

RESPIRATOR RESEARCH: WHERE IT NEEDS TO GO
THE MAN-RESPIRATOR INTERFACE

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Since the time of Silverman in the early 1940's we have accepted the reproducibility of machine testing as a means of certifying the respirator for human use. In this presentation I shall endeavour to highlight the inadequacies of the respirator when challenged by the working human, even though the respirator meets the requirements of test certification by machine. From the outset, I wish for you to understand that the ideas which will be expressed in this presentation are my own and not those of any specific group. I will present information concerning problems of the self contained breathing apparatus (SCBA), although I contend that these problems may be inherent to all types of respirators. This presentation will include details of data obtained from four major projects supported by Los Alamos Scientific Laboratories (LASL) in New Mexico. This work was carried out at LASL (1), Brooks Air Force Base - School of Aerospace Medicine in San Antonio (2) and at the Texas College of Osteopathic Medicine in Fort Worth, Texas (3, 4, 5).

In general, respirators are utilized for submaximal work tasks (light or moderate work equivalent to less than 50% of maximal capacity) in situations where inhalation of the atmosphere may prove injurious or fatal. However, work tasks such as fire-fighting will require maximal work performance while wearing an SCBA. As an exercise physiologist, I felt the first requirement was to determine that degree of work impairment that occurred during the wearing of the respirator. Subsequently, in light of the recent fatal accidents that have occurred I have been documenting both the physiological and psychological responses of the healthy and the impaired human worker during respirator wear at various workloads. In the first investigation (1) we have shown that, although the greatest decrement in work performance was observed during "demand" breathing (21% decrement), the major factor in reducing maximal work performance was the weight of the SCBA itself. Regardless of breathing mode, the extra weight (approximately 35 lbs) of the SCBA produced a 20% decrement in performance (Figure 1). This would suggest that an increased energy requirement of 20% is required to perform a routine work task. This has been confirmed by the work of Myrhe et. al. (2) at Brooks AFB during workloads of 50%, 65% and 80% of an individual's maximal work capacity (Figure 2). From this data we can propose an area of research as being related to the need of reducing the weight factor of the breathing bottle to a minimum. The new lightweight bottle is a step in the right direction. For those interested in worker safety and job performance, individuals who only have a 20% or less energy reserve, due to age, disease or low fitness, will be severely compromised when wearing an SCBA. Hence, yearly physicals including a fitness evaluation may become a necessity for all SCBA wearers, who when faced with the emergency use of SCBA in the course of their work, might compromise the life of themselves or their fellow workers.

Although difference in maximal work performance due to "breathing" mode were obscured by the problem of the weight of the SCBA (1), our evaluation of subjective responses indicate that breathing mode has a strong psychological involvement (Table 1). Also, Myrhe et. al.'s (2) data indicate that ventilation volumes were increased as a result of the imposed breathing modality whether "demand" or "pressure demand" (Figure 3). The increases in ventilation (6 l/min), although minor, may be related to the increased work of breathing or more likely the psychologically imposed demand for more

ventilation, which **Morgan et. al.** (6) have demonstrated in **previous** work (Figure 4). As will be noted by Morgan later in this **workshop**, there is a strong link between the psychological and physiological components of breathing with a respirator which may prove detrimental in crisis situations. The questions raised by this interaction have not been attended to in a prospective fashion. The data to be presented by **Morgan**, should provide us with a direction by which a prospective type investigation can be **established**.

Physiologically, inspiration generates an air flow into the lungs which gradually increases from zero to a maximum (peak flow = PF) and as the lungs **fill** the flow returns to zero again (Figure 5). On expiration a similar process occurs. The peak flow, whether inspired or expired, is dependant upon the workload and as has been shown by Myhre et. al (2) individual PF of 360 liters/minute can be obtained at 80% of maximal work capacity. In our data (3) we have observed PF in excess of 240 l/min for both impaired and non-impaired subjects while working at only 62% of their maximal capacity (Figure 6). I suggest that in exceptional circumstances (i.e., large individuals and for large athletes) the peak flows may reach as high as 600 l/min. **Unfortunately**, to date many of the regulators used today are only capable of delivering a PF of 400-500 **liters/min** with many of them passing the **NIOSH** certification test with a flow of 200 l/min instantaneous flow (the minimum required criterion for **certification**). Obviously then, the required performance standard in terms of PF is inadequate.

