Multidomain Subjective Response to Respirator Use During Simulated Work

Philip Harber, MD, MPH
Siddharth Bansal, MD
Silverio Santiago, MD
David Liu, BS
David Yun, BS
David Ng, MD
Yihang Liu, MD, MS
Samantha Wu, BA, BS

Objective: *Evaluate subjective tolerance to respirator use outside of traditional industrial settings by users including persons with mild respiratory impairment.* ***Methods:*** *The response to respirator use (half face mask dual cartridge and N95) was measured during eight types of work activities as well as in an exercise laboratory setting. The 43 research subjects included persons with mild respiratory impairments. Multiple domains of subjective response were evaluated.* ***Results:*** *Mixed model regression analyses assessing the effect of respirator type and task type showed: 1) most tolerated respirator use well; 2) half face mask respirators typically had greater adverse impact than N95 types; 3) multiple subjective outcomes, rather than only comfort/breathing impact, should be measured; and 4) rated subjective impact during work activities is less than in exercise laboratory settings.* ***Conclusions:*** *The results suggest that respirator use may be feasible on a widespread basis if necessary in the face of epidemic or terror concerns.* (J Occup Environ Med. *2009;51:38–45*)

Personal respiratory protection (respirators) has been widely used to reduce inhalation of potentially toxic materials. In the past, these devices have been used primarily in occupational settings with well-recognized specific inhalational hazards (eg, by firefighters, lead foundry workers, asbestos workers); more recently, certain respirator types have been used more widely by health care workers because of concern about potential bioaerosol exposures from infectious patients. Nevertheless, in the future, much more widespread utilization may become necessary because of concerns about extensive epidemics such as H5N1 (avian) influenza or severe acute respiratory syndrome,[1–3] extensive mold exposure due to natural disasters (eg, hurricane Katrina), and fear about biologic/chemical/nuclear terrorism.[4]

One approach to significant public health threats is to "shelter in place," implying that individuals should remain home with windows sealed to avoid potential adverse exposures. Nevertheless, for problems potentially affecting a large proportion of the workforce, such an approach would create widespread impacts. Therefore, an alternative to "shelter in place" is to maintain work activities using respiratory protection.

It is not known, however, whether workers or community members will work safely and effectively with respirators. Most prior research concerning respirators has focused on healthy industrial workers or members of the military. For most industrial applications of respiratory protection, preassignment medical evaluation and self-selection may exclude many

From the Occupational-Environmental Preventive Medicine, Department of Family Medicine (Dr Harber, Dr Bansal, Mr Liu, Mr Yun, Dr Liu, Ms Wu), David Geffen School of Medicine at UCLA, Wilshire, Los Angeles, Calif.; and Division of Pulmonary Medicine, Department of Medicine (Dr Santiago, Dr Ng), VA Greater Los Angeles Healthcare System, Los Angeles, Calif.

Address correspondence to: Philip Harber, MD, MPH, UCLA Occupational Medicine, 10880 Wilshire, #1800, Los Angeles, CA 90024; E-mail: pharber@mednet.ucla.edu.

DOI: 10.1097/JOM.0b013e31817f458b

persons with mild disorders from respirator using positions. Therefore, the current study assesses the ability of a mixed population including individuals with mild respiratory impairments to work safely and effectively using typical respirators. Because prior work has demonstrated significant impact of respirator use on subjective responses, this study evaluates the subjective response to respirator use during simulated work.

Materials and Methods

Potential research subjects were recruited by several methods including alerting clinicians to the availability of the study for their eligible patients, newspaper advertisements, and brochures available in several locations. All subjects underwent a preliminary screening interview and discussion of the protocols; each signed an informed consent statement. Subjects were told the general purposes of the study. Spirometry was performed for subjects who had not recently undergone such testing. Potential subject were excluded if the forced expiratory volume in 1 second (FEV_1) was $<50\%$ of predicted or if they had been recently hospitalized or received urgent care.

Simulation studies used two types of respirators—an elastomeric reusable half face mask (HFM) with dual replaceable particulate filters (Comfo-Elite, Mine Safety Appliance Co, Pittsburgh, PA) and an N95 single use type (8210, 3M, St Paul, MN). Several sizes of each were available as needed for the subjects' facial configurations. Each subject participated on 3 separate days—work simulation with HFM (Sim-HFM), work simulation with N95 (Sim-N95), and pulmonary exercise laboratory.

