American Industrial Hygiene Association Journal

ISSN: 0002-8894 (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/aiha20

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To cite this article: STEVEN SHIMOZAKI , PHILIP HARBER , THOMAS BARRETT & PETER LOISIDES (1988) Subjective Tolerance of Respirator Loads and Its Relationship to Physiological Effects, American Industrial Hygiene Association Journal, 49:3, 108-116, DOI: 10.1080/15298668891379477

To link to this article: https://doi.org/10.1080/15298668891379477

Published online: 04 Jun 2010.

Am. Ind. Hyg. Assoc. J. 49(3):108–116 (1988)

Subjective Tolerance of Respirator Loads and Its Relationship to Physiological Effects

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Subjective and physiological responses to a variety of respiratory loads were measured in a group of 52 normal volunteers during steady, moderate treadmill exercise. Subjective response (SR) was determined with two visual analogue scales developed for this study: EXERT (perceived limitation of exercise duration) and DISC (perceived discomfort). There was a linear relationship between inspiratory resistance and SR. Expiratory and inspiratory resistance loading produced similar subjective effects. Dead space loading, however, produced very little subjective effect on either scale. The study suggests that subjective response can be measured quantitatively and should be considered in respirator design.

Introduction

Respirator use is an integral part of occupational safety practice. Ten percent of workers required to use respirators, however, may have interfering psychological reactions;[1] also, noncompliance with proper use appears common.[2,3] Thus, it is important to determine which components of respirators cause difficulty with respirator tolerance. Difficulty with respirator use can have two possible adverse outcomes: first, the effect of the respirator itself (*e.g.*, insufficient ventilation) and second, noncompliance (non-use and improper use) and the subsequent risk from exposure to hazardous materials.

Studies on respirator tolerance have emphasized the physiological effects of respirator use.[4–11] Considering only the physiology of respirator use, however, may be inadequate in fully understanding actual compliance; one of the main effects of respirators is the adjustment of respiratory pattern.[7–9,12,13] Studies have shown that psychological factors can affect respiratory pattern.[14,15]

This study measures the subjective tolerance of respirator loads with visual analogue scales during moderate exercise with respiratory loads simulating the physiological loads of respirators — inspiratory resistance, expiratory resistance and external dead space — individually and in combination. Physiological data were collected during each condition. The study also compared the effect of individual respiratory loads with those of two actual respirators, a single-use (disposable) model and a full-face mask cartridge (FFMC) model.

Methods

Fifty-two volunteer subjects from the ages of 20 to 57 (37 male, 15 female; mean age = 34.9 ± 8.2 yr) participated. The subjects received a complete description of the study, and they completed Informed Consent Statements in accordance with the Human Subject Protection Committee at the University of California at Los Angeles (UCLA). Each underwent a short medical exam and spirometry testing. All subjects completed the study.

Each subject was assigned randomly to one of five protocols, each consisting of four conditions (listed on Table I). Studies were conducted while the subject exercised on a treadmill (Quinton, Seattle, Wash.) at a moderate rate (1.18 m/sec, 5.0% grade). This level of exercise was chosen so that subjects could finish the protocol and the order of conditions would not affect the results. All protocols had two common experimental periods: no load (NL) and DIM, defined as dead space (DS, 200 mL) plus medium inspiratory resistive (IM) loading (6 cm H_2O/L/sec). In addition each subject completed two additional periods that differed among the protocols.

Each subject wore a noseclip and breathed through a mouthpiece connected to an Otis-McKerrow valve (Collins, Braintree, Mass.) that separates inspiratory and expiratory flow. Resistive loads were built from 10.2 cm (4 in.) diameter plastic tubing with metal mesh, highly compacted gauze and paper filters. The loads were calibrated over a flow range from 0.5 L/sec to 2.0 L/sec and were found to have linear resistances over this range. Three levels of resistance were used, designated low (2.0 cm H_2O/L/sec); medium (5.6 cm H_2O/L/sec); and high (9.0 cm H_2O/L/sec). The medium resistance is similar to that of a standard filter cartridge (Acid Mist, MSA, Pittsburgh, Pa.). External DS were constructed from 2.86 cm (1 1/8 in.) diameter flexible tubing with volumes of either 200 mL (DS) or 300 mL [high DS (DSH)]; the DS was placed between the mouthpiece and the Otis-McKerrow valve. In addition to the simulated respirator components, two actual respirators were used: a single-use (disposable) model (No. 9920, 3M, St. Paul, Minn.) recommended for dust, mist and fumes and a FFMC model (No. 4151, Scott, Lancaster, N.Y.). No filter cartridges were attached to the FFMC; however, the medium resistance filter described above was attached to the inspiratory valve of the FFMC. Experimental conditions were assigned in random order.

