Comparison of Three Respirator User Training Methods

Philip Harber, MD, MPH, Robert J. Boumis, BS, Jing Su, MS, Sarah Barrett, BS, and Gabriela Alongi, BS

Objective: This study addresses methods for training respirator users, particularly when occupational health professionals are not immediately available. **Methods:** A randomized trial compared three training methods—printed brochure, video, and computer-based training—for two respirator types (filtering facepiece and a dual-cartridge half facemask). Quantitative fit testing (PortaCount) measured the effectiveness of training. The study included 226 subjects. **Results:** For both respirator types, video was significantly superior to either print or computer-based training methods. Conclusions were consistent, whether determined by average fit factor (analysis of variance), log-transformed fit factors, or the number of users in the lowest quartile of achieved fit. **Conclusions:** Video training for proper respirator use can be effective when direct training from an occupational health professional is unavailable. These methods are particularly relevant to "rapid rollout" situations, such as natural disasters, epidemics, or bioterrorism concerns.

Respirators (respiratory personal protective devices) are only effective if users select and use them properly. Workers in high-risk workplace settings frequently benefit from occupational health professional involvement when selecting the proper respirator and measuring the quality of the fit (with quantitative or qualitative tests). Nevertheless, respirators are also often used in small workplaces (eg, fewer than 50 employees) lacking occupational health professional expertise, such as industrial hygienists or occupational physician/nurses.[1,2] In addition, circumstances may require rapidly deploying respirators for use by community members and previously nonhazardous workplaces (eg, when faced with an epidemic, natural disaster, or terrorism threat).[3,4] Traditional training and fit testing by occupational health professionals are less feasible during rapid rollout in a public health emergency.[5]

Several studies demonstrate that individuals frequently misuse respirators. Improper use is common,[6,7] even in workplaces such as infectious disease areas of hospitals.[8,9] The frequency of misuse increases in community settings, which has been studied in both observational (eg, after Hurricane Katrina) and experimental situations.[3–5] In the United States, the number of well-trained occupational health professionals (eg, industrial hygienists, occupational doctors, and nurses) is inadequate.[2] Small worksites with limited access to trained professionals use a high proportion of the country's workers. These workplaces and the community urgently require an effective training method that does not rely on occupational health professionals and can be rapidly deployed.

This study used a randomized trial to directly compare three methods—(1) printed instructions, (2) a short video presentation, and (3) computer-based training (CBT)—to rapidly train users of two types of commonly used respirators of different complexity: filtering facepiece (FFP) and dual-cartridge half facemask (HFM) devices. Quantitative fit testing assessed the relative training effectiveness.

From the Community, Environment, and Policy Division, Mel and Enid Zuckerman College of Public Health, University of Arizona, Tucson.

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Address correspondence to: Philip Harber, MD, MPH, 1656 E Mabel St, Room 112, MRB, University of Arizona, Tucson, AZ 85721 (pharber@email.arizona.edu).

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METHODS

The study was conducted at the University of Arizona, and the University's institutional review board approved the protocol. Subjects were recruited by Web announcements, bulletin board postings in the community, and brochure and flyer distribution. Participants received compensation for completing the study. Recruitment strategies focused on groups unlikely to use respirators on a regular basis.

Two respirator types were studied. Subjects were randomly assigned to use either a FFP N95 respirator without an exhalation valve (1860 series; 3M, St Paul, MN) or a dual-cartridge HFM device (MSA ComfoClassic®, SOFTFEEL®, MSA, PA) fitted with P99 cartridges.

Researchers designed three training methods—a set of printed instructions, a video, and a CBT—each for both masks (six total combinations). When possible, they preserved content across all three methods. For example, the CBT incorporated much of the printed-training text. Furthermore, training content was comparable for both masks when applicable.

The total sample size was 237 subjects. Assignment to the training method was performed randomly, but all subjects in a half-day session received the same method to avoid possible contamination from seeing other items.