The work simulation tasks and exercise laboratory periods are summarized in Table 1. The simulations were selected to include a variety of tasks. Some were sedentary (eg, driving) or required only mild exertion (eg, standing casing), whereas others required greater exertion (such as carrying and loading). None, however, required heavy exertion. The exercise laboratory periods were designed to evaluate the effects of individual respirator load surrogates including inspiratory resistance, expiratory resistance, and dead space[5]; in addition, periods included mask only without connection to apparatus and exercise without any device.

Each simulation and exercise period was approximately 8 to 10 minutes in length. Subjects were permitted short breaks ad hoc between each period and a longer break after the fourth. The order of experimental day (ie, pulmonary exercise laboratory, Sim-N95, Sim-HFM) and the order of experimental periods within each day were randomized. Nevertheless, in the exercise laboratory, the three periods with and the three without dead space were done in a block (order randomized).

The exercise laboratory studies were performed using a calibrated bicycle ergometer (Ergometric 800, SensorMedics, West Germany); the work level was set at 40 W, corresponding

TABLE 1
Experimental Periods

Task	Code	Description	Exertion	Body Position	Concentration
Exercise laboratory periods					
	dsre	Dead space + expiratory resistance	40 W	Exercise biking	Low
	dsri	Dead space + inspiratory resistance	40 W	Exercise biking	Low
	dsxx	Dead space added (200 mL)	40 W	Exercise biking	Low
	mask	No load/resistance	40 W	Exercise biking	Low
	nlxx	No mask; no load	40 W	Exercise biking	Low
	rexx	Expiratory resistance	40 W	Exercise biking	Low
	rixx	Inspiratory resistance	40 W	Exercise biking	Low
Work simulation periods					
Bolt	Bolt	Sort bolts into bins	Sedentary	Sitting	Low
Carry rice	Carr	Pick up and deliver buckets of rice	Moderate	Bending, walking	Low
Case	Case	Walk across room, obtain paper, and place into proper bins	Low	Upright, bending	Moderate
Drive	Driv	Simulate driving	Sedentary	Sitting	High
Lego	Lego	Produce towers with plastic blocks following prescribed instructions	Sedentary	Sitting	Moderate
Learn	Lern	Familiarize subject with rating procedures	Low/moderate	Sitting/walking	Moderate
Magnet stand	MagS	Place magnets on boards at proper coordinates based on aural instruction	Low	Above head level	High
Magnet walk	MagW	Walk to obtain magnets, then place on boards at proper coordinates based on aural instruction	Low/moderate	Walking, above head level	High
Store	Stor	Stock store shelves with cereal boxes and juice jugs (includes walking)	Moderate	Walking, bending, above head level	Low

to moderate-heavy work. Subjects were monitored by a physician as well as by electrocardiography. Subjects wore a tight fitting modified half face respirator (Comfo-Elite, Mine Safety Appliance Co, Pittsburgh, PA). Respirator valves were modified for connection to the apparatus. Several respiratory physiologic measures were determined using a respiratory inductive plethysmograph and pressure and flow transducers.

Experimental loads were constructed from respirator filter cartridges for inspiratory resistance and expiratory resistance. The measured resistance of each was approximately 2.10 cm of H_2O/L/s; resistance was determined to be similar at low and high airflow rates (25 and 83 L/min, respectively). Dead space was added by inserting a 200-mL length of tubing between a low resistance flow valve and the subject's mask.

Before initiating the study, subjects received a short learning section about how to perform the subjective ratings. Each subject was shown how to properly wear the respirator and perform a qualitative fit check. This learning period was not included in the formal statistical analyses.

Subjective Response Rating Methods

Subjects were asked to rate subjective responses to 13 subjective response domains: breathing, comfort, concentration, face, hearing, heavy, hot, nose, slippery, speech, vision, wet, work continuation. For each, the subject selected among a set of fixed choices. For the first 12 items, subjects were asked to determine how much the respirator affected the sensation of X, where X is the specific domain queried. They responded with a modified Borg type scale with a range from 6 to 20. Several descriptive terms were used to provide reference (eg, "not at all . . . moderately . . . severely"). Impact on self-assessed ability to continue work was assessed with two questions: "How long could you continue this task with/without the respirator?" Choices were nonlinear: 0, 1 minute, 5 minutes, 15 minutes, 1 hour, 2 hours, 4 hours, 8 hours; responses were transformed to a 1 to 8 scale according to choice selected. A derived variable, WorkReduction was calculated as the difference in category of continuation without respirator minus category with respirator. A full page display, using either paper or a computer touch screen, was used for each domain, with large print and a graphic image to facilitate recognition. In addition, the rating scales and graphics were displayed on a large poster in front of the subjects. Subjective ratings were performed at 4 minutes and at the end of each period.

