A STUDY OF THE RELATIONSHIP BETWEEN HEART RATE AND MINUTE BREATHING VOLUME AT VARIOUS LEVELS OF WORK DEMONSTRATING THE SPREAD BETWEEN INDIVIDUALS IN A GROUP AND THE IMPLICATIONS IN INDUSTRY.

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Abstract

This paper describes the results of work carried out at the Sydney location of Safety Equipment Australia Pty Ltd late in 1996 to study the relationship between Heart Rates and Minute Breathing volumes in a sample population at various levels of work.

A volunteer test group of 25 subjects of both sexes and a variety of ages were asked to perform light work standing in one location. They were then asked to walk on a treadmill at a constant speed with the treadmill set level with the floor. The angle of the treadmill was then inclined in stages up to 7 degrees to increase the work load.

Throughout the trials, heart rates were continually monitored as were the Minute Breathing volumes.

Large variations in heart rates and Minute Breathing volumes were observed. This has implications for both users and designers of respiratory equipment for industrial use.

About the author

The author has worked in the Health and Safety fields of industry for over twenty-five years, both as an employee in the aluminium smelting industry and later as a consultant to many organisations in this part of the world, with particular interests in respiratory protection. He is formally qualified in Analytical Chemistry and Management with post-graduate qualifications in Occupational Safety and Health. He is currently involved in completing an MBA degree in International Management and commencing a PhD degree in Industrial Safety.

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Introduction

This study was conducted in Sydney, Australia at the end of 1996 and was part of a larger study for which two other papers at this conference have also been contributed.

The purpose of this part of the study was to investigate the relationship between heart rate and Minute Breathing Volume at different levels of work while subjects were wearing a half-face respirator.

The test group comprised a group of twenty five volunteers of both sexes and variety of ages. Details are given in Table 1. The tests were carried out over a period of 6 weeks. Subjects walked at a steady pace on a treadmill set at a constant speed while both heart rate and Minute flows were continuously monitored. Details of the breathing equipment used is given further in this paper, and involved the use of a half-face respirator fitted with a calibrated cartridge through which pressure variation was recorded for each breathing cycle.

There is a close relationship between the external power which is produced and the oxygen consumption of a subject [(1)]. As work done increases, the amount of air used increases, but the amount and speed of the air used at various levels of work are also dependant on other factors such as lifestyle factors (such as sedentary versus regular exercise), age, altitude, temperature and sex of the subject. There are limits to the relationship which is described in detail in other literature [(1)] although it is generally believed that the ventilatory system does not limit exercise in normal subjects.

Pulmonary ventilation usually refers to the amount of air exhaled per minute. The amounts of inhaled and exhaled air are not necessarily equal [(2)] . In this work the inhaled volume is more critical since this relates to the requirements for the design of respirators, particularly those used in heavy industry and by people working for short periods of maximal activity. This is a common practice in industry. From a resting value reported of about 6 litres of air per minute, the ventilation increases to 200 litres/minute and the increase is not linear [(2)].

Oxygen uptake cannot be used as an indicator of pulmonary ventilation at maximal work load because of the limiting ability of the respiratory system to utilise the oxygen availability of the air at these loads. Many studies have used the determination of physical work load by assessing the oxygen uptake at maximal work loads [(3)] [(4)] .

Heart rates have been used as an indicator of work load in many trials and work loads, including those related to respirator use [(3) (4) (5).]

In this work, a direct relationship has been experimentally derived between heart rate from the 25 subjects and the associated Minute Volumes while wearing a half-face negative pressure respirator, with equipment specifically designed, manufactured and calibrated for this purpose.

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Experimental Procedure

Subjects were fitted with a Sundstrom half-face respirator and fit tested using Portacount ® equipment.

A variety of physical characteristics of the test subjects were measured such as weight, height, BMI (Body Mass Index) and Spirometry as well as test room conditions such as temperature and humidity were noted.

