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Buffalo 25 Feb 1988.

The enclosed literature review "Effects of added dead-space on ventilation (air usage) in humans as it pertains to the endurance and performance of protective breathing gear. A literature review." was performed on the request of Hans Almquist, Interspiro Inc. It is submitted to you at the request of Mr Almquist and contains a part of his comments regarding the public hearing on proposed 42 CFR Part 84.

Sincerely

Dan E Warkander, M.S.E.E., Lic. o E.

cc Hans Almquist, president
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Effects of added dead-space on ventilation (air usage) in humans as it pertains to the endurance and performance of protective breathing gear. A literature review.

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February 1988

The reason for this study is the need among both manufacturers and users of protective breathing gear to gain information on the importance of dead space in such gear. A literature search for publications relevant to the topic was performed on MEDLINE (1966 - Feb 1988) and Occupational Safety & Health (NIOSH) (1973 - Aug 1987). The keywords used were: CO2, carbon dioxide, ventilation, human, breathing, breathing gear, breathing apparatus, breathing protection, and dead space. A total of 208 articles fit combinations of these keywords. After removing duplicates and using the references given in some of the publications 3 relevant publications remained that were available from the open literature.

Previous studies

Jones et al (1971) used four subjects exercising on a bicycle ergometer with workloads set at 50 and 100 W. The subjects breathed through a cylinder with moveable ends, allowing the dead space volume to be changed. The ends were fitted with small propellers to ensure mixing of the air. The added dead space volumes were 700 and 1400 ml.

Bartlett et al (1972) used five subjects at exercise levels ranging from rest to very heavy work on a treadmill. They used commercially available valves used for laboratory studies, and the dead space volumes were less than 300 ml.

Kelman et al (1973) used six subjects at workloads ranging from rest up to 70 % of their maximum continous physical power on a bicycle ergometer. Dead space volumes were either minimal or 1200 ml.

Treatment of the data

The following is our synthesis and interpretation of the results in the publications just mentioned. A mouthpiece or facemask will introduce some amount of dead space. However, if the dead space volume is small its effect on the ventilation is minimal. The smallest dead space volume in each study referenced was less than 60 ml and was for this review considered not to have affected the breathing. The ventilation with dead space volumes less than 60 ml was set to 100%. The relative changes were then calculated from these numbers and are presented in Figures 1 to 3 and Tables 1 to 3. The best fitting straight line (linear regression) was calculated and is plotted together with all data points from the three studies in Figure 4.

In none of the studies was the average inspired CO_2-level measured or calculated and unfortunately not enough parameters were published to allow this calculation to be done.

Results and discussion

The calculated best fitting straight line has a slope of about 53 % per liter added dead space, i.e. if a dead space of 1 liter would be added the ventilation would, on the average, go up by 53%. The range of dead space volumes for commercially available breathing gear (from dust masks to full face masks) is 0.15 to 0.7 liters (150 to 700 ml), Warkander (1986). This means that the ventilation, when using such gear, would increase by about 10 to 40 %. When using self contained breathing apparatus (SCBA) this is a major concern since the increased air consumption will directly affect the endurance of the apparatus, e.g. an apparatus with a nominal endurance of 60 min may be empty after 43 minutes. It may be predicted that even when using filter masks in which environmental air is used for breathing, an added dead space will put an extra demand on the user's ventilation and limit his ability to perform heavy exercise.

It is important to realize that the considerations just presented apply to the average of the subjects studied. In a group of users there will, by necessity, be users that are affected more severly than the average. It may be proposed that good breathing gear should show acceptable performance with at least 99 % of a user group. The data in the referenced publications do not allow the calculation of the maximum ventilation that would be encountered in 99% of a potential user population exposed to added dead space. It may safely be predicted that in a large user group there will be individuals who will be more limited when using protective breathing gear and who will exhaust their air supply much faster than the line in Figure 4 indicates. Put differently, designing breathing gear according to the average user would be as inadvisable as designing the height of a doorway according to the average tallness of the population.

It is sometimes erroneously proposed that air consumption can safely be reduced by the user holding back his or hers ventilation. This may be extremely dangerous since it may lead to CO_2 intoxication inducing mental disturbance, lack of judgement which may be potentially be catastrophic in a life threatening situation.

