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Respirators

Temporal Pattern of Adaptation to Respirator Use

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ABSTRACT

Medical determination of who may safely and effectively utilize a respirator for protection against inhaled toxins is often a difficult task. (). Observation of subjects working at submaximal exercise levels is helpful in two circumstances: First, in laboratory research studies designed to elucidate the physiologic adaptation to respirator use, and second, during preplacement examinations for jobs entailing respirator use. Although, several examination schemes () and specific tests have been suggested for respirator medical certification, only actual respirator use permits integration of all of the factors affecting respirator tolerance ().

The current study was performed to determine the length of observation necessary to assess the pattern of a person's physiologic adaptation to respirator use during submaximal exertion. In addition, we examined the time course of physiologic adaptation to determine if there is any indirect evidence of respiratory muscle fatigue, as postulated by some investigators ().

METHODS

Ten subjects participated in a protocol approved by the UCLA Human Subjects Protection Committee. After providing informed consent to participate, each underwent limited medical history study, examination and spirometry. Eight subjects were male; subjects' ages fell between 21 and 40. All had forced expiratory volume in one second (FEV_1), forced vital capacities (FVC) greater than 80% of predicted value () and an FEV_1/FVC ratio greater than 70%. None had clinical evidence of significant acute or chronic cardiopulmonary disease. Each received nominal financial compensation for participation.

A mouth piece and nose clip were used. After a period during which the subject became accustomed to the apparatus, the study began. One experimental section was performed without additional respiratory loading ("unload", UL), and the other was done with a respirator surrogate load (":loaded", L). The load consisted of a single respirator cartridge (MSA Acid Mist, MSA, Pittsburgh) in the inspiratory limb plus a dead space of 300 ml between the mouth piece and the one way valve directing airflow. The order of the L and UL sections was varied between subjects. The study was performed standing or walking on a treadmill.

Each set of physiologic measurements was made during a two minute period. In each section (UL or L), the first set was made at rest after respiratory and heart rates were stabilized (i.e., the subject became accustomed to the apparatus). (Sets 1 and 6 for UL and L respectively). Then, the subject walked on the treadmill

at 3 miles per hour with 5 percent grade for 2 minutes. Sets of measurements were made beginning 2, 5, 10, and 27 minutes after starting exercise (Sets 2-5 for UL and 7-10 for L). A rest period of 10-15 minutes off the apparatus was provided between the two sections. The studies were performed under ambient conditions of temperature and humidity in an air conditioned and heated indoor laboratory. All subjects successfully completed the study.

A Koegel valve (Collins, Braintree, MA) provided one way airflow. Large bore tubing was used on both sides of the valve. Mouth pressure was measured from a tap in the mouth piece using a pressure transducer (Validyne MP-50, Northridge, CA); Validyne carrier-demodulator; and Hewlett-Packard amplifier(Model 8802, Corvallis, OR). Inspiratory and expiratory flow rates were measured with Fleish #3 pneumotachographs (Hewlett-Packard; amplifiers 8805, 8802 respectively).

Oxygen, nitrogen, and carbon dioxide tensions of expired air, sampled as mixed expired and from the mouth piece were measured with a mass spectrometer (Perkin-Elmer 1100, Pomona, CA). Heart rate was determined with a cardiometer (model _____, Hewlett-Packard, _____), and EKG was continuously monitored. Pressures, flows, gas tensions, and heart rate were digitized with analog-to-digital converters (47310A, Hewlett Packard). Pressures and inspiratory flow data were recorded on-line with a microcomputer (HP85, Hewlett-Packard, Corvallis, OR). The expiratory flows, heart rate, and gas tensions were analyzed on-line with another microcomputer (HP825, Hewlett-Packard, Corvallis, OR) using a

previously described program (Sue). Because the latter program does not calculate oxygen consumption accurately with the respirator dead space in place, oxygen consumption was also determined by the mixed expired gas technique (). Only the latter results are reported here; the results in the UL section were similar by the two techniques.

From the recorded data, the parameters shown in Table 1 were calculated using standard techniques (). Several methods were used to assess whether a trend over time was present. First, the data for all subjects were plotted for each variable, and the graphs were examined for any suggestion of time trend in order to choose an appropriate statistical technique (e.g., whether to use a linear or non-linear analytic mode). Second, Analysis of Variance (ANOVA), using subject and set as source of effect was performed (). If the overall ANOVA showed significant ($p, .05$) effects, linear contrast ANOVA was employed to determine if section (UL versus L), set, subject, or set within section had any effect. Third, paired t-tests () were performed between the first and last set during exercise in each section. Furthermore, we made the a priori decision prior to data analysis to perform paired t-tests between the second and last sets if the graphic display suggested differences; we recognized that this might lead to a bias towards finding temporal differences, and we determined in advance to interpret statistical tests in this light. Fourth, we evaluated the possibility of a temporal difference in the increment produced by respiratory loading; this was done by paired t-tests of the

difference: $[\text{Set (10)} - \text{Set (5)}] - [\text{Set (7)} - \text{Set (2)}]$. All statistical hypothesis testing calculations were performed on microcomputers (HP85 and HP 87xM, Hewlett-Packard, Corvallis, OR).

