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Respirators

Respirator Effect on Oral-Nasal  
Flow Partition

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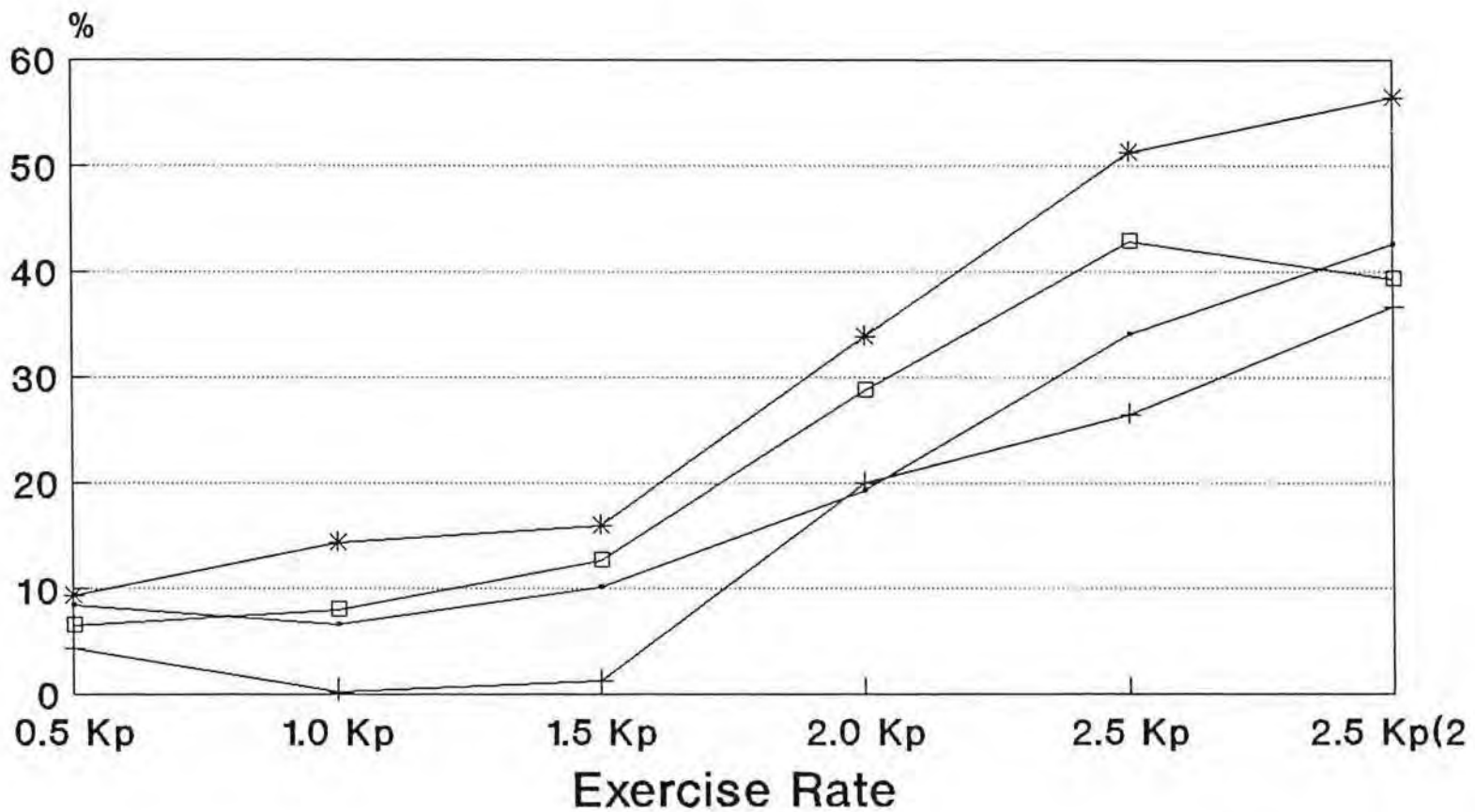
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# MB



—•— No Load    —+— Disconnect    —\*— PEEP    —□— Insp Res.

## Abstract

Respirators (respiratory personal protector devices) are used by many industrial workers for protection against inhaled toxins. While it was considered traditionally that ventilatory limitation accounted for poor tolerance of them by many workers, more recent analyses have suggested that tolerance is multi-factorial (Harber, 1991). Understanding of the factors leading to respirator tolerance is likely to improve the design of respirators, establish appropriate medical certification procedures, and provide insight into causes for workers who are particularly intolerant. Several studies have suggested that the respiratory pattern, rather than simply respiratory work to overcome resistance of the respirator, may be important as a determinant of the effect of respirators.