Subjects were asked to walk at a steady rate of 6.5 Kph while both heart rate, Minute Flow volumes and Peak Inspiratory Air Flows were logged electronically. The load was then increased by inclining the treadmill upwards at 3^0, 5^0 and finally 7^0. All the data was downloaded to computers for storage and subsequent analysis.

The experiment was repeated at least three times on separate days for each person, with a number of subjects repeating the same test procedure over subsequent days for statistical analysis.

Experimental details

Specific experimental details were:

Subjects: A total of 25 subjects from both sexes volunteered for this work, varying widely in age group and physical fitness. No preselection process was undertaken, although care was taken to ensure that subjects would be able to undertake the test. All subjects were also instructed to abandon the test in case of any discomfort being experienced.

All subjects had the purpose and the experimental procedure explained and care was taken to ensure that the subjects had experienced the use of a treadmill prior to any testing.

Respirator used A Sundstrom SR-90 respirator (in two sizes) were used for the work, fitted with a flow meter designed, built and calibrated by SEA Pty Ltd in Sydney. Calibration was capable of being traced to a Reference Standard.

Flow meter The flow meter utilises the pressure drop over a standard Sundstrom P3 particle filter to measure the air flow. The pressure drop is measured by a Honeywell Differential Pressure Transducer

Treadmill A treadmill (Spectra Mattan) was set at a steady speed of 6.5 Kph
A lower speed had to be used for some individuals.

Calibration equipment

IPZ test bench at SEA Pty Ltd with Flow meter 0 to 600 L/min and X/Y chart recorder. Flow meter used to calibrate the IPZ test bench was a ROTA YOKOGAWA type RHN.01 950215.0701.

Calibration

The unit was calibrated using the IPZ test bench a SEA Pty Ltd. Calibration is a two-point calibration: High Limit flow value and Low Limit flow value. The equipment response has been measured and verified to be linear. The calibration procedure is automated in the software. The software will request a High Limit flow value. It will then average 1500 samples over 30 seconds. The numerical value is then entered via the keyboard. The process is repeated for the Low Limit flow value. Gain and offset factors are calculated and stored in separate files as calibration constants.

Calibration of the system was repeated a second time towards the end of the test series to check for change of flow resistance of the filter due to airborne contamination. The difference was negligible.

Measuring accuracy

Accuracy of the system is affected by errors in the equipment as well as the inaccuracies of the calibration equipment. The ROTA YOKOGAWA reference flow meter has an error of +/-5%. The estimated error of the IPZ will be 6.7% according to the principle of Gaussian distribution and using a 3sd limit for maximum error.

The precision of the AD converter is specified to be 2 bits. Two bits over a 12 bit range equals an error of 0.1%.

Non-linearity of the particle filter response introduces errors also. The filter was measured for linerity response on the IPZ test bench using the Spirograph XY chart recorder. Maximum linearity erroe is 3% located at 150 L/min flow.

The resultant maximum error of the SEA Flow Meter is 10%.

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Results

Volunteer test group physical characteristics

Table 1 gives the physical characteristics of the volunteer test subjects.

Subject	Sex Male	Female	Age
10	1		23
11	1		37
12	1		19
13	1		44
14	1		46
15	1		33
16	1		47
17	1		38
18		1	39
19		1	53
20	1		31
21	1		28
22	1		21
23	1		23
24	1		43
25	1		43
26	1		35
27		1	49
28		1	19
29	1		30
30		1	45
31	1		21
32	1		55
33	1		46
34	1		50
Sum	20	5	
Average			**36.7**