One important note, when measuring the added dead space, is that the effective dead space volume may not be the same as the geometrical volume measured with, for instance, water displacement in the breathing mask. The effective dead space volume can be smaller or bigger. If all of the geometrical volume is not washed out during each breath the effective volume will be smaller. The level of wash out depends very much on the aerodynamics of the mask and will vary with the ventilation. The volume may be bigger if there is a leak around the face seal and the amount of leakage will also depend on the level of ventilation.

For these reasons it is necessary to measure the dead space volumes in each type of breathing gear at different ventilations up to the maximum that may be encountered during heavy exertion.

Conclusions

Information on the effect of added dead space as it applies to the design and field-use of protective breathing gear is very incomplete.

It may be predicted that commercially available breathing gear (from dust masks to full face masks) might, on the average, increase the ventilatory demand by 10 to 40%, and, in case of self contained breathing apparatus (SCBA), decrease the endurance time by a corresponding amount.

Measurements of effective breathing gear dead space and its effect on equipment endurance and user performance should be done at different levels of exertion. Different types of breathing gear must be tested individually. A host of well established scientific methods for such studies are available. The results of such measurements should be of considerable interest to both designers and users of protective breathing equipment.

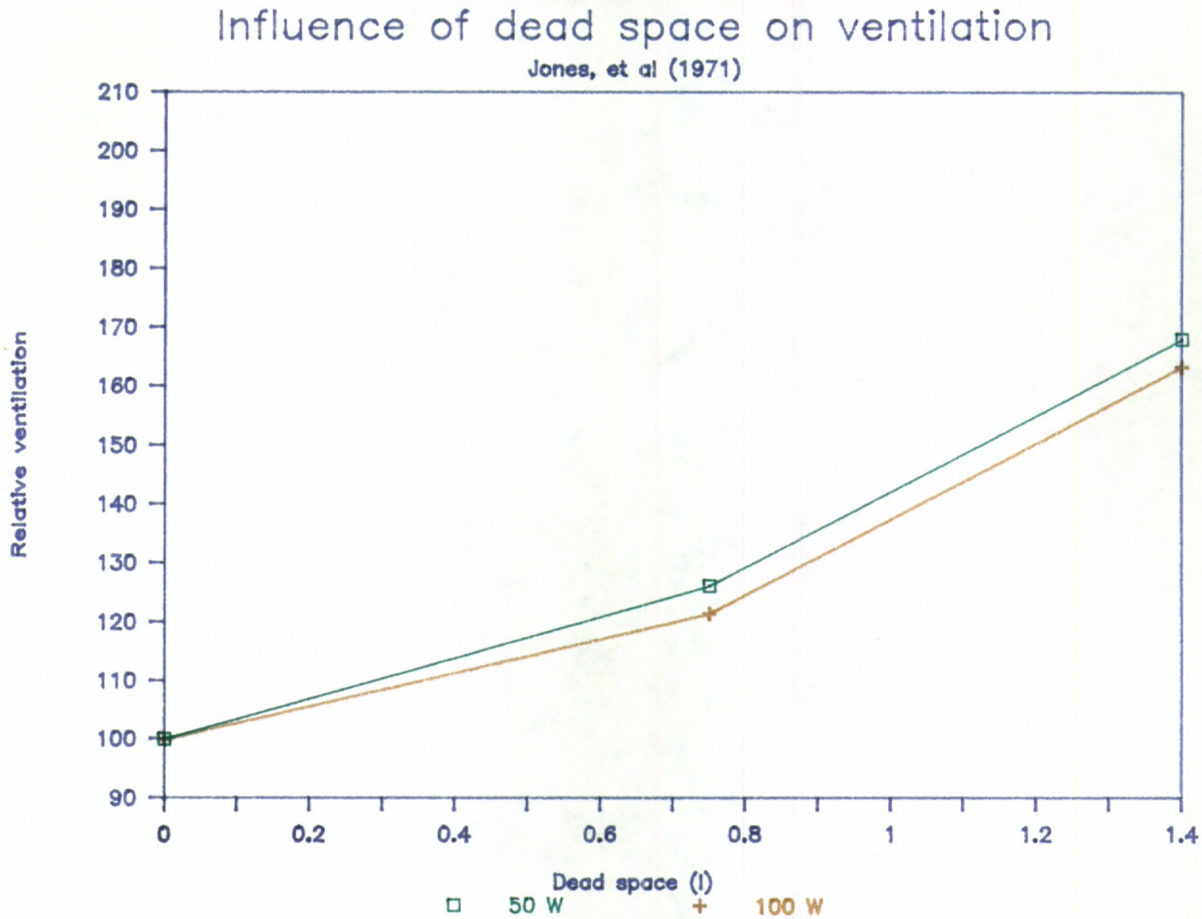

Figure 1. Relative ventilation when exposed to added dead space. The data points are averages from four subjects exercising on bicycle ergometer. Data from Jones et al (1971).