Each experimental period was 3 to 5 min in duration. Physiological data were collected for 30 sec after steady state

TABLE I
Protocols of Study[A]

Protocol	Symbol	
Protocol 1[B] (n = 14)		
No Load	NL	
Dead Space + Medium Inspiratory Load	DIM	
Dead Space + Medium Expiratory Load		DEM
Dead Space + Medium Inspiratory Load and Low Expiratory Load		DIMEL
Protocol 2 (n = 15)		
No Load	NL	
Dead Space + Medium Inspiratory Load	DIM	
Dead Space + Low Inspiratory Load		DIL
Dead Space + High Inspiratory Load		DIH
Protocol 3 (n = 5)		
No Load	NL	
Dead Space + Medium Inspiratory Load	DIM	
No Dead Space, Medium Inspiratory Load		IM
No Dead Space, Medium Expiratory Load		EM
Protocol 4 (n = 13)		
No Load	NL	
Dead Space + Medium Inspiratory Load	DIM	
High Dead Space		DSH
High Dead Space + Medium Inspiratory Load		DSHIM
Protocol 5 (n = 5)		
No Load	NL	
Dead Space + Medium Inspiratory Load	DIM	
Disposable Face Mask		DISP
Full-Face Mask Cartridge		FFMC

[A]Dead Space = 200 mL; High Dead Space = 300 mL; Low Resistance = 2.02 cm H_2O/L/sec; Medium Resistance = 5.64 cm H_2O/L/sec; and High Resistance = 9.02 cm H_2O/L/sec.

[B]Order of periods in each protocol was randomly varied.

had been reached. Mouth pressure was measured through a tap at the mouthpiece with a pressure transducer (MP-45, Validyne, Northridge, Calif.) and amplifier (Hewlett-Packard 8802, Corvallis, Oreg.). Inspiratory flow rates were measured with a pneumotachograph (Hewlett-Packard Fleish No. 3; MP-15, Validyne; Hewlett-Packard 8805 amplifier). Data were collected and stored at 50 Hz with a microcomputer (Hewlett-Packard, HP 9816) after digitization (HP 47310A). Data analysis was done off-line on the HP 9816 microcomputer in which software developed for this purpose was used.

Several groups of physiological parameters were measured. Measures of ventilatory work to overcome external resistance include mouth pressure and external pressure-volume work. Mouth pressure parameters include peak inspiratory mouth pressure (PMAXi); the average inspiratory mouth pressure (PAVGi); and the inspiratory pressure-time integral (PxT). Work parameters include the total external inspiratory work of breathing given by the pressure-volume integral (Wtot) and the peak work rate (WMAXi, calculated by multiplying peak inspiratory flow by the peak inspiratory mouth pressure). Respiratory timing parameters include the inspiratory time (Ti), the expiratory time (Te), the total time per breath (Ttot), the respiratory rate (RR, breaths/min), and the duty cycle (DC, the proportion of Ttot devoted to inspiration). Flow parameters include the peak inspiratory flow (FMAXi) and the average inspiratory flow (FAVGi). The two ventilatory parameters are the tidal volume (V_t) and the inspiratory minute volume (Vi). Volumes are expressed in liters adjusted to body temperature and pressure saturated with water vapor (BTPS), flows in liters BTPS/sec, pressure in cm H_2O and time in seconds.

During use of the disposable respirator, respiratory timing parameters were measured with a respiratory inductive plethysmograph (RIP) (Respitrace, Ambulatory Monitoring, Ardsleigh, N.Y.).[16-18]

At the end of each data collection period, the subject completed the subjective visual analogue scales by marking the vertical axis in response to two questions listed: "How long could you continue like this?" (EXERT); and "How uncomfortable is this?" (DISC). The direction for response to increasing difficulty was opposite in the two scales to avoid bias from marking either the top or botton of the scale. The phrases listed along the vertical axis indicated reference points, not specific responses; this created a continuous scale variable measured as the distance of the subject's mark on the vertical axis from the bottom of the scale in millimeters (full scale = 70 mm). Subjects were not allowed to see previously completed scales. Data were analyzed with BMDP statistical programs.[19] Means and standard deviations were provided by the BMDP program 9D, grouped t-tests between means by 1V, and the results of linear regressions by 1R.

