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USE OF THE EXPOSED WORKER AS AN AIR SAMPLING UNIT FOR CONTAMINANTS*

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A RECENT article by Harrold, Meek, Collins, and Markell (1) has proposed for air sampling procedures a device described as a "packed tube collector" which is worn by the exposed worker for the collection of air-borne lead dust and fume. Results are given in terms of dust or fume which would otherwise have been breathed by the wearers in a given time. The authors established the filtering efficiency of the apparatus, but do not discuss the physiological factors involved in the use of this type of apparatus. The purpose of the present note is to discuss in detail the fundamental physiological factors which should be considered in air sampling by breathing devices.

The use of the worker as a suction source for air sampling units is not new. Such a device is described fully by Higgins et al. (2) but they measured the air volumes breathed during the sample collection.

In the use of any device in which the exposed human subject acts as the suction source several factors should be considered:

The volume of air breathed per minute by humans varies greatly and is affected by (a) practice or training, (b) resistance to respiration, (c) exercise, and (d) psychic factors. Variations due to practice and training are known and can be estimated within reasonable limits. These are variations due to normal physiological reactions. In contrast, psychic factors influence air volumes considerably and are wholly inestimable until the amount of work performed reduces their influence.

Volume of Air Breathed by Humans

The volume of air breathed per minute or minute volume of human subjects, regardless of sex, varies as much as 200 to 300 per cent. Schneider (3) gives values for sedentary conditions ranging from 3 to 10 liters per minute. The minute volume under working conditions depends upon the amount, rate, and type of work per-

formed. At work rates within the range of body accommodation, it is possible for man to reach a steady state condition in which the energy requirements of the body can be supplied at a uniform rate. Under such a condition the minute volume can reach a steady value. The duration of time this steady value can be maintained depends upon the magnitude of the work performed and the training of the individual. If the effort is too severe, a steady minute volume cannot be maintained. Our work has shown that men can maintain for short periods (5 to 15 minutes) steady minute volumes of 80 to 100 liters doing bicycle ergometer work. Rates as high as 50 liters per minute have been maintained over one hour periods. In this respect Schneider (3) states "A sustained ventilation of the lungs of from 100 to 110 liters a minute is unusual. It is a rare occasion when one is called upon to maintain the maximum lung ventilation of 150 liters for as much as a minute or two."

It is well recognized among physiologists that training or adaptation to a given task reduces the minute volume considerably. Schneider and Ring (4) showed a reduction of 15 to 23 per cent in minute volume in 4 to 6 weeks of training with bicycle ergometer work loads of 4000 to 8000 foot pounds per minute (553.5 to 1107 Kg.M per minute).

The minute volume varies considerably in most persons. The data given in Table 1 were obtained in this laboratory on male subjects sitting quietly. A full-face type of mask with minimal dead space and provided with inlet and outlet valves was employed. The inspiratory resistance, including a 100 liter gasometer used for measuring air volumes, was 15 mm. of water at 85 l.p.m. The expiratory resistance was also 15 mm. of water at 85 l.p.m. The subjects were normal males, ages ranging from 21 to 37 years.

Table 1 shows that there is 25 per cent variation in air flow from minute to minute and also 100 per cent variation in air volume among men in this group of subjects.

* Received for publication June 2, 1944.

The Effect of Practice

Daily variations under sedentary and working conditions are shown in Table 2. These values were obtained after the subjects had reached steady state conditions. The Krogh bicycle ergometer work rate at 60 r.p.m. was 4500 foot pounds per minute (622 Kg.M per minute). The subjects were normal males, ages 28 to 36. Air volumes were measured after five minutes of riding. The subjects rode the ergometer five days per week for five minutes each day during the first five weeks of the five month period

TABLE 1

MINUTE VOLUMES FOR MALE SUBJECTS UNDER
SEDENTARY CONDITIONS
Inspiratory and Expiratory Resistance 15 mm. of water
at 85 l.p.m.

TIME	MINUTE VOLUMES						
	G. L.		J. L. W.			L. S.	
	Date		Date			Date	
	3/9/44	3/10/44	2/28/44	2/29/44	2/15/44	2/22/44	3/6/44
minutes	liters	liters	liters	liters	liters	liters	liters
0							
1	7.8	9.4	10.7	7.9	11.8	11.1	10.7
2	8.0	9.4	9.6	7.3	11.8	11.8	10.7
3	7.5	8.2	9.6	7.1	9.6	10.1	9.4
4	8.9	9.1	10.0	7.5	10.4	11.1	10.0
5	7.1	8.0	14.1	7.6	8.6	12.3	10.7
6	7.5	8.6	8.0	7.4	12.0	9.5	9.7
7	7.1		8.0	7.3	9.3	9.5	
8			8.0			10.4	
9			9.7				
10			6.9				
Mean.....	7.7	8.8	9.5	7.4	10.5	10.7	10.2

covered in Table 2 and minute volumes were measured at approximately weekly intervals. At the end of the five weeks the daily rides were discontinued. A one month period followed in which no work was performed. After this period, occasional measurements were made. Table 2 indicates that the highest minute volumes for a given work output on a bicycle ergometer occur during the first exposure to the work. Adaptation to the work or task therefore produces a significant lowering in air volumes breathed per minute. There is also a considerable variation shown in Table 2 between the subjects in the individual air

requirements to perform a given amount of work. There is also a large daily and subject difference in the sedentary minute volumes similar to Table 1.