In general, subjects completed a set of ratings in less than 30 seconds. Subjects were trained in the use of the scales before initiating the study by a "Learning" period. In the Learning period, subjects were familiarized with the rating procedures by verbal descriptions and by performing ratings at rest and during rapid walking in the hallway. (Ratings from this period were not included in the statistical analyses.) Although the research technician avoided any influence on ratings during the simulated work, he or she did provide verbal advice during the Learning periods.

Statistical Analyses

Data were managed with custom interfaces using a relational database (Microsoft Access). Statistical analyses were conducted with Access or with SAS, Inc, Cary, NC (version 9.1) as appropriate. Descriptive measures were described by counts, means, and standard deviations as appropriate. Hypothesis testing and estimation of the effects of main factors (respirator type, task) were conducted using a mixed regression model. In the model, the subjective rating was the outcome variable, and predictor variables included task, respirator type, and their interaction. The model recognized that the measures were repeated within subjects. The analysis was repeated without the interaction term as well. The least squares adjusted mean value for each experimental condition was also calculated by the model, adjusting for the other main variables (ie, the mean for a particular task was adjusted for the respirator types used).

Results

The subjects included 32 men and 11 women. The average age was 48.8 years (standard deviation = 9.8 years); men and women did not differ in average age. The average FEV_1 was 84% of predicted.[6] The group included 11 without known respiratory abnormalities, 7 with chronic rhinitis, 11 with asthma, and 14 with chronic obstructive pulmonary disease.

Exercise Laboratory Studies

Figure 1 summarizes the results for the exercise laboratory studies. The regression analysis demonstrated that there were statistically significant effects of the experimental loads on each of the subjective domains ($P < 0.001$). Figure 1, in which the average values for each experimental condition are shown, suggests that there are three groupings: a) Ratings for both hearing and vision were very similar, and they varied only slightly by period. Furthermore, their ratings were lower than those for the other variables. b) The subjective ratings for speech, concentration, and nose impact appear to form another group. The ratings, particularly for speech and concentration, were similar and show the same pattern of changes across different experimental periods. The magnitude of the impact was intermediate. c) The third group includes the variables breathing, comfort, hot, heavy, face, slippery, and wet. Their values were similar and showed similar patterns of response to the different experimental periods. The ratings in this variable group were generally higher than in the other groups.

The data also suggest that effect of combined loads (dead space plus a resistance) tended to be higher than those with a single load (eg, either resistance or dead space), which

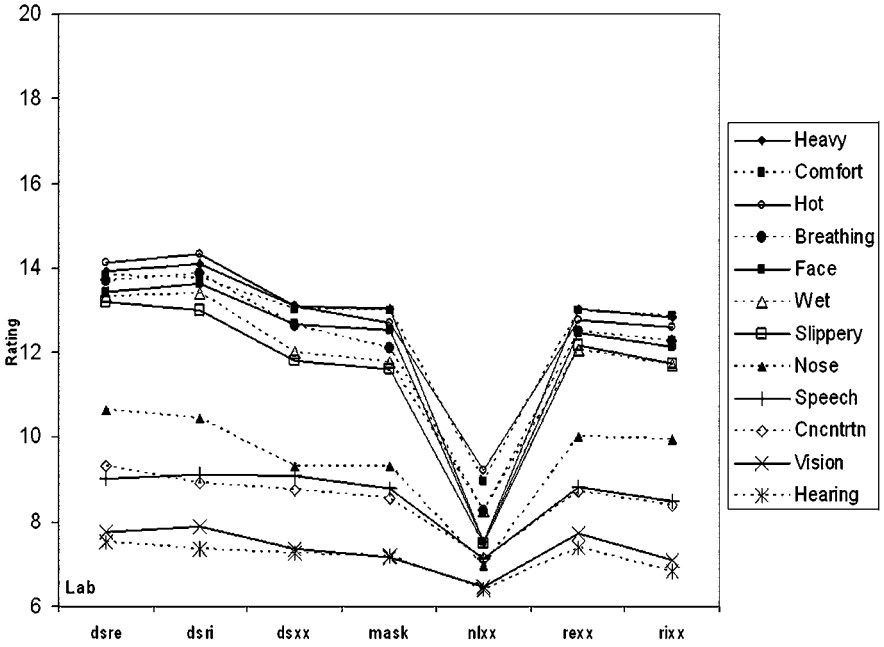

Fig. 1. Exercise laboratory: the adjusted mean value for each experimental period is shown for each of the subjective rating domains. The periods are defined in Table 1. The vertical scale (6 to 20) represents the range of choices available to the subjects.

were higher than the mask only condition. Furthermore, even without any additional load, the mask only period was generally more adverse than unfettered breathing (nlxx period).

