CALIBRATION OF TEST SUBJECTS

Minute Flows

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Results of experiments carried out at the Safety Equipment Australia Pty Ltd offices in November and December, 1996.

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Abstract

The report summarises the background, experimental methodology and results of practical trials to relate work load in 24 widely varying subjects to heart rate and respiration Minute Flows. Not all the test results are quoted in this report as these will be published separately, but sufficient information and results are given to demonstrate the practicality of the technique.

Design of equipment as well as software development and calibration to ensure accurate and real-time results for analyses was required and this is briefly described.

The report shows from experimental data that there is a direct relationship between heart rate and breathing rates for an individual within the limits tested, that heart rate is a valid indicator of the Minute Flow through the respirator and that a treadmill can be used to increase the individual load so that the desired Minute Flow is obtained for the calibration of test subjects.

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Introduction

Background

At the last Standards Australia meeting of the 20th-21st August, 1996, a sub-committee was formed to gather a protocol to determine the significance of Total Inward Leakage testing of particulate respirators.

In particular:

> Rate of Work-Tread Mill or Exercise Bike
>
> The use of people with varying cardiovascular capacity may mean that the flow rate through the respirator may vary significantly. It was suggested that the person should be calibrated, i.e., the breathing rate correlated to the person's heart rate values.

In this work, a treadmill was used to simulate work and increase the load on individuals wearing a respirator, as this provides standardised conditions and permit comparisons to be made [(6)]. The general use of treadmills and exercise testing has been documented elsewhere [(7)] and is not repeated here. In addition, respirator performance has been measured for many years using treadmills (Silverman et al [(11)], De Roza [(12)], and others).

The work reported on here is a small portion of the current applied research being carried out at the present time to better understand the human/respirator interface. Results from these studies will be published.

The draft ANSI Standard Z88.8, issued November 1996 [(4)], reports on the need:

> "to establish a relationship between work load and ventilation
> rate for each test subject using treadmill exercises. The conditions that
> produce the required ventilation rate can be taken from the curve for each
> test subject and used for testing the respirator"

The applicability to the AS/NZS testing of Total Inward Leakage by investigating the possibility of calibrating test subjects, is the primary subject of this report by demonstrating this possibility, significant improvements in the development and fit testing of respirators will be possible.

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The current situation

Minute Flows

The AS/NZS 1716:1994 (Appendix D) refers to the measurement of Total Inward Leakage of Assembled Respirators, by using a quantitative sodium chloride test on respirators worn by 10 pre-selected subjects. The subject simulates work on an exercise machine such as walking on a treadmill at 6.5 Kph for 10 minutes, while carrying out a range of head and facial movements [(1)].

In addition, the physiological load (strain) imposed on an individuals varies widely, depending on age, sex, physical fitness and other factors. This is widely recognised and reported, for example, the European Guideline For Use of respirators prCR 529:1991 [(2)]. Also, individuals physiological requirements may change over a relatively short time, depending, for example, on exercise undertaken.

Variations in Minute Volume have also been documented [(3)] and data has been reported typically in comparison to metabolic rate or heart rate.

Variations between the data on Minute Flows has implications for the design and testing of respiratory equipment and has been repeated in the work carried out here.

Peak Inspiratory Air Flow

Some of the reported literature reports on Peak Inspiratory Air Flow being three times the Minute Volume [(2)], although variations from 2:1 to 4:1 (Peak Inspiratory Air Flow: Minute Flows) are quoted elsewhere [(5)]. Peak flows are in many performance criteria of respirators, but are rarely reported on.

The Peak Inspiratory Air Flow is not specifically the subject of this report, but could be of significant value for the work of the Committee in the future.

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.

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%.

