Respirator Testing in Non-Clinical Settings:

I. Relative consistency of field versus laboratory measurements.

Philip Harber, M.D., M.P.H.

Paul Hsu, B.S.

John Beck, B.S.

Carol Brown, B.S.

From the Occupational Medicine Branch, Department of Medicine, University of California, Los Angeles.

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Abstract

This study compared the intra-person consistency in measurements of respirator effect when determined in a laboratory and when determined in a field course setting. Results demonstrated that for physiologic parameters (including respiratory timing and ventilatory volumes) as well as subjective responses, field course measurements were at least as consistent as laboratory measurements. Because field measurements are inherently more likely to be work-related than routine clinical testing, their use may become increasingly important due to changes in the standard of practice and legal requirements, such as the Americans with Disability Act. A simple standardized field course may be developed without extensive equipment, and workers may be tested using their routine respirators on this course as a screening procedure to select the small number of workers who require extensive medical evaluation.

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Good medical practice, as well as specific regulations (e.g., United States CFR 1910.134) require that workers be medically evaluated for respirator use. There have been several suggestions about how to accomplish this (ANSI, Raven, Harber, Hodous, Boehleke). In general, these suggest assessing the worker's ability to use a respirator in an industrial setting based upon extrapolation from physiologic testing in a medical clinical setting. Furthermore, there is an apparent paradox: modern respirators are generally well-designed and impose only a limited physiologic load. However, in spite of the findings suggesting that physical ventilatory limitation due to respirators (at sub-maximal exercise level) is generally not limiting, numerous other studies have suggested the presence of poor tolerance among many workers. For example, many have found that they are uncomfortable, and compliance with proper use is relatively low. Thus, there is a paradox between the relatively minimal ventilatory limitation effects and the significant poor tolerance. Many clinicians have

experienced workers who appear to state validly that they cannot comfortably utilize such a device. For example, Wilson ( ) and Raven ( ) have performed extensive studies and suggest that the amount of ventilation which an individual can voluntarily maximally achieve during a fifteen second test period is the best predictor of the ability to use a respirator safely and effectively. Other studies, however, have suggested that ventilatory limitation may not be the only determinant of safe and effective respirator use in the industrial setting. Hodous found that for individuals with mild to moderate respiratory impairment, ventilation limitation as examined in a pulmonary exercise test did not show limitation of respirator use. Our studies () suggest that respiratory control adaptation is another significant adjustment and may predict respirator tolerance. White () and ___(Finland) demonstrated the importance of knowledge and attitude. Morgan found that psychologic factors may be an important determinant in up to ten percent of potential users (). Hence, while there is both intuitive appeal and practical benefit to using a standard clinic administered pulmonary function test to evaluate worksite ability, the increasingly diverse set of factors identified as important indicate the need to carefully evaluate the choice of testing criteria.

All pre-placement medical testing is increasingly subject to stringent work-relatedness requirements. If information is to be used for possible work placement decisions, it must be uniformly acquired and be capable of withstanding increasingly stringent legal tests. For example, the soon to be implemented Americans with Disability Act (ADA) severely restricts placement decision criteria. Because of this, an increasing use of work simulation for placement advice is anticipated.

Furthermore, there is increasing recognition that subjective tolerance differs among workers and that this may affect the likelihood of properly using a respirator in an actual industrial setting. Studies of several groups have shown that subjective response may be measured in the course of experimental studies.

(Raven, Harber, etc.)

Clinic based physiologic tests (e.g., spirometry) have been favored in the past partly because of their purported consistency and objectivity. This study reports short term consistency of physiologic and subjective measures of respirator effect determined under laboratory and field conditions. A closely related study (__) determines whether simple subjective questions can separate tolerant from intolerant workers. Together, these studies suggest that respirator user testing in the worksite (rather than clinic) using subjective (rather than only physiologic) parameters must be strongly considered.

Methods

This study compared the short-term consistency of respirator effects when determined under laboratory and field conditions. A group of __ subjects participated in a protocol in which several experimental periods were repeated. The difference in results between comparable periods in the same individual is a measure of the consistency of response. In the course of the study, experimental loads included those shown in Table 1a. Each experimental period was approximately six minutes in length, and measurements were made in the final minute.

The experimental respirator loads were chosen to be comparable to those of previous studies. Inspiratory resistance was approximately 6 cm/l/s and was composed of a single cartridge (acid mist, MSA, Pittsburgh); deadspace was a 300 ml added volume. To simulate a pressure-demand respirator, a 5 cm positive end expiratory pressure valve (___) was used in the pressure biased breathing (PBB) periods. An actual full-face mask dual cartridge respirator (____ model) was employed with a nasal deflector in place (Fd) and with no deflector (Fn). Methods of measurements have been described in previous reports ( ). Laboratory based studies employed pneumotachographs and pressure transducers during exercise on a calibrated bike ergometer. Field studies were performed using a respiratory inductive plethysmograph (RIP), with

data being recorded on an ambulatory FM tape recorder and subsequently analyzed by computer (Hankinson, Harber).