Work Simulation Studies

The mean values for each of the rating domains are shown in Table 2. The least squares means adjusted values are shown for each according to respirator type, and task. The average values for each task while using the HFM respirator (Sim-HFM) and for the N95 (Sim-N95) are illustrated in Figs. 2, 3, respectively. There were statistically significant differences between the two respirator types for all domains except wet. For all variables except hot, the HFM respirator was rated as more adverse than the N95.

As was the case for the exercise laboratory studies, there was clustering of response patterns for the various subjective domains. The ratings for vision and hearing were less adverse than for the other variables. The greatest adverse ratings were for comfort, face, breathing, hot, and heavy. Intermediate impacts were reported for wet, slippery, concentration, vision, and speech.

The greatest differences between the two respirator types were for nose and heavy. The HFM device had particularly adverse ratings for these variables as might be expected based on the design.

Regression analyses for both the exercise laboratory and the work simulation sessions were repeated without including the interaction term. This did not lead to any significant differences in results.

The results described thus far reflect the central tendency (eg, mean value). The overall distributions are illustrated by the cumulative distributions shown in Fig. 4. Separate curves are displayed for each of the

TABLE 2
Respirator and Task Effects During Work

	Respirator Effect		Task								Effect Significance		
Domain	HFM	N95	Bolt	Carry	Case	Drive	Lego	Magnet Stand	Magnet Walk	Store	Respirator	Task	Interaction
Breathing	10	9.3	9.4	10	9.8	9.3	9.6	9.4	9.4	10.3	<0.0001	0.000	ns
Comfort	10.6	9.4	9.7	10.4	10.4	9.6	10.1	9.8	9.7	10.4	<0.0001	0.000	ns
Concentration	8.5	8.1	8.4	8.2	8.5	8.4	8	8.2	8	8.7	<0.0001	0.015	ns
Face	10.3	9.4	9.5	10	10.1	9.6	10.1	9.8	9.6	10.3	<0.0001	0.029	ns
Hearing	7.4	7.2	7.3	7.2	7.4	7.3	7.1	7.4	7.1	7.5	<0.014	ns	ns
Heavy	10.6	8.6	9.3	9.9	9.9	9.2	9.7	9.5	9.2	10	<0.0001	0.003	ns
Hot	9.4	9.9	9.3	9.8	9.9	9.4	9.7	9.4	9.4	10	<0.0001	0.016	ns
Nose	10.4	8.6	9.4	9.8	9.8	9	9.4	9.3	9.5	10.1	<0.0001	0.003	ns
Slippery	8.8	8.4	8.4	8.7	8.8	8.4	8.9	8.4	8.4	9	0.002	0.022	ns
Speech	8.1	7.5	7.9	7.7	8	7.7	7.7	7.8	7.6	8	<0.0001	ns	ns
Vision	8.1	7.7	7.8	8	8.1	7.8	8	7.8	7.5	8.2	0.001	0.023	ns
Wet	9.1	8.9	8.6	9.1	9.3	8.9	9	8.9	8.8	9.3	ns	0.016	ns
WorkReduction	1.1	0.9	0.8	1	1.1	1	1.1	0.9	0.9	1.1	<0.0001	0.011	ns

Subjective ratings for each of the rating domains are shown for each simulated task (defined in Table 1 and in Materials and Methods). WorkReduction refers to the subjects' estimate of reduction in duration of task performance due to respirator use (see Materials and Methods). Values shown are least square adjusted means according to respirator type and task. The *P* values for effects of respirator type, task, and interaction are shown in right three columns. ns = "not significant." Results were similar in the model without the interaction term.