As flow demand increases with increases in workload, one would expect to observe (and does observe) a greater and greater amount of insufficient delivery of air during a specific phase of the respiratory cycle. In order to maintain protection, the regulatory valves themselves work on an **"all"** or **"none"** principal such that a specific negative pressure must be generated before air flow (inspiration) can occur and a positive pressure must be produced before expiration can occur. Hence, when the lack of inspiratory air delivered and the need to produce a negative pressure are combined in each breathing cycle there is a specific time, especially at the initial portion of the breath, when the air delivered to the person working **is** inadequate to meet their demands. This is reflected by a negative pressure being generated in the mask during the inspiratory phase of respiration. This was **confirmed** for both "demand" and "pressure-demand" breathing by work by Myhre (2), (Figures 7 A&B). The greatest negative pressures were observed with "demand" breathing at the heaviest workloads. In fact, at all levels of peak flow or workload the "demand" breathing produced a **significantly** greater inspired negative pressure than during **"pressure-demand"**. Therefore, the potential for breaking the face-mask seal was greater during "demand" and created a more potentially lethal system to work with, concerning high workloads, in a toxic atmosphere.

In more recent work on **"demand" type respirators**, negative mask pressures in excess of 10 cm of water at peak flows at 240 l/min and ventilation volumes of 60 l/min were observed during workloads of 62% of maximal capacity (4). **Confirmation** of the negative mask pressure generated during high workloads while using **"pressure-demand"** breathing has also been achieved during our latest work (5). **Obviously**, the amount of negative pressure generated is related to individual differences such as the size of the worker and the actual workload related to the **worker's** maximal capability.

Figures 8 A&B are representations of maximally performed flow/volume loops obtained from the healthy and distinct **individuals**, performing with and without a **"demand" type respirator**. As they begin to inspire a negative pressure is generated. When the negative pressure exceeds the valves opening pressure (usually 5 cm H₂O at 85 l/min air flow) air flow occurs up to its maximal level which in these cases was 200 l/min. **However**, the actual PF required in one case was 250 l/min and in the other case 380 l/min. Hence, a state of air deprivation **exists** (Figures 8 A&B). In many cases this air deprivation is thought to produce the feelings of dyspnea and thereby triggers the major psychological effect accompanying respirator wear.

Here lies a major need for research which should be interdisciplinary in nature. First, the engineer is challenged to design and to produce a regulator valve which, when triggered to open, has the capability of following the individuals flow/volume characteristics without distortion. Secondly, the work physiologist is challenged to verify that the design of the regulator valve does in fact meet the flow/volume characteristics of the human during maximal performance. **Thirdly**, the physiologist needs to describe the maximal inspiratory and expiratory resistances, throughout the range of flows, experienced in the respiratory cycle, which do not **psychophysiologically** interfere with work performance. Fourthly, in order to improve the bench test **certification** of new **respirators** the engineer must provide a calibrated yet variable dynamic flow pump which will mimic the respiratory cycle in total and thereby **provide** a calculated measure of **variable** resistance.

Another area of concern, which must be addressed, deals with a point already alluded to by **Mary-Winn O'Brien**. 29 CFR 1910 134 (b)(10), OSHA indicates that the physician be left to determine what health and physical conditions are pertinent. However, no guidelines in terms of specific disease conditions or **work** levels have been proposed. In a preliminary attempt, we are evaluating the effects of **"demand"** and **"pressure-demand"** respirator wear during rest and work for a group of subjects with **subclinical** but mild lung function impairment (3,4,5). Most of the data obtained during these investigations will be presented later in the program. Preliminary findings suggest that the physiological effect of the respirator is no different for the impaired subject than for the normal subject. However, specific evaluative tests of pulmonary function, work performance and psychological condition all appear to have some predictive capacity as to their response to a respirator. It is in this area that I feel the major thrust of physiological research should focus.

First we must identify the problems of respirator wearers with a specific disease entity. Secondly, can we provide a scientifically predictable screening test(s) for the physician to use in his office? This screening must be able to accurately predict a workers' response to respirator wear (both physiological and psychological) and relate it to the stresses of the specific work tasks required. Finally, we need to document the changes in physiological and psychological responses by a period of job specific training with a respirator.

In conclusion, 1 would like to reiterate our research needs in priority order:

- a. produce a regulator valve capable of following the true respiratory demands of the human
- b. devise a dynamic flow/resistance calibrating pump
- c. describe the psychophysiological responses of specific diseased population to respirator wear during rest and work
- d. provide a simple yet specific clinical test(s) which is response and job related
- e. validate the predictability of the screening test(s)
- f. evaluate training programs
- g. reduce the weight bearing load of the respirators to a minimum

1 would like to make an appeal to those people concerned with the use of industrial respirators, be it business, government, labor or the scientific community. Because of our need to promulgate standards for the protection of the individual when using a respirator, we have established a position (akin to the gold standard) which is used in adversary situations between groups. The implicit problems of this situation have been succinctly identified by Mary-Winn O'Brien in her position statement. However, most of our righteous indignation is expounded using the gold standard (respirator certification) as our base of support, yet this standard is an inadequate representation of the human's demands. Therefore, I appeal to all concerned to consider the man, that is being required to wear this device, as a human life that may be endangered, and not just a machine which responds only in a designed fashion.