It is also important to note that it is not practical to assess working conditions as requiring the same ventilation rate without making actual measurements. Operations which require untrained muscular efforts will always incur higher ventilation rates and oxygen consumption until the body can adapt itself to the new requirements.

TABLE 2

DAILY VARIATIONS IN MINUTE VOLUMES UNDER
SEDENTARY AND WORKING CONDITIONS FOR
3 SUBJECTS
(Working rate 4500 foot-pounds per minute at 60 r.p.m.
on Krogh ergometer)

DATE	SUBJECT L. S.		SUBJECT G. L.		SUBJECT R. C. L.	
	Seden- tary	Work- ing	Seden- tary	Work- ing	Seden- tary	Work- ing
June 24.....	8.2	65.8	6.9	79.4		
June 26.....					6.1	
June 29.....						45.5
July 7.....		48.4		42.7		38.1
July 9.....			6.7			
July 11.....	7.6	52.3	7.6	69.0	6.7	36.9
July 18.....	9.1	57.0	6.7	49.5	6.4	42.9
July 24.....	9.9	52.2	7.0	49.0	6.3	40.2
July 25.....	8.1	51.7				
Sept. 1.....	9.0	47.9				
Sept. 4.....			7.0	46.6		
Sept. 5.....	7.1	51.2				
Oct. 5.....					5.8	38.8
Nov. 9.....			7.7	43.2	6.7	35.8
Nov. 10.....	10.8	48.0				

The Effect of Resistance

The effect of inspiratory or expiratory resistance is to reduce the minute volume of air breathed. Killick (5) has shown that the insertion of resistance to inspiration reduces the minute volume 5 to 30 per cent. When the resistance is removed the minute volume increases to a value greater than its previous non-resistance conditions. This latter increase, which is probably over-compensatory, also appears to be about 5 to 30 per cent of the original value before resistance was inserted. This effect of resistance has also been noted by other observers (6) and has been confirmed by our work.