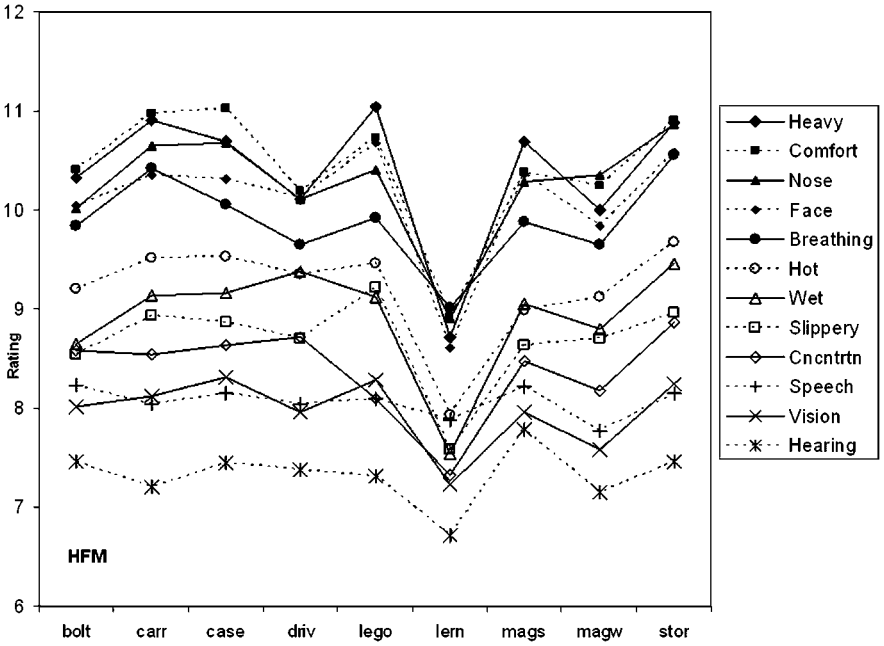

Fig. 2. Simulated work—HFM respirator: the adjusted mean value for each simulated work task is shown for each of the subjective rating domains. The tasks are defined in Table 1. Note that the vertical scale has been truncated in the figure for clarity.

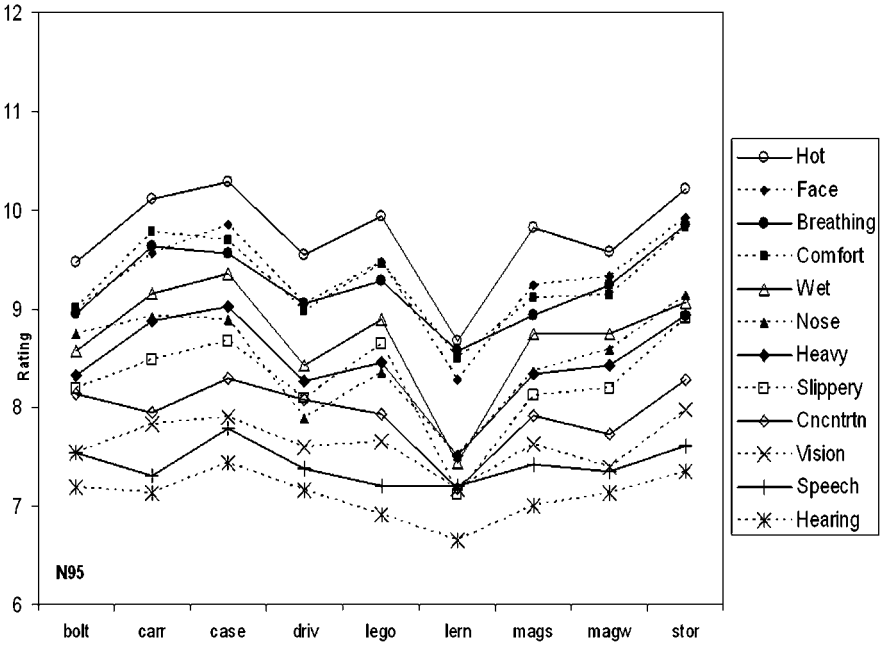

Fig. 3. Simulated work-N95 respirator: the adjusted mean value for each simulated work is shown for each of the subjective rating domains. The tasks are defined in Table 1. The vertical scale has been truncated in the figure for clarity.

domains. The figure is based on average ratings for the work simulation studies, averaged across subjects, task, and respirator type. Each y axis value represents the percentage of scores equal or lower than the corresponding x axis value. The figure suggests three findings. First, there are groupings of variables: One is composed of hearing, speech, and vision, whereas the other grouping includes the other variables. Within each cluster, the overall distributions are quite similar. Second, the adverse impact for the first group is considerably less than for the second group of domains. For example, 75% of the ratings for hearing were less than 7, whereas the corresponding 75th percentile for breathing was 12. Third, the distribution patterns do not suggest that the subject group consists of a small number of highly adversely affected individuals and a separate larger population of minimally affected persons; rather, the distribution appears to be fairly continuous.

Discussion

The study evaluated the impact of two types of respirator use on subjective tolerance in a variety of sedentary to moderate work type activities and in a laboratory setting. The study was conducted in a mixed population including normal individuals and persons with mild upper and lower respiratory impairments. Nevertheless, recognizing that persons with advanced respiratory disease would be unlikely to continue working in circumstances requiring respiratory protection, severely affected persons were not included.

