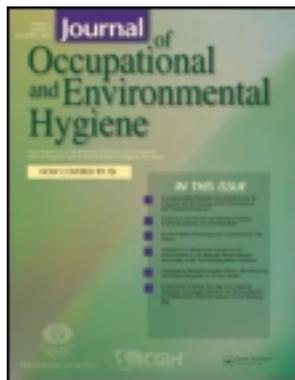


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Component Analysis of Respirator User Training

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Respirators must be properly used to be effective. In an experimental protocol, 145 subjects were trained and then observed donning and doffing respirators. Filtering facepiece and dual cartridge half face mask types were studied. Subjects were then tested for knowledge and for proper performance using video recording analysis. Knowledge tests showed adequate learning, but performance was often poor. Inspection, strap tension (half mask), seal checking, and avoiding mask contact during doffing were particularly problematic. Mask positioning was generally well done. Correlation between knowledge and performance for specific items was generally poor, although there was a weak correlation between overall knowledge and overall performance ($\rho = 0.32$) for the half mask users. Actual unprompted performance as well as knowledge and fit-testing should be assessed for user certification. Respirator design approval should consider users' ability to learn proper technique.

Keywords respiratory protection programs, donning/doffing, personal protective equipment training

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INTRODUCTION

Effective use of personal respiratory protective devices (respirators) depends on correct use by workers and community members seeking protection. Compliance with protection practices includes both the decision to use the device and adherence to appropriate procedures so that using the device will be effective. Several studies have demonstrated that workers frequently do not even attempt to use the device.^(1–10) There have been fewer efforts to validate proper respirator use.

Most workplace protection programs include training. The U.S. Occupational Safety and Health Administration (OSHA) requires mandatory training. Such programs use several modalities, often one-on-one or small group oral presentations. Frequently, there is little confirmation that learning has actually occurred. These training programs occasionally include

knowledge tests, often immediately following the educational effort.⁽¹¹⁾ The worker may undergo respirator fit-testing with the assumption that incorrect technique will lead to failure. Such tests often focus on mask leak assessment rather than user performance characteristics. To achieve a fit, the test supervisor may even prompt the worker to place it properly. Hence, the actual performance capability of the worker is generally not tested directly.

Respirator use is a multi-step process. This includes inspecting the device to ensure its physical integrity, donning it correctly, making adjustments for a secure facial seal, confirming the fit, and properly removing it. Little information exists concerning which component requires the greatest attention in training endeavors to maximize safety.

Proper respirator use training is particularly unlikely when circumstances instigate a rapid surge in number of users, when individuals use the device in non-occupational settings, and when well-trained occupational health professionals are not available (e.g., in small business units). This article reports initial results of a research study evaluating the efficacy of training methods which do not necessitate the active presence of a trained professional. The study assesses proper use after simple respirator user training. Since knowledge alone (e.g., measured by written tests) does not guarantee protection; the study measures both knowledge and performance outcomes. In order to guide training emphases, the study gauged performance based on several distinct components of proper respirator use.

METHODS

The study was conducted at the University of Arizona and sponsored by Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health (CDC/NIOSH). The university Institutional Review Board approved the protocol. Researchers informed subjects that the study was primarily designed to assess respirator use training methods.

Subjects were recruited by several methods, including posting in community settings, e-mails to community

organizations, and Internet/Web announcements. Recruitment targeted groups unlikely to use respirators on a regular basis. Eligible participants were 18–70 years of age and had no medical conditions precluding participation. Only English speakers were included because of the training method. Once recruited, each subject completed an informed consent statement.

Self-administered respirator user training programs were developed separately for half face mask dual cartridge respirators (HFM) and filtering facepiece respirators (FFP). The training programs were constructed in a stepwise fashion. First, published literature and existing training materials were reviewed. Second, major educational points (EP) were delineated. For each EP, three corresponding components were designed: (1) The specific educational content (e.g., when respiratory protection is appropriate, need for inspection), (2) a written knowledge assessment question using a combination of words and pictorial representations, and (3) a behavioral observation item. For example, proper strap placement for the FFP required a complementary knowledge test question asking the subject to differentiate pictures of the FFP in use, some of which depicted incorrectly crossed straps. During the actual donning process, crossing the straps was an associated behavioral observation item. Third, the specific educational message for the EP was textualized. Fourth, without reducing the educational content, potentially ambiguous knowledge test questions or behavioral observation items were eliminated, as well as those resistant to consistent coding.