Results

Tables II through V summarize the results of the subjective visual analogue scales and the p-values for t-tests between experimental conditions. "EXERT" pertains to the question, "How long could you continue working like this?"— the subjective measure of perceived exertion limitation; more negative values indicate more perceived difficulty. The heading "DISC," measuring subjective discomfort, summarizes responses to "How uncomfortable is this?" with more positive numbers indicating more difficulty. The data have been transformed to represent the difference in rating for each condition from the NL condition for each subject. (Thus, values for NL are, by definition, zero.)

Table II A (upper portion) and Figure 1 show the effect of increasing inspiratory resistive load upon the subjects. The right columns in Table II A indicate the p-values for grouped t-tests between conditions. Increasing inspiratory loads caused increasing intolerance that was reflected on both scales. The DS plus low inspiratory load (DIL) results were quite similar to the NL results, whereas the medium and high inspiratory resistances were similar and were both significantly different from NL and from the low resistance.

Table II B (lower portion) summarizes the linear regression of the subjective response on inspiratory resistance (in cm H_2O/L/sec) for both scales. Results from Protocol 2

TABLE II
Subjective Response to Inspiratory Resistive Loads[A]

	EXERT Delta Mean ±SD	P-Value Matrix NL	DIL	DIM	DISC Delta Mean ±SD	P-Value Matrix NL	DIL	DIM
(n = 15)								
DIL	-1.1 ±9.2	ns			2.5 ±7.7	ns		
DIM	-7.7 ±1.4	*	+		9.4 ±12.6	*	+	
DIH	-8.2 ±14.5	*	+	ns	16.3 ±15.3	**	**	+

Linear Regression of Subjective Response on Inspiratory Resistance Levels[B]

	R	BO	B1	Coeff. T-Test
(n = 45)				
EXERT Delta	0.2577	0.54	-1.061	+
DISC Delta	0.4288	-1.76	1.912	**

[A]Table II shows the subjective responses, measured as Deltas (difference between rating during experimental period from rating during NL period). "P-value matrix" summarized grouped t-tests between periods described. Period symbols are summarized in Table I. Symbols for p-values: ** = p-value ≤ 0.01; * = p-value ≤ 0.05; + = p-value ≤ 0.10; ns = not significant (p-value > 0.10).

[B]Regression model: Delta = BO + B1 (Resistance).

TABLE III
Subjective Response to High External Dead Space Loads[A]

	EXERT Delta Mean ±SD	P-Value[B]	DISC Delta Mean ±SD	P-Value
a. High Dead Space				
(n = 13)				
DSH	0.6 ±6.2	ns[C] (0.88) (DSH versus NL)	0.8 ±8.7	ns (0.86)
b. Dead Space in Presence of Inspiratory Resistance				
(n = 5)				
IM	-20.0 ±14.8		22.8 ±17.7	
DIM	-18.2 ±12.8	ns (0.80) (DIM versus IM)	15.2 ±14.2	ns (0.88)
c. Dead Space versus High Dead Space in Presence of Inspiratory Resistance				
(n = 13)				
DIM	-7.4 ±17.8		7.8 ±17.3	
DSHIM	-9.2 ±7.6	ns (0.64) (DIM versus DSHIM)	13.0 ±11.5	ns (0.25)

[A]Conditions are described in Table I.

[B]Symbols for p-values are described in Table II; p-values in parentheses.

[C]ns = not significant.

TABLE IV
Responses to Expiratory Resistive Loads[A]

	EXERT Delta Mean ±SD	P-Value Matrix		DISC Delta Mean ±SD	P-Value	
a. Without an External Dead Space						
(n = 5)		NL	IM		NL	IM
NL	0.0 ±0.0	-		0.0 ±0.0	-	
IM	-20.0 ±14.8	*	-	22.8 ±17.7	*	-
EM	-18.8 ±11.6	*	ns	19.8 ±15.5	*	ns
b. With an External Dead Space						
(n = 14)		NL	DIM		NL	DIM
NL	0.0 ±0.0	-		0.0 ±0.0	-	
DIM	-8.9 ±13.2	*	-	13.2 ±15.7	**	-
DEM	-5.3 ±11.5	ns	ns	12.1 ±13.2	*	ns
c. Inspiratory Resistive Load with a Low Expiratory Resistive Load						
(n = 14)		NL	DIM		NL	DIM
NL	0.0 ±0.0	-		0.0 ±0.0	-	
DIM	-8.9 ±13.2	*	-	13.2 ±15.7	**	-
DIMEL	-11.8 ±12.7	**	ns	16.6 ±16.3	**	ns

[A]P-value matrix describes p-values for grouped t-tests between indicated periods. Symbols are described in Tables I and II.