References

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2. Myrhe, L.G., R.D. Holden, F.W. Baumgardner and D. Tucker. Physiological limits of firefighters. Technical report #ESL-TR-79-06, 1979. Available Tyndall AFB, Florida 32403.
3. Raven, P.B., R.F. Moss, K. Page, R. Garmon and B. Skaggs. Clinical pulmonary function and industrial respirator wear. (submitted) Am. Ind. Hyg. Assoc. J. July, 1980.
4. Raven, P.B., A.W. Jackson, K. Page, R.F. Moss, O. Bradley and B. Skaggs. The physiological responses of mild pulmonary impaired subjects while using a "demand" respirator during rest and work. (submitted) Am. Ind. Hyg. Assoc. J. August, 1980.
5. Raven, P.B., R.O. Garmon, A.W. Jackson, R.F. Moss, O. Bradley and B. Skaggs. The responses to "pressure-demand" respirator wear of normals and pulmonary impaired subjects during rest and work. (in preparation)
6. Morgan, W.P., P.B. Raven, B.L. Drinkwater and S.M. Horvath. Perceptual and metabolic responsivity to standard bicycle ergometry following various hypnotic suggestions.

TABLE 1
Subjective Comments Reported
as reasons for
Termination of Exercise

<u>Comments</u>	Conditions			
	A	B	C	D
	11	14	8	7
leg pain				
general fatigue	4	1	2	4
lack of air	--	--	8	—
claustrophobia	--	--	4	4
hot mask	--	--	1	1
expired resistance high	--	--	—	1
dry throat	--	--		
Total	15	15	23	18

FIGURE LEGENDS

- Figure 1 Group mean data of maximal work performance in relation to time obtained for each condition of respirator wear, see legends in figure. Adopted from the data presented in reference #1.
- Figure 2 Group mean data describing increases in oxygen uptake for specific relative workloads as a result of respirator wear. Adopted from the data presented in reference #2.
- Figure 3 Average increases in ventilation volume (6 l/min) due to breathing mode compared to weight bearing along. Adopted from the data presented in reference #2.
- Figure 4 Increases in ventilatory volume during actual work of 600 Kpm/min (control) and hypnotic suggestion of 900 Kpm/min yet actually working at the same control workload. Adopted from data presented in reference #6.
- Figure 5 Schematic representation of changes in flow during inspiration and expiration.
- Figure 6 Changes in peak flow (l/sec) and ventilation volumes (l/min) during respirator wear with increasing workloads.
- Figure 7 Changes in respirator mask pressures relative to atmospheric pressure with respect to relative workloads (A) and peak flows (B). Adopted from data presented in reference #2.
- Figure 8 Comparisons of two maximal flow volume loops obtained on normal subjects with and without a "demand" type respirator.

**FIG I Tests of Maximum Work Performance
during various respirator conditions**

[From Raven, et al (1977) , with permission]