Three different educational media contained the finalized training content. To the greatest extent possible, the specific text and images were consistent across all three. These media included: (1) printed training booklet; (2) non-interactive video viewed on a computer monitor; and (3) computer-based training (CBT). CBT was an interactive program combining text, images, and video clips and containing computer-interface interactions and short quiz items, that were intentionally different from those used in the subsequent knowledge test.

The printed booklet was 24 pages for both mask types, and participants took 9.6 and 8.7 min, respectively, to complete reading the HFM and FFP booklets. The corresponding video lengths were 9.2 and 7.4 min for HFM and FFP. Subjects typically took 17.0 and 14.5 min to complete the CBT for the HFM and FFP. Each subject completed the training without staff assistance.

Table I briefly describes the knowledge test and coded observational items. A single staff member coded recordings of subject performance after extensive pilot testing to facilitate consistency. A 4-point scale was employed in which major errors occasioned scores of 3 (definite but minor oversight) or 4 (major deviation from training). Results exclude video segments that did not allow clear visualization. Participants were randomly assigned to an educational medium-type and either a dual cartridge half face mask (HFM) respirator (ComfoClassic, SOFTFEEL, MSA, Pittsburgh, Pa.) or an N95 filtering facepiece (FFP) respirator without exhalation valve (1860 series, 3M, St. Paul).

After completing the training, subjects selected an appropriate mask size without staff assistance; if it fit poorly, they could choose an alternative size. (Three sizes of the HFM and two of the FFP were available) The subject proceeded to don and doff the selected respirator and undergo quantitative fit-testing using ambient aerosols (PortaCountPro Plus, Shoreview, Minn.). Staff completed infrared and standard digital imaging for each outfitted subject, averaging approximately 5 min per subject. Participants executed a series of simulated work tasks over approximately 30 min. These tasks included sedentary activities (e.g., card sorting) and more moderate activity such as loading and carrying 4.4 kg buckets of rice for 5 min.

Participants then repeated the doffing and donning procedures while being video recorded. Performance analyses depend on this last occurrence of donning/doffing the respirator. Staff recorded with a camcorder in a single plane (Canon ELURA100, Ota Japan, or Sony Handycam HDR-CX190, Tokyo, Japan). Subjects knew about the video recording, but it was accomplished as unobtrusively as possible. Research staff did not influence the process. The knowledge test was then administered using a multiple-choice paper format. Staff later enumerated correct answers.

Data were managed in a relational database (Microsoft Access, Redlands, Wash.). Statistical analyses were conducted using SAS for PC (version 9.3, Cary, N.C.). Continuous variables were compared by t-tests or Kruskal-Wallis tests as appropriate; categorical variables were assessed using chi-square tests. Relationships between performance and knowledge measures were assessed with the Spearman nonparametric correlation test.

Subjects were characterized in several ways. The subject was considered a “respirator user” if he/she ever used a respirator at least 5 days per year or currently uses a respirator. For the knowledge test, the proportion correct for each individual item was determined; in addition, a composite knowledge score (TotalScore) was calculated as the sum of correct answers for relevant items. A composite performance score (Perf.total) was calculated from the four point performance codes, with high scores representing good performance; the scores were adjusted to a 100-point maximum.

RESULTS

Table II summarizes the characteristics of the participants. Sixty-nine subjects used the FFP, and 76 used the HFM. Most subjects had very little prior experience or training; only 16% reported any prior respirator use, most of which was minimal. The participant ages spanned 18 to 65 years (mean = 33 years). No statistically significant differences existed between FFP and HFM users for any of the variables in Table II.

Results compare those assigned to FFP and HFM devices. Tables III and IV present the average knowledge and performance values and the “percentage unacceptable” for