(Table I) were used. Both scales showed significant correlation of subjective response with the level of inspiratory resistance; this verifies the tendencies shown in Table II A. DISC values are more statistically significantly correlated to resistance levels than are EXERT limitation values.

Table III shows the effect of the external DS loads individually and in conjunction with an inspiratory load. The large DS (300 mL) does not lead to significant subjective effects. The smaller DS (200 mL), similarly, had no significant effect in the presence of an inspiratory resistance (IM). There appears to be no significant difference between the effect of the high or low DS.

Table IV and Figure 2 show the effects of expiratory resistive loading with and without a DS. Each subject also breathed through an inspiratory load in these protocols. Inspiratory and expiratory loading both produced significant effects which were of similar magnitude. Thus, although response to both inspiratory and expiratory loads differed significantly from the NL period, there was no significant difference between inspiratory and expiratory loading with or without DS present. As shown in Table IV, section c, addition of a small expiratory load [2.0 cm H_2O L/sec, DS plus medium inspiratory load and low expiratory load (DIMEL)] to an inspiratory load produced minimal, statistically insignificant increments in sensation.

Table V and Figure 3 demonstrate the effect of actual respirators from Protocol 5, a pilot study including only five subjects. The disposable (single-use) mask had insignificant effects on both scales in comparison to the unloaded condition; it differed from the FFMC and DIM, but these differences reached statistical significance only for DISC because of the small number of subjects.

Table VI summarizes the physiological data for conditions with inspiratory loading. Symbols for p-values in the right column represent results of unpaired t-tests between all subjects with the stated condition and the NL condition. All inspiratory pressure and work variables increased with inspiratory loading [by DIL, DIM, DIH (DS plus high inspiratory load), and IM (as defined in Table I)] as expected. Also, timing parameters of respiration were affected by inspiratory loading; most notably, the inspiratory time and the duty cycle increased. Respiratory rate declined in the DIM and DIH conditions; the inspiratory flow rate parameters also declined significantly. Thus, physiological response to inspiratory loads can be characterized by prolongation of inspiratory time, decrease in inspiratory flows, and increase of inspiratory work.

Comparison of the physiological data from DSH condition to the NL condition showed results similar to the subjec-

TABLE V
Effects of Actual Respirators (Pilot Data)[A]

	EXERT Delta Mean ±SD	P-Value Matrix			DISC Delta Mean ±SD	P-Value Matrix		
		NL	DIM	FFMC		NL	DIM	FFMC
(n = 5)								
DIM	-11.0 ±16.0	ns	-		2.0 ±6.8	ns		
FFMC	-10.6 ±10.5	ns	ns	-	9.6 ±12.6	ns	ns	
DISP	-0.6 ±15.4	ns	ns	ns	-6.6 ±13.6	ns	ns	*

[A]P-values describe t-tests between indicated periods. Symbols are described in Tables I and II.

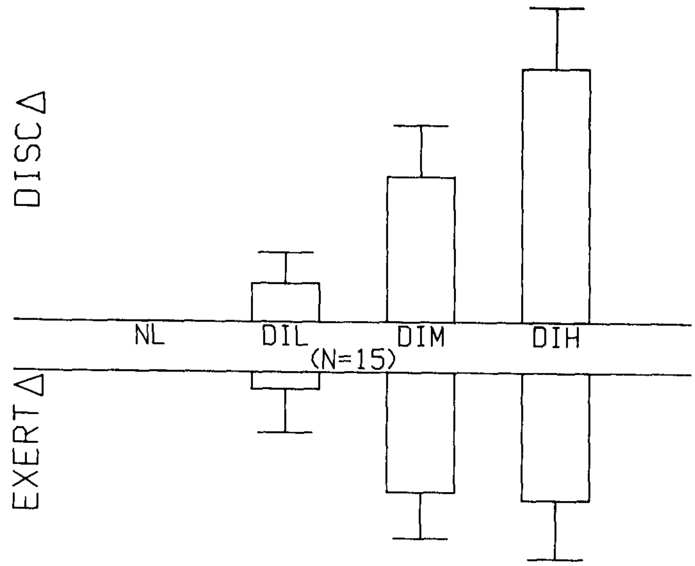

Figure 1 — Subjective responses for the discomfort (DISC) and the exertion limitation (EXERT) scales are shown. Each bar represents the mean for the scale, and each line indicates the standard deviation. No load (NL) by definition is zero for both scales. Increased height of the DISC scale indicates increasing perceived discomfort and increased depth of the EXERT scale shows greater perceived limitation of exertion. Periods are defined in Table I.

tive responses of Table IV. No statistically significant effects upon work or timing were found from large DS. Vi and Vt increased (240 mL for Vt, approximately the size of the added DS) to overcome the external added DS.

