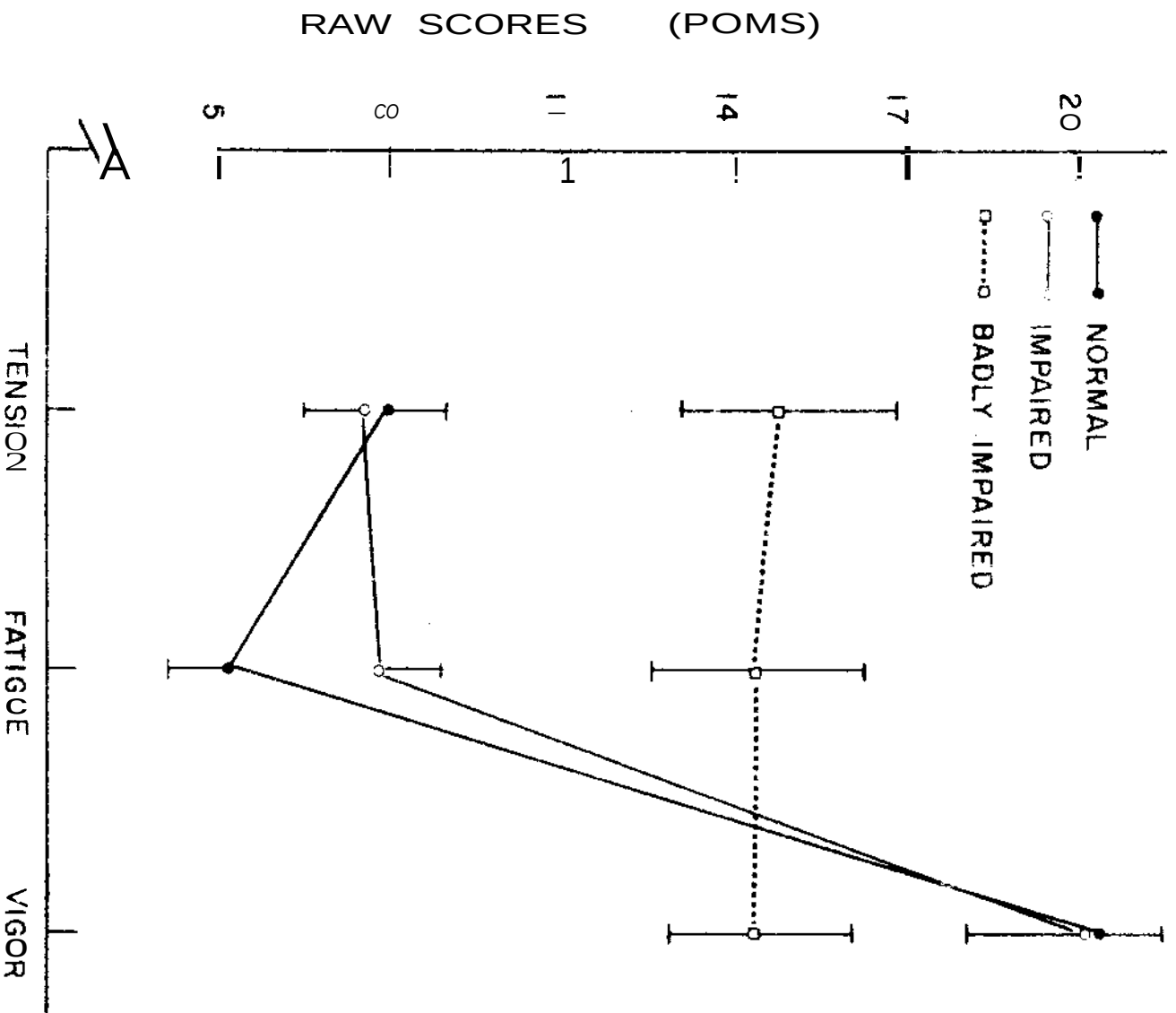


FIGURE 4¹⁰⁶⁻