Previous studies of respiratory control adaptation to respirator use have emphasized respiratory timing and intensity control. This study evaluated another aspect--the switching of airflow from the nasal route to the oral route. This can affect respiratory sensation directly, or by changing inspired air conditions, or total airway resistance.

## Methods

The study was performed in \_\_ normal volunteers who gave informed consent to participate in a protocol approved by the UCLA Human Subjects Protection Committee. After a screening medical examination and full explanation of the study, each was introduced to the experimental apparatus. The subjects included \_\_ males and \_\_ females. The age range was \_\_ to \_\_ years with a mean of \_\_ years.

Subjects participated in a series of experimental periods. This report describes results obtained during the rapidly incremental exercise protocol. During this protocol, subjects exercised on a calibrated bicycle ergometer (Monarch model \_\_, Sweden). Starting from unloaded cycling, the exercise level was increased by \_\_ kpm every 60 seconds until the subject was too fatigued to continue or \_\_ kpm was reached. The exercise regimen was repeated four times with a minimum of a ten minute break between each run.

Each run was conducted with a different experimental load in place; the order was randomized among subjects. The loads were as follows:

- No Load (NL): The subject breathed through the full circuit without any added resistance or expiratory pressure. However, he/she did breathe through the slight resistance of the pneumotachograph and the circuitry hosing.
- Disconnected (D): The subject breathed through the respirator mask but this was completely disconnected from the circuit.
- Resistance (R): An inspiratory resistance composed of a single acid-mist cartridge (MSA, Pittsburgh) was placed in the inspiratory limb of the circuit. The resistance of this is approximately 6 ml H<sub>2</sub>O/s measured at one to two liters per second flow.
- Pressured Biased Breathing (P): End expiratory pressure was introduced by the use of a peep valve (Model \_\_, manufactured by \_\_\_\_). This valve, commonly used in association with ICU mechanical ventilators, is designed to keep the end expiratory pressures at least \_\_ centimeters above atmospheric. It was used to simulate the effect of use of a self-contained breathing apparatus (SCBA) in pressure demand mode.

During these studies, the subject wore a full-face mask, (Model \_\_, \_\_). This mask is commonly used with a canister on the inspiratory limb. Therefore, the flexible hose connector for the mask was instead attached to the inspiratory limb of the research apparatus. Under normal circumstances, the mask vented exhaled air to the outside, but it was modified by attaching another flexible hose to the expiratory port. The one-way valves normally incorporated in the mask were employed for this study (and therefore the effects of dead space is likely to be similar to that of the actual industrially used masks).

A pneumotachograph (Fleisch No.3) was placed in the inspirator limb. Flow was measured from this using a differential transducer (Valadyne, MP-5, Northridge, CA) and carrier demodulator/amplifier (valadyne\_\_). In addition, a small tap for pressure measurement was drilled through the faceplate of the respirator, and mask pressure near the mouth was measured with a transducer (MP-45, Valadyne) and carrier demodulator. Signals were digitized at 50 Hz with a metrabyte card (\_\_ < Massachusetts) and a personal computer (Zenith Supersport 286 with external chasse). Data were analyzed with programs previously described (\_\_) using flow criteria, the beginning and the end of each breath was automatically marked, and the inspiratory volume was calculated by integration of the flow signal. Inspiratory time, expiratory time, total respiratory cycle time, respiratory rate (reciprocal of total cycle time), duty cycle (DC, ratio of inspiratory time to total time) were then determined. Minute ventilation was determined as the product of respiratory rate and tidal volume. All volumes were adjusted to BTPS conditions.

Separation of nasal versus oral route of breathing was determined using rapidly responsive thermocouple (YSI Model \_\_ with transducer YSI Model \_\_, Colorado). The time constant for this thermocouple is \_\_ seconds. After

considerable experimentation, a method was devised to allow this to operate effectively. The thermocouple was passed through a small bore orifice in the facepiece and placed near the oral airstream. A small cardboard cutout (constructed from a 3x5 inch card) was fabricated for each individual and placed within the mask approximately between the upper lip and nose in order to shield the thermocouple from the nasal exhaled air. The signal from the thermocouple amplifier was recorded on a strip chart recorder (Model \_\_, \_\_). Each subject was asked to "calibrate" this by intentionally breathing through the oral or nasal route. The strip chart recording was analyzed for the last \_\_ seconds of each experimental exercise level. The laboratory technician marked the strip chart recording on a continuous basis to indicate whether breathing at that point in time was predominantly nasal or oral. In some instances, prior to initiation of exercise, it was necessary to adjust the thermocouple or 3x5 card baffle to obtain clearly differentiable tracings. Once this was successively accomplished for each subject, there was little difficulty in such grading. Mouth-breathing percentage (MB%) was graded as the percentage of time in an experimental period during which breathing was predominantly by the oral route.