The EM and DEM columns in Table VI summarize physiological data for conditions with expiratory resistive loading. In general, expiratory loading caused the duty cycle to decrease and expiratory time to increase. Inspiratory work of breathing was not affected in a significant manner.

The DISP and FFMC columns of Table VI describe the physiological data for conditions with the single-use (disposable) and FFMC respirators. Variables measured with the mouthpiece (*i.e.*, flow and mouth pressure) are unavailable for the disposable respirator. FFMC increased the inspiratory work of breathing, as expected from the inspiratory resistance; duty cycle also increased.

Discussion

Previous studies of respirator effects have emphasized the physiological response;[4-11] however, subjective response also may have important effects. This study, therefore, was performed to develop a means for quantifying subjective response to respirator loads and to determine which respirator load components have adverse subjective effects. Two visual analog scales were developed for this study. One scale estimated perceived EXERT limitation. The second asked, "How uncomfortable is it?" to estimate DISC. Similar scales have been used for exertion and dyspnea scales.[20-23]

As shown in Table II A, standard deviations for similar experimental conditions are large, suggesting there is considerable interpersonal variability in subjective response to respirator loads. The differences among workers in subjective tolerance partially may account for differences in compliance with proper use. Other studies also have demonstrated a wide distribution of subjective response during exercise in normal subjects,[24] though NL breathing was unaffected by subjective response differences. Subjective response, however, may cause significant differences in physiological responses for loaded respiration not seen in unloaded breathing. Some studies have suggested such relationships between physiological and subjective responses during loaded respiration.[24] The magnitude of interpersonal difference in the general population actually may be underestimated in this study because the study group was not selected randomly but composed of volunteers, probably excluding persons with great subjective fear.

Inspiratory and expiratory resistive loads had comparable subjective effects, although most of the measured physiological variables were more affected by inspiratory than by expiratory loading. The physiological inspiratory load response followed an expected pattern of adaptation (increased Ti, decreased flow rate).[7-9,12,13] This suggests a possible physiological basis for inspiratory subjective response. Physiological considerations do not fully explain the subjective effect of expiratory loading, however, as little physiological change was seen. One possible explanation is that the subjects perceived the level of resistance to be the same and assigned equal subjective rating to both types of loading. It has been shown that subjects accurately can judge levels of inspiratory loading. Inspiratory load detection has been hypothesized to occur because of a phase shift between neuronal stimulus of respiratory muscles and actual contraction.[25] (Expiratory load detection is not well understood, but could be caused by a phase shift in relaxation of respiratory muscles and stoppage of muscle stimulation.) Alterna-

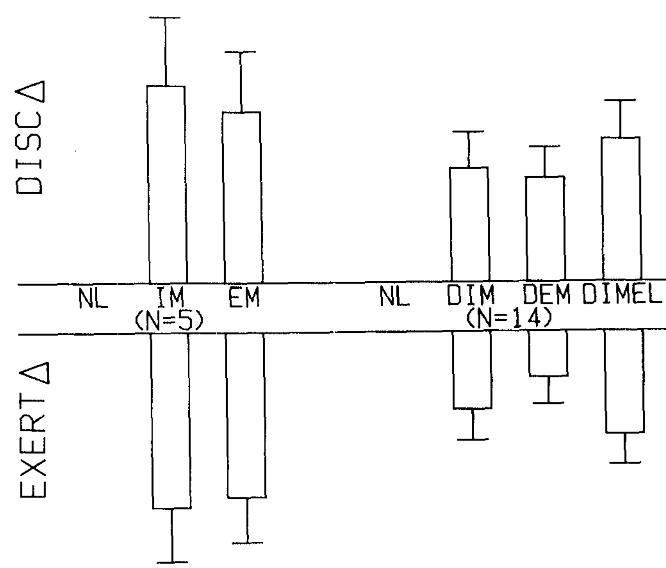

Figure 2 — Subjective responses for the EXERT and DISC scales are shown for experimental periods including expiratory loading. DIM responses are included for comparison. Format of the table from the figure is the same as that of Figure 1.