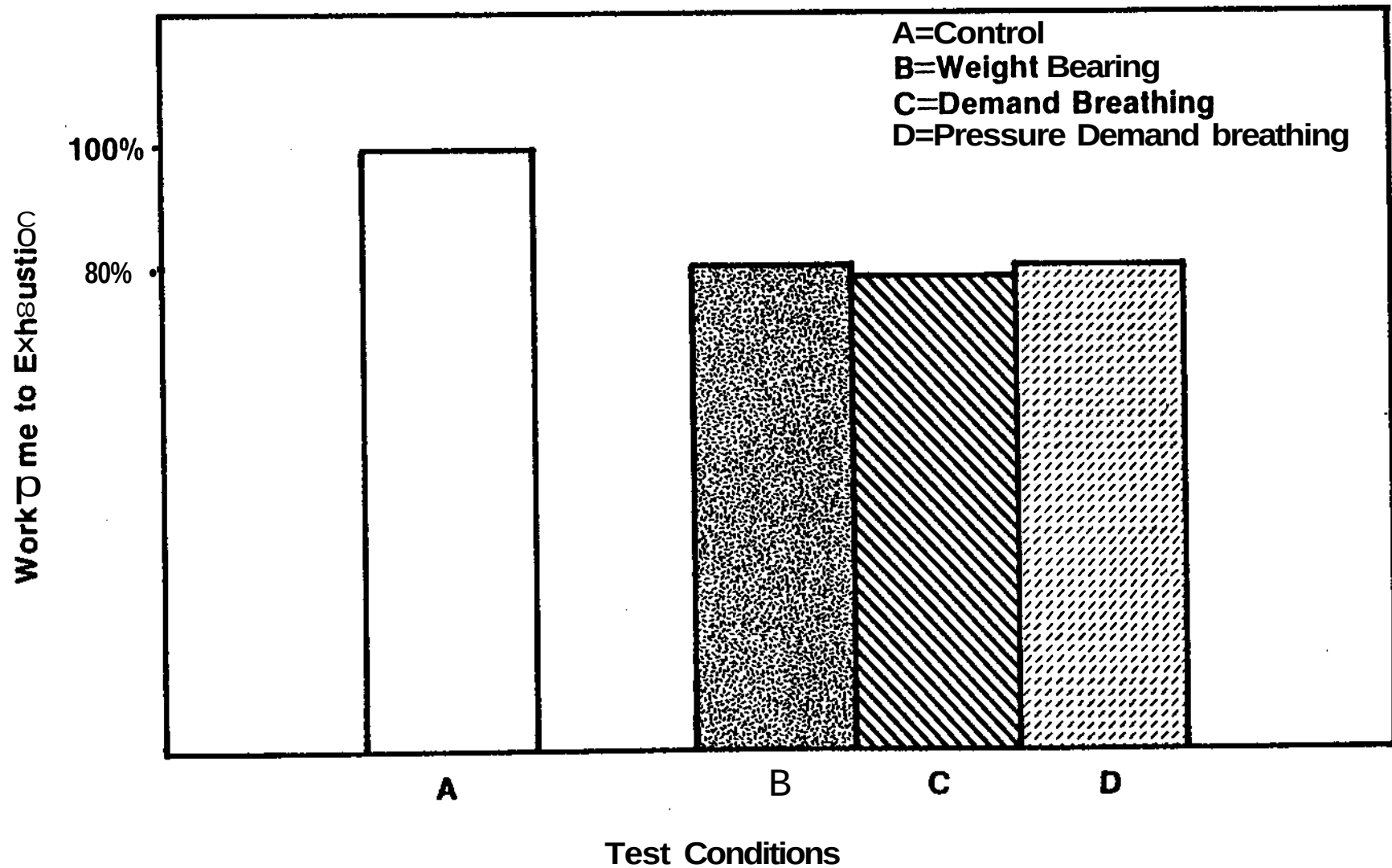


FIG. 2 Increase In Energy needs In response to respirator wear.

[From Myhre, et al (1979), with permission]