Statistical analyses were performed using BMDP (\_\_\_). Because the data was censored (some subjects reached their maximal exercise sooner than others), the analysis was performed two ways: First, only actual data points for any subject were used, therefore producing different subject numbers at the higher exercise levels than at the lower. Second, the MB% achieved at the highest level achieved by the subject was used for the subsequent (unaccomplished) exercise periods. This method was employed because the MB% generally reached a plateau prior to the terminal exercise periods (i.e., it did not change with added exercise levels). Results obtained by either method

were quite similar. Analyses were performed by examination of graphic data and by analysis of covariance using exercise level or minute ventilation as the linear covariation and evaluating the effect of experimental load (N, D, R, P). Analyses which employed flow signals (respiratory timing, volumes) were not available for the D periods (since the subject was disconnected from the respiratory apparatus).

## Results

Results are shown for the analyses performed in which the data for the highest exercise level achieved by each subject are projected for the remaining levels. Comparable results were obtained with the other form of analysis, considering only data actually acquired.

Figure 1 summarizes the data concerning mouth-breathing percentage (MB%) at various exercise levels under the four different experimental conditions. It shows that at low levels of exercise, breathing is predominantly nasal. As the exercise level increases, the proportion of mouth-breathing increases so that at the highest levels, the regimen is primarily oral. The loaded conditions--I and P--are associated with higher proportions of mouth breathing. Analysis of covariance was performed to determine if the load type had an effect, adjusting for exercise level (NKP) as a covariant. Load type did have a statistically significant ( $P < \_$ ) effect, and there was a statistically significant relationship between MB% and KP (regression coefficient =  $\_$ ,  $p < \_$ ).

Several multiple regression analyses were performed to determine which physiologic variables were best related to MB%. This was done to attempt to identify the physiologic variable through which the different loads have their effect on MB%. Regression analyses were performed with all load data combined

and for each of the four individual loads. Results are shown in Table \_\_. Expiratory time (TE) was most regularly related to MB%. Shorter expiratory times were associated with a higher proportion of oral breathing. In evaluating this, however, one must remember that the actual trans-nasal pressure was not directly measured.

### Discussion

The nose is a very important part of the respiratory system, yet its role in adaptation to respirator use has not been studied previously. This preliminary study has shown that two respirator type loads do significantly affect the partition of airflow between the oral and nasal routes, increasing the diversion of airflow from nasal to oral route. It is quite possible that this factor may be one determinant of proper respirator tolerance or intolerance.

The nose is a high resistance component of the respiratory system. In normal individuals, resistance to airflow through the nose is as much as the resistance of the rest of the respiratory system combined. The nasal resistance during normal resting breathing may serve two useful purposes. First, the resistance is a consequence of the narrow, intricate passages through which inspired air must pass, allowing extensive contact with mucosal surfaces. This is important for "air conditioning" the inspired air, heating it and adding humidity. Any lower resistance, laminar flow, non-turbulent system would not permit adequate contact for this purpose. In a similar manner, expiratory air also passes through the same high mucosal contact nasal system, allowing recovery of exhaled heat and moisture. Second, nasal resistance may provide an important braking mechanism for expiratory airflow,

preventing it from becoming too fast with consequent airway collapse. there also may be indirect effects of nasal airflow, including the presence of several nasopulmonary reflexes. Thus, changes in airflow at the nose may induce secondary neurally mediated pulmonary effects. The intricate air passages through the nose, with their many sharp turns, are also important in the filtering action of the nose by facilitating inertial impaction of inhaled particulate.

Although the oral route provides lower resistance than the nasal route, it does not allow the benefits of air conditioning, expiratory braking, and air filtering described above. Furthermore, since the "natural" respiratory path is nasal, switching may in itself induce some adverse sensation. Mouth breathing also leads to drying of the oral mucosa. Oral cooling may also be a problem in certain environments; the nose is an effective heat exchanger, recovering heat from air as it is exhaled, but the mouth is not. The drying and cooling of the oral mucosa may be particularly a problem with supplied air respirators using cool, dry air and in atmosphere purifying respirators used in cold environments.

These effects of the nasal air conditioning versus the oral route become particularly important as the airflow rates increase. At very low airflow rates, the mouth and pharyngeal mucosa can condition the inspired air, but at higher flow rates, there is inadequate contact time to accomplish this.