The field course was adjusted to be comparable in exercise level to the laboratory study by adjusting the field course until heart rates of subjects in the field course were comparable to the same subject on the laboratory bike ergometer. The field course consisted of a walking course at moderate pace, including mild inclines in a shaded area. Checkpoints were established approximately every forty yards with specific times between checkpoints (to assure that the pace was steady).

In addition to the physiologic variables, subjective response was ascertained with two visual analog scales reflecting current level of respiratory discomfort (DISCO) and projected ability to continue working at the current pace with the load in place (EXERT) (Shimozaki, Harber).

This analysis is based on those periods which were repeated in a single day of experimentation for the subject. The differences between the repeated periods for each subject represent the measure of consistency and were calculated separately for the laboratory no-load (LN), laboratory inspiratory resistance dead space (LID), laboratory pressure biased breathing (LP), field no-load (FN), field full-face mask with deflector (FFD), and field full-face mask, no deflector (FFN) periods. Analysis of variance (ANOVA) with repeated measures determined whether location (field versus laboratory) significantly affected repeatability. In addition, a correlation matrix was calculated, correlating the subjects' results for each experimental period. The ANOVA and correlation matrix were developed for each of the variables shown in Table 1b.

Results

The test-retest consistency measures are shown in Table 2. ANOVA demonstrated that there was no consistent difference in consistency between field and laboratory for the physiologic variables under the load or no load conditions. For measurements made during loaded breathing, consistency tended to be greater

during field testing than during laboratory testing; this held true for both physiologic and subjective variables.

However, under the no-load conditions, consistency was greater in the laboratory than in the field for several of the physiologic variables, but not for the subjective variables. When the test-retest difference is expressed as proportion of the mean, the field consistency appears to be improved for the no-load periods as well.

Table 2 also demonstrates that consistency is as good for the subjective variables as for the physiologic variables.

Discussion

This study measured the short-term consistency in physiologic and subjective responses to respirator loads as measured under laboratory and field conditions. Surprisingly, measurements in the field were as consistent as or more consistent than laboratory based determinations. This has significant implications for worker medical evaluation for respirator use. If future studies confirm that test-retest consistency in field settings is at least comparable to laboratory or clinical settings, then a greater degree of more directly work-related testing may be utilized.

There are several reasons for strongly considering use of field tests to complement or replace "routine" pulmonary function tests administered in the clinical setting. First, during moderate exercise with respirators, most workers will not be ventilation limited, and those with severe lung disease of sufficient magnitude to produce ventilatory limits will likely be identifiable by other means. Hence, routine spirometry based tests (e.g., FEV_1, MVV) are unlikely to directly predict respirator effect. For example, Hodous (__), investigating ventilation and other parameters in treadmill exercise by moderately impaired individuals, concluded that during submaximal exercise, additional ventilatory limitation due to the respirator would not preclude the worker from doing a job if he otherwise could perform it. Second, multiple other factors have been shown to be relevant and should be considered (Harber, 1991). Third, subjective factors directly due to the

respirator warrant consideration.

Finally, and most importantly, any clinical test used for evaluation must be demonstrably work-related if it is to be used for work placement decisions. This study suggests that measurements can be made in a carefully designed field course with sufficient repeatability to be useful. A field course may be set out which is explicitly related to the work demands. Tests performed in such a manner may be more defensible on an a priori basis for work relatedness than a measurement of a maximal amount of air expired in one second (FEV_1) or the maximum hyperventilation which the subject can achieve for fifteen seconds (MVV). While treadmills and calibrated bicycle ergometers may be unavailable outside of selected pulmonary function laboratories, nearly any clinical setting or worksite can establish a calibrated field course.

This study also showed that there is good test-retest consistency for subjective variables as well as the physiologic variables. Because the consistency measure was calculated as the difference between two periods, rather than an absolute rating by the worker, it does not simply represent an individual's baseline tendency to complain. (For example, a "complainer" would have a baseline shift from a "non-complainer" but this would not affect the "complainer's" difference from period to period). The stability of subjective responses suggests that such information is potentially useful in clinical assessment for respirator use.

The relatively good consistency in the field setting is particularly notable since the physiologic measurement technique (respiratory inductive plethysmography) is typically considerably less precise than the laboratory based pneumotachograph technique (Hankinson, Harber). It is therefore more likely that the difference in consistency truly reflects the subject response than differences in precision of measurement. This conclusion is further supported by the results for the subjective responses, in which exactly the same method was used in field and laboratory settings.