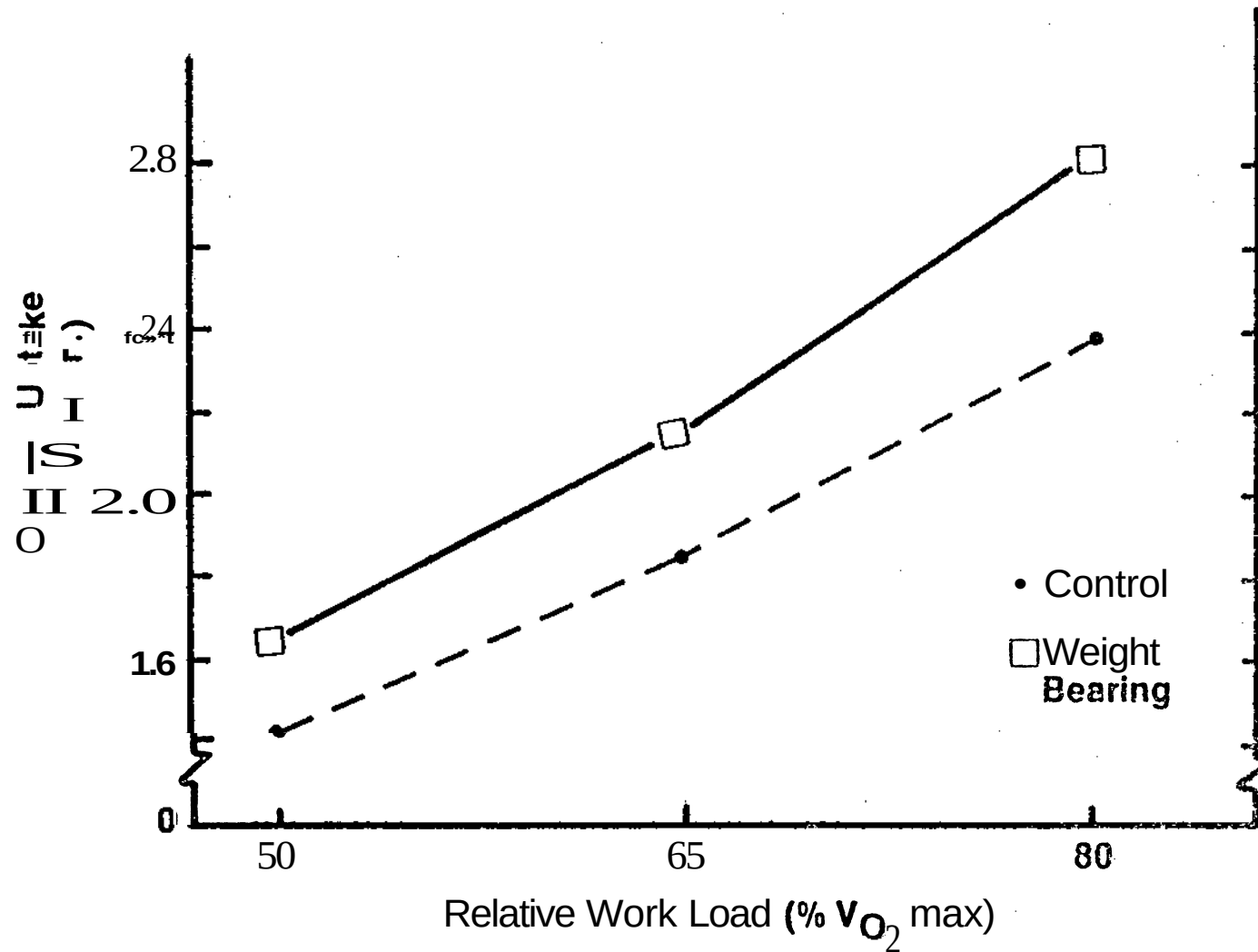


FIG. 3 Increases in ventilation volumes
as a result of breathing mode

[From Myhre, et al (1979) , with permission]

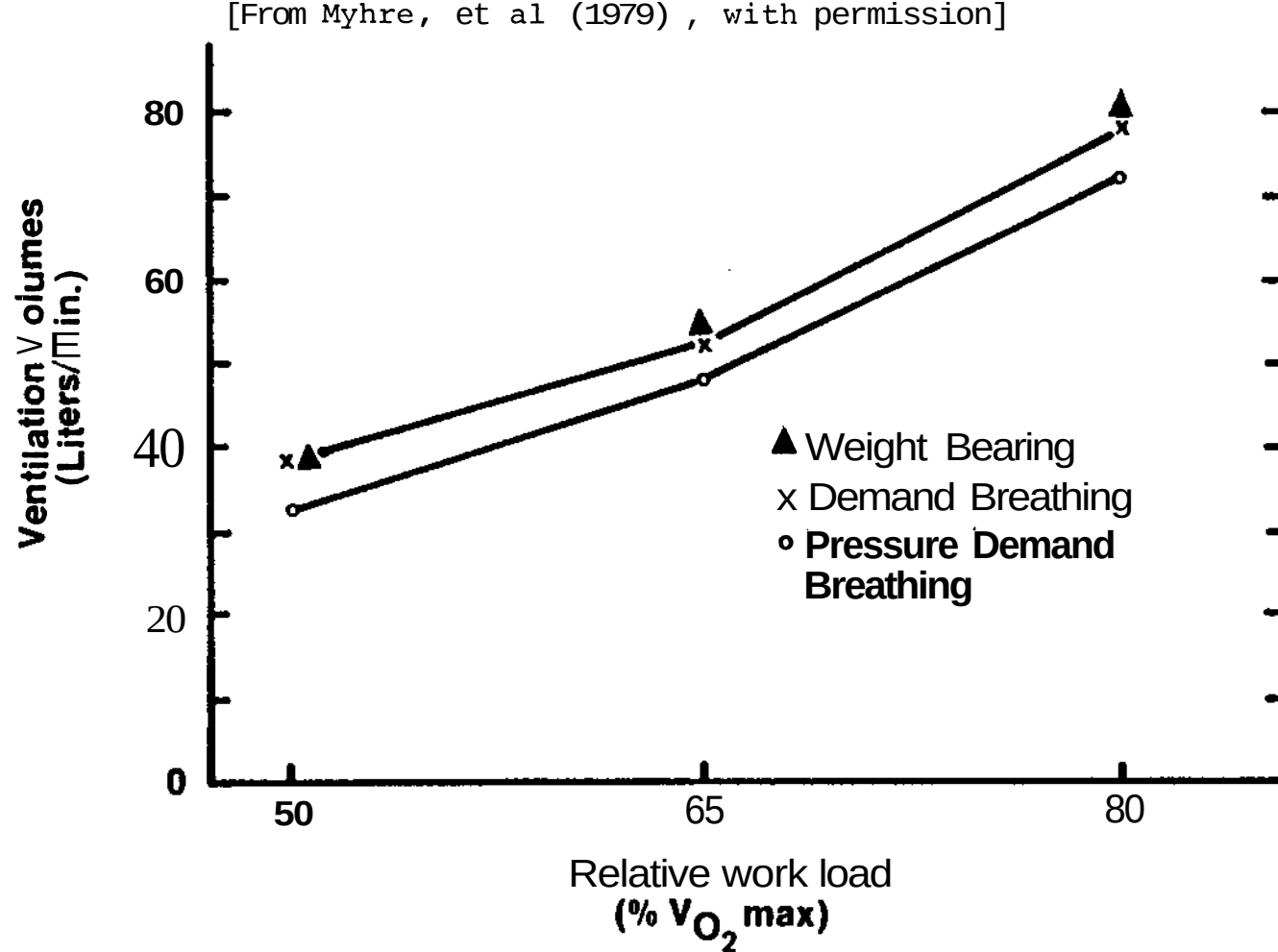


FIG. 4 Increases in ventilation **volume** as a **result** of **suggested** hard work.