TABLE I. Knowledge and Performance Evaluation Items^A

Knowledge Test Respirator Type			
FFP		HFM	
K1 Respirator types		K1 Respirator types	
K2 Re-usability		K2 Re-usability	
K3 N95 applicability		K3 N95 applicability	
K4 Mask Selection criteria		K4 Mask Selection criteria	
K5 Use of poorly fitting mask		K5 Use of poorly fitting mask	
K6 Beards		K6 Beards	
K7 Straps & nose clip		K7 Strap placement	
K8 Cross straps		K8 Cartridge missing	
K9 Facial positioning of mask		K9 Facial positioning of mask	
K10 N95 use situations		K10: HFM use situation	
K11 Seal check need		K11: Seal check need	
K12: Seal check performance		K12: Seal check performance	
K13: Seal check importance		K13: Seal check importance	
K14: Removal steps		K14: Removal steps	
KnowTotal: Total Score		KnowTotal: Total Score	
Performance Observation—Donning			
FFP		HFM	
Code	Measure	Code	Measure
Insp_Gen	Inspected mask- general	Insp_Gen	Inspected mask-general
Insp_Face	Inspect face piece	Insp_ValveIn	Inspiratory valve inspected
		Insp_ValveOut	Expiratory valve inspected
		Insp_ValveCover	Valve cover: remove and replace
Strap_Straight	Straps straight, not twisted	Strap_Order	Proper strap order
		Strap_Straight	Straps straight, not twisted
		Strap_Tension	Adjusted strap tension
Nosepiece	Bent metal nosepiece		
Mask_Center	Mask centered properly		
Mask_Stable	Not move mask on face after placement	Mask_Stable	Not move mask on face after placement
Mask_Symmetric	Symmetric, not twisted		
Mask_Obstruction	Obstruction	Mask_Obstruction	Obstruction
Mask_Correct	Appears correct	Mask_Correct	Appears correct
Seal_Check	Checked seals	Seal_In	Inspiratory seal check
		Seal_Out	Expiratory seal check
Performance Observation—Doffing			
FFP		HFM	
Code	Measure	Code	Measure
DOF_Order	Proper strap order	DOF_Order	Proper strap order
DOF_Touch	Not touch cartridge/filter media	DOF_Touch	Not touch cartridge/filter media
DOF_Disposal	Disposal	DOF_Disposal	Disposal
Performance Observation—Summary Scores			
Perf_Total	(Calculated score based on relevant variables-select later)		
Major_Errors	(Number of items with a score of 3 or 4)		

^AThe table summarizes the measures of knowledge and observed performance. Codes in this table are used in the subsequent tables and figures. All observational results are based upon the second set of observations (approximately 2 hours after training). FFP = filtering facepiece respirator (N95); HFM = half face mask dual cartridge respirator.

TABLE II. Participant Characteristics^A

Number of subjects		All Subjects 145	FFP 69	HFM 76	
Age	Mean (sd)	32.96 (13.27)	34.12 (13.34)	31.89 (13.20)	ns
	Range	18–65	18–64	18–65	
Gender	Female	85 (59%)	43 (60.6%)	42 (58%)	ns
Smoking	Current	9 (6%)	5 (7.0%)	4 (6%)	ns
	Former	29 (20%)	17 (23.9%)	12 (16%)	
	Never	106 (74%)	49 (69.0%)	57 (78%)	
Occupational status	Not working	16 (11%)	9 (12.9%)	7 (10%)	ns
	Working	82 (57%)	41 (58.6%)	41 (55%)	
	Student	36 (25%)	16 (22.9%)	20 (27%)	
	Other	10 (7%)	4 (5.7%)	6 (8%)	
Education	High school or less	15 (10%)	6 (8.6%)	9 (12%)	ns
	Some college	70 (49%)	38 (54.3%)	32 (43%)	
	College graduate	27 (19%)	12 (17.1%)	15 (20%)	
	Postgraduate	32 (22%)	14 (20.0%)	18 (24%)	
Language	Primarily English	108 (75%)	56 (78.9%)	52 (70%)	ns
	Other	37 (26%)	15 (21.1%)	22 (30%)	
Respirator Experience					
Current user	Yes	20 (14%)	11 (15.9%)	9 (12%)	ns
	No	124 (86%)	58 (84.1%)	66 (88%)	
Current frequency	Often	5 (25%)	3 (27.3%)	2 (22%)	+
	Occasional	4 (20%)	4 (36.4%)	0 (0%)	
	Never	11 (55%)	4 (36.4%)	7 (78%)	
Ever used > = 5 days/year	Yes	13 (10%)	7 (10.5%)	6 (10%)	ns
	No	113 (90%)	60 (89.6%)	53 (90%)	
Respirator user		24 (17%)	14 (20.3%)	10 (13%)	ns
Training and Respirator Type					
Brochure		FFP	HFM		
		22	20		
Video		21	31		
Computer-based training		26	25		

^AThe table summarizes subject characteristics and assignment to groups by respirator type (FFP = filtering facepiece (N95), HFM = dual cartridge half face mask) and training type. *Statistical* significance of differences is denoted as: **: $p < 0.01$. *: $p < 0.05$. +: $.05 < p < 0.10$. ns: not significant.

performance items (defined as a score of 3 or 4). For meaningfully comparable individual items, measures of statistical significance of difference between the FFP and HFM groups were assessed for both the average and the “% unacceptable” measures.

