Respiratory flow patterns during physical work with respirators

Kuklane, Kalev; Holmér, Ingvar

2002

Respiratory flow patterns during physical work with respirators

Kalev Kuklane, Ingvar Holmér
Department of Ergonomics
National Institute for Working Life
Solna, Sweden

Introduction

Filter respirators are personal protective equipment, advised for use in contaminated atmospheres. Various types of respirators are available and their protective capacity differs depending on construction and filter type. Basically, the inhaled air passes through a filter via the facemask to the lungs of the wearer. The protection offered to the wearer depends on filter properties and the sealing of connections, tubes, valves and mask. Various types of tests are designed to measure and classify the performance of the different pieces of a respirator equipment. Assuming that other parts of the respirator are tight and the mask is optimally fitted to the wearer, the final protection level offered to the wearer is the capacity of the filter to stop/absorb the contaminant.

Filters are tested at defined flow rates in order to simulate the dynamics of a human breath. In Europe the level is 95 l/min (EN143). This level should correspond to a low to moderate physical work load. However, during an inhalation the flow pattern is not constant, but a dynamic function of the breathing work and the properties of the airways. Assuming a sinusoidal shape of the breathing phase the curves in the graph of figure 1 can represent the inhalation and the expiration phase. The mean flow rate during inhalation (and expiration) is 1/3.14=0.32*V, where V is the top value (1 in the figure). The peak flow rate is the differential of the Sin-function. This is equal to 1*V and is found when the curve crosses y=0.During light to moderate work a breathing minute volume around 30 l/min can be expected. If the mean breathing minute volume is 30 l/min, the peak flow rate with this pattern is 94 l/min. This is probably the reason for choosing a test flow of 95 l/min.

However, breathing pattern is often not sinusoidal. During higher work intensities and during talking the inhalation phase becomes steeper and the peak flow rates higher. Studies have reported peak flow values way above 95 l/min during work with filter respirators (Dunn 1996), in particular in association with strenuous, physical work. The introduction of fan-supplied positive pressure respirators create conditions that facilitates the inspiratory work and allow for higher flow values. It has also been discussed that this may reduce the protection factor for a particular filter device (Howie 2001).

The present study was requested by the Swedish Work Environment Authority. The aims were to study the respiration patterns during work in a fan-supplied positive pressure breath responsive respirator.

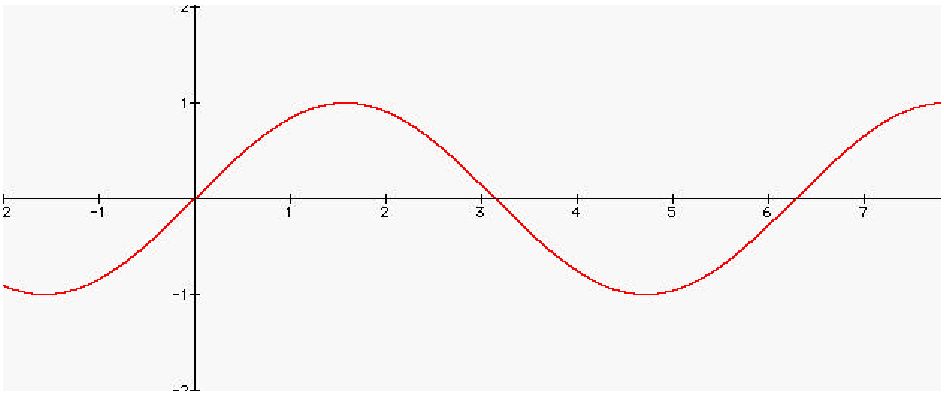

Figure 1. Sinus curve to illustrate respiratory flow patterns. The peaks at +1 and –1 represent the inspired and expired volume, respectively. The mean flow rate is defined by the area between the curve and the abscissa. The peak flow rate is the derivative of the sinus function and is found where it crosses the abscissa.