Age and sex of volunteers in the study

Table 1

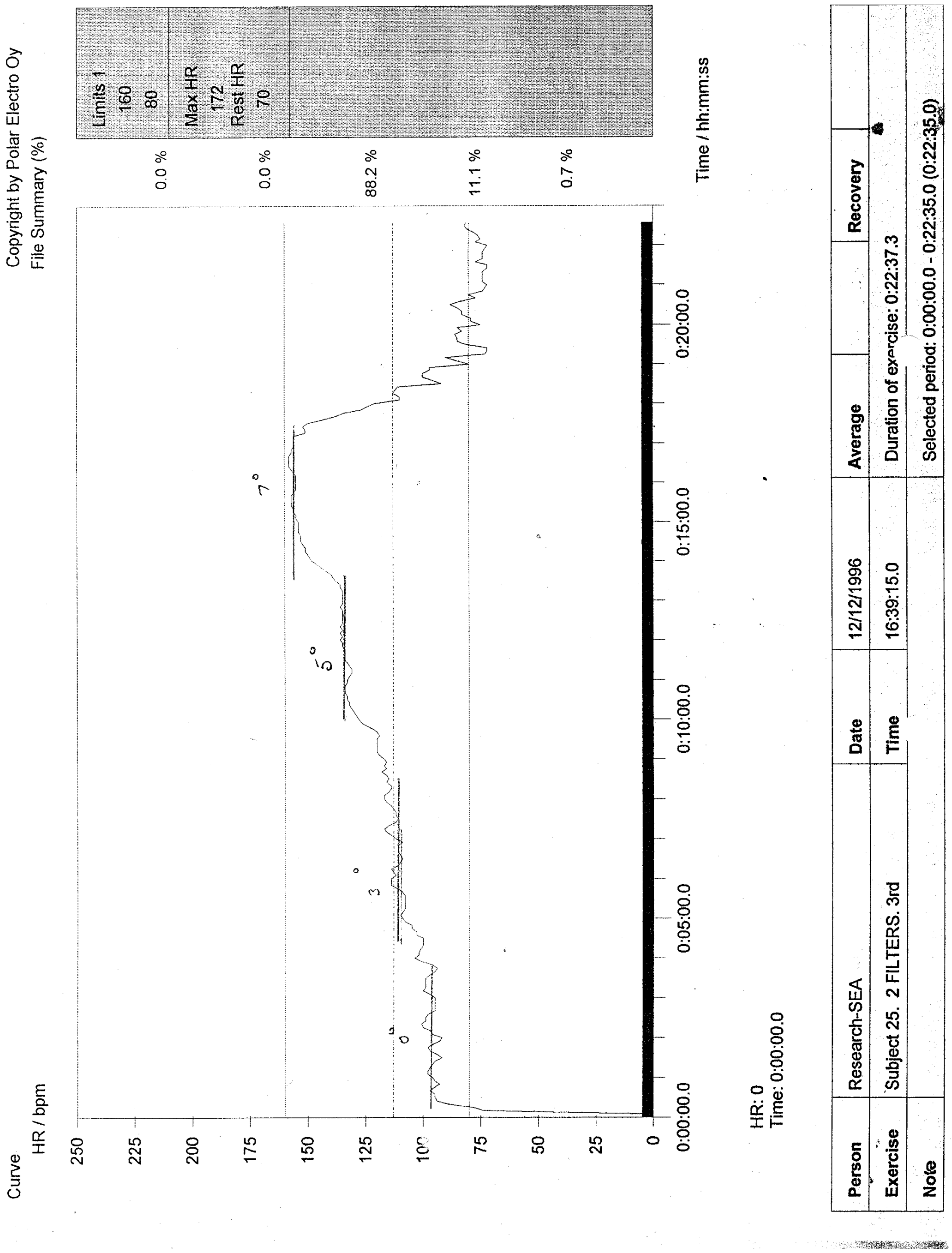
Photographs of subjects exercising in the study.

Photograph of one of the subjects walking on a treadmill at 6.5 kph on an angle of 0 degrees uphill.

Photo 1

Photograph of equipment used in the experiments. Subjects were wearing a continuous heart rate monitor.

Photo 2



Showing typical heart rate pattern obtained from a test subject while walking on a treadmill .

Graph 1

Results-table 1

Table 1 gives the summary of results of Minute Flow, average heart rates recorded during each test at different inclined angles of the treadmill set to a constant speed of 6.5 kph-a fast walk for most people in the test group.