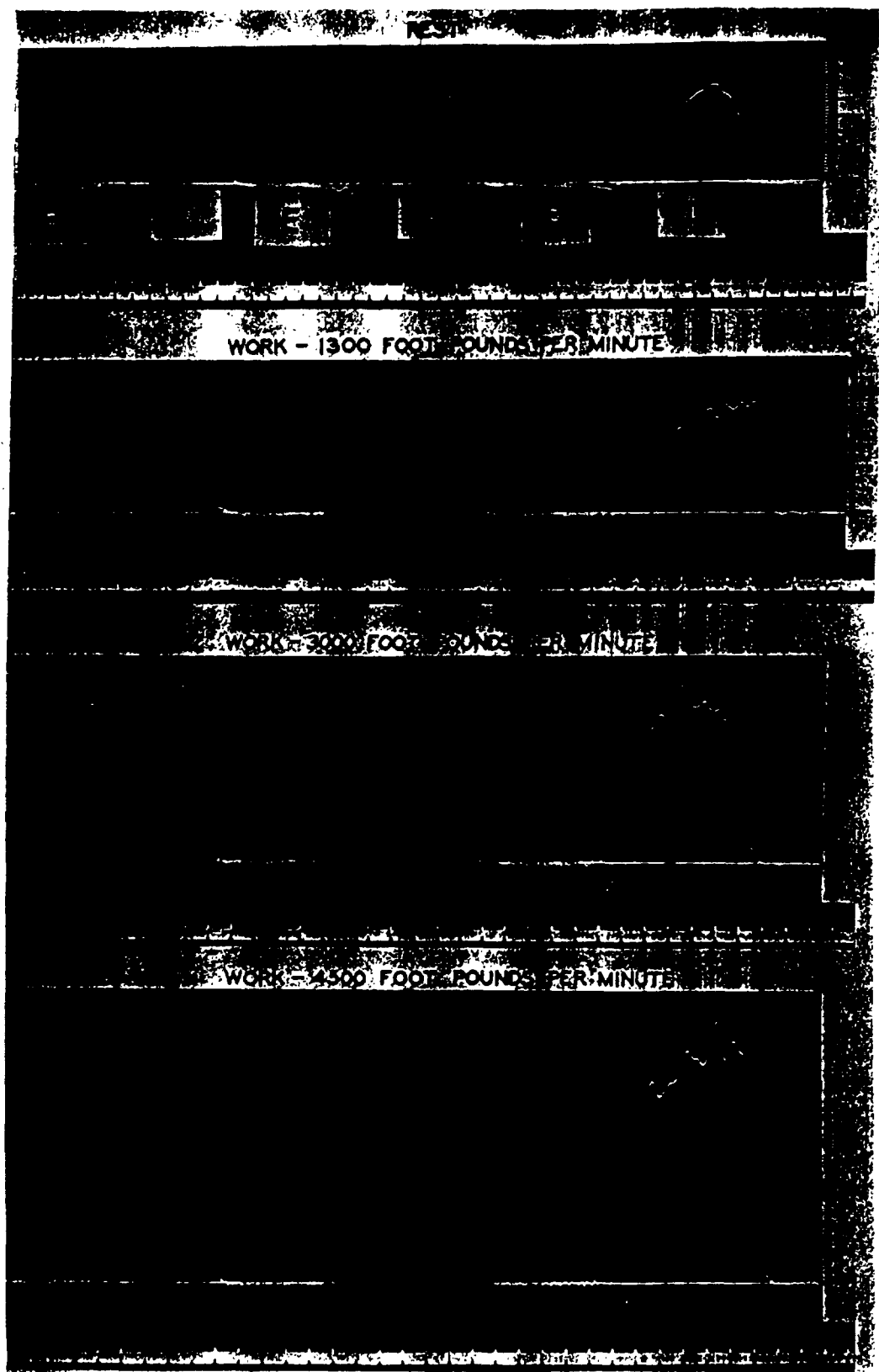


FIG. 1. Record of inspiratory air flow on normal male subject under sedentary and working conditions. Time intervals are $\frac{1}{4}$ second. Vertical displacements in cm. are directly proportional to air flow. Approximate calibration: 1 mm. = 1 liter per minute. I = Inspiration. E = Expiration. The small portion below the horizontal line is due to "overshoot" caused by lag in valve closure.

Changes in Air Flow During the Respiratory Cycle

The rate of air flow during the respiratory cycle for both inspiration and expiration varies from zero to maximum and then returns to zero. The shape of the inspiratory curve is shown in Figure 1 for a male subject sitting in a chair (rest) and working on a bicycle ergometer. The curves were obtained by a new instrument which is instantaneous in response and does not introduce any appreciable resistance to air flow (7). The vertical increment in the curves of Figure 1 are directly proportional to air flow in liters per minute. The horizontal movement is time, each marker representing $\frac{1}{2}$ second, thus the area bounded by the curve and the base line represents the air volume per breath (tidal volume). The curves read from right to left.

It can be noted that under sedentary conditions, inspiration is approximately 30 to 40 per cent of the respiratory cycle. The rest of the cycle consists of expiration and occasionally a brief pause before the next inspiration. Pauses between inspiration and expiration are rare under sedentary conditions and never seen on work records. Under working conditions, the inspiratory and expiratory cycles become more nearly equal in length. At maximum effort, inspiration may even exceed 50 per cent of the total respiratory cycle. The effect of inspiratory resistance is threefold: it tends to prolong the inspiratory cycle, it smooths or damps out the variations in the contour produced by jerky muscular movements, and it decreases the curve amplitude or maximum air flow.

It is evident from these curves that the average inspiratory flow varies from two, or less, to three times the minute volume. The maximum flow by measurement is from three to five times the minute volume. This range of ratios of maximum flow was found by Bretschger (8). It was also shown that the ratio depends upon the shape of the inspiratory curve; three distinct types of curve were found in several subjects.

The sampling instrument to be worn by the

worker should therefore have a constant efficiency or an efficiency of 100 per cent at the highest air flows during the respiratory cycle. Harrold et al. (1) do not show the efficiency of their device when tested under steady flow conditions corresponding to the same type of sampling as their other comparative data with impinger and precipitator. Such data at rates corresponding to human peak flows for the work encountered are fundamental in proving the efficacy and constancy of their device. A filter type instrument which is efficient at the highest flows attained under the working conditions will be satisfactory throughout the flow range¹, whereas an impingement type instrument which depends upon maintaining a fixed velocity will be unsatisfactory. In the laboratory the efficacy of the device can be established using a respiration pump which simulates ventilation of men under the exposure conditions. If results are to be based on the amount inhaled per day or working period, it is necessary only that the sampling device have a known efficiency. Naturally high efficiency such as the U. S. Bureau of Mines (10) requires for certain fume and dust respirators, using filters or filter papers, is desirable.

SUMMARY

The factors to be considered in using the exposed worker for air sampling are 1) constancy of air sampler performance under a wide range of minute volumes, and 2) low resistance of the collecting device. Assumptions that minute volumes are constant for any individual from day to day and that they are constant among different persons performing identical tasks are unwarranted and can cause very large errors. It is necessary to measure the volume of air at the same time as sampling in order to express concentrations on an accurate volumetric basis.

¹ The commercial approved dust or fume respirator is highly efficient and can serve as a very simple collection apparatus. Pierce (9) has actually analyzed filters from respirators worn by men exposed to lead dust and fume and compared the quantities obtained with impinger samples taken at the same location. His results, however, are limited to a few comparisons.

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