Material and methods

Equipment

A fan-supplied positive pressure breath responsive respirator (SE400 AT system; S.E.A.) was used with AB EP3 Combination filter. The respirator has a built-in flow meter that is based on pressure transducers.

Subjects

Ten subjects (5 male and 5 female) consented to participate in the study after a description of purpose and procedures. Anthropometric details are given in table 1. They were instructed in the details of the study and were allowed to stop at any time whatever the reason. The activities and exposures were so designed that there would be no need for special physiological break criteria.

Table 1. Anthropometric date for the five male and female subjects

Subject	Age	Height	Weight
Average all	**38**	**172**	**73**
SD	*16*	*6*	*14*
min	19	165	53
max	70	183	98
Average female	**39**	**168**	**64**
SD F	*23*	*3*	*8*
min	19	165	53
max	70	171	70
Average male	**38**	**176**	**83**
SD M	*6*	*5*	*11*
min	31	170	69
max	46	183	98

Measurements

A special airflow tube was mounted in the outlet of the normal tube from the combined fan/filter house (figure 2). This sensor was manufactured and calibrated by SWEMA. The principle of the sensor is to measure air velocity. Values from the flow meter were logged 10 times per second with a SWEMA Air 300 logger. Data were then transferred to a computer for analysis.

Heart rate of subjects was measured with a Polar Electro Hear rate meter. On the basis of mean heart rates the metabolic rate was estimated for the different periods of activity (ISO 8996).

Perceived exertion was rated by each subject for the different activities on a 15 points scale (Borg scale).

Procedures

Experiments were carried out in a climatic chamber kept at an air of 21 °C. Subjects reported to the laboratory either for a morning or an afternoon session. Heart rate sensors were mounted. Subjects dressed in a light coverall, donned the respirator and facemask and entered the chamber (figure 2). A 25-minutes activity program was designed to simulate various relevant work tasks and intensities. This program was completed after several pre-tests had been done. The exposure with respirator in the chamber comprised the following elements:

Procedure of the exposure period.

Standing still	2 min
Lifting 10/20 kg	1 min
Walking 5 km/h	5 min
Walking 5 km/h talking	2 min
Walking 3 km/h	8 min
Walking 3 km/h talking	3 min
Walking 6.5 km/h	5 min
Walking 6.5 km/h talking	2 min
Lifting 10/20 kg	3 min
Lifting 3 kg	4 min = 35 min