This study demonstrated that the use of respirator-type loads increased the proportion of oral versus nasal breathing. This may significantly affect the subjective and perhaps physiologic effects of respirator use. Because recent data suggests that ventilatory limitation does not adequately explain tolerance, attention to such additional factors is obviously important. It is yet to be determined, however, whether this indeed directly translates to

impaired work performance.

There are several mechanisms by which the respiratory loading could theoretically affect the flow partitioning. First, it may simply represent an added respiratory load, increasing the existing tendency to use oral route when the load increases. For example, it has been well-demonstrated (as well as being known to any jogger) that individuals switch to an oral route with exercise. This study also showed that, even in the unloaded situation (disconnect periods), the flow regimen changed from predominantly nasal to predominantly oral at higher exercise levels. This relationship was maintained throughout, but the switch occurred earlier in the P and I loaded periods. Thus, the route switch may simply be another method to decrease load. Therefore, the respirator load limits the ability to compensate for the increased burden of exercise since the respirator itself induces flow switching.

Another possible mechanism is illustrated by the dynamic changes that occur in nasal airflow resistance. For example, there may be changes in the vascular volume within the nose over a short term period. Exercise, per se, decreases the vascular congestion of the nasal erectile tissues. This is not a consequence of the increased ventilation but is directly due to the exercise. Hyperventilation itself actually leads to increases in the pulmonary vascular volume. Theoretically therefore, respirators might actually directly increase nasal resistance by producing excessive ventilation due to added dead space from the mask itself. The consequent increase in resistance would of course lead to an increase in the oral relative to the nasal route.

Respirators may also markedly increase the nasal resistance by the mechanism of closing a flow limiting segment (FLS). An FLS of the respiratory

system commonly has a "starling resistor." This is a collapsible segment of the airway, such that highly negative intra-luminal pressures will collapse the airway if the pressure gradient exceeds the counteracting tissue elastic forces which would otherwise maintain patency. The inspiratory resistance imposed by the respiratory requires that the thorax generate a greater negative pressure. This in turn is transmitted through the nasal airway, and therefore increases the tendency of the flow limiting segment to collapse. When such collapse occurs, flow must automatically cease. Any attempt to overcome the obstruction by increased respiratory effort will be unsuccessful since this would decrease the negative intrathoracic and subsequently the negative intranasal pressure. This in turn leads to a greater tendency of the floppy segment to collapse inward. Hence, since adequate airflow cannot be obtained via the nasal route, preferential switching to oral breathing may become necessary at lower exercise levels with respirators than without. Positive end expiratory pressure, conversely, would not be expected to have this effect directly. However, it may lead to increased nasal airflow obstruction by two additional mechanisms. First, as shown in Table \_\_ (\*\*\*\*), PEEP leads to prolongation of expiratory time (to overcome the expiratory loading) with consequent shortening of inspiratory time. Consequently, the average inspiratory flow rates must increase in order to maintain constant tidal volume. This in turn is associated with an increased pressure gradient, again possibly collapsing the starling resistor flow limiting segment. In addition, the positive end expiratory pressure may cause compression of the ala of the nose, thereby leading to added resistance as well.

This study employed a thermocouple to determine airflow partitioning. Once the intra-mask baffle was properly placed for each individual, the distinction between the nasal and oral routes could generally be made quite

easily with little uncertainty. To avoid biases, the laboratory staff were instructed not to code uncertain areas. Theoretically, if uncertainty were always associated with one particular flow regimen, one might have a systematic bias. Examination of the tracings did not suggest this to be the case.

More complex methods have been used by other investigators to directly quantify airflow via the oral and nasal routes. Such methods are, however, not directly applicable to the respirator situation wherein such instrumentation would likely interfere with the direct impact of the respiratory personal protective device.

This study demonstrated that respirators do significantly affect the oral-nasal route partitioning, and that the magnitude of this increases with exercise level. Further, the effect is present for both the load types associated with atmosphere-supplying and air-purifying respirators. This study did not, however, demonstrate that the effects truly determine tolerance. However, since premature change from nasal to oral route will obviously decrease the normal adaptation to exercise, it is likely that it is significant. Furthermore, particularly at higher exercise levels, loss of nasal air conditioning of inspired air and moisture/heat recovery from expired air is also likely to have relevant effects. For these reasons, measurement of flow partitioning with actual        should be considered in evaluating new designs. Furthermore, the normal inter-individual variability in nasal resistance and in flow regimen switchpoint may partially explain differences in respirator tolerance. Designs which minimize the tendency to switch flow regimen or minimize its impact...

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