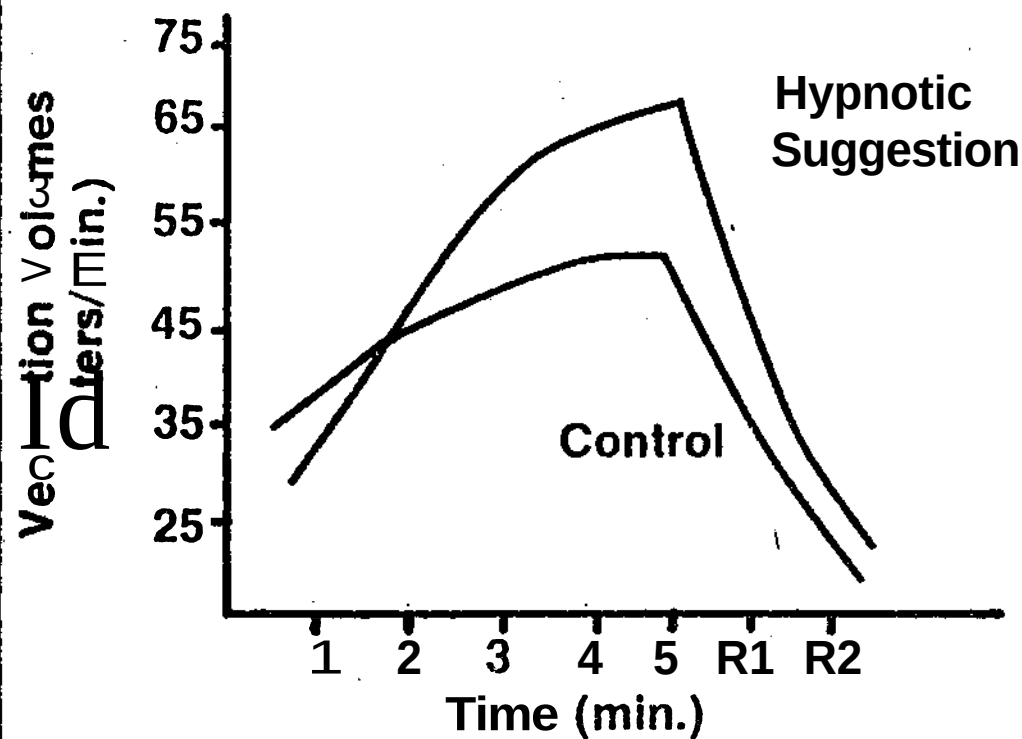
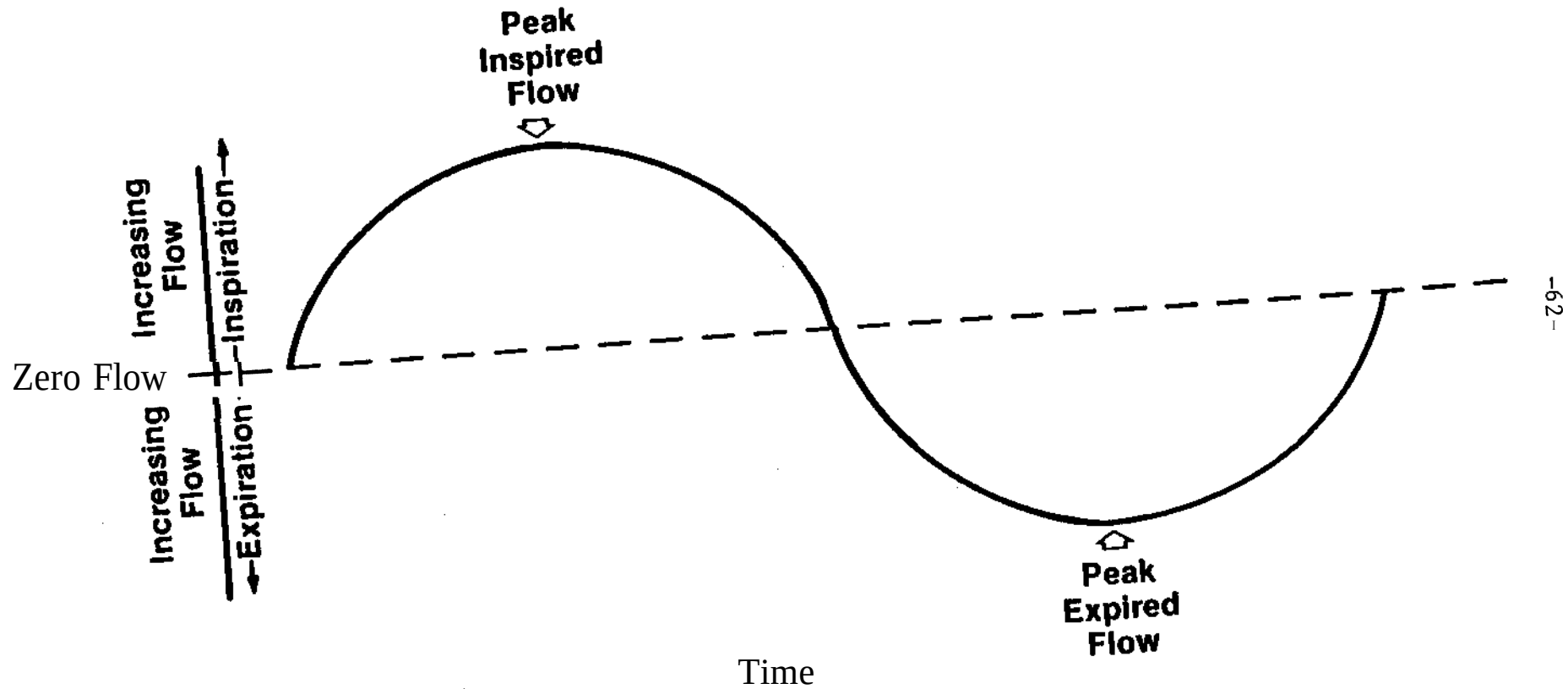