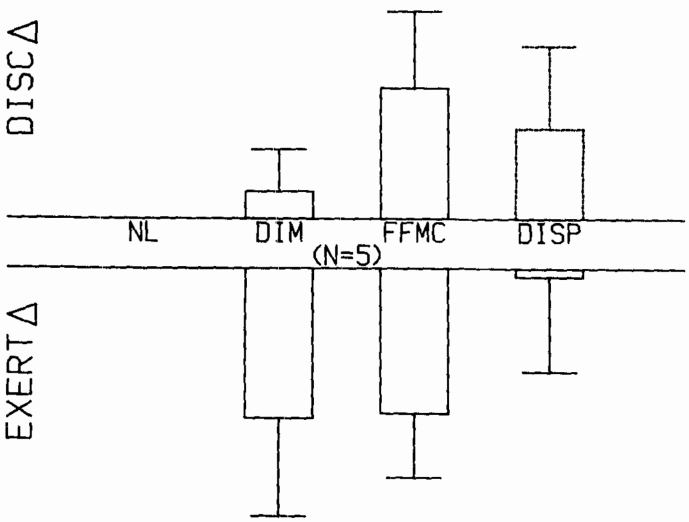

Figure 3 — Subjective responses to the full-face mask cartridge (FFMC) respirator and the single-use (disposable) (DISP) respirator are shown with format similar to that of Figure 1. DIM responses are shown for comparison. The DISC scale for DISP is shown with a dashed line to indicate a negative value.

tively, the effect of expiratory loading may be mediated by changes in a physiological variable not measured in this study. For example, expiratory resistance may lead to increased lung volumes with consequent adverse changes in respiratory muscle length-tension relationships. Such an effect has been demonstrated to occur in asthmatics.[26] In any case, expiratory loading has a significant subjective effect that should not be ignored.

In contrast to resistive loads, DS loading did not produce large increases in subjective intolerance. Large external DS effects are relatively insignificant subjectively. Physiological effects of DS loads can be characterized by an increase of tidal and minute volume and inspiratory flow rate as shown in Table VI.[27] This is consistent with the theoretical and experimental observations that subjective dyspnea is related to a disproportion between ventilatory effort expended by the respiratory muscles and the ventilation achieved. While resistive loading during inspiration would produce increased work of breathing without increased achieved ventilation, DS loading would increase the work or breathing only in proportion to the increase in actual ventilation (to overcome the added DS). Perception of the work of breathing is related to respiratory muscle force rather than from airflow.[25,28,29] Thus, adaptation to DS loads with only limited effects on muscle force is not perceived greatly and has limited subjective effect. Subjective effects might be seen at larger DS than used here, but it is unlikely that respirator design would need to incorporate an effective DS larger than 300 mL.

Respirators impose several types of physiological ventilatory loads, including inspiratory flow resistance, expiratory flow resistance and DS loading.[30] Table VI demonstrates the physiological effects of these load components alone and in combination. The physiological effects found in this study are consistent with those previously noted for respirator-type loading. Specifically, inspiratory resistive loading led to prolongation of the inspiratory phase of the ventilatory cycle (both as absolute inspiratory time and as duty cycle). Expiratory loading, conversely, prolonged expiration. Flow resistive loading during inspiration led to decreases in peak and average flow rates during inspiration. DS loading led to increases in tidal volume and minute ventilation (to overcome the added DS) but did not directly affect respiratory timing significantly. Because the total work of breathing is related largely to inspiratory respiratory work, it is expected that inspiratory loading rather than DS or expiratory loading would have the major physiological effects.

Inspiratory resistance and expiratory resistance both had significant subjective effects that were similar in magnitude. Thus, although physiological effects in increasing the work of breathing were related mainly to inspiratory resistance, expiratory resistance had a significant subjective effect; therefore, expiratory flow resistance should not be ignored in respirator design and certification procedures. External DS loading had little subjective effect, however. For inspiratory resistance, there was a linear relationship between level of resistance and the subjective response (Table II B).

The use of actual respirators in this study was included for the pilot study only. Hence, the small number of subjects participating prevents firm conclusion. It may be seen that use of visual analogue scales, however, is an effective means for assessing the subjective responses to such actual respirators. Further, because subjective response does relate to physiological effect (Table II), use of formal subjective response methods may facilitate study of respirator effects under actual industrial field conditions rather than in laboratory settings. Table VI does suggest that the single-use (disposable) respirator has less subjective adverse effect than does the FFMC respirator with its associated DS and resistance load.

Respiratory function is unique within the body because, although partially automatic, it also can be controlled voluntarily. Thus, respiration can be affected profoundly by subjective factors (*i.e.*, sighing under emotional duress). The physiological change caused by subjective response can reach adverse levels; one well-documented example is hyperventilation syndrome. Lum[31] proposes that hyperventilation is the chronic, subjective response to the sensations caused by hypocapnia. Also, fear of the sensations of dyspnea can cause a vicious cycle of increased dyspnea.[32] This phenomenon is quite relevant to respirator tolerance, as inspiratory resistive loads cause dyspnea.[33,34]

The subjective scales used in this study do not measure dyspnea specifically; reference points are work levels (walking, running uphill, *etc.*) and predicted work duration as opposed to breathless and not breathless. Work level, however, is highly correlated to dyspnea;[23,33,35] also, increasing inspiration load (another correlate to dyspnea) is shown to be significantly correlated to the scales used in this study (Table II). Thus, dyspnea is a major component of the subjective scales.