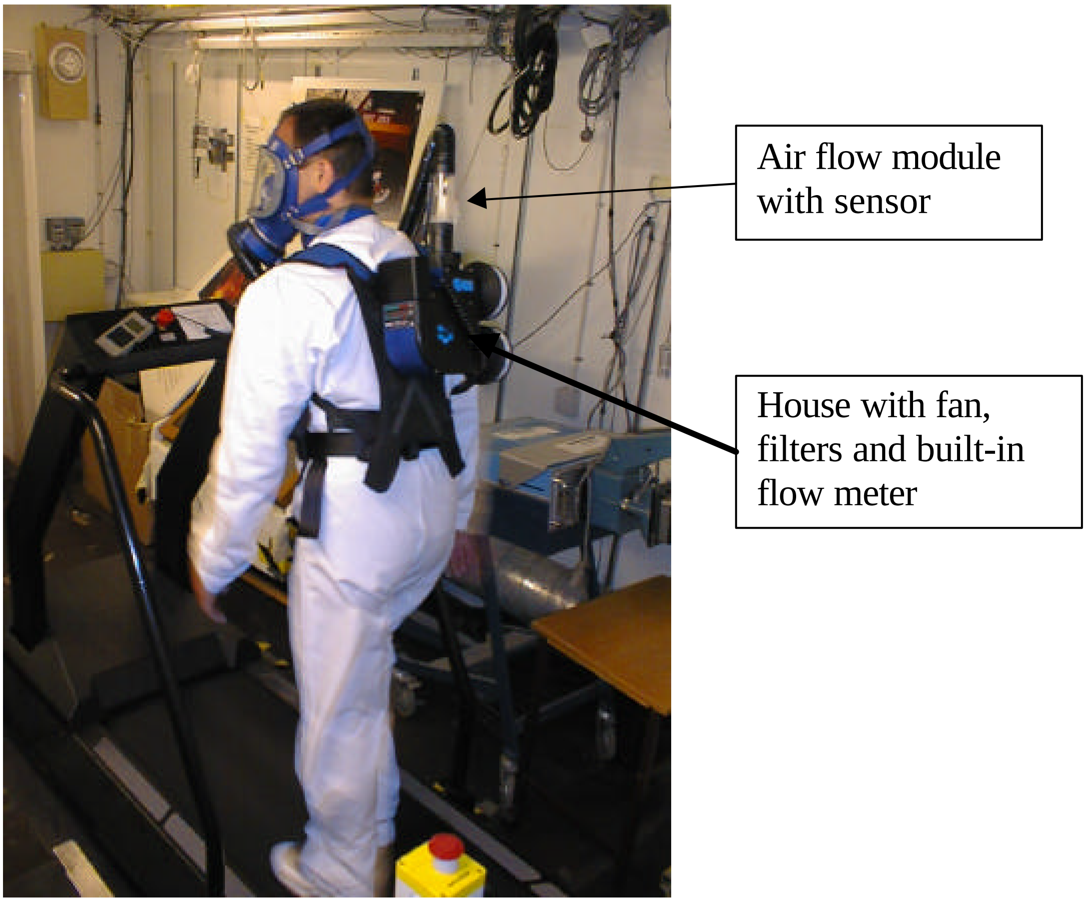

Figure 2. Experimental setup in climatic chamber with treadmill for graded exercise levels. Fan and filter are worn in a separate house on the back. Full face mask is connected to the house via a flexible tube. At the tube end nearest to the house a separate flow meter was mounted.

Subjects were asked to report their perceived exertion towards the end of each activity period. Heart rates were recorded at 10 s intervals and mean values per minute were determined.

After the experiment data were transferred to a computer and analysed. Mean values for heart rate and respiratory flow rates were calculated for representative intervals of the different activity periods.

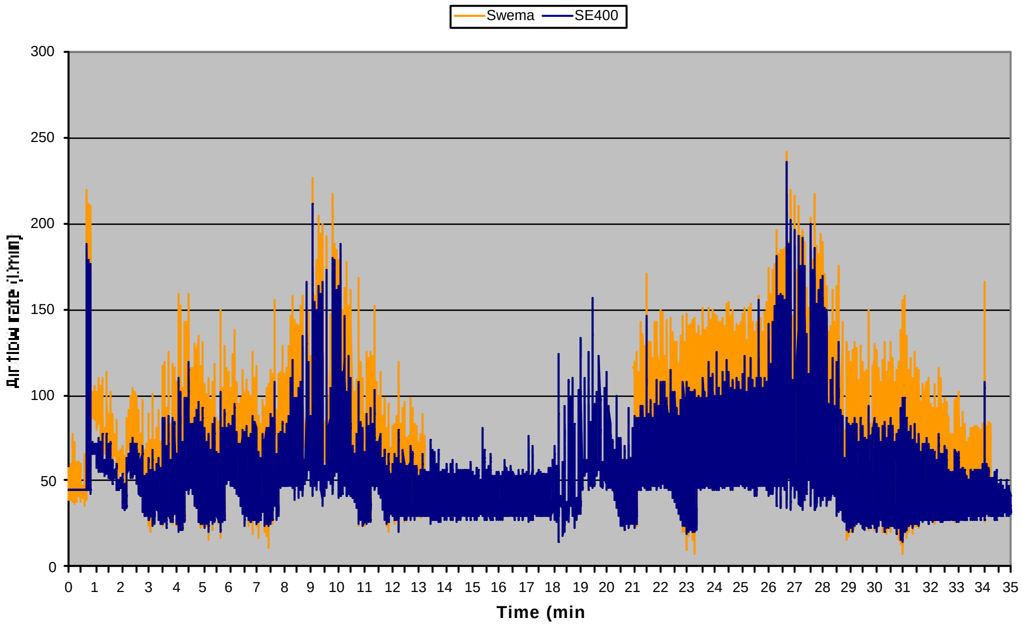

Figure 3. Time record of airflow rate measured with the two independent sensors for a complete exposure in one subject. The black lines indicate the built-in sensor's readings (SE300). Values for the tube-mounted sensor (Swema) were not recorded between minutes 13 to 21.

