Respirator Impact on Work Task Performance

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Objective: Respirators are used to maintain work performance and protect against inhaled toxins. The study compared the effects of two commonly used respirator classes—dual cartridge half face mask (HFM) and filtering face piece (N95)—upon work productivity.

Methods: 107 volunteers performed eight simulated work tasks when using the HFM and N95 respirators. Tasks included several body positions, exertion levels, and concentration requirements. Objective measures of accuracy and speed were developed for each task. Scores for each task were based on the subject's rank among all subjects.

Results: All subjects were capable of performing the tasks. There were no statistically significant differences between respirator types in either task performance metric.

Conclusions: Productivity impact can be measured effectively and should be considered as part of respirator design testing and when selecting the optimal respirator for a worker.

Respirators are used to protect workers and community members against inhaled toxic and biologic materials. Frequently, however, they serve an additional purpose—allowing continuation of productive activities that would otherwise be precluded. While there has been extensive investigation of the degree of protection afforded by respirators, their physiologic consequences,[1–6] and exercise limitation,[7–13] the actual impact upon work productivity has not been carefully evaluated.[14,15] Impact on accomplishing activities may be relevant in nonoccupational[16,17] as well as workplace settings, particularly if use will be prolonged.

Therefore, the current study considered work productivity as an important effect to be measured in conjunction with assessment of subjective effects and physiologic consequences. The project compared two commonly used respirator types during a variety of simulated work tasks.

MATERIALS AND METHODS

A diverse group of subjects was recruited, including individuals with normal lung function and persons with mild asthma, early chronic obstructive pulmonary disease, and chronic rhinitis. Selection and exclusion criteria have been described elsewhere.[2,18] The research protocol was approved by the institutional review boards of the University of California, Los Angeles (UCLA) and of the Greater Los Angeles Veterans Administration Medical Center. Subjects were recruited from clinics associated with the Greater Los Angeles Veterans Administration Medical Center and the UCLA as well as by newspaper and other advertisements. Participants received a small fee for their involvement.

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DOI: 10.1097/JOM.0b013e3181febc75

Research participants included 71 men and 36 women. Of these, 27 were free of respiratory disorders, 49 had asthma, 15 had chronic obstructive pulmonary disease, and 36 had chronic rhinitis. (Several subjects had concomitant conditions, so the total is greater than the total number of participants). The subjects were not selected from known respirator users.

Each subject participated on three separate days: one session was devoted to a cardiopulmonary exercise laboratory study, and the remaining two were devoted to work simulation tasks. The subject wore an N95 filtering face piece respirator without exhalation valve (3M model 8210, Minneapolis, MN) on one day and a dual cartridge half face mask respirator (MSA, Comfo Elite with P100 cartridges, Pittsburgh, PA) on the other day; in this article, these are abbreviated as "N95" and "HFM," respectively. On each of the work simulation days, the subject completed a series of eight tasks, each lasting approximately 8 to 10 minutes including task set up time. The order of experimental days and the order of tasks within day were randomized. The work was conducted at standard indoor temperatures (ie, 25°C). Subjects had a break after the fourth period, during which they removed their respirators, had access to water, and rested. If the subject felt it was necessary, he or she could briefly remove the respirator between the other periods (eg, to cough), but they rarely did so. Each task included a short set up time (eg, 1 to 2 minutes such as to sit down at the simulated driver device and turn it on), eight minutes of task performance, and completion of the rating questionnaires (typically, 1 to 2 minutes). In addition, each subject spent a few minutes initially donning and adjusting the respirator. Thus, the subjects typically used the respirator for about 1.5 hours each day.

Tasks are summarized in Table 1. The tasks were selected to be comparable to many types of normal work and to be feasible for most individuals without special training. Several were sedentary, such as sorting bolts while seated. Others required standing, such as simulated casing operations; others required moderate exertion, such as carrying buckets of rice or stocking store shelves. Some tasks required considerable attention (eg, sorting and constructing with plastic blocks or simulated driving). Furthermore, some required frequently lifting the hands above head level, allowing investigation of whether the respirator mask would interfere with such activities. Subjects were allowed to utilize their own eyeglasses if necessary. Prior to initiating the study, the subject was introduced to research methods and to each of the tasks. Subjects were told that both the speed and accuracy of performance were important.

Specific performance measures were designed and pilot tested for each task. They were developed to be objective, reproducible, and easy to apply. Two performance scales were devised for each task: Speed reflected the amount of work accomplished, and Accuracy summarized the degree to which the task was completed accurately. Scale ranges varied among tasks. A single research staff member measured performance without interfering with task performance or providing feedback.