One may speculate on chronic, psychological response to respirator use. As mentioned before, a vicious cycle can occur because of adverse subjective response to dyspnea. The increased level of dyspnea caused by a respirator may place subjects not normally at risk in danger of an adverse feedback dyspneic response. Asthmatic subjects have been shown to have more neuroticism and anxiety than normal subjects, suggesting that the internal resistance[36] caused by asthma has long-term psychological effects. The external resistance caused by respirator loads could have analogous psychological effects. One study has shown that physiological temporal adaptation to respirators occurs within three days, but subjective response is unchanged after one week.[37] Thus, some regular wearers may develop chronic, subjective difficulty to respirators. Whereas asthmatic patients have no recourse, however, respirator users can alleviate symptoms by noncompliance.

For two reasons, adverse subjective responses also may be hazardous to workers who use respirators very rarely (*e.g.*, for emergency escape only). First, self-selection (by which poorly tolerant workers move to jobs not requiring respirator use) is less likely to occur for intermittent than for regular

TABLE VI
Physiological Effects of Resistive Loading, External Dead Space and Respirators[A]

	Condition										
	NL Mean SD (n = 52)	DIL Mean SD (n = 15)	DIM Mean SD (n = 52)	DIH Mean SD (n = 15)	IM Mean SD (n = 5)	DIMEL Mean SD (n = 14)	DSH Mean SD (n = 14)	EM Mean SD (n = 5)	DEM Mean SD (n = 14)	DISP Mean SD (n = 5)	FFMC Mean SD (n = 5)
Pressures:											
PMAXi	0.95 0.25	3.30 ** 0.86	6.53 ** 2.69	9.76 ** 2.84	7.59 ** 4.48	7.28 ** 2.06	1.26 ns 0.36	2.12 ns 1.39	1.64 ns 1.60	na na na	9.13 ** 4.59
PAVGi	0.61 0.20	2.34 ** 0.46	4.62 ** 1.71	6.85 ** 1.74	5.09 ** 2.69	5.19 ** 1.41	0.87 ns 0.24	0.54 ns 0.31	1.16 ns 1.21	na na na	6.81 ** 3.63
PxT	0.69 0.27	2.98 ** 1.06	7.05 ** 3.81	11.94 ** 5.34	8.24 ** 8.42	1.40 ** 2.19	1.01 ns 0.29	0.57 ns 0.46	1.40 ns 1.90	na na na	8.67 ** 4.30
Work:											
Wtot	0.80 0.43	3.11 * 1.49	6.50 ** 4.54	9.79 ** 6.33	8.97 ** 11.97	6.94 ** 2.64	1.36 ns 0.67	1.61 ns 1.51	0.64 ns 0.58	na na na	9.21 ** 7.34
WMAXi	1.37 0.64	4.19 * 1.52	7.33 ** 4.79	9.98 ** 5.67	9.17 ** 8.71	8.11 ** 4.07	2.11 ns 1.14	2.36 ns 1.46	3.61 ns 3.16	na na na	11.23 ** 8.45
Respiratory Timing:											
Ti	1.22 0.37	1.38 ns 0.41	1.55 ** 0.62	1.85 ** 0.60	1.48 ns 0.63	1.66 ** 0.70	1.28 ns 0.27	1.20 ns 0.34	1.06 ns 0.40	1.68 + 0.94	1.44 ns 0.47
Te	1.61 0.51	1.73 ns 0.63	1.53 ns 0.57	1.76 ns 0.69	1.32 ns 0.34	1.83 ns 0.61	1.64 ns 0.32	1.88 ns 0.61	1.74 ns 0.26	na na na	1.41 ns 0.42
Ttot	2.72 0.82	3.01 ns 1.01	2.94 ns 1.09	3.45 * 1.18	2.63 ns 0.77	3.36 * 1.23	2.81 ns 0.55	2.97 ns 0.90	2.71 ns 0.62	3.66 + 2.14	2.69 ns 0.75
DC	0.45 0.05	0.47 ns 0.05	0.51 ** 0.12	0.54 ** 0.06	0.54 ** 0.08	0.49 + 0.05	0.46 ns 0.03	0.41 + 0.07	0.38 * 0.05	na na na	0.53 * 0.06
RR	23.91 6.63	22.13 ns 7.32	20.50 ** 7.05	19.31 * 6.46	24.08 ns 5.42	19.52 * 5.26	22.05 ns 3.94	21.75 ns 5.22	22.99 ns 4.88	24.22 ns 14.36	23.50 ns 5.45
Flows:											
FMAXi	1.25 0.26	1.12 + 0.18	0.92 ** 0.28	0.87 ** 0.20	0.95 * 0.30	0.97 ** 0.18	1.44 * 0.37	1.43 * 0.25	1.38 * 0.37	na na na	0.99 * 0.33
FAVGi	0.98 0.21	0.89 ns 0.14	0.75 ** 0.22	0.69 ** 0.15	0.76 * 0.20	0.89 ** 0.15	1.15 ** 0.29	1.15 ** 0.18	1.11 ns 0.29	na na na	0.84 ns 0.30
Ventilation:											
Vt	1.20 0.40	1.23 ns 0.4	1.22 ns 10.53	1.28 ns 0.52	1.23 ns 0.90	1.29 ns 0.47	1.44 + 0.37	1.37 ns 0.40	1.25 ns 0.76	na na na	1.19 ns 0.41
Vi	27.02 7.34	24.94 ns 4.45	23.92 * 6.91	22.62 * 6.25	26.04 ns 10.37	23.32 + 3.15	31.25 + 7.50	27.98 ns 3.15	26.14 ns 9.67	na na na	27.62 ns 10.82