Results and discussion

Example of a complete recording of flow rates for one subject is shown in figure 3. Each spike represents a breathing phase. High flow rates are detected for sessions with high activity level, in particular in combination with talking. Values with the tube-mounted sensor are generally higher than values from the built-in sensor. At high flow rates the values become more equal. These results can be readily explained by the different locations of the sensors. The built-in sensor is placed in the housing of the fan and filters and should measure over a relatively large, cross-sectional area. The second sensor measures in the circular tube with a well-defined and smooth area. The flow is likely to be more damped in the housing, then in the tube. There are two causes of flow in the respirator system. One is the breathing work and the second is the fan. In this product the fan is demand controlled and its work becomes partly a function of the wearer's respiration. The baseline value is 40 l/min to create a positive pressure in the facemask.

Mean values for all subjects attained during the different activity periods are presented in figures 4-6.

Figure 4 shows the average values for perceived exertion during the various intervals. Values represent discrete votes of each subject towards the end of the interval. The first period "standing" is not included. It is readily seen that exertion increases with exercise. The highest activity levels correspond to votes of "heavy" and "very heavy".

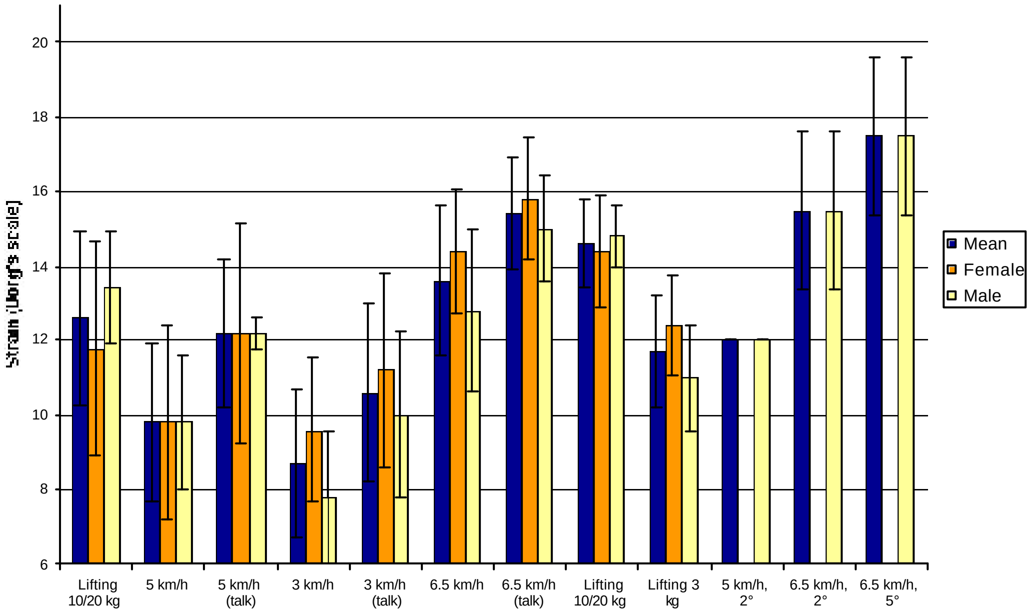

Figure 4. Average values for perceived exertion during the exposure. The six last columns represent values for two subjects in pre-trials. A value of 6 represent very, very light work and 20 very, very heavy work (Borg scale).