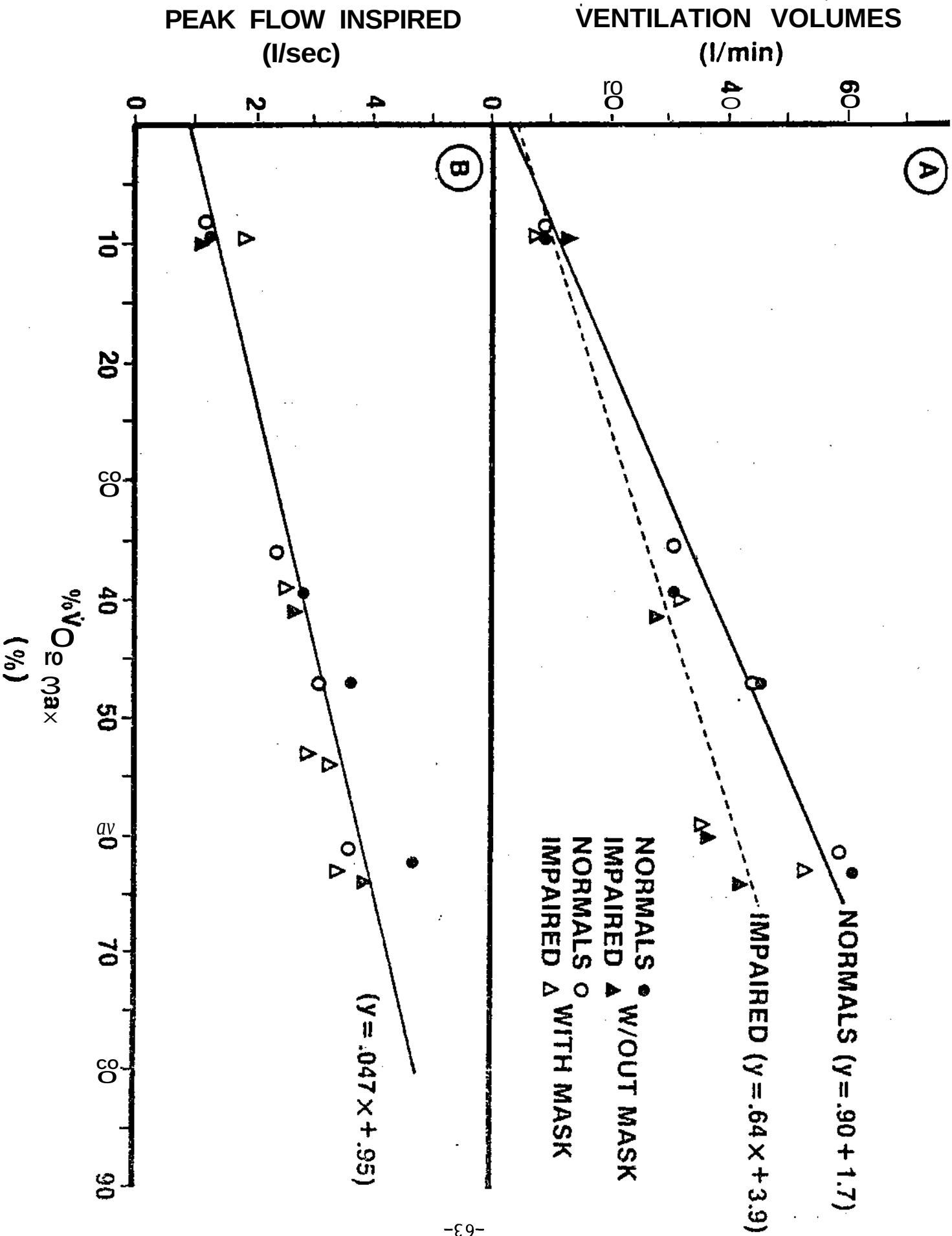