Respirators (respiratory personal protective devices) have been widely used in many industrial settings for protection against inhaled toxins. More recently, health care workers have used respirators, particularly the N95 single use type. After hurricane Katrina, many residents of Louisiana used respirators during their cleanup of molds contaminated homes.[7,8] In addition, during the severe acute respiratory syndrome epidemic, community members in addition to workers[1,2] used respiratory protective devices. The United States, planning for the possibility of H5N1 (avian) influenza epidemic has also considered widespread use of respirators.[3] Therefore, there is a need for assessing the feasibility of a much expanded role of respirators with very widespread use in the event of a major epidemic or widespread perceptions of terrorist threat.

The current study seeks to overcome some of the factors limiting

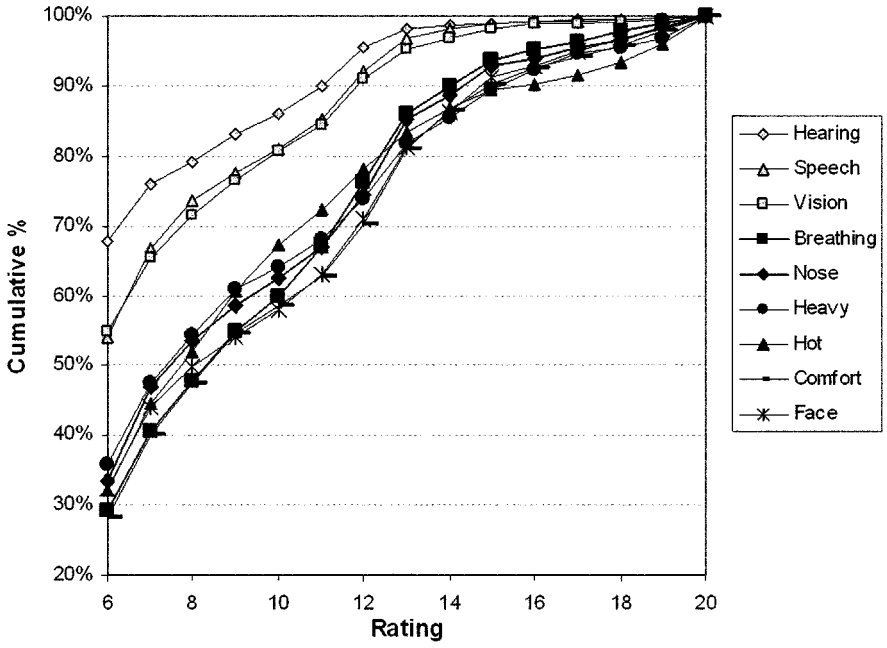

Fig. 4. Cumulative distribution of responses: the figure shows the distribution of subjective rating for each domain. The value on the y axis represents the proportion of ratings that were less than or equal to the corresponding rating value on the x axis.

relevance of prior studies to use under such circumstances:

1. The population of users will differ. Many of the prior studies of the physiologic and subjective impacts of respirator use have focused on healthy workers such as members of the military services, firefighters, and healthy volunteers. Furthermore, the age of our subjects (mean 48 years) was greater than that of most other studies. Although one published study suggested that age per se did not affect acceptability,[9] data applicable to a general population should be derived from a comparable subject group.
2. Most of the studies have not included persons with mild respiratory impairments. Nevertheless, in the event of widespread use, users will include a high proportion of persons with mild respiratory impairments because such disorders are very common (eg, 5% of the general population has asthma,[10] 20% to 25% have rhinitis,[11–13] and 12% has undiagnosed airflow obstruction[14]) and because heretofore healthy individuals may develop mild respiratory symptoms due to infections. A few studies have explicitly focused on persons with obstructive or restrictive abnormalities, generally focusing on physiologic response only.[15–18] A study of coal miners found that workers with respiratory symptoms are more likely to use respirators than those without, whereas FEV_1 did not show a statistically significant relationship to respirator use.[19] Although the number of subjects in each of the health status categories is currently insufficient to compare responses among these subgroups, future analyses with a larger number of participants may foster such comparisons.
3. Many of the jobs which are conducted by the general worker population have lower exertion levels than previously studied. Many respirator effect studies have been conducted at very high exercise levels appropriate for firefighters or military personnel.
4. Personal respiratory protection will be used in the "real-life" jobs rather than in exercise laboratory settings. Although several studies have assessed the comfort of respirator used in actual work settings (eg, anatomy laboratories[20] or work simulations), most have been conducted in research laboratory settings.
5. Earlier studies of subjective tolerance had generally used a unidimensional measure of subjective response (eg, asking about general comfort) or relied on a small set of factors. The current study used a multidimensional approach to assess subjective response. Many of the subjective assessments were based on the impact on breathing only.[21] Other unidimensional measures focused on "comfort" per se.[22] Some combined multiple scales into a single aggregate value for analysis.[23] A few, however, used multiple questions. For example, some distinguished "general discomfort," "unacceptability," and specific symptoms such as respiratory.[20] Impact on six distinct elements of mood during treadmill exercise using respirators was not affected by use of respiratory protection.[24]

Several conclusions may be reached from the current study. First, the subjective assessment methods appear to be valid. This is suggested by the face validity of the results, achieving higher adverse ratings for those activities with greater exercise than those with less exertion requirements. Further, consistent patterns of differences among activities were noted although measured on different days. Similarly, the finding that impact on nasal discomfort and respirator heaviness were particularly great for the HFM respirator is consistent with reasonable a priori expectations.