RESULTS

Group mean results for selected variables are shown in Tables 2 and 3. In addition, results of statistical hypothesis testing as defined in Methods section, are shown. As the tables show, there were no significant temporal changes in the physiologic variables after the first few minutes of exercise. Although use of multiple statistical tests, each with a fixed probability of a Type II (Á) error, would bias towards finding significant differences, they were not noted.

Examination of the graphic displays also failed to suggest any pattern of change within the exercise sets for any experimental section (UL or L). Selected respiratory timing parameters and oxygen consumption and heart-rate are shown respectively in Figure 1 and 2. The results of individual subjects are shown in dotted lines, each offset vertically for clarity. The group averages are shown in the solid lines; because analysis did not depend on comparison of group means, group standard deviations are not shown.

The effects of the respirator load per se were also examined. the last ____ columns of Tables 1 and 2 show that several variables were significantly affected. Inspiratory time (T_i) and the fraction of the respiratory cycle devoted to inspiration ($T_i:T_{tot}$) declined due to loading. Notably, oxygen consumption and heart rate were not significantly affected by the respirator load. Expiratory time showed a slight tendency to decrease.

DISCUSSION

This study was undertaken to determine the time course of physiologic adaptation to use of air purifying type respirators. We found that the respirator type load does have significant physiologic effects and that the time course of adaptation is rapid in normal subjects during mild to moderate exercise.

The physiologic loads imposed differs between types and specific model (). However, many, particularly the commonly used air purifying types, have loads similar to those used in this study, being composed of dead space and inspiratory flow resistance. We have used this load in previous studies () and can therefore compare its effects. The effects of the respirator load were similar to those which we and other investigators have found. External inspiratory work and mouth pressure (an indirect reflection of the pleural pressure generated) increased. The subjects adapted respiratory muscles. Inspiration was prolonged in both absolute terms (seconds) and as a fraction of the respiratory cycle. Because many previous studies have demonstrated that simple measurements of flows and peak pressures do not demonstrate the limiting factor, additional parameters must be examined. Adaptation of an appropriate respiratory pattern, which makes respiratory use subjectively "tolerable", may be an essential factor determining who can safely, comfortably, and reliably use a respirator in a field setting. Because this response may be poorly detectable by indirect methods, such as physical examination of the chest or performance of spirometry, actual observation of a

potential respirator use during actual respirator use may be essential.

This study suggests that even a short period of observation will be useful in determining the pattern of a worker's adaptation to respirator use. It is therefore practical to use an observation period as part of the preplacement medical evaluation for jobs entailing respirator use. Several minutes of respirator (or respirator surrogate use) during limited exercise should allow the worker to reach a stable physiologic response, permitting formal (i.e., with precise measurement) or informal (i.e., "using clinical judgement") assessment. Until the single physiologic variable which limits respirator use is identified, a useful strategy for medical evaluation may be to use observation during simulated respirator use with formal physiologic measurements (including respiratory pattern) for those workers noted to have possible abnormal responses or who report significant subjective discomfort.

The absence of progressive change in any of the physiologic parameters suggests that respiratory muscle fatigue or other limiting factor is occurring. If respiratory muscle fatigue did occur, it is likely that some progressive change would have been noted. Our previous work has suggested that each of the variables determined in this study is capable of further change; that is, as subjects in previous studies increased exercise level from submaximal to maximal, the further changes in these variable occurred (). Therefore, since each variable could change during the course of this study, the observed absence of change suggests

that a stable physiologic state had been achieved early in the exercise period. Therefore, progressive fatigue was unlikely to have occurred. Because of the work necessary to overcome the inspiratory resistance, T_i or $T_i:T_{tot}$ might lengthen progressively if fatigue occurred. Peak mouth pressure (P_{max}) or external inspiratory work, indirect measures of the work of the inspiratory muscles, might also have changed.

This study was performed at mild-moderate exertion levels, and the results may not necessarily apply to higher submaximal or maximal levels. In particular, it is possible that inspiratory muscle fatigue might occur at peak exercise, particularly in persons with ventilatory impairment due to disease. In normal persons, however, unloaded exercise is not limited by ventilation (), and the magnitude of loads used to induce experimental muscle fatigue is much greater than used here ().

Therefore, this study has several possible implications: First, research studies of physiologic adaptation to respirators with normal subjects at low-moderate exercise levels may employ relatively short (e.g., 5 minute) experimental periods in a manner analogous to studies of exercise without loads. Second, observation for a relatively short time period may be useful in the "routine" respirator medical certification evaluation. Third, if a subject shows progressive changes (e.g., if the pattern of respiratory adaptation differs between 5 and 26 minutes after starting low-moderate steady exercise), then his/her response may be abnormal, and he/she should be evaluated very carefully ().