[A]P-values represent grouped t-tests between stated condition and the unloaded (NL) condition. Symbols for p-values are described in Table II and physiological variables are defined in the Methods section of the text.

users. Second, added psychological anxiety because of unfamiliarity with respirator use may lead intermittent users to employ maladaptive respiratory patterns (*e.g.*, vicious cycle of dyspnea, hyperventilation).[31,32] Thus, subjective response, in addition to physiological response, should be considered carefully in the medical certification of intermittent workers for respirator use.

The sensation of dyspnea is often a limiting factor in incremental exercise and inspiratory resistance tolerance. Subjective response to factors other than dyspnea, however, may affect respirator tolerance. The weight of the mask, contact with the skin, decrement in vision and hearing, decreased blood circulation around the face and psychological fears (*e.g.*, claustrophobia) are all components not related to dyspnea. (Anecdotally, welders often complain of the weight of the respirator in addition to the protective shield.) A more general discomfort scale may be useful in determination of these factors and the effect of dyspnea. Comparison of the FFMC with a condition of comparable inspiratory resistance and DS (DIM) suggests the presence of other subjective factors. The exertion limitation scale results were similar, but the discomfort scale differed between DIM and FFMC (Table V, Figure 3). Although specific causes of discomfort from the mask could not be determined, differences of discomfort other than that from the physiological loads (inspiratory resistance and DS) and ensuing dyspnea are likely.

One possible adverse outcome of subjective response to components of respirators other than respiratory loads is an adverse change in respiratory adaptation. Hypothetically, a pattern of breathing to avoid fogging in the mask may not be the same pattern best suited to respond to the inspiratory load. Another example might be an effort to speak more loudly to overcome the loss of communication caused by a respirator, increasing the ventilation necessary and the subjective intolerance. One study has shown that the act of speaking itself causes differing respiratory patterns during hypercapnia, which could affect subjective tolerance.[38] Such interactions between respirator components could accentuate adverse subjective effects.

Workers with particularly adverse subjective effects might be trained for proper respirator use to minimize adverse effects (*e.g.*, by prolongation of inspiratory time). Lum[31] has shown that hyperventilators can be treated (trained) effectively. Respirator design, however, obviously must consider reducing components that cause adverse effects regardless of possible worker training. (By analogy, lower back pain can be reduced by proper lift technique, but, where possible, that should not prevent reducing the number or weight of the objects lifted.)

Conclusions

This study demonstrates that inspiratory and expiratory resistance loads have significant subjective effects, and these effects should be considered in respirator design. Conversely, large external DS has little effect. Thus, faced with a trade off between resistance and DS, it appears that the designer should decrease resistance even at the expense of increased DS. This study also suggests that other non-respiratory components of the respirator may have a significant role in respirator tolerance and that a scale of general discomfort can be used to gauge such subjective response and dyspneic effects.

Acknowledgments

The authors thank Myron Lew for programming assistance, Arlene Feingold and Peter Bellin for data collection, Kathy Kelley for scheduling and Leslie Krallis and Nancy Marshello for manuscript preparation.

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27 May 1987; Revised 4 December 1987