A 24-page booklet comprised the printed instructions for each mask type. The CBT included a series of frames. Many included short video clips matched to the still photos of the print version or derived from the training video. The CBT also allowed a subject to repeat sections if desired, and it included a series of quiz items throughout the course. For the CBT, the average training time was 14 minutes (range, 7 to 16 minutes). The video lengths were 7.4 and 9.2 minutes for FFP and HFM, respectively. Each subject completed the training without staff assistance. Further details are described in an earlier publication.[10]

Participating subjects were randomly assigned to a respirator (2 available types) and a training method (3 available methods). Thus, there were six possible combinations. All subjects on a particular experimental day received the same combination.

Each subject completed an informed consent process. Subjects then submitted a brief medical questionnaire before participation. The study excluded individuals with identified risk factors (eg, active significant cardiorespiratory or psychiatric disorders, significant musculoskeletal limitations). In addition, only subjects who stated they could speak, read, and write fluent English could participate. Subjects were told that the study aims included assessing the efficacy of training.

Before initiating respirator training, each subject also completed a questionnaire identifying personal characteristics, computer-use ability, and any prior respirator experience. These characteristics are shown in Table 1. Subjects possessed "respirator experience" if they either recently used a respirator or ever used one at least 5 days in a year. Computer-use ability was classified on the basis of the frequency of computer, e-mail, and Internet use.[10]

After their designated training, the subject selected mask size and attempted to place it. Two sizes of FFP and three sizes of HFM were available. If the subject felt that he or she chose incorrectly, he or she was allowed to switch to another mask size. Staff video-recorded the donning procedure as described elsewhere.[10] The subject then had standard digital and infrared facial imaging completed and underwent quantitative fit testing, which staff conducted

TABLE 1. Subject Characteristics[a]

Respirator Type Training Method	FFP (N95)				Dual-Cartridge HFM			
	Printed	Video	CBT	P	Printed	Video	CBT	P
Number	39	37	41	NS	35	33	41	NS
Sex								
Male	21 (55%)	15 (41%)	17 (41%)	NS	18 (51%)	14 (42%)	20 (49%)	NS
Female	17 (45%)	22 (59%)	24 (59%)		17 (49%)	19 (58%)	21 (51%)	
Age, yr								
Mean (SD)	36.1 (12.8)	34.3 (13.4)	35.2 (14.8)	NS	33.9 (13.3)	27.8 (12.2)	40.2 (14.6)	**
Range	19—63	19–67	19–65		18–66	18–60	19–71	
Computer experience								
Yes	22 (56%)	22 (59%)	24 (59%)	NS	26 (74%)	29 (88%)	30 (73%)	NS
No	17 (44%)	15 (41%)	17 (41%)		9 (26%)	4 (12%)	11 (27%)	
Education								
High school or less	6 (16%)	9 (25%)	6 (15%)	NS	8 (23%)	4 (12%)	5 (12%)	NS
Some college	15 (39%)	17 (47%)	19 (48%)		12 (34%)	21 (64%)	16 (39%)	
College graduate	7 (18%)	3 (8%)	8 (20%)		6 (17%)	4 (12%)	10 (24%)	
Some graduate	10 (26%)	7 (19%)	7 (18%)		9 (26%)	4 (12%)	10 (24%)	
Work status								
Not working	3 (8%)	4 (11%)	11 (28%)	**	2 (6%)	3 (9%)	7 (17%)	NS
Currently working	25 (68%)	20 (56%)	12 (30%)		23 (66%)	15 (45%)	22 (54%)	
Retired	8 (22%)	9 (25%)	12 (30%)		8 (23%)	13 (39%)	6 (15%)	
Student	1 (3%)	3 (8%)	5 (13%)		2 (6%)	2 (6%)	6 (15%)	
Primary language								
English	31 (79%)	28 (76%)	30 (73%)	NS	24 (69%)	27 (82%)	29 (71%)	NS
Other	8 (21%)	9 (24%)	11 (27%)		11 (31%)	6 (18%)	12 (29%)	
Respirator experience[b]								
Yes	9 (23%)	8 (22%)	9 (22%)	NS	8 (23%)	1 (3%)	6 (15%)	NS
No	30 (77%)	29 (78%)	32 (78%)		27 (77%)	32 (97%)	35 (85%)	

**$P < 0.01$.
[a]Subject characteristics are shown according to respirator type and training method.
[b]Respirator experience is present if the subject either uses a respirator currently or ever used one at least 5 days per year.
CBT, computer-based training; FFP, filtering facepiece; HFM, half facemask; NS, not significant.

using a commercially available system (PortaCount Pro+; TSI, Shoreview, MN). The imaging data will be analyzed separately to assess potential utility as measures of facial seal.