Figures 5-6 show the inspiratory flow rates. These are values calculated for 30 seconds within each of the activity intervals. Figure 5 shows the mean of the 10 subjects' 30 sec mean values. Values vary between 60 and 180 l/min. Highest values were achieved during high activity. Talking in combination with work produced an additional increase in flow rates. The reason for this is the changed breathing pattern during talking. Inhalation phase becomes shorter, since talking takes place during the expiration phase and requires more time. The shorter inhalation increases flow rates.

The flow patterns are similar for the average maximal values. These values are 50-100 % higher than the mean flow rates (figure 5). These values were only achieved once per inspiration cycle during the investigated interval of each activity (30 sec). This result indicates the intra-individual as well as the individual variation in breathing patterns.

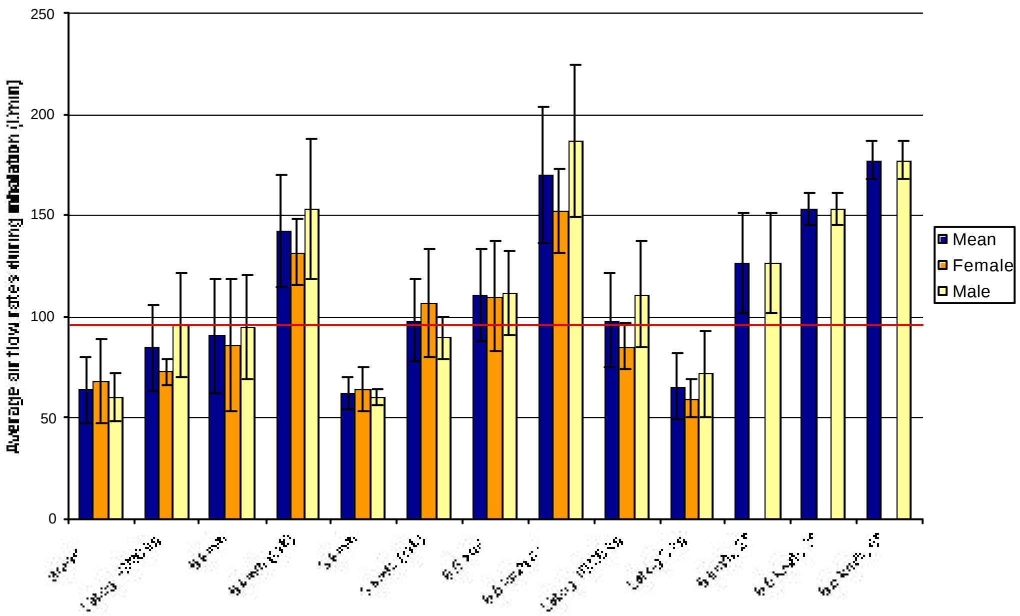

Figure 5. Average values for inspiratory mean flow in 10 subjects. The six last columns represent values for two subjects in pre-trials. The horizontal line at 95 l/min represents the required airflow rate for filter testing

Figure 7 shows the relation between mean flow rates and metabolic rate. As expected the flow rate increases linearly in this range of activity. It can be seen that the addition of talking rises flow rates by about 50 % at given activity levels.

During several activities of exposure the inspiratory flow rates exceed the nominal value 95 l/min, required for filter testing indicated by a horizontal line in figures 5-7. Sometimes values are more than 3 to four times higher.

High flow rates are achieved during a short phase of the inspiration cycle. Due to the high sampling rate (10 Hz) it is possible to calculate the duration of the periods when flow rate exceeds 95 l/min. This information is given in figure 8. During light activity the fraction is less than 20 %. At high activities this value may rise to about 50 %. With the addition of talking the flow rates exceed 95 l/min during 90-95 % of the inspiration cycle, i.e. that is for almost the whole inspiration time. The inspiration part of the breathing cycle is about 30 % during light work. It increases to about 50 % with higher activity. When talking the fraction reduces to 20-30 %.