Subjects may have been more consistent in the field because walking is a more familiar activity than is bicycle ergometer riding, permitting them to concentrate more on the respirator effect in the field setting. Furthermore, the respirator loading, particularly in the absence of an unfamiliar exercise modality, also provided a focus for subjective rating. In the field setting, this was unfettered by attention to the exercise mode per se.

Recent studies as well as the changing legal environment affecting pre-placement and work fitness evaluations warrant reconsideration of the optimal method. One must determine which workers can and will properly use respirators in the course of their usual work. A work simulation test can be developed for convenient delivery in clinical settings or worksites without the need for extensive ergometers and physiologic monitors. The test can be well-standardized and matched to the worker's job (e.g., by matching average heart rates). Evaluation of relatively simple parameters, such as subjective response, heart rate, and respiratory rate while the worker completes the field course with or without his actual respirator, may be particularly useful in selecting the small number of workers who warrant referral for more intensive medical evaluation. Furthermore, measurement of respiratory pattern adaptation, rather than actual ventilatory volumes, could be accomplished relatively easily with a simple modification of the respiratory inductive plethysmography system. (Respiratory timing, unlike volumes and flows, does not require extensive calibration or critical transducer placement). Information presented elsewhere suggests that respiratory pattern adaptation may be particularly important as a determinant of respirator tolerance during submaximal (routine) work.

In summary, this study has demonstrated that both physiologic and subjective measures of respirator effect may be measured during a simulated work field course with as much intra-person short-term consistency as in a laboratory setting. Because field course measurements are more inherently likely to be work-related than are routine pulmonary function testing, use of such simple methods

(testing a worker using his/her routine respirator) may be particularly consistent with current trends in placement procedures.

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TABLE 1. **Experimental Conditions.**

1a. Experimental Periods

FFN	Field, Face Mask, No Nose Deflector
FFD	Field, Face Mask, Nose Deflector
LN	Lab, No Load
LFN	Lab, Full Face Mask, No Nose Deflector
LID	Lab, Inspiratory Resistance with Dead Space
LP	Lab, PEEP

1b. Variables Measured

HR:	Heart Rate (beats/min)
Ti:	Inspiratory Time (secs)
RR:	Respiratory Rate (breaths/min)
Vt:	Tidal Volume (liters)
Ve:	Minute Ventilation (liters/min)
EX:	VAS Scale of how much longer subject can continue (VAS units)
DI:	VAS Scale of discomfort in breathing (VAS units)

TABLE 2. **Differences in repeated measurements: FIELD vs LAB.**

		NO LOAD		LOAD	
		LAB	FIELD	LAB	FIELD
Physiological Variables					
HR	mean	6.2500	7.1898	11.000	1.6125
	std dev	7.2284	8.3579	15.086	2.5236
	Percent Mean	5.34	4.99	8.66	1.14
	F/P	2.74/ns		2.02/ns	
Ti	mean	0.1775	0.2717	0.4876	0.3263
	std dev	0.1576	0.3073	0.6608	0.4404
	Percent Mean	10.44	26.32	29.21	19.52
	F/P	5.09/*		0.49/+	
RR	mean	2.3823	4.7117	2.3793	4.2700
	std dev	1.9099	4.6372	3.4833	3.3781
	Percent Mean	11.62	14.00	10.64	15.29
	F/P	15.66/**		2.06/ns	
Vt	mean	0.1881	0.2650	0.5205	0.3038
	std dev	0.0625	0.1792	0.5445	0.2574
	Percent Mean	12.81	23.68	30.21	18.18
	F/P	2.42/ns		1.38/ns	
Ve	mean	4.8345	3.6667	6.0823	4.8513
	std dev	2.4727	2.9982	9.0460	3.8584
	Percent Mean	17.29	9.53	15.18	10.60
	F/P	11.42/**		0.10/ns	
Subjective Variables					
EX	mean	0.6700	0.3900	0.6167	0.5000
	std dev	0.6482	0.4557	0.8953	0.5461
	Percent Mean	16.54	7.81	17.23	11.44
	F/P	1.46/ns		0.15/ns	
DI	mean	1.1800	0.6800	0.9250	0.3250
	std dev	0.9271	0.8080	0.8646	0.3306
	Percent Mean	42.52	28.69	25.88	12.04
	F/P	1.70/ns		4.42/+	

ANOVAS comparing the absolute value of the difference calculated between two similar Lab periods and the difference calculated between two similar Field Periods were done for Load Periods and No Load Periods. Percent Mean expresses the difference as a percentage of the overall mean for the period. F/P represents the F value and P value (ns = not significant, + = $p < .10$, * = $p < .05$, ** = $p < .01$) comparing the lab and field differences.