Subject I.D	Heart rate at 0 degree incline bpm	Average minute flows at o degrees incline litres/min Most over 3 days at one minute intervals	Heart rate at 3 degree incline bpm	Average minute flows at 3 degree incline litres/min Most over 3 days at one minute intervals	Heart rate at 5 degree incline bpm	Average minute flows at 5 degree incline litres/min Most over 3 days at one minute intervals	Heart rate at 7 degree incline	Average minute flows litres/min Most over 3 days at one minute intervals
10	100	22.1	117	25.8	134	29.3	149	32
11	104	22.1	116	29.7	139	38.6		
12	113	30.2	130	28.9	144	29.3	158	34.4
13	113	36.9	134	48	148	66.8	158	85.5
14	109	20.4	125	27.9	138	36.6	158	50.4
15	109	24.4	136	38.6	156	48.5	138	39.3
16	97	31.3	112	43.8	125	51.7	145	64.3
17	127	46.1	150	65.9	156	71.5		
18	118	33.4	140	41				
19	108	16.5						
20	111	24.6	127	29.7	145	32.9		
21	123	26.2	142	30.7	155	40.7		
22			117	31.8	128	38.2	131	43.4
23	100	26.3	121	37.6	135	46.7	155	52.1
24	111	31	142	52.6				
25	110	26.8	127	33.2	138	48.9	162	49.3
26	107	22.3	122	28.4	143	37.5	161	41.7
27	98	18	109	24.6	146	34.3	129	34
28	112	16.5	133	23.1	122	28.1		
29	120	22.6	150	29.8				
30	128	21	148	29				
31	102	23.1	120	29.5	117	28.1		
32	95	20.7	114	28.5	145	31	142	41
33	104	26.2	120	37.1				
34	113	17.2	126	20.5	131	34.4		

Experimental results-Minute Flows and Heart Rates of subjects walking at 6.5 kph at no incline, 3 degrees, 5 degrees and 7 degrees incline.

Repeatability data

Subject 13	Heart rate 0 degrees	Minute volume 1st min 0 degrees	Minute vol. 2nd min 0 degrees	Minute vol. 3rd min 0 degrees	Heart rate 3 degrees	Minute vol. 1 st min 3 degrees	Minute vol. 2nd min 3 degrees	Minute vol. 3rd min 3 degrees	Heart rate 5 degrees	Minute vol. 1st min. 5 degrees	Minute vol. 2nd min 5 degrees	Minute vol. 3rd min. 5 degrees	Heart rate 7 degrees	Minute vol. 1st min. 7 degrees	Minute vol. 2nd min. 7 degrees	Minute vol. 3rd min. 7 degrees
13	114	37.2	38	39	137	48.7			147	67.9	63.8	74	162	83.7	92.7	97.7
	109	38.1	39.4	41.3	131	48.3	49.3		146	66.5	66.3		159	78.9	82	90.1
	115	29.9	32.1	36.6	136	42.8	49.2	47.7	149	58.3	67.7	70.4	154	77.8	79.9	86
	108	29.5	35.5	36.1	126	41.3	49.4	51.5	144	59.4	60.9	68	148	70.9	77.6	72
	101	27.4	33.7	31.2	120	42.5	47.9	48.4	135	52.1	60.5	62.5	150	64.8	72.6	75.7
	115	21.6	26.7	27.3	127	46.2	51.4	52.2	141	54.7	56.8	59.7	148	71.5	61.2	66.4
	105	26.6	34.4	31	120	42.8	49.2	46.7	133	49.1	52.2	54.1				
Average	110.3	30.6	34.2	35.3	129.5	45	49.4	50	143.7	59.8	62.7	66.9	153.5	74.6	77.7	81.3
SD	5..5	6.2	4.6	5.2	6.5	3.2	1.3	2.2	5	6.3	4.1	5.8	5.9	6.8	10.5	11.9
16	103	34.8	37.6	37	114	43.2	47.8	47.4	129	46.5	50.1	56.7	146	55.1	64.2	69.3
	96	26.3	31.8	31.7	115	36	41.3	44.6	123	46.7	51.2	49.5	143	55	64	69.3
	100	21.4	26.1	32.2	108	39.2	48.3	46.8	122	47.3	58.9	58.2	146	60.1	68.7	73.2
	91	30	31.5	32.9	102		41.2	40.7	115	47.6	51.2	54	128	60.2	66.6	64
	89	24.2	30.8	31.8	101	35.2	40.5	47.9								
	90	26.9	32.1	33.6	105	34.4	42.5	44.4	118	51.3	57.6					
	86	24.4	30.8	31.8	99	35.4	45.5	42.7	115	47.6	53.4	55.3	129	60.4	66	68.3
	83	17.5	28	26.4	95	35.5	40.7	44.3	107	38.7	41.8	50.2	126	54.2	65.1	64
	91	25.8	31.1	31.9	105	42.6	46.9	47.9	112	48.9	51.2	48.9	123	52.6	61.7	59.9
	84	23.9	29.5	29.8	100	35.3	40.6	41.4	107	44	45	48.1	118	50.2	54.8	57.3
Average	91	25.5	30.9	31.9	104	37.4	43.5	44.8	116	46.5	51.2	52.6	132	56	63.9	65.7
SD	6.6	4.7	3	2.7	6.4	3.4	3.2	2.7	7.4	3.5	5.4	3.9	11	3.9	4.2	5.3