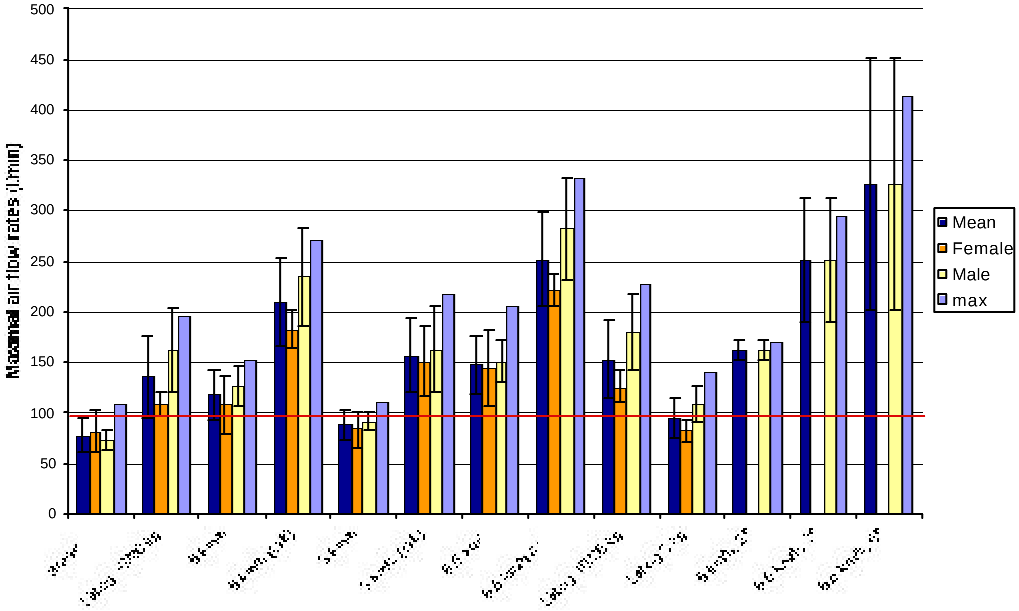

Figure 6. Average values for inspiratory maximal flow in 10 subjects. The six last columns represent values for two subjects in pre-trials. The horizontal line at 95 l/min represents the required airflow rate for filter testing

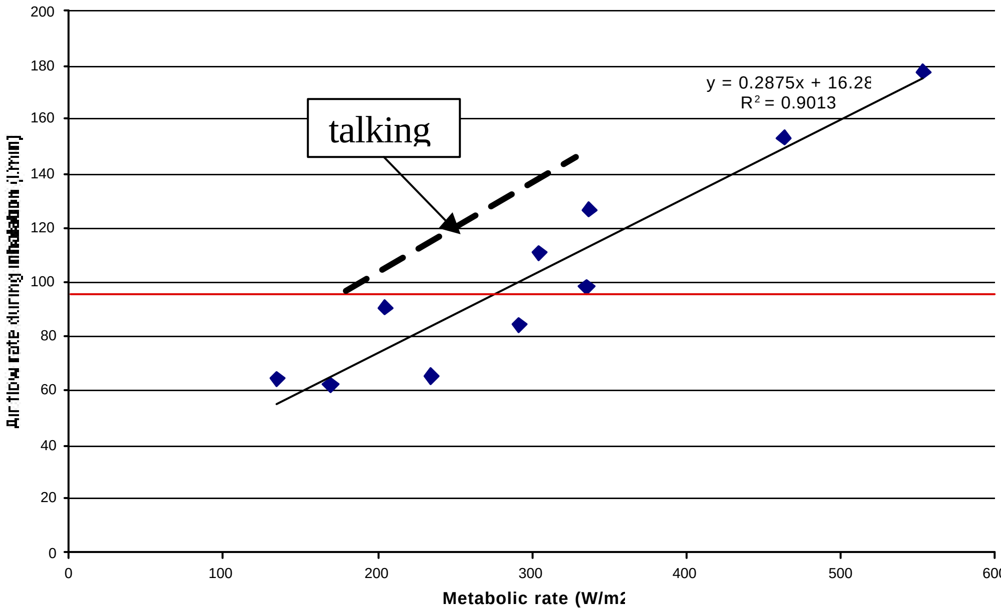

Figure 7. Relation between average air flow rate during inhalation and activity level (metabolic rate). The broken line represents values obtained when subjects were talking during exercise. The horizontal line at 95 l/min represents the required airflow rate for filter testing.