Table 1. Relative ventilation when exposed to added dead space. The data points are averages from four subjects exercising on bicycle ergometer. Data from Jones et al (1971).

Vd (liters):		0	0.75	1.4
Workload :	50 W	100.0	126.1	168.0
	100 W	100.0	121.5	163.3

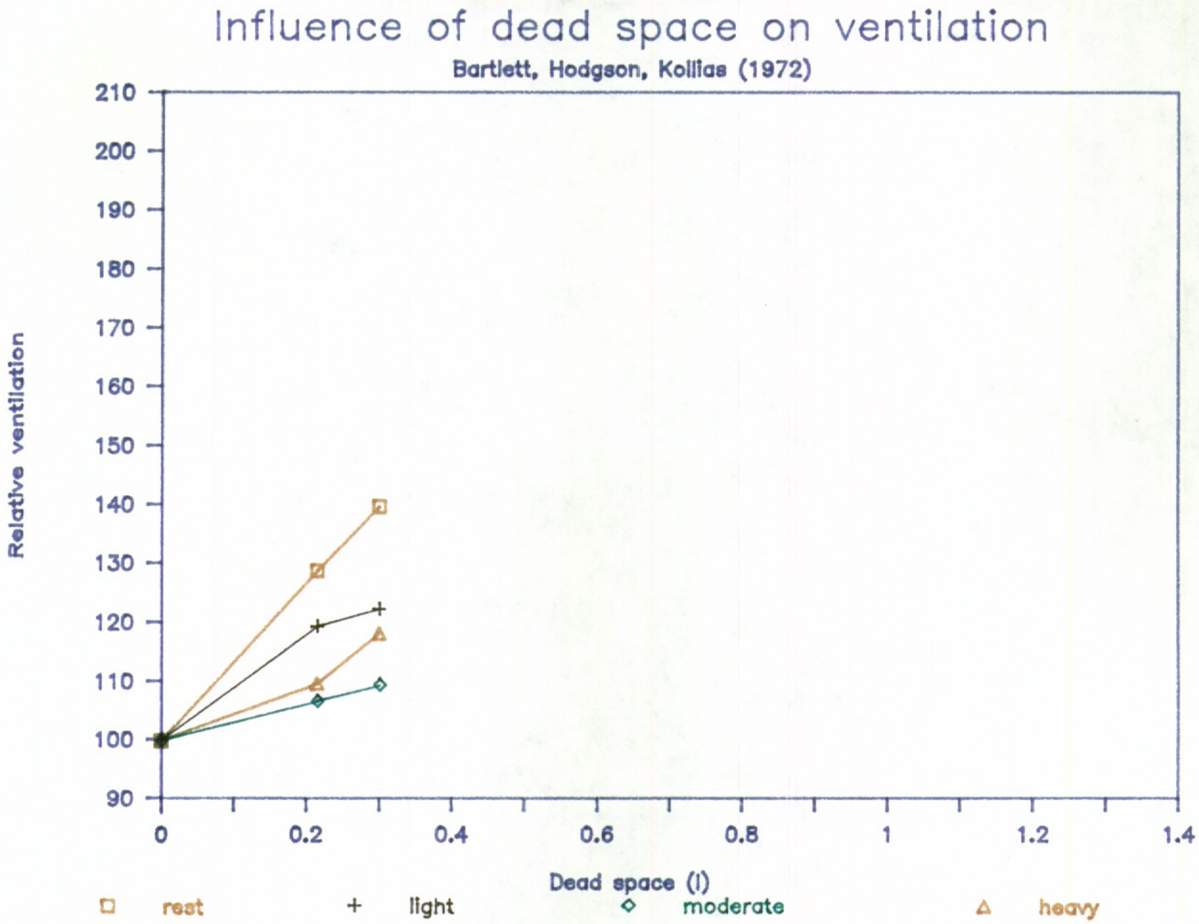

Figure 2. Relative ventilation when exposed to added dead space. The data points are averages from five subjects exercising on a treadmill. Data from Bartlett et al (1972).