Comparison of the exercise laboratory and the work simulation data also supports the validity of the results: The subjective ratings for vision and hearing, which were not likely to have been affected, were fairly consistent across the exercise and simulation days, whereas the

other variables showed greater effects. If the subjects were "globally rating" based on general discomfort in the exercise laboratory, then one would have expected to see that the vision/hearing variables would also be affected. In this study, the subjects were able to meaningfully differentiate among the domains of subjective effect.

Second, the data also suggest that respirators of both types are likely to be relatively well tolerated. The magnitude of the adverse impact in most individuals was limited. For example, only 14% rated breathing discomfort higher than the midpoint of the Borg scale even during the moderate exertion level work activities. The cumulative distribution of responses, shown in Fig. 4, does not suggest a bimodal distribution of users, including one subgroup that is extremely sensitive; rather, the distributions appear to be continuous.

Third, the magnitudes of adverse effects reported during the work simulation laboratory sessions were considerably lower than those during the exercise laboratory studies. This was noted across most variables. This suggests that impacts measured in exercise laboratory studies may represent the upper bound, rather than the typical response expected during field utilization.

Fourth, the study directly compared the subjective responses to the two types of respirators; they were selected to be representative of types that are likely to be widely used in nontraditional settings. For nearly all the domains studied, the HFM was rated as more adverse than the N95. This strongly suggests that N95 respirators are likely to be better tolerated and more utilized.

Fifth, results from both the exercise laboratory and work simulation studies suggest that there are several distinct clusters of responses. Although seen most clearly in the figure representing the results of the exercise laboratory study (Fig. 1), a similar pattern is discernible in the simulation studies. The three groupings may be termed "minimally affected," "functional impact," and "physiologic impact." The first – "minimally affected" – reflects the variables of hearing and vision, which had low impact ratings and did not vary among experimental periods. The "physiologic impact" variables included those which are likely to reflect actual physiologic sensations such as work of breathing, facial temperature, pressure on the face, etc. Variables in this group received the highest impact ratings and varied considerably among the experimental periods. An intermediate impact was seen for measures of impact on functional performance.

Factors other than respiratory sensation may be significant. Temperature and humidity, corresponding to one of our indices, affect mask comfort.[25,26] Although this study found little impact on vision, studies have reported impact on vision, probably because they used full face mask respirators.[1,27]

Implications

The study suggests several implications: 1) Respirators can be tolerated fairly well by the general population. Therefore, it may be possible to continue work with respiratory protection rather than relying on "shelter in place" public policies. Nevertheless, tolerance of respirator use is just one of several factors to consider; others include availability of respirators, knowledge of proper use, ability to select the appropriate respirator for the hazard, and demonstration that the respirator type is adequately protective. 2) N95 respirators may be preferable to HFM types even if the protection factor under optimal use situations is higher for the latter. The better tolerance and the greater simplicity of the N95 respirator make it more likely to be actually used consistently by members of the general public in the face of an epidemic or terrorist threat. 3) Workers were able to continue their work using respirators. 4) Assessment of impact on respirator users should consider physiologic and other subjective responses. The subjective assessment must be multidimensional rather than rely on a single rating variable.

Acknowledgments

Supported by Grant # R01 OH-8119 from CDC/NIOSH.