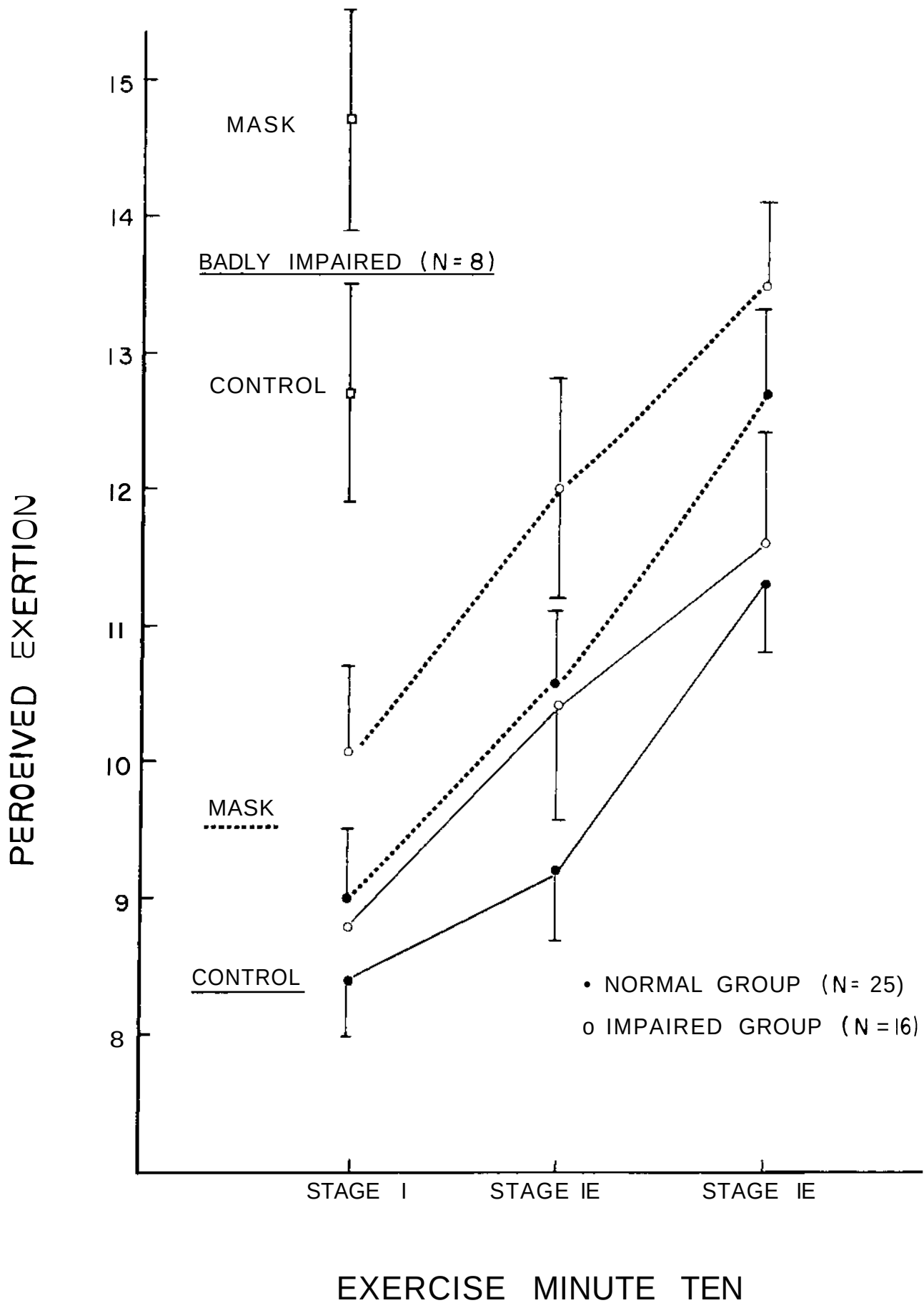


FIGURE 5