The fit test sampled aerosol concentration in the ambient air and within the mask by using small sampling ports placed in both the N95 and HFM devices. An aerosol-generating humidifier increased the background particle count. All subjects (FFP and HFM users) had quantitative fit determined using the standard PortaCount method. In addition, 45 of the FFP users also had fit assessed using the PortaCount Pro+ N95 (PCP+) modified measurement technique, in which the particle counting approach is more sensitive to particle sizes relevant to N95 devices. During fit testing, each subject performed three maneuvers—quiet breathing, reading the "rainbow passage," and gently nodding their heads. Each was conducted for 60 seconds. The investigators did not instruct subject to change mask sizes if the fit factor was low. The harmonic mean of the three maneuvers' results determined the overall fit factor. Data were recorded separately for the standard and N95 protocols.

The average of the overall fit factors from the first and second fit tests represented the efficacy of training. Results from the standard PortaCount measurement technique and the PCP+ technique were analyzed separately.

After completing the quantitative fit testing, subjects performed a series of simulated work tasks. Some were sedentary, such as sorting cards. Others required walking and raising arms above shoulder level (eg, obtaining and placing magnets at specified positions on a whiteboard). One task included moderate exertion (filling and carrying buckets of rice weighing 2.2 kg). Altogether, the tasks typically spanned 20 minutes. After the completion of the simulated work tasks, fit testing and standard and infrared photography were repeated, and the staff again video-recorded the subject removing and donning the device.

Data were managed in a relational database (Microsoft Access, Redmond, WA). Data from the PortaCount were exported and transferred to the database by using software developed by the investigators. Researchers conducted univariate comparisons by using chi-squared or *t* test, as appropriate, using SAS (PC version 9.3; SAS, Inc, Cary, NC). Analyses of variance directly compared the three training methods for each respirator type. Because quantitative fit testing data in other studies have shown nonnormal distributions, researchers repeated the analyses by using the log-transformed quantitative fit factor. In addition to comparing mean values, analyses assessed the frequency of poor fit. For this purpose, subjects were separated into fit factor quartiles. Analyses compared the proportion of subjects in the lowest quartile among the three training methods for each respirator type. Possible associations between personal characteristics and fit factor were assessed using analysis of variance. Statistical significance was considered present for $P < 0.05$.

RESULTS

Table 1 shows participant characteristics. Subjects had little or no prior respirator experience, and most were familiar with basic computer use. The quantitative results according to training method type are compared in Table 2. The analyses report the two respirator types separately. Results for the modified PCP+ protocol are also shown.

For each fit measure, the video method corresponded to greater respiratory protection than the other training types. The analyses of variance were repeated using log-transformed quantitative data, which resulted in similar conclusions. For both respirator types, video-based training had smaller proportions in the lowest quartile of fit factors than either printed instruction or CBT. Persons in the lowest quartile had fit factors less than 34.5 and 63.5 for the FFP and HFM, respectively. Differences among training methods were statistically significant for all respirator types for all measures in Table 2, except the PCP+ ("method 2"), for which the effective sample size was smaller.

Several possibly relevant personal factors are shown in Table 3. Sex, educational level, prior respirator use, and primary language were not associated with differences in fit factor. Persons with computer experience achieved greater mean fit factors for FFP but not for HFM devices.

DISCUSSION

Respirators (respiratory personal protective devices) may provide protection to workers and community members when other methods are less readily available. Unlike engineering controls, which provide protection without requiring specific technical training of users, respiratory protection from respirators depends completely on the knowledge and actions of the individual user. Even apparently simple devices, such as FFP respirators, require the user to properly execute a sequence of steps for effective use. Observational and laboratory studies have demonstrated that individuals frequently misuse FFP devices. Proper use has been less studied for HFM-type devices, but the relative complexity of that type makes it likely that improper use occurs at least as frequently as with FFP devices. As such, respirator selection and placement should be a central component of respiratory protection training programs.