The measures are summarized in Table 1. For example, sorting to the bins (Task), counting total number of items placed (Speed), and percentage placed in correct bin (Accuracy).

Other measurements during the studies included respiratory pattern and ventilatory volumes determined with a respiratory inductive plethysmograph (Vivometrics, Ventura, CA). The methods and hardware/software are described in detail elsewhere.[2] The fixed

TABLE 1. Tasks and Rating Methods

Task	Code	Description	Productivity	Accuracy	Exertion	Position/Concentration
Bolt	Bolt	Sort bolts into bins by color and size.	Number sorted	Points deleted for wrong bin or dropping bolts.	Sedentary	Sitting/low
Drive	Driv	Simulate driving with wheel, pedals, and computer video game.	Number of laps completed in specified time	Best lap time; the video game provides a score automatically.	Sedentary	Sitting/high
Lego	Lego	Produce towers with plastic blocks following prescribed instructions.	Combined height of towers created in specified time	Compliance with instructions for bricks: points subtracted for protrusions from flat surface, indentations, or blank core space.	Sedentary	Sitting/moderate
Case	Case	Walk across room, obtain paper, and place into proper bins (simulated mailroom casing).	Number of stacks of papers cased.	Points subtracted for dropping paper or placing in incorrect bin.	Low	Upright, bending /moderate
Magnet Stand	Mags	Place magnet objects on a board at coordinates according to oral (taped) direction in a machine paced mode (requires concentration).	Score reduced each time the subject fails to maintain pace with the system) (comparable to component assembly jobs).	Subtract points for incorrectly placed locations, multiple placements at same coordinate, or carrying more than one item at a time (contrary to instructions).	Low	Above head/high
Magnet Walk	Magw	As above, but instructions require walking to obtain items before placement and coordinates.	As above	As above	Low/moderate	Above head/high
Store	Stor	Stock store shelves with cereal boxes and juice jugs (includes walking).	Number of items placed on shelves	Points are subtracted for dropping items or not following instructions about placement method.	Moderate	Bending and above head level/moderate
Carry	Carr	Pick up, deliver, and transfer buckets of rice. Record each on counter.	Number of transfers completed.	Points subtracted for each rice spill, not recording transfer according to instruction, not transferring materials in complete units.	Moderate	Bending and walking/low

volume method was used for calibration. The subjects also completed a series of subjective ratings concerning comfort, facial conditions, concentration, and other variables. The physiologic and subjective data are summarized elsewhere.[2,18]

Statistical analyses were performed with SAS for PCs (Version 9.1, SAS Institute, Cary, NC). Analyses addressed three questions: (1) For each task, did the respirator type affect productivity? (2) Was there an overall effect of respirator type? (3) How correlated were the two measures of performance?

To compare productivity scores within each task, nonparametric analyses were used since descriptive analyses showed skewed distributions (as most subjects performed well). The Wilcoxon signed rank sum test compared paired scores according to respirator type for each task. A common scale across all the tasks was created as follows: The raw data for each task (including both respirator types) were used to assign rankings for each person-respirator combination. With this analytic approach, an effect of the respirator type could be detected by comparing each individual's ranks by using the HFM and the N95; if the users consistently ranked better with the HFM than the N95, one could conclude that the N95 adversely affected work performance in comparison to the HFM.

The primary analysis was based on all subjects. A secondary analysis was stratified into two groups—subjects with one or more respiratory disorder (n = 80) and subjects free of respiratory disorders (n = 27).

In addition to the scores for individual tasks, composite scores for Accuracy and for Speed were calculated for each subject for the HFM and the N95 by adding the individual's ranks for each of the eight tasks for each of the respirators (ie, there were four scores for each person: HFM-Speed, HFM-Accuracy, N95-Speed, and N95-Accuracy). The composite scores were used to evaluate the overall effect of respirator type using paired *t* tests.

Analyses were further conducted for the degree to which the two measures, Speed and Accuracy performance, were correlated within individuals. To do so, the correlations between raw score for Accuracy and for Speed were determined for each experimental period. The correlation between composite scores for Accuracy and for Speed was also conducted to present the overall correlated degree.

RESULTS

Table 2 summarizes the data and analyses. The directly observed (raw) scores were different for each task, reflecting the fundamental differences in scales used. For many of the scales, the distributions were asymmetric.

Evaluating the individual tasks, there were no statistically significant differences between the HFM and the N95 when analyzed by the paired data nonparametric analysis (Wilcoxon signed rank test).

