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**THE PHYSIOLOGICAL COSTS OF WEARING  
RESPIRATORY PROTECTIVE DEVICES**

**A THESIS IN PARTIAL FULFILMENT OF  
THE REQUIREMENTS FOR THE DEGREE OF  
DOCTOR OF PHILOSOPHY**

**at**

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## ABSTRACT

This thesis is concerned with the use of respiratory protective devices in New Zealand industry and the physiological costs the respirator imposes on the wearer. Two cross sectional surveys of respirator users were undertaken to determine the extent and nature of use or non-use in the working environment and which factors contribute most to non-use. Evidence is presented that indicated that non-use is common (50% of those surveyed) and that difficulty breathing, thermal discomfort and difficulty communicating and seeing were all important reasons for non-use. In addition, it was found that respirators are worn for extended lengths of time and that many users believe that their work when wearing a respirator was physically demanding. Evidence is presented that this is not the case.

The physical characteristics of respiratory protection in terms of resistance to airflow, weights and dead space volumes, were measured in a selection of commonly used respirators in NZ industry. It was evident that most pressure-flow relationships were below recommended limits for inspiratory and expiratory resistances and that some masks in particular, offered little external resistance to breathing.

The physiological consequences of wearing respirators was examined in a series of studies measuring relationships in heart rate, oxygen consumption, ventilation, facial skin temperatures and perceived exertion, with and with-out subjects wearing respirators and at differing levels of external work. It was found that the respirator imposed little physiological strain (in terms of heart rate, gas exchange and minute ventilation), but that psycho-physiological sensations (perceived difficulty breathing and rated perceived exertion) increased significantly. In addition, increases in facial skin temperatures, particularly the lip temperature under the mask when worn, caused a sensation of thermal discomfort that may be the predominant cue that influences reasons for non-use. Finally, the incongruence between physiological and psycho-physiological measures of distress was clearly demonstrated in this thesis. It is apparent that not only is a respirator a complex device, but the micro-climate it produces on the skin surface and the effect this has on an individuals' perception of discomfort, is also enigmatic.

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**TABLE OF CONTENTS**

	Page
ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
ABBREVIATIONS	ix
LIST OF FIGURES	xi
LIST OF TABLES	xii
LIST OF PLATES	xv
CHAPTER 1 INTRODUCTION	1
1.1 Historical Background	1
1.2 The Anatomy of the Respirator	5
1.3 The Use of Respiratory Protection	9
1.4 Physiological Measures	10
1.5 Psycho-physiological Measures	21
1.6 Theoretical Framework for the Thesis	22
1.7 Aim of the Study	25

CHAPTER 2	A SURVEY ON THE USE AND NON-USE OF RESPIRATORY PROTECTIVE EQUIPMENT IN WORKPLACES IN NEW ZEALAND	
2.1	Introduction	27
2.2	Materials and Methods	29
2.2.1	Surveys of Workplaces in the Palmerston North and Horowhenua Region	29
2.2.2	A Survey of a Manufacturing Site in the South Island	31
2.3	Results	32
2.3.1	Palmerston North and Horowhenua Region	32
2.3.2	South Island Manufacturing Site	37
2.4	Discussion	42
CHAPTER 3	LABORATORY STUDIES ON PHYSICAL CHARACTERISTICS OF RESPIRATORY PROTECTIVE EQUIPMENT	48
3.1	Introduction	48
3.2	Materials, Methods and Equipment	52
3.3	Results	56
3.4	Discussion	59
CHAPTER 4	LABORATORY STUDIES ON THE PHYSIOLOGICAL COSTS OF WEARING RESPIRATORY PROTECTIVE EQUIPMENT	66
4.1	Introduction	66
4.2	Materials, Method and Equipment	69
4.2.1	Subjects	69
4.2.2	Experimental Design	70
4.2.3	Experimental Measurements and Technique	71
4.2.4	Environmental Variables	74

4.2.5	Statistical Analysis	74
4.3	Results	78
4.4	Discussion	86
4.4.1	Physiological Factors	86
4.4.2	Possible Sources of Error	90
4.4.3	Psychological Factors	91
CHAPTER 5 LABORATORY STUDIES ON RATED PERCEIVED EXERTION AND RESPIRATOR USE		94
5.1	Introduction	94
5.2	Materials, Methods and Equipment	98
5.2.1	Subjects	98
5.2.2	Experimental Design and Measurements	98
5.2.3	Environmental Variables	99
5.2.4	Statistical Analysis	99
5.3	Results	100
5.4	Discussion	106
CHAPTER 6 LABORATORY STUDIES ON THE EFFECT OF RESPIRATOR USE ON SKIN TEMPERATURE		110
6.1	Introduction	110
6.2	Materials, Methods and Equipment	113
6.2.1	Subjects	113
6.2.2	Experimental Design	113
6.2.3	Measurements and Techniques	113
6.2.4	Environmental Variables	114