This article reports a randomized trial directly comparing three methods of respirator training in a large number (237) of subjects, most of whom lacked respirator experience. The effectiveness of training was determined by conducting quantitative testing directly after training and again later in the same day after a series of work-simulation tasks. In a preliminary analysis, investigators found very little correlation between knowledge test results and proper technique scores based on video recording.[10]

This study shows a clear increase in respiratory protection when an individual is trained with a video rather than a printed booklet or a CBT program. This result was seen for both types of respirators—a simple N95 FFP device and a dual-cartridge HFM respirator. Because fit factors as determined by a Porta-Count often do not follow a normal distribution, the data were analyzed also by using log-transformed fit factors, yielding the same results.

Many workplaces require effective training methods that do not depend on delivery by well-qualified occupational health professionals, because very few workplaces have such trainers. A 2002 Bureau of Labor Statistics study found that only 3.2% of establishments had an industrial hygienist as the training program administrator. The proportion varied considerably by the number of workers; even in establishments with at least a thousand workers, only 28% had an industrial hygienist. Overall, the program administrator had no professional occupational health training in 42% of establishments.[1]

Community settings that require respirator use present an even greater challenge to developing effective standalone programs. After Hurricane Katrina, a National Institute for Occupational Safety and Health study found frequent improper use among New Orleans respirator users (of whom 39% had received some formal prior training), possibly exposing them to high levels of mold or other hazards. For example, on observation, 22% used FFP respirators upside down, and 21% used only one strap.[4]

In the United States, the Occupational Safety and Health Administration mandates training as part of a full respirator program for relevant workers.[11] Nevertheless, Occupational Safety and Health Administration standards provide little specific guidance about how training should be conducted and evaluated. Furthermore, user training has received far less research focus than improving filtration/adsorption performance and assessing the physiologic effects of respirators.

Nevertheless, there are some research studies that have addressed respirator training in a systematic fashion. One evaluated a limited training method (a printed version accompanying an N95 device) for use when an influenza epidemic threatens.[5] Others examined the potential of CBT[12,13] or self-paced learning[14] to provide respirator education, but relied on knowledge rather than actual

TABLE 2. Quantitative Fit Factors by Training Method[a]

Respirator Type Training Method	FFP (N95) Printed	FFP (N95) Video	FFP (N95) CBT	FFP (N95) *P*	Dual-Cartridge HFM Printed	Dual-Cartridge HFM Video	Dual-Cartridge HFM CBT	Dual-Cartridge HFM *P*
Quantitative fit factor, mean (SD)								
Quantitative fit	52.9 (37.6)	106.8 (66.8)	74.3 (49.8)	**	1440.2 (1752.0)	2357.2 (2117.5)	1126.2 (1858.6)	*
Log-transformed quantitative fit	3.63 (0.95)	4.36 (0.93)	4.00 (0.93)	**	5.81 (2.34)	6.90 (1.85)	4.93 (2.64)	**
Quantitative fit for PCP+ (method 2)	55.5 (45.2)	102.0 (64.8)	98.5 (60.0)	*				
Log-transformed quantitative fit for PCP+	3.73 (0.78)	4.35 (0.88)	4.28 (1.07)	NS				
Subjects in lowest quartile, *n* (%)								
Lowest quartile	13 (33)	6 (16)	10 (24)	*	9 (26)	3 (9)	15 (37)	*
Other quartiles	26 (67)	31 (84)	31 (76)		26 (74)	30 (91)	26 (63)	

*0.01 < P < 0.05; **P < 0.01.

[a]The table shows the measured fit factor for each respirator and training method type. Analyses based on direct and log-transformed fit factors are shown. It also shows the number of subjects (%) who were in the lowest quartile for each respirator type. In addition, a subset of FFP users were tested using the modified PCP+ fit method for N95 devices ("method 2"). Analysis of variance was used to assess statistical significance for protection factors, and chi-squared test for lowest-quartile data.

CBT, computer-based training; FFP, filtering facepiece; HFM, half facemask; NS, not significant; PCP+, Portacount Pro Plus.