The composite scores, which considered all data in aggregate, are also summarized in Table 2. For Speed and for Accuracy, there were no statistically significant effects of respirator type.

Figure 1 shows the relationship between the composite Accuracy and Speed scores for each individual, including data for both the HFM and for the N95. In addition, the correlation coefficients between Speed and Accuracy according to task for the raw scores are shown in Table 3. There was only a weak correlation (0.19) between the overall speed and accuracy performance for each individual. In

TABLE 2. Summary of Analyses of Effects of Respirator Type*

	Raw Score				
	N95		HFM		Respirator Effect
Task	Mean	SD	Mean	SD	*P*
Speed					
Bolt	1.91	0.61	1.95	0.67	0.38
Carr	55.67	11.41	54.65	13.27	0.28
Case	4.72	1.17	4.81	1.18	0.47
Driv	2.8	0.94	2.88	0.97	0.58
Lego	167.05	60.46	174.43	68.38	0.15
Mags	99.86	1.46	99.91	0.68	1
Magw	99.72	1.67	99.72	1.8	1
Stor	50.39	11.92	48.61	11.37	0.02
Composite score	3.96	1.01	4.03	1.05	0.48
Accuracy					
Bolt	91.75	16.24	94.19	11.27	0.31
Carr	98.11	7.29	99.15	3.05	0.18
Case	97.43	5.93	95.77	10.31	0.19
Driv	304.48	79.65	301.86	71.24	0.27
Lego	87.09	20.44	90.91	15.9	0.06
Mags	97.95	4.99	97.5	5.18	0.32
Magw	97.22	5.69	97.83	4.83	0.39
Stor	96.69	8.68	96.89	6.81	0.93
Composite score	3.96	0.74	3.99	0.83	0.85

*For each of the simulated work tasks, the table shows the mean and standard deviation of the raw scores for Accuracy and Speed. A separate scoring system was established for each task, as shown in Table 1. In addition, the results of nonparametric comparison of the two respirator types (*P* value by Wilcoxon signed rank test) are shown for each task. The composite scores are based on the sum of ranks (adjusted to 0−1 range) for all tasks within N95 or HFM (half face mask) adjusted; *P* value is based on paired *t* test).

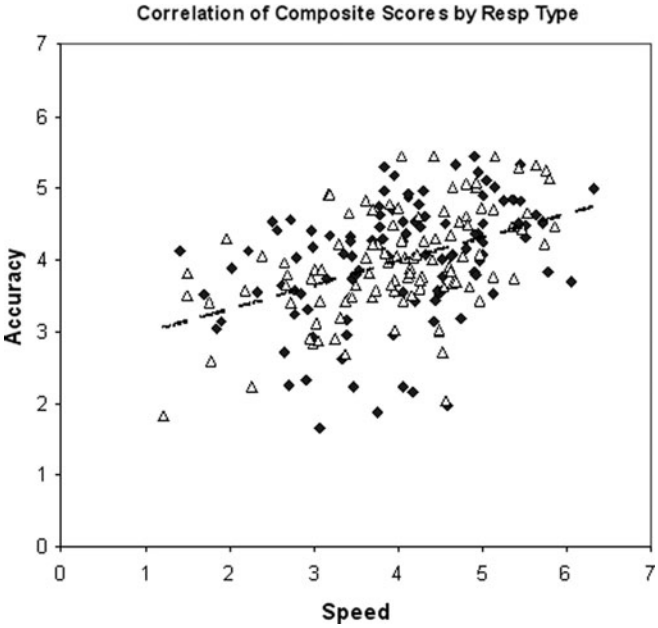

FIGURE 1. Relationship between Speed and Accuracy scores. The figure shows the composite Speed and Accuracy scores on the x and y axes, respectively. Solid diamonds represent HFM, and open triangles represent N95. Scores were derived from subjects' rankings standardized to a 0 to 1 range within task type (ie, are unitless).

TABLE 3. Correlation of Accuracy and Speed Rank Measures for Each Subject*

Task	*r*	*P*
Bolt	0.06	0.359
Carr	0.07	0.303
Case	0.13	0.059
Driv	0.79	<0.0001
Lego	0.19	0.006
Mags	0.34	<0.0001
Magw	0.34	<0.0001
Stor	0.23	0.0009
Composite score	0.43	0.0001

*For each work simulation task and for the composite scores, the table shows the correlation coefficient between the Speed and Accuracy measures for each subject.

addition, there were statistically significant correlations between the two performance measures for five of the eight tasks studied. However, for most of the tasks, the correlation coefficients were relatively small, suggesting that the two scales measure different underlying characteristics.