FIG. 5 Changes in flow during one respiration





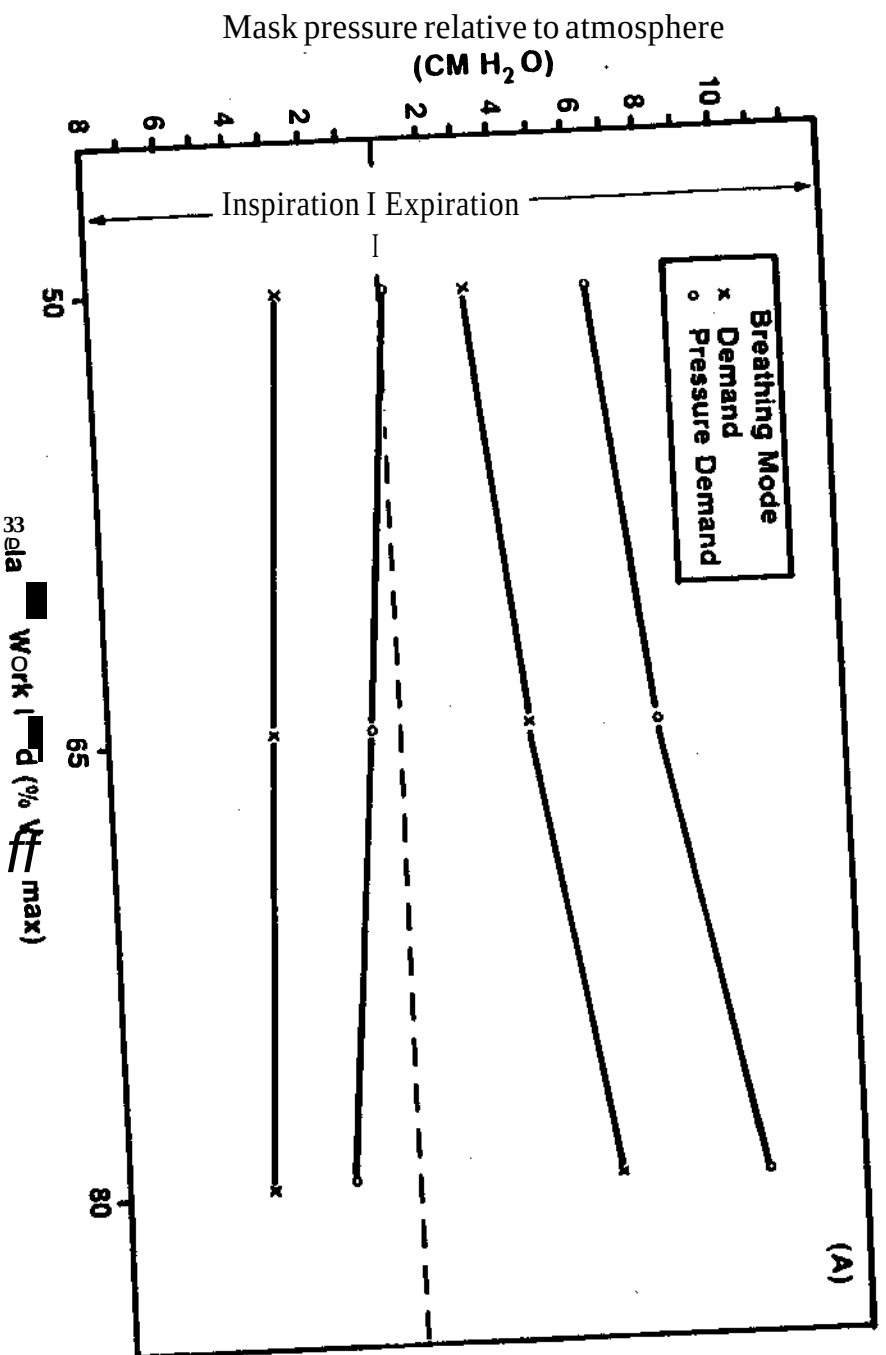


FIGURE 7 Changes in mask pressure in relation to work load (A) and peak flow (B) [From Myhre, et al (1979), with permission]