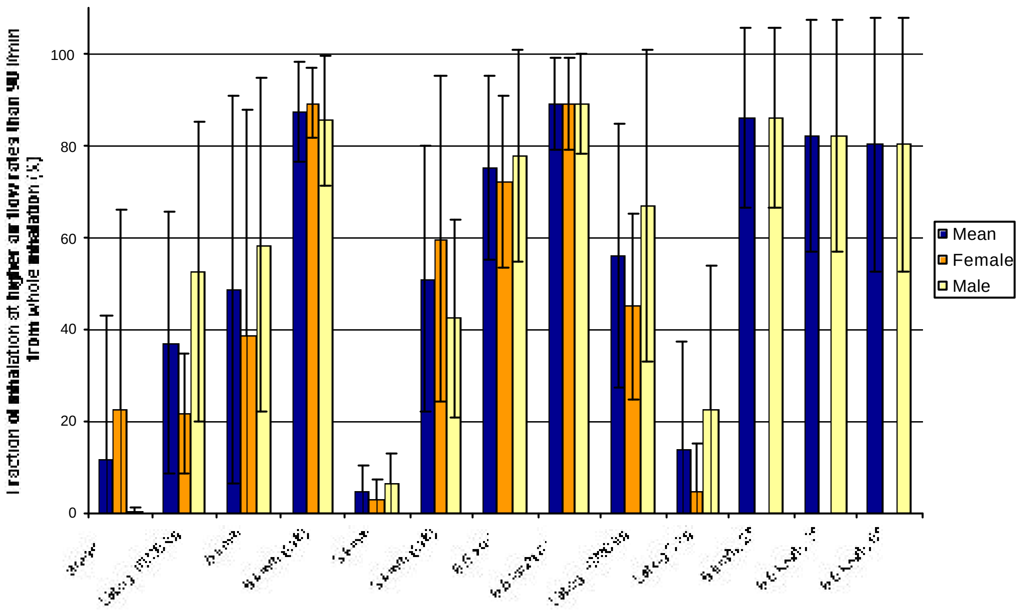

Figure 8. Fraction of inhalation time when flow rate exceeds 95 l/min. During normal breathing

Conclusions

1. Inspiratory air flow rates have been measured with an independent sensor in the tubing of a fan assisted positive pressure respirator.
2. Dynamics of the flow response pattern was very similar to the built-in sensor.
3. Values for the tube sensor were higher than the built-in sensor at low flow rates, but become close to each other at large flow rates (150-300 l/min).
4. High activity produces high inspiratory peak flow rates often in excess of 95 l/min.
5. Talking during the inspiration cycle increases flow rates by abut 50 % for the given activity level.
6. The fraction of the inhalation cycles that flow rate exceeds 95 l/min vary between almost none at very light work to 90-95 % during heavy work in combination with talking.
7. The protection offered by the respirator for this part of the inhalation cycle when flow rate exceeds 95 l/min has not been tested.
8. Performance of filters at least for this type of respirators should be tested at higher flow rates. A value of 200 l/min appears to be reasonable in order to accommodate the vast majority of flow rates that are expected to occur during use.

This investigation was made under contract with National Work Environment Authority, contact person Birgitta Carlsson.

References

Dunn B (1996) A study of the relationship between minute volume and instantaneous peak flows during the inspiration phase of the respiratory cycle and the factors influencing the worker's respiration. University of South Wales.

Howie RN (2001) Effectiveness of safety equipment Australia SE400AT positive pressure demand filtering device during asbestos removal operations. Robin Howie Associates, RMH/01/196.