Repeatability data. Using the same subjects, recorded the heart rate and Minute Flow measurements over progressive days.

Table 1

The relationship between Heart Rate and Minute Breathing volumes at various levels of work.

Conclusion

The determination of the Minute Flows from a range of volunteer subjects representative of what could be found in most industrial situations has been the subject of this work, and forms part of a larger project being conducted at the present time in collaboration with the Health and Safety Department of the University of New South Wales (in Sydney, Australia). This includes work on Peak Inspiratory flow rates, breathing patterns and breathing flow patterns while communicating.

Minute flows are a critical factor in the design of respirators and respirator cartridges, since the flow of gas including airborne contaminants, for example, is one of the factors which determine the practical life of cartridges. Much of the research and the setting of National Standards work in many countries with respirators is based, on this data such as the determination of Total Inward Leakage testing [8] [9] [10]. In addition, the data is a critical factor in the design and development of new respirators. Typical Minute Flows given may be as **[3] [4] [5]**.:

Work Load	**Heart rate** bpm	**Minute Volume** Litres/min
Resting	60-70	6-7
Low	75-100	11-20
Moderate	100-125	20-31
High	125-150	31-43
Very High	150-175	43-56

Typical values for Heart Rate and Minute Flows shown in current literature.

These values can vary substantially in the available literature, for example prCR 529:1991 [13].

Most of the currently available information on this topic appears to have generated from work carried out by Silverman and others at over three decades ago [6] [15]. It was recognised that two critical physiological considerations were the maximum rate of airflow during inspiration through the protective element and the length of time this continued [6]. In addition, at high work rates with increased inspiratory resistance, the oxygen consumption is lowered considerably as compared with minimal resistance [7] [14]. It is further complicated by the variation in the physiological characteristics and response of human subjects [11].

There is an increasing need to verify that a chosen respirator will perform as designed in the workplace. There appear to be many gaps in the current knowledge and existing data will need to be better quantified. While this may have been difficult in the past, it is now eased by the availability of real-time measurement equipment and automated recording of data.

The data obtained from these recent experiments show that the values currently obtained for Minute Volumes in the literature should be reviewed.

The experimental data obtained here show large variations between subjects, but also values are indicated higher than normally indicated in the literature, as well as incorporating large variations. These values have an impact on most of the current standards used by varying nations in the testing, design, manufacture and export of many varieties of respirators.

End

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