In general, subjects performed very well on the knowledge tests. Since most had little or no prior respirator experience, this indicates that the training was effective. As seen in Table III, the average total score was 11.79 out of a possible total of 14. Acquisition of knowledge appeared to be adequate even for the training for the more complex HFM respirator, which corresponded to an average total score of 11.62 vs. 11.99 for FFP training.

In contrast, performance had significant limitations. For each of the performance measures, the table includes the mean value and the standard deviation. In addition, it shows the “% unacceptable,” which is defined as performance code 3 or 4. As

seen in Table IV, most subjects adequately placed the respirator on their face and adjusted the straps. However, they frequently performed other aspects of respirator use incorrectly. For both the HFM and the FFP, many subjects (80%) did not inspect the respirator or its components (such as the inhalation and exhalation valves of the HFM) despite emphasis in the training materials. A high proportion of FFP users (25%) did not attempt to mold the metal nosepiece as trained. Subjects (55% and 50% for the FFP and HFM, respectively) often failed to perform the seal check with either device.

Several of the knowledge test (written) components were designed to correlate with observed performance criteria. Table V describes the relationships between exhibited knowledge and actual behavioral aspects. As seen, no statistically significant relationships existed between knowledge and performance for any of the FFP individual items and most of the HFM items.

TABLE III. Knowledge Test Results^A

	FFP			HFM			FFP vs. HFM *
	Item	Mean	sd	Item	Mean	sd	
K1	Respirator types	0.99	0.12	Respirator types	0.88	0.33	*
K2	Re-usability	0.51	0.50	Re-usability	0.66	0.48	+
K3	N95 applicability	0.86	0.35	N95 applicability	0.71	0.46	*
K4	Mask Selection criteria	0.91	0.28	Mask Selection criteria	0.93	0.25	ns
K5	Use of poorly fitting mask	1.00	0.00	Use of poorly fitting mask	0.99	0.11	ns
K6	Beards	0.86	0.35	Beards	0.88	0.33	ns
K7	Straps & nose clip	0.87	0.34	Strap placement	0.75	0.44	+
K8	Cross straps	0.99	0.12	Cartridge missing	0.82	0.39	N/A
K9	Facial positioning of mask	0.94	0.24	Facial positioning of mask	0.88	0.33	ns
K10	N95 use situations	0.90	0.30	HFM use situation	0.87	0.34	N/A
K11	Seal check need	1.00	0.00	Seal check need	0.99	0.11	ns
K12	Seal check performance	0.84	0.37	Seal check performance	0.75	0.44	ns
K13	Seal check importance	0.38	0.49	Seal check importance	0.59	0.49	**
K14	Removal steps	0.96	0.21	Removal steps	0.92	0.27	ns
KnowTotal	Total Score	11.99	1.30	Total Score	11.62	1.98	ns

^AThe table summarizes results of the written knowledge tests for key indicator variables and summary measures. P values were based upon Mann-Whitney nonparametric test. FFP vs. HFM: These values reflect differences between FFP and HFM. N/A: No relevant comparison question. Other symbols are defined in Table II.

TABLE IV. Performance Observation Results^A

Code	FFP			HFM				p
	Mean	sd	% Unaccept*	Code	Mean	sd	% Unaccept*	
Insp_Gen	3.35	1.11	82.6%	Insp_Gen	3.28	1.19	77.9%	ns
Insp_Face	3.38	1.13	78.3%	Insp_ValveIn	3.27	1.25	75.3%	N/A
				Insp_ValveOut	3.57	1.03	85.7%	N/A
				Insp_ValveCover	3.55	1.07	84.4%	N/A
				Strap_Order	1.00	0.00	2.6%	N/A
Strap_Straight	1.10	0.52	2.9%	Strap_Straight	1.17	0.69	7.8%	ns
				Strap_Tension	1.96	1.36	32.5%	N/A
Nosepiece	1.75	1.28	24.6%					N/A
Mask_Center	1.04	0.27	1.4%					N/A
Mask_Stable	1.03	0.24	1.4%	Mask_Stable	1.01	0.12	2.6%	ns
Mask_Symmetric	1.01	0.12	0.0%					N/A
Mask_Obstruction				Mask_Obstruction	1.05	0.28	3.9%	N/A
Mask_Correct	1.04	0.36	1.4%	Mask_Correct	1.00	0.00	2.6%	ns
Seal_Check	2.65	1.46	55.1%	Seal_In	2.44	1.51	49.4%	N/A
				Seal_Out	2.68	1.50	57.1%	N/A
DOF_Order	1.32	0.74	7.2%	DOF_Order	1.32	0.80	16.9%	ns
DOF_Touch	1.93	1.20	24.6%	DOF_Touch	1.90	1.11	31.2%	ns
DOF_Disposal	1.00	0.00	0.0%	DOF_Disposal	1.01	0.12	9.1%	ns
Perf_Total	71.50	14.11		Perf_Total	63.64	14.63		N/A
Major_Errors	2.78	1.44		Major_Errors	5.47	2.57		N/A