Unlinearity 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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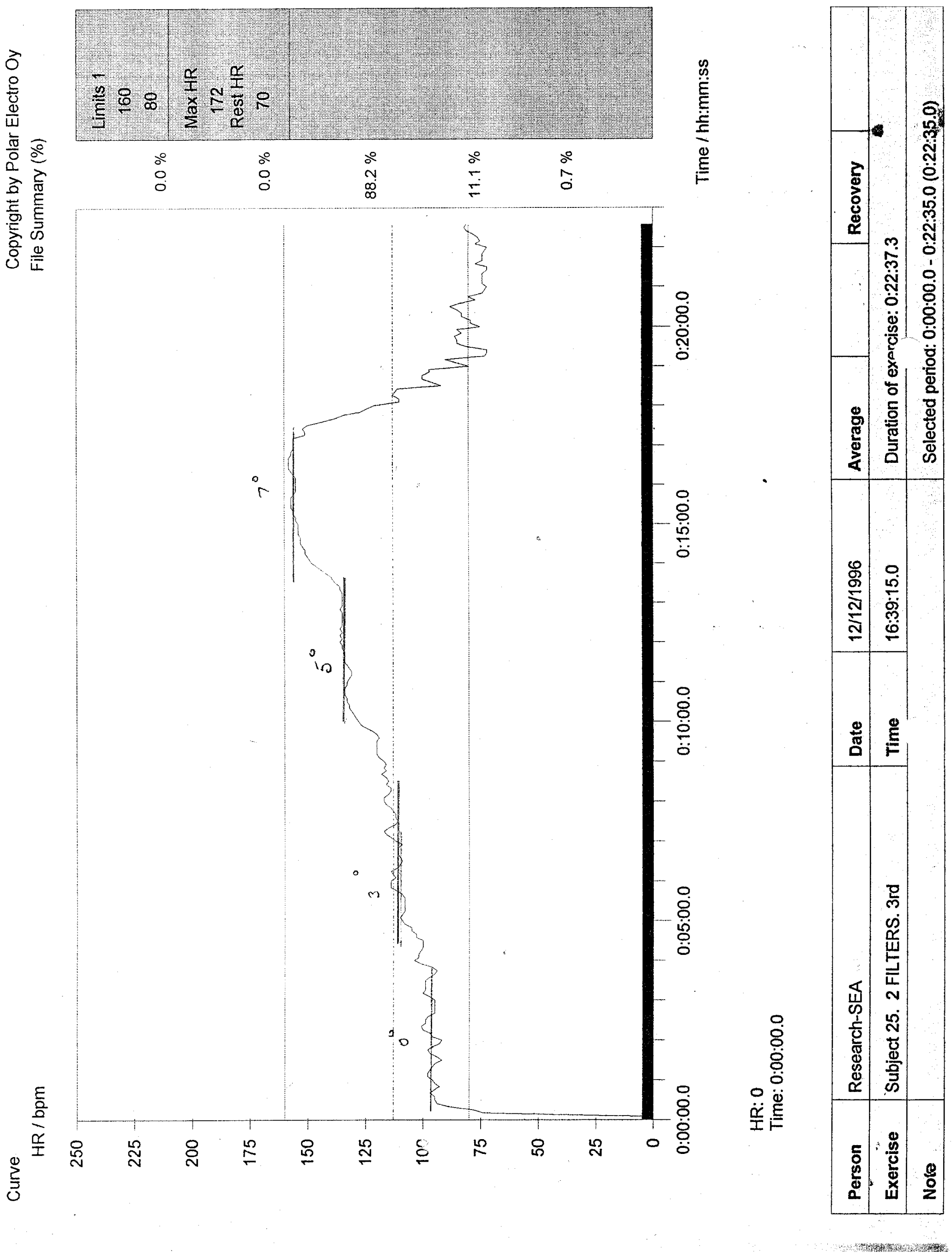
Results

The heart rate of each subject was continually recorded and monitored while exercising on the treadmill. For the same load between different people, there were large variations in recorded heart rate and this observation has been well documented elsewhere.

A typical heart rate pattern is shown in Graph 1 on page 9. Age and sex distribution is shown in table 1 on page 10.



A typical heart rate pattern for an individual while exercising on a treadmill at various loads.

Chart 1

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

Physical measurements were taken from each volunteer.

Photo 1

Close-up photograph of attachments to the respirator

Photo 2

Photograph of testing procedure used. Subject walking on a treadmill while heart rate and Minute Flows are monitored.

Photo 3

Photograph showing test equipment is use.