Table 1. Parameters Measured

<u>Respirator Timing</u>	<u>Symbol</u>	<u>Units</u>
Respiratory Rate	RR	min ⁻¹
Inspiratory time	T _i	secs
Duty Cycle (T _i :T _{tot})	T _i :T _{tot}	-
Expiratory time	T _e	secs
 <u>Ventilation</u>		
Minute ventilation	V _e	L/min
Tidal volume	V _t	L
 <u>Work of Breathing</u>		
Peak Inspiratory Pressure	P _{max}	cm H ₂ O
Average Inspiratory Pressure	P _{avg}	cm H ₂ O
Pressure-Time Integral/min	PxT	cmH ₂ O·sec/min
Pressure-Time Integral/breath	PxT/Br	cmH ₂ O·sec
Pressure Flow Product/min	PxF	cmH ₂ O·L/sec/min
Pressure Flow Product/breath	PxF	cmH ₂ O·L/sec
 <u>Metabolic</u>		
Oxygen Consumption	VO ₂	L/min STP
Carbon Dioxide Excretion	VCO ₂	L/min STP

Table 2. Period Means

	<u>Unloaded</u>		<u>Loaded</u>	
	<u>Set 2</u>	<u>Set 5</u>	<u>Set 7</u>	<u>Set 10</u>
RR	19.2 p4.60	21.6 p3.70	19.3 p4.70	21.8 p3.50
T _i (secs)	1.44 p0.41	1.27 p0.25	1.66 p0.26	1.47 p0.21
T _i :T _{tot}	43.5 p4.80	44.6 p3.40	51.8 p6.70	52.6 p5.80
T _e (secs)	1.92 p0.80	1.58 p0.28	1.61 p0.58	1.35 p0.33
Peak Inspiratory Pressure (cmH ₂ O)	1.91 p0.31	1.85 p0.26	5.68 p0.82	6.04 p0.91
Average Inspiratory Pressure (cm H ₂ O)	0.983 p0.19	0.941 p0.15	4.73 p3.00	4.75 p2.40
PressurexTime/min	22.78 p0.12	19.6 p0.11	16.9 p0.172	14.1 p0.104
PressurexTime/Breath	1.04 p0.58	0.961 p0.59	6.84 p4.10	6.63 p2.38
PressurexFlow/min (cmH ₂ O L/sec/min)	37.6 (p0.20)	31.3 p0.11	149.8	148.1 p0.51
PressurexFlow/min (cm H ₂ O L/sec/min)	2.05 (p1.50)	1.20 p0.25	5.67 p3.10	7.24 p2.10
PressurexFlow/Breath (cm H ₂ O L/sec)	18.6 (p8.00)	24.6 p5.90	26.3 p0.14	27.60 p7.80
Minute Ventilation (L/min)	1.04 (p0.40)	1.14 p0.23	1.37 p0.41	1.38 p0.37
Tidal Volume (liters)	0.74 (p0.36)	0.93 p0.24	0.88 p0.58	0.90 p0.37
CO ₂ Excretion (L/min)	0.92 (p0.20)	0.89 p0.16	0.98 p0.53	0.87 p0.24

Mean values p standard deviation for illustrative periods are shown.

~~OP~~

(p) will be changed to ±

Table 3. Significant Test Results for
Respirator Load and Time Period

	Paired T-Tests			ANOVA for temporal effect	Overall ANOVA	Effect of LOAD during Exercise
	<u>1st - Last Exercise Set</u>					
	Loaded	Unloaded	Respirator Increment			
RR	ns	ns	ns	ns	**	(ns)
T _i (secs)	ns	ns	ns	ns	**	(**)
T _i :T _{tot}	ns	ns	ns	ns	**	(**)
Te (secs)	ns	ns	ns	ns	**	(ns)
Peak Inspiratory Pressure (cmH ₂ O)	ns	ns	ns	ns	**	(**)
Average Inspiratory Pressure (cm H ₂ O)	ns	ns	ns	ns	**	(**)
Pressure _{ex} Time/min	ns	ns	ns	ns	**	(**)
Pressure _{ex} Time/Breath	ns	ns	ns	ns	**	(**)
Pressure _{ex} Flow/min (cmH ₂ O· L/sec/min)	ns	ns	ns	ns	**	(**)
Pressure _{ex} Flow/Breath (cmH ₂ O· L/sec)	ns	ns	ns	ns	**	(**)
Minute Ventilation (L/min)	ns	ns	ns	ns	**	(**)

Tidal Volume (liters)	ns	ns	ns	ns	**	(**)
CO ₂ Excretion (L/min)	ns	ns	ns	ns	**	(ns)
O ₂ Consumption (L/min)	ns	ns	ns	ns	**	(ns)
End Tidal CO ₂ (mmHg)	ns	ns	ns	ns	**	(**)

ns = not significant; * = $p < .05$; ** = $p < .01$