^AThe results table summarizes performance scores for key variables and the summary measures (performance total). The scoring system and “percent unacceptable” are defined in the Methods section. Codes are defined in Tables I and II. Variables which are analogous for the FFP and HFM are shown on the same line. The rightmost column compares the performance results for FFP and HFM as determined by Kruskal-Wallis testing. N/A = non-applicable comparison. Chi-square testing for “percent unacceptable” showed no significant differences between FFP and HFM.

TABLE V. Correlation of Knowledge and Performance^A

Knowledge test item	Performance item	Rank Corr	p
FFP			
K7_FFP:Straps & nose clip	Nosepiece	-0.03	ns
K9_FFP:Fascial positioning of mask	Mask_Symmetric	0.03	ns
K12_FFP:Seal check performance	Seal_Check	-0.16	ns
K13_FFP:Seal check importance	Seal_Check	-0.11	ns
K14_FFP:Removal steps	DOF_Order	-0.10	ns
KnowTotal:Total Score	Perf_Total	0.05	ns
KnowTotal:Total Score	Major_Errors	-0.06	ns
HFM			
K8_HFM:Cartridge missing	Insp_Gen	-0.12	ns
K12_HFM:Seal check performance	Seal_In	-0.28	*
K13_HFM:Seal check importance	Seal_In	-0.18	ns
K12_HFM:Seal check performance	Seal_Out	-0.13	ns
K13_HFM:Seal check importance	Seal_Out	-0.16	ns
K14_HFM:Removal steps	DOF_Order	-0.03	ns
KnowTotal:Total Score	Perf_Total	0.32	**
KnowTotal:Total Score	Major_Errors	-0.35	**

^AThe table summarizes the relationship between measures of performance and of knowledge. The Spearman correlation coefficient is based upon rank among all subjects for the respirator type (overall knowledge and performance scores as well as selected individual items for which there is a direct correspondence between the knowledge test and performance measure). **: $p < .01$; *: $p < 0.05$; ns: not significant.

Table V also describes the relationships between the overall measures of knowledge with the overall measures of observed performance. While rank correlation did show statistically significant relationships for the HFM, HFM knowledge alone certainly did not guarantee effective performance (the Spearman correlations were 0.32 between total performance and knowledge scores and 0.35 between knowledge scores and number of errors, both with $p < 0.01$). These items were not correlated for the FFP.

Participant performance varied considerably. The Total Performance (TP) scores varied from 33.3 to 100.0 for FFP and 38.1 to 100.0 for HFM. The coefficient of variability was 0.20 for the FFP users and 0.23 for the HFM users.

The six training method-respirator type combinations limited the number of subjects for each individual combination. Future reports will assess training type effect as additional subjects are accrued in the study.

DISCUSSION

Effective respiratory protection depends on proper use of the respirator. This study examined the relationship between knowledge and actual performance. In addition, it identified particularly problematic aspects of respirator use. This information should be helpful for designing respirator training programs and assessing the qualification of individual users.

The training methods effectively imparted knowledge. Even though the training was of short duration and not directly issued by humans, subjects generally answered the knowledge questions correctly. Actual respirator user performance was

less optimal. "Unacceptable" performance characteristics may be reasonably expected to increase the risk of exposure. The frequency of serious errors and the disparity between knowledge and performance suggest that proper donning and doffing should be evaluated carefully and specifically. This may be as important for assuring quantitative fit factor as measuring the protection factor itself, particularly if fit-testing includes direct or subtle prompts about proper use.