Photo 4

Heart rate and Minute Volumes recorded for volunteers at a 0 degree treadmill angle

At 0 degrees uphill

Subject	Heart rate	Minute Flows recorded at the 0 degree plateau (MF = Minute Flows)				Average Min Flow for the day	Last Minute Flow for the day	Average Minute Flow for all trials	Average last Minute Flows for all trials
		MF 1	MF 2	MF 3	MF 4				
10	**98**	24.9	28.3	31.4	28.2	28.2	31.4		
	99	19.3	19.8	20		19.7	20		
	104	17.1	20.1	18		18.4	18	**22.1**	**23.1**
11	**103**	22.5				22.5	22.5		
	97	22.4	21.9	23.9		22.4	23.9		
	111	19	22.8	22.3		21.4	22.3	**22.1**	**22.9**
12	**103**	31.6				31.6	31.6		
	123	26.8	29.7	29.5		28.7	29.5	**30.2**	**30.6**
13	**114**	37.2	38	39		38.1	39		
	109	38.1	39.4	41.3		39.6	41.3		
	115	29.9	32.1	36.6		32.9	36.6	**36.9**	**39**
14	**103**	20.8				20.8	20.8		
	110	17.6	21.1	21.2		20	21.2		
	115	17	20	23.8		20.3	23.8	**20.4**	**21.9**
15	**108**	27.1				27.1	27.1		
	110	16.9	21.4	29.1		22.5	29.1		
	103	20.7	21.9	20.5		21.0	20.5		
	113	22.3	27.2	31.7		27.1	31.7	**24.4**	**27.1**
16	**102**	34.8	37.6	37		36.5	37		
	96	26.3	31.8	31.7		29.9	31.7		
	100	21.4	28.1	32.2		27.2	32.2		
	91	30	31.5	32.9		31.5	32.9	**31.3**	**33.5**
17	**129**	40.2	49.9	46.7		45.6	46.7		
	122	39.2	44.8	48.6		44.2	48.6		
	130	45.1	50.3	49.8		48.4	49.8	**46.1**	**48.4**
18	**118**	33.5	33.3			33.4	33.3	**33.4**	**33.3**
19	**108**	16.5	16.5			16.5	16.5	**16.5**	**16.5**
20	**111**	17.3	21.4	23.4	25.7	22.0	25.7		

(Heart rates in bpm and Minute Flows in litres/min).

Comments on Table 2:

Data on the horizontal line is the result of data obtained on the same day.
Data on the next line was obtained on another day.

	110	29.1	27.1	25		27.1	25		
	113	22	25.6	26.8		24.8	26.8	**24.6**	**25.8**
21	**129**	28.3	29.3			28.8	29.3		
	120	23.9	29.3			26.6	29.3		
	120	24	23.4	22.4		23.3	29.3	**26.2**	**29.3**
23	**95**	25.6	27.7	29.7		27.7	29.7		
	99	27.4	27.3	25.1		26.6	25.1		
	106	17.8	26.7	29.6		24.7	29.6	**26.3**	**28.1**
24	**113**	26.5	29.7	33.6		29.9	29.7		
	105	28.7	32.6	37.4		32.9	25.1		
	114	22.9	33	35		30.3	29.6	**31.0**	**28.1**
25	**113**	24.3	27.9	32.9		28.4	29.7		
	112	26.5	26.9	27		26.8	25.1		
	105	22.6	24.5	28.4		25.2	29.6	**26.8**	**28.1**
26	**110**	21.6	23.1	22.7		22.5	29.7		
	108	18.4	22.7	24.1		21.7	25.1		
	102	20.4	23.1	24.4		22.6	29.6	**22.3**	**28.1**
27	**88**	17.4	19.4	19.2		18.7	29.7		
	93	18.8	18.7	18.8		18.8	25.1		
	112	14.4	17.7	17.2		16.4	29.6	**18.0**	**28.1**
28	**115**	15.5	18.1	18.9		17.5	18.9		
	109	14.5	15.8	15.9		15.4	15.9	**16.5**	**17.4**
29	**120**	22.5	23	22.3		22.6	22.3	**22.6**	**22.3**
30	**127**	19.1	20.6	22.5		20.7	22.5		
	130	20.3	22.2	21.5		21.3	21.5	**21.0**	**22**
31	**102**	22.1	23	24.3		23.1	24.3	**23.1**	**24.3**
32	**92**	21.4	23.6			22.5	23.6		
	98	15.1	20.7	19		18.3	19		
	95	20.4	22.4	21		21.3	21	**20.7**	**21.2**
33	**104**	23	27.9	27.7	29	26.2	29	**26.2**	**29**
34	**110**	15.4	17	16.9		16.4	22.5		
	115	16.1	17.2	18.4		17.2	21.5	**16.8**	**22**

Volunteers walking at 6.5 K/hr on a 0 degree slope.

Table 2

To determine the reproducibility of the test subject data, a number of people were subjected to the treadmill exercise program once per day over an extended period and statistical information derived. One noticeable error in this technique was caused by the individuals rapidly gaining fitness as a result of the daily load.