6.2.5	Statistical Analysis	114
6.3	Results	115
6.3.1	Subjects	115
6.3.2	Mean Heart Rates	116
6.3.3	Skin Temperatures	117
6.4	Discussion	122
CHAPTER 7 WORK ENVIRONMENT STUDY		127
7.1	Introduction	127
7.2	Materials, Methods and Equipment	131
7.2.1	Subjects	131
7.2.2	Measurements and Techniques	132
7.2.3	Experimental Design	132
7.2.4	Activity Recording	133
7.2.5	Environmental Variables	133
7.2.6	Statistical Analysis	134
7.3	Results	135
7.3.1	Description of Work Activities	136
7.3.2	Mean Heart Rates	140
7.3.3	Skin Temperatures	144
7.4	Discussion	148
CHAPTER 8 GENERAL DISCUSSION		154
8.1	Physiological Variables	154
8.1.1	Heart Rate	158



	viii
8.1.2 Gas Exchange	162
8.1.3 Pattern of Breathing	164
8.1.4 Facial Skin Temperature	167
8.2 Limitations of the Experimental Studies	168
8.3 Psycho-physiological Responses to Respirator Use	169
8.4 Surveys of Respirator Use and Non-use	173
8.5 Studies of the Physical Characteristics of Respiratory Protective Equipment	178
8.6 Implications for Respirator Design and Manufacture	182
8.7 Summary	183
 CHAPTER 9 CONCLUSIONS	 185
 REFERENCES	 189
 APPENDICES	
1. Questionnaire Used in Respirator Usage Survey.	206
2. Pressure Flow Curves for the Eight Respirators Evaluated.	214
3. Description of Ergolab 2 Programme.	219
4. Calibration Data for the Datex Normocap Gas Analyser.	223
5. Description of the Statistical Analysis in the Analyses of Variance of Experimental Designs with Replicate Latin Squares (Munford, 1994).	225
6. Modifications to the Socially Acceptable Monitoring Device (SAMI).	231
7. Facial Skin Temperatures and Heart Rate Data for the 12 Subjects in the Work Environment Study With and Without Wearing a Respirator.	233

## ABREVIATIONS

### Breathing Pattern

$T_i$	=	inspiratory time, seconds
$T_e$	=	expiratory time, seconds
$f$	=	breathing frequency, breaths per minute
$V_t$	=	tidal volume, litres
$\dot{V}_{min}$	=	pulmonary ventilation, litres per minute

### Gas Exchange and Heart Rate

$\dot{V}_{O_2}$	=	oxygen consumption, litres per minute, millilitres per minute per kilogram
$\dot{V}_{CO_2}$	=	the production of carbon dioxide, litres per minute, millilitres per minute per kilogram
$R$	=	respiratory exchange ratio
$\dot{V}_{O_2 \max}$	=	maximal oxygen consumption, litres per minute, millilitres per minute per kilogram
$\% \dot{V}_{O_2 \max}$	=	$(\dot{V}_{O_2 \text{ at work}} / \dot{V}_{O_2 \max} \times 100)$ relative aerobic strain, %
$\%RW$	=	percentage relative workload (mean $\dot{V}_{O_2} / \dot{V}_{O_2 \max} \times 100$ ), %
$HR$	=	heart rate, beats per minute
$HR_{\max}$	=	maximal heart rate, beats per minute
$\%HRR$	=	percentage heart rate range ( $HR_{\text{work}} - HR_{\text{rest}} / HR_{\max} - HR_{\text{rest}}$ ) $\times 100$ , %

### Others

s.d.	=	standard deviation
NS	=	not significant
$T_s$	=	temperature (skin), °C
$T_r$	=	temperature (rectal), °C
$T_d$	=	temperature (dry bulb), °C
$T_{wb}$	=	temperature (wet bulb), °C

%RH	=	relative humidity, %
RPE	=	rated perceived exertion
PDB	=	perceived difficulty breathing
W	=	Watts
W/m <sup>2</sup>	=	Watts per metre squared
SCBA	=	self contained breathing apparatus
P.N.	=	Palmerston North
S.I.	=	South Island
NIOSH	=	National Institute of Occupational Safety and Health
ECG	=	electrocardiogram
CNS	=	central nervous system
MANOVA	=	analysis of variance
SAMI	=	socially acceptable monitoring instrument

## LIST OF FIGURES

	Opposite/ Page
Figure 1.1 Diagrams of air-purifying respirators	6
Figure 1.2 Diagrams of expiratory valves types	7
Figure 1.3 Theoretical framework for the study of the physiological cost of wearing respiratory protective devices	24
Figure 2.1 Length of time respirators worn by P.N. respondents	34
Figure 2.2 Reported use of respirators by P.N. respondents	35
Figure 2.3 Reasons for not wearing respirators by P.N. respondents	36
Figure 2.4 Length of time respirators worn by S.I. respondents	39
Figure 2.5 Reported use of respirators by S.I. respondents	40
Figure 2.6 Reasons for not wearing respirators by S.I. respondents	41
Figure 3.1 Continuous flow resistance measurements for cartridge type respirators	57
Figure 3.2 Continuous flow resistance measurements for dust-mask type respirators	57
Figure 3.3 Pressure-volume curves for cartridge type respirators	58
Figure 3.4 Pressure-volume curves for dust mask type respirators	58
Figure 4.1 Seven point psychophysical category scale used to quantify respiratory difficulty	72
Figure 5.1 Values of rated perceived exertion (RPE) and their verbal descriptions	95
Figure 5.2 Regression lines, formulae and correlation coefficients for the experimental trials	103
Figure 5.3 Environmental conditions during the experimental trials	104