The study identified specific poorly performed aspects. In general, mask placement per se was done well, but pre-use inspection was often skipped. During doffing, avoiding mask surface contact was the most neglected behavioral aspect.

The observed frequency of improper use may underestimate the frequency of misuse under actual workplace conditions. The study conducted performance assessments within two hours of training, and the subjects were told that a purpose of the study was to assess training methods.

Several observational studies of healthcare workers have reported frequent improper technique. In several California hospitals, 65% of observed respirator donnings were incorrect.⁽¹²⁾ A Brazilian study of healthcare workers found that 39% had visible face seal leakage locations, often due to incorrect strap placement; many FFPs were in unsuitable condition.⁽¹³⁾ Performance in non-occupational settings was worse; although 60% reported some training, community members using respirators following Hurricane Katrina in New Orleans made frequent mistakes such as not tightening the nose-clip (71%) or placing the mask upside down (22%). In an experimental study of respirator-naïve subjects which included ample opportunity for reviewing instructions immediately before assessment, straps

were incorrectly placed about 25% of the time and 20% of subjects did not perform a seal check.⁽¹⁴⁾

It is unlikely that poor quality training caused the observed poor performance. The training materials specifically emphasized the areas measured. Knowledge test results were good even for questions lacking a self-evident answer. Staff rigorously developed and pilot-tested the coding method; they intentionally emphasized aspects that they could easily determine objectively. In addition, results were generally consistent for the FFP and the more complex HFM.

The various domains of use differed considerably in adequate performance. Proper placement of the mask and straps was done much more effectively than behaviors in the other domains (see Table IV). Proper inspection of the respirator occurred much less frequently (e.g., 82.6% of FFP users did not inspect it before donning, and 77.9% of HFM users did not check the valves). Similarly, despite generally correct mask placement, users often neglected procedures to adjust the respirator mask to their face (e.g., adjusting the nosepiece of the FFP or the strap tension of the HFM). Misplacement of the mask or straps is visible throughout use and may be easily detected by the users' colleagues. Unfortunately, the two domains with poorest performance—inspection and adjustment—are least likely to be identified and corrected by others. Hence, these errors may constitute a greater risk.

These differences may reflect users' perceptions about importance of the various items. For example, placing the mask on the face obviously benefits users, whereas the importance of confirming the device's integrity may be less apparent. When exposures generate noticeable warning properties, neglecting pre-inspection may be less important since device failure will be evident. Conversely, for protection against infectious agents or the possibility of bioterrorism, users will not identify a lack of structural integrity without respirator checks. Similar comments apply to failure to properly tension the straps or mold the nosepiece.

The role of respirator use in the classic hierarchy of controls underscores the role of the user. This study extends several prior studies that focused on user decisions to use a respirator in the first place. The current data suggest that users frequently misuse even simple devices, and therefore assessment of public health protection must consider *how* it is used in addition to *whether* it is used.

Because of the incongruity between knowledge and performance (see Table V), assessing a user's knowledge does not guarantee proper use. This is consistent with studies of healthcare workers' performance demonstrating that effective use necessitates regular use. Studies and audit processes that rely upon knowledge tests alone^(11,15,16) may overestimate the effectiveness of respiratory protection programs.

Non-occupational settings, emergency use circumstances, or small businesses require particular attention to designing respirator user enablement programs, including training. Under such circumstances, training programs must be particularly effective because of the absence of both quantitative fit and professional observation of proper technique. For example,

the US Food and Drug Administration's emergency approval of several FFPs for use in influenza epidemics permitted use without training other than reading printed material accompanying the respirator.^(14,17)

CONCLUSION AND RECOMMENDATIONS

Despite recent training, many respirator users did not don and doff the respirators properly. Subjects generally demonstrated adequate knowledge, but actual performance was poor. The study identified specific steps of donning and doffing which were poorly done.

The study has several practical implications:

1. Respirator user evaluations should include observation of donning and doffing without expert assistance or prompting. Qualitative or quantitative fit-testing is not an adequate substitute.
2. Actual performance—not just knowledge—should be evaluated as part of the worker respirator certification process.
3. Respirator training materials should put greater emphasis on the identified problematic areas. Training materials should be designed and assessed on a point-by-point basis to optimize effective protection.
4. Further studies are needed to assess the relationship between observed performance measures and actual measured exposure.
5. Regulatory agencies should consider developing specific criteria for evaluating new respirator designs to facilitate ease of use.
6. Agencies certifying new respirator designs should evaluate the accompanying instructions as well as the device itself.

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