Additional observations included the change in breathing pattern and requirements while communicating and these will be the subject of further reports.

Repeatability of data

Comments on the table:

MF is the Minute Flow.

Data on the horizontal line the results obtained the same day.

Data on the next line are the results obtained on another day.

For 0 degrees

Subject	Heart rate	MF1	MF2	MF 3	MF4
13	114	37.2	38.0	39.0	
	109	38.1	39.4	41.3	
	115	29.9	32.1	36.6	
	108	29.5	35.5	36.1	
	101	27.4	33.7	31.2	
	115	21.6	26.7	27.3	
	105	26.6	34.4	31.0	
Average	**110**	**30**	**34**	**35**	
SD	**5**	**6**	**4**	**5**	
16	103	34.8	37.6	37	
	96	26.3	31.8	31.7	
	100	21.4	28.1	32.2	
	91	30	31.5	32.9	
	89	24.2	30.8	31.8	
	90	26.9	32.1	33.6	
	86	24.4	30.8	31.8	
	83	17.5	29	26.4	
	91	25.8	31.1	31.9	
	84	23.9	29.5	29.8	
Average	**91**	**26**	**31**	**32**	
SD	**7**	**5**	**3**	**3**	
25	113	24.3	27.9	32.9	
	112	26.5	26.9	27	

	105	22.6	24.5	28.4	
	115	20.5	25.9	24.9	
	109	24.9	21.5	28	30.8
	109	24.7	26.7	30.1	31
	101	25	30.9	31.2	
	108	25.5	33	31.4	
Average	**109**	**24**	**27**	**29**	**31**
SD	**5**	**2**	**4**	**3**	

Repeatability of data gathered from the same volunteers, measurements taken each day over a period of days.

Table 3

Conclusions

To make it possible to reproduce test results in the Total Inward Leakage procedure so as to note if the respirator provides an acceptable level of protection under use conditions, it is necessary to calibrate the test subjects. In this way, it is ensured that the same amount of air is drawn through the respirator regardless of the subject's physical size, gender, age or fitness level. This is in line with the proposed ANSI Z88.8 standard (Nov. 1996).

The use of treadmills to increase a steady load has been well documented and is frequently used for this type of work. The work required for exercise and the work required for breathing are also well documented [(6) (8)]. Work load for an individual can be estimated from the heart rate under standardised conditions [(10) (6)].

It should be noted that the speed of the treadmill established in the current AS/NZS 1716:1994 is too high and is incapable of being held by many subjects. For most subjects, this speed is ackward and unnatural. The equivalent load should be applied by setting the speed at a slower rate and inclining the treadmill.

Heart rate and breathing rates vary widely between individuals in any group. However, breathing rates can be plotted against heart rate for each individual. The Minute Volumes can then be held at the same set of pre-determined values over a wide range of people by monitoring the individual heart rates.

Most of current knowledge regarding the design of respirators and testing has it's origins in a document written in 1942 [(11)] and much of the subsequent details of Standards are based on their results, even surprisingly, today. This detailed document discusses the measuring apparatus, experimental methods and results, measurement of resistances related inspiratory air flows and other critical issues related to gaining scientific insight into human respiratory protection.

Particularly important is the data relating pulse rate (i.e, load) to Minute Volumes and similar information on which much of the equipment of today is based.

There have been increasing concerns in the last decade about the adequacy of the information. Equipment progress as well as electronic advances such as computer technology and micro-processing of information is allowing much more detailed and accurate scientific information to be derived. Little has been published in this important area in relation to respiratory protection.

It will be important for future respiratory standards to adopt the technique of calibrating test subjects. Without this knowledge, there is the potential to adopt unscientific methods for evaluating different types of respiratory equipment. Literature and advice may not be soundly based on standardised information, and much misinformation and myth may perpetuate the industry into the next decade.

It is recommended that the Committee appoint a work group to establish new methods and values for breathing rates, work loads, test procedures and subsequent calibration methods. Much of the work done in this and subsequent reports yet to be written has highlighted the need to re-evaluate most of the information on which current thinking on respiratory protection is based and that new insights have to be derived.

Results indicate that test subjects for testing inward leakage of respirators should be calibrated based on the relationship between heart rate and Minute Volumes of air used. Predetermined Minute Volumes can be set by increasing the angle of the treadmill while monitoring the heart rate.

It has been shown that heart rates can be used as a measure of breathing volumes and hence calibration of test subjects becomes possible.

End

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