TABLE 3. Influence of Personal Characteristics on Quantitative Fit by Training Method[a]

Respirator Type Training Method	FFP (N95)				Dual-Cartridge HFM			
	Printed	Video	CBT	*P*	Printed	Video	CBT	*P*
Sex								
Male	46.5 (31.1)	95.5 (49.0)	74.4 (48.7)	NS	1840.9 (1939.5)	2298.5 (2411.2)	862.5 (1487.4)	NS
Female	56.6 (42.0)	114.4 (76.8)	74.2 (51.6)		1016.0 (1467.8)	2400.5 (1941.0)	1377.4 (2161.4)	
Age quartile, yr								
<24	58.9 (50.6)	100.9 (51.4)	72.6 (57.4)		2131.7 (2499.3)	3154.9 (2354.3)	1483.2 (2200.4)	
24–32	49.8 (31.3)	155.7 (71.9)	86.9 (41.4)		1502.9 (1391.6)	979.8 (695.5)	1959.1 (1797.4)	
33–45	47.9 (26.5)	66.9 (52.4)	63.3 (35.4)	*	1059.9 (1622.6)	1268.4 (1587.4)	1311.9 (2535.9)	
>45	52.5 (36.8)	92.3 (67.5)	78.0 (61.5)		1006.3 (1050.1)	2339.2 (1883.1)	448.3 (931.2)	*
Computer experience								
Yes	58.9 (33.7)	131.5 (60.6)	74.5 (54.9)	*	1416.5 (1793.6)	2451 (2143.4)	1398.3 (2086.7)	
No	45.1 (41.8)	70.4 (59.9)	74.1 (43.1)		1508.9 (1727.9)	1677.6 (2061)	384.3 (602.4)	NS
Education								
High school or less	58.4 (39.1)	96.0 (75.0)	70.4 (60.5)		1607.0 (2591.2)	1456.3 (1686.3)	764.5 (1131.6)	
Some college	45.9 (48.5)	92.0 (61.3)	68.5 (47.7)		1427.3 (1585.4)	2844.6 (2267.1)	716.9 (1404.5)	
College graduate	58.0 (26.9)	129.4 (70.1)	85.4 (44.9)	NS	827.3 (1690.1)	1718.2 (2135.0)	1314.3 (1516.3)	NS
Some graduate	51.9 (24.9)	156.4 (53.9)	90.8 (53.5)		1717.8 (1237.9)	1338.3 (1219.4)	1774.1 (2884.7)	
Not working	45.2 (26.8)	109.2 (42)	70.8 (54.1)		1241.8 (297.3)	1739.1 (1645.2)	1011.4 (2002.6)	
Currently working	47.8 (33.3)	114.6 (77.1)	70.8 (51.7)	NS	1184.8 (1474.8)	1807.0 (1690.3)	1528.1 (2164.4)	
Work status								
Retired	62.8 (55.4)	117.4 (52.5)	80.2 (51.7)		2537.3 (2449.9)	3137.8 (2485.2)	291.5 (427.6)	NS
Student	72.0 (NA)	42.0 (19.2)	72.8 (50.0)		187.4 (249.8)	2337.8 (3216.3)	621.5 (1046.4)	
Primary language								
English	55.6 (39.6)	102.5 (66.1)	73.7 (53.4)	NS	1325.1 (1519.9)	2418.3 (2185.5)	698.1 (1249.9)	NS
Other	42.2 (28.1)	119.9 (71.2)	76.0 (40.3)		1691.4 (2241.0)	2082.5 (1936.2)	2160.8 (2633.4)	
Respirator experience[b]								
Yes	53.0 (38.8)	112.6 (67.7)	75.9 (48.3)	NS	1204.4 (1221.3)	8287.0 (NA)	468.8 (931.6)	
No	52.4 (35.4)	85.6 (62.7)	68.7 (57.6)		1510.1 (1894.8)	2171.9 (1859.7)	1238.9 (1961.4)	NS

*$0.01 < P < 0.05$.

[a]The influence of personal characteristics on quantitative fit (standard method) by training method is shown by mean (SD); NS indicates too few subjects in cell to calculate SD. Analyses were based on analysis of variance. *P* values refer to significance of the personal factor.