References

1. Khoo KL, Leng PH, Ibrahim IB, Lim TK. The changing face of healthcare worker perceptions on powered air-purifying respirators during the SARS outbreak. *Respirology*. 2005;10:107–110.
2. Loeb M, McGeer A, Henry B, et al. SARS among critical care nurses, Toronto. *Emerg Infect Dis*. 2004;10:251–255.
3. Mitka M. Face masks, respirators might help during pandemic flu outbreak. *JAMA*. 2007;297:2338.
4. Golan E, Arad M, Atsmon J, Shemer J, Nehama H. Medical limitations of gas masks for civilian populations: the 1991 experience. *Mil Med*. 1992;157:444–446.
5. Harber P, Tamimie RJ, Bhattacharya A, Barber M. Physiologic effects of respirator dead space and resistance loading. *J Occup Med*. 1982;24:681–689.
6. Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general US population. *Am J Respir Crit Care Med*. 1999;159:179–187.
7. Cummings KJ, Cox-Ganser J, Riggs MA, Edwards N, Kreiss K. Respirator donning in post-hurricane New Orleans. *Emerg Infect Dis*. 2007;13:700–707.
8. Cummings KJ, Van Sickle D, Rao CY, Riggs MA, Brown CM, Moolenaar RL. Knowledge, attitudes, and practices related to mold exposure among residents and remediation workers in posthurricane New Orleans. *Arch Environ Occup Health*. 2006;61:101–108.
9. Love RG, Muir DC, Sweetland KF, Bentley RA, Griffin OG. Acceptable levels for the breathing resistance of respiratory apparatus: results for men over the age of 45. *Br J Ind Med*. 1977;34:126–129.
10. Arif AA, Delclos GL, Lee ES, Tortolero SR, Whitehead LW. Prevalence and risk factors of asthma and wheezing among US adults: an analysis of the NHANES III data. *Eur Respir J*. 2003;21:827–833.
11. Sly RM. Changing prevalence of allergic rhinitis and asthma. *Ann Allergy Asthma Immunol*. 1999;82:233–248; quiz 248–252.
12. Turkeltaub PC, Gergen PJ. Prevalence of

upper and lower respiratory conditions in the US population by social and environmental factors: data from the second National Health and Nutrition Examination Survey, 1976 to 1980 (NHANES II). *Ann Allergy*. 1991;67:147–154.
13. Jessen M, Janzon L. Prevalence of nonallergic nasal complaints in an urban and a rural population in Sweden. *Allergy*. 1989;44:582–587.
14. Coultas DB, Mapel D, Gagnon R, Lydick E. The health impact of undiagnosed airflow obstruction in a national sample of United States adults. *Am J Respir Crit Care Med*. 2001;164:372–377.
15. Hodous TK, Boyles C, Hankinson J. Effects of industrial respirator wear during exercise in subjects with restrictive lung disease. *Am Ind Hyg Assoc J*. 1986; 47:176–180.
16. Hodous TK, Petsonk L, Boyles C, Hankinson J, Amandus H. Effects of added resistance to breathing during exercise in obstructive lung disease. *Am Rev Respir Dis*. 1983;128:943–948.
17. Raven PB, Jackson AW, Page K, Moss RF, Bradley O, Skaggs B. The physiological responses of mild pulmonary impaired subjects while using a "demand" respirator during rest and work. *Am Ind Hyg Assoc J*. 1981;42:247–257.
18. Harber P, Barrett T, Shimozaki S, Kanter R. Respirator effect in pulmonary impaired subjects. *Am Rev Respir Dis*. 1989;139:A491.
19. Li H, Wang ML, Seixas N, Ducatman A, Petsonk EL. Respiratory protection: associated factors and effectiveness of respirator use among underground coal miners. *Am J Ind Med*. 2002;42:55–62.
20. Akbar-Khanzadeh F, Pulido EV. Using respirators and goggles to control exposure to air pollutants in an anatomy laboratory. *Am J Ind Med*. 2003;43:326–331.
21. Wilson JR, Raven PB, Morgan WP. Prediction of respiratory distress during maximal physical exercise: the role of trait anxiety. *Am Ind Hyg Assoc J*. 1999; 60:512–517.
22. Akbar-Khanzadeh F, Bisesi MS, Rivas RD. Comfort of personal protective equipment. *Appl Ergon*. 1995;26:195–198.
23. Hooper AJ, Crawford JO, Thomas D. An evaluation of physiological demands and comfort between the use of conventional and lightweight self-contained breathing apparatus. *Appl Ergon*. 2001;32:399–406.
24. Caretti DM. Cognitive performance and mood during respirator wear and exercise. *Am Ind Hyg Assoc J*. 1999;60:213–218.
25. Laird IS, Goldsmith R, Pack RJ, Vitalis A. The effect on heart rate and facial skin temperature of wearing respiratory protection at work. *Ann Occup Hyg*. 2002; 46:143–148.
26. Gwosdow AR, Nielsen R, Berglund LG, DuBois AB, Tremml PG. Effect of thermal conditions on the acceptability of respiratory protective devices on humans at rest. *Am Ind Hyg Assoc J*. 1989;50: 188–195.
27. Zelnick SD, McKay RT, Lockey JE. Visual field loss while wearing full-face respiratory protection. *Am Ind Hyg Assoc J*. 1994;55:315–321.