Table 2. Relative ventilation when exposed to added dead space. The data points are averages from five subjects exercising on a treadmill. Data from Bartlett et al (1972).

Vd (liters):		0	0.215	0.3
Workload :	rest	100.0	128.8	139.8
	light:	100.0	119.3	122.2
	moderate	100.0	106.6	109.4
	heavy	100.0	109.7	118.2

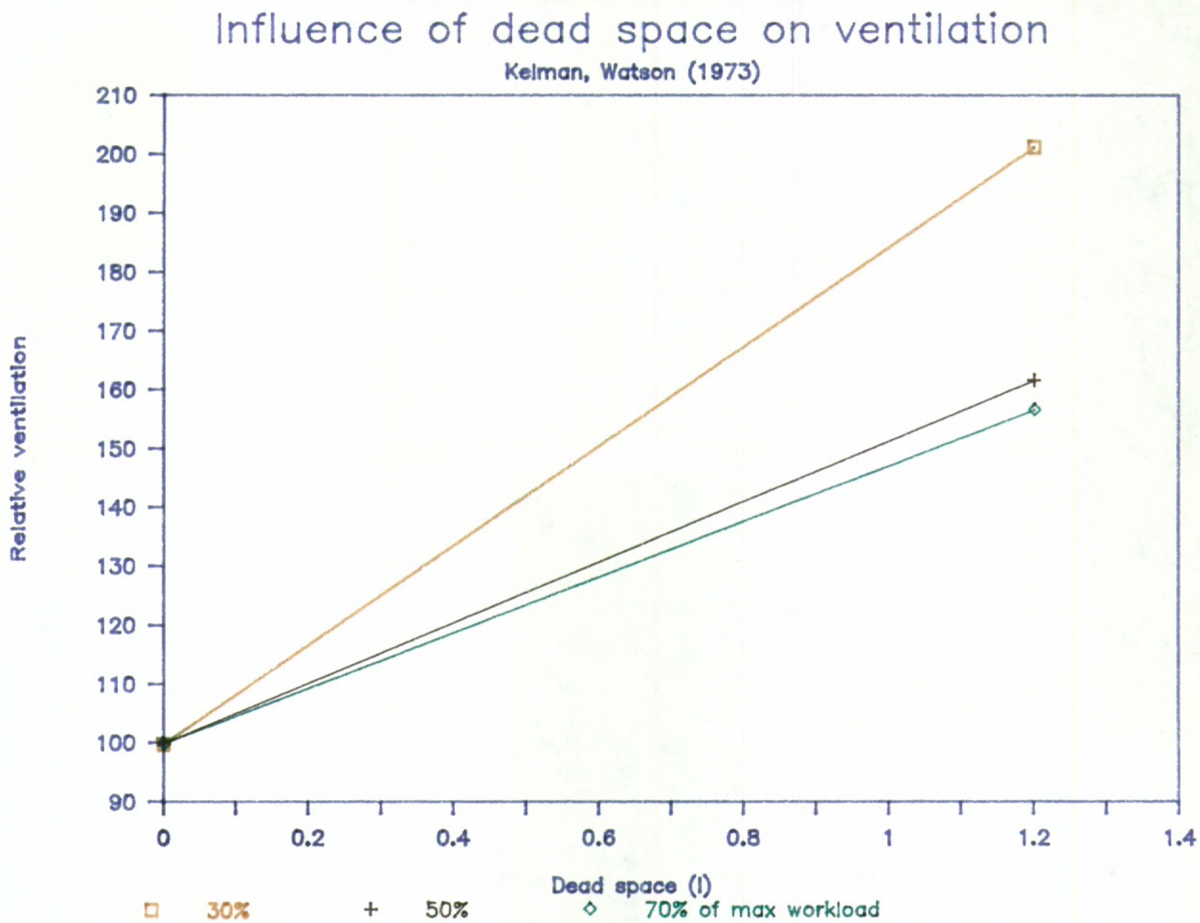

Figure 3. Relative ventilation when exposed to added dead space. The data points are averages from six subjects exercising on a bicycle ergometer. Data from Bartlett et al (1973).

Table 3. Relative ventilation when exposed to added dead space. The data points are averages from six subjects exercising on a bicycle ergometer. Data from Bartlett et al (1973).