DISCUSSION

Respirators are used to allow activities to continue despite the presence of potentially toxic or biologically adverse agents in the user's ambient air. The study therefore compared the effects of two commonly used respirator types upon work performance while conducting a series of work activities.

The simulated tasks included a range of work activities comparable to those in most work situations.[19–21] The simulated work included both sedentary and low-to-moderate levels of activity. In addition, tasks differed in the degree of concentration that was necessary. The work was selected to be representative of many common situations in which respirators would be employed.

Overall, the results show that the use of a respirator did not prevent carrying out the tasks. Furthermore, since the users were naive to respirator use and to the tasks, longer-term use might lead to adaptation and learning. The project compared the effects of two different types of respirators rather than investigating the difference between respirator use and nonuse. As respirator use increases, the focus of research should shift from finding a basis for excluding some workers from respirator use to comparing different types of respirators to select the optimal respirator for the worker and work situation. Of course, the nature and magnitude of the hazard must be the primary determinants of the necessary protection factor.

In the study, there were no significant differences between a dual cartridge half face mask respirator and a filtering face piece N95 type. The study did not directly compare either type to work with no respirator use at all. The study compared two respirators rather than perform two smaller studies that each compares one type to no use; this research design increased the power to address the primary question: Assuming respirator use is mandatory, which type is better?

Similarly, the tasks were each relatively simple. Additional productivity factors may apply to more complex work such as health care. Nevertheless, the results indicate that employers should not discourage appropriate respirator use for fear of productivity impact.

The current study complements the earlier studies by directly evaluating work performance rather than surrogate measures such as maximal exertion. Other studies have considered the impact of respirator use upon work performance in high exertion work (eg, military work or firefighting)[3,8,22–24] or at high exertion in research laboratory settings.[25] Studies that measure work performance as the ability to conduct heavy physical exertion may not be directly applicable to the low/moderate exertion typical of most applications.[20,21] For heavy self-contained breathing apparatus type equipment, physiologic limitation due to the device' s weight may be at least as significant as impact upon productivity.[13,26]

In addition, several studies have examined the impact of specific respirators upon specific job activities. These activities include automobile encapsulating,[27] anatomy laboratory work,[28] and emergency medical procedures.[15] The magnitude of perceived health threat may change perceptions about the acceptability of a respirator (eg, the Severe Acute Respiratory Syndrome, SARS, epidemic led to increased acceptability of powered air purifying respirators.[29]

Studies have also examined whether respirator use interferes with several occupational functions. For example, they have addressed interference with telephone communication,[30] hearing,[31] cognitive processing,[32,33] and vision.[34] In one study, performance in a laboratory test reaction time was improved by respirator use, possibly due to the arousal caused by using the device.[14]

The current study has several limitations. Subjects were encouraged to use their own eyeglasses, and therefore the results cannot be directly extended to full face masks that would interfere with such use. The study did not evaluate if respirator use interferes with the ability to communicate by talking.[10] In addition, each task was of short duration, and therefore longer-term adaptation to respirator use did not occur. However, although each task was brief, in aggregate, the study volunteers used the respirators for an extended time; therefore, a cumulative adverse impact upon productivity would have been reflected in the overall composite scores and appears unlikely. Since participants in this study were generally naive both to respirator use and to the specific tasks, the observed results represent an upper bound to adverse impact upon work performance because the opportunity for adaptation was limited. It is hypothetically possible that the measures of productivity were too insensitive to detect small differences in productivity according to respirator type. The performance metrics were selected to be as objective as possible to reduce the likelihood that the technician might introduce bias.

While the two respirator types in this study did not have detectable differences, more extensive study of other respirator types may identify significant differences among respirator designs. Therefore, assessment of respirator designs should include measures of productivity impact. In the future, development of a standardized set of work tasks for respirator testing might be considered as part of the respirator certification process. Rather than using the full set of tasks, a standard set might be limited to only 3 to 4 tasks. The comparability of findings across tasks suggests that this simplification is reasonable. Because of their limited correlation, both accuracy and speed should be ascertained. This is particularly important because respirators will be increasingly used by workers and community members in a wide variety of circumstances.[16,35] Understanding the determinants of proper use will help improve the overall protection afforded to workers and community members.[6,36]

ACKNOWLEDGMENT

This study was supported by grant R01 OH-8119 from the Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health.

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