## LIST OF TABLES

	Opposite/ Page
Table 2.1 Summary of information sought in the respirator usage questionnaire	29
Table 2.2 List of industries approached and responding to the questionnaire	32
Table 2.3 Age characteristics of P.N. respondents	32
Table 2.4 Age characteristics of S.I. respondents	37
Table 2.5 Percentage of subjects that perceived their workloads physically hard, moderate or light	44
Table 3.1 Exhalation resistances from the study by Burgess and Anderson (1967)	49
Table 3.2 Resistances for air-purifying respirator (Kemira) from the study by Louhevaara <i>et al</i> (1984)	49
Table 3.3 Regression equations for pressure-volume curves	57
Table 3.4 Expiratory resistances for respirators with twin and single exhalation valves	59
Table 3.5 Dead space and relative weights of respirators evaluated	59
Table 3.6 Comparison of inspiratory and expiratory resistances with earlier studies	59
Table 4.1 Physical characteristics of twelve subjects for physiological costs study	78
Table 4.2 Analysis of MANOVA Latin Square variable by Day for subjects at rest	82
Table 4.3 Analysis of MANOVA Latin Square variable by Run for subjects at rest	83
Table 4.4 Analysis of MANOVA Latin Square variable by Type for subjects at rest	83
Table 4.5 Analysis of MANOVA Latin Square variable by Day for subjects at work	84
Table 4.6 Analysis of MANOVA Latin Square variable by Run for subjects at work	84

Table 4.7 Analysis of MANOVA Latin Square variable by Type for subjects at work	85
Table 4.8 Summary of analysis of variance for replicated Latin Squares using pooled data	85
Table 5.1 Physical characteristics of subjects in Rated Perceived Exertion study	100
Table 5.2 Mean heart rates for subjects at differing levels of external work in RPE study	101
Table 5.3 Mean rated perceived exertion (RPE) values at differing levels of external work, with and without wearing a respirator	102
Table 5.4 Comments from subjects on respirator use	105
Table 6.1 Physical characteristics of subjects in skin temperature study	115
Table 6.2 Mean heart rate data for the five subjects in the skin temperature study, with and without wearing a respirator	116
Table 6.3 Mean facial skin temperature (cheek) with and without wearing a respirator	117
Table 6.4 Mean facial skin temperature (lip) with and without wearing a respirator	118
Table 6.5 Correlation coefficients between heart rate and skin temperature	119
Table 6.6 Environmental variables and subjects observations in the experimental study	120
Table 6.7 Comments reported by subjects in the experimental study	121
Table 6.8 Summary of research involving respiratory protection and the effects on heart rate and skin temperature	124
Table 7.1 Physical characteristics of subjects in work environment study	131
Table 7.2 Subjects work activity, type of respirator and clothing worn, and ambient air temperatures	135
Table 7.3 Summary of work tasks and length of time taken to perform the task	136

Table 7.4 Mean values for cheek and lip temperatures, and heart rates for subjects with and without wearing a respirator, during simulated and actual work activities	139
Table 7.5 Mean heart rate for 12 subjects at work and at rest	140
Table 7.6 Subjects estimated maximum heart rate and index of cardiorespiratory strain	141
Table 7.7 Overall changes in mean heart rate and skin temperature for the 12 subjects	146
Table 7.8 Summary of heart rate data from the present study and the studies by Louhevaara <i>et al</i> (1985)	149
Table 7.9 Summaries of heart rate ratios for the work tasks	150
Table 8.1 Summary of results of studies involving maximal and submaximal work with respirators and the effects on the variables listed	155
Table 8.2 Range of mean facial skin temperatures (lip temperatures) measured in the laboratory and field studies	167
Table 8.3 Range of mean facial skin temperatures (cheek temperatures) measured in the laboratory and field studies	167
Table 8.4 Summary of results of experimental and field studies in comparison to previous research	184

**LIST OF PLATES**

Plate 3.1 Respirator fitted to dummy head for pressure flow determinations	52
Plate 3.2 Equipment used for pressure-flow determinations	53
Plate 3.3 Equipment used for pressure-flow determinations	54
Plate 3.4 J-Rak system showing Validyne amps, Maclab and MacIntosh computer	54
Plate 4.1 Equipment used for laboratory determinations of physiological cost of respirator use	71
Plate 4.2 Equipment used for laboratory determinations of physiological cost of respirator using Ergolab2	71