Vd (liters):		0	1.2
Workload :	30%	100.0	201.5
(% of max aerobic	50%	100.0	161.7
power)	70%	100.0	156.7

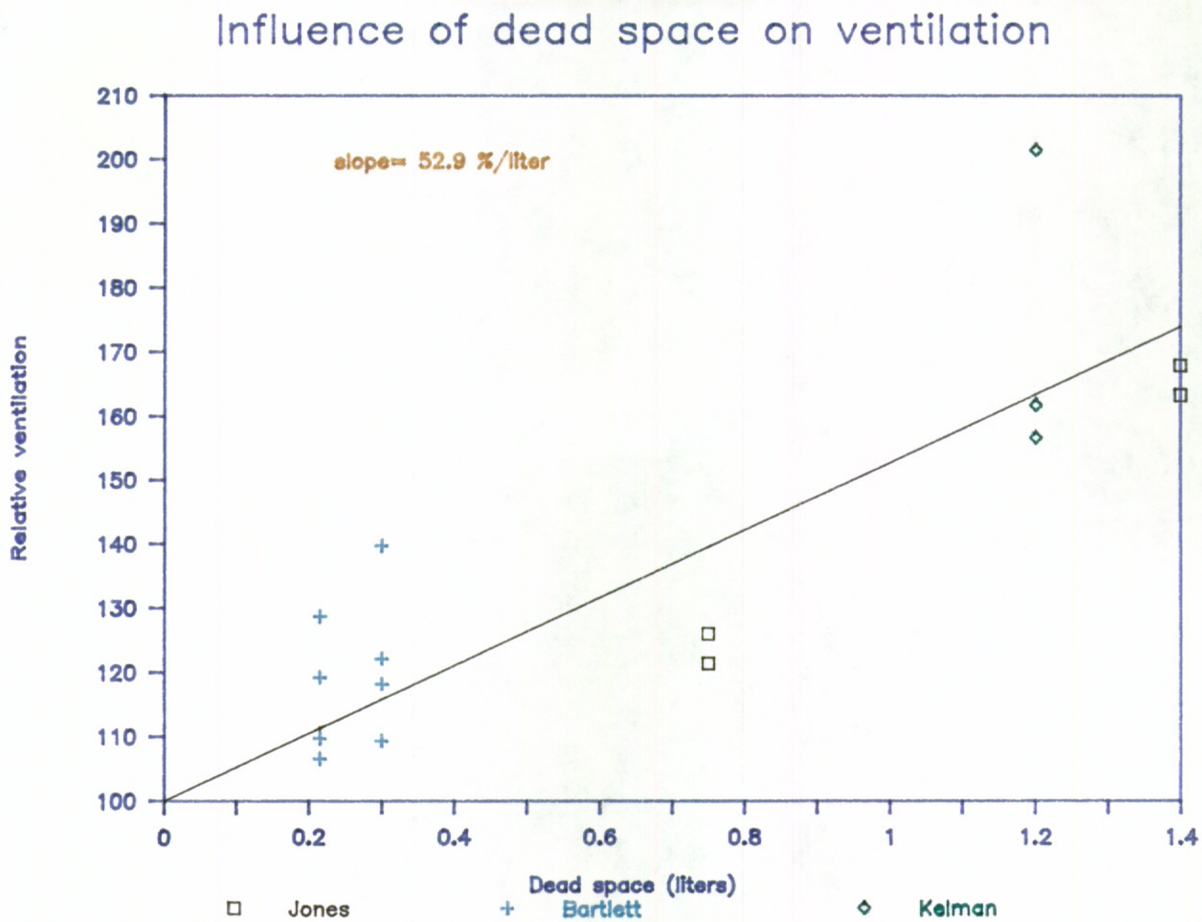

Figure 4. Relative ventilation when exposed to added dead space. The data points are all the data points from the studies referenced. The straight line is the best fitting line. See text for its interpretation.

References

Jones, N. L., G.B. Levine, D.G. Robertson, S.W. Epstein. The Effect of Added Dead Space on the Pulmonary Response to Exercise. Respiration 28: 389-398 (1971).

Bartlett H.L., J.L. Hodgson, J. Kollias. Effect of Respiratory Valve Dead Space on Pulmonary Ventilation at Rest and During Exercise. Medicine and Science in Sports, vol 4(3), 132-137 (1972).

Kelman G.R., A.W.S. Watson. Effect of Added Dead-Space on Pulmonary Ventilation during Sub-Maximal, Steady-State Exercise. Quarterly Journal of Experimental Physiology. 58, 305-313 (1973).

Warkander D.E. Measurements of external dead space. Preliminary studies.