[b]Respirator experience is present if the subject either uses a respirator currently or ever used one at least 5 days per year.

CBT, computer-based training; FFP, filtering facepiece; HFM, half facemask; NS, not significant.

user performance or protective efficacy as the outcome measured. We believe that quantitative fit measurement is more accurate than assessing knowledge alone; in an earlier analysis, we reported that knowledge test results and actual performance were very weakly related.[10]

Responsibility for conducting the respirator training program is frequently assigned to the same occupational health professionals (eg, industrial hygienists) responsible for respirator selection and fit testing. This makes it difficult to assess training independently from other aspects of the program. For example, a failed fit test may lead the industrial hygienist to readjust the mask, select a new respirator size, and/or provide sufficient supplemental instruction to ensure that the test is passed. Although such ad hoc efforts lead to passing quantitative fit tests, longer-term protective effectiveness may be suboptimal.

The investigators developed the training materials to minimize potential biases by maintaining content as consistently as possible across the three methods. Wherever possible, the three training materials used the same illustrations and graphics, albeit in different formats.

Adequate protection requires selecting the proper mask size in addition to properly placing it on the face. The quantitative measures used in this experimental study integrate both of these steps, because while some workplace programs may be fortunate enough to have an in-house industrial hygienist, others do not and the user must choose the mask himself or herself.

Quantitative fit testing more directly represents protection than knowledge assessments per se. All subjects underwent fit testing, using an abbreviated protocol with replicate measurements. Several investigators report that an abbreviated protocol (using fewer than the eight maneuvers in the standard Occupational Safety and Health Administration protocol) adequately discerns respirator fit. In these reports, replicated measurements after several redonnings were more accurate than multiple individual measurements at a single time.[15] It is unlikely that various tasks in the current study led to respirator mask malformation because of the limited time and character of the tasks performed.[16]

All subjects had quantitative fit determined using the standard PortaCount methodology. Some of the FFP users were also tested with the PCP+ modified counting system, which nominally emphasizes facial seal leakage alone rather than the combination of filter penetration and facial seal leakage. As shown in Table 2, the relative effectiveness of the three training methods was the same as when using the standard approach.

Despite their inexperience and the intentional absence of direct assistance from professional staff, users of both the FFP and HFM respirators generally achieved useful protection. The average measured fit factor for FFP devices was greater than that from an experimental study evaluating donning with only a printed instructional card and was also greater than the Food and Drug Administration's minimum criterion of 2.0 for use in public health emergencies.[17]

Several personal factors did not have statistically significant effects on which training method is most effective. Although age group statistically affected fit factor, there was no trend by age group. The a priori hypothesis that CBT would be particularly effective for computer-experienced individuals was not confirmed, perhaps because of the broad definition of "computer experience."

Although the results from this single study seem to be clear, additional studies and replications are warranted. The study was conducted using only two specific respirator types and a single set of training materials. The study evaluated training effectiveness over a short time, so it is unclear how long acceptable respirator use skills would endure (the investigators are currently conducting a longer-term follow-up study to assess this long-term effect).

Implications

This study demonstrated significant differences in the effectiveness of several respirator training methods. Effective training becomes particularly important when formal validation by fit testing may not be available (eg, small employers, community settings, rapid rollout). The video format, which was most effective, allows delivering the same message in several ways simultaneously—written text, illustrations, and demonstrations of respirator placement and use. On the contrary, CBT and printed media allow learners to proceed at their own pace and return to sections with which they feel uncomfortable, and CBT provides incremental feedback during training with review questions.

All three of the methods can be delivered without the direct involvement of trained professionals. Thus, an individual who acquires a respirator (whether from an employer or a hardware supply store) could also easily receive appropriate training. Although the most effective training method (video) is more expensive to produce and distribute than, for example, a printed brochure, the incremental cost of a digital versatile disc (DVD) may be warranted. Alternatively, the respirator manufacturer or a public health care agency could make the information available via a Web site. Agencies approving respirator designs (eg, the National Institute for Occupational Safety and Health and Food and the Drug Administration in the United States) may consider requiring respirator manufacturers to provide effective training materials as part of the certification process rather than solely focusing on the mechanical efficacy of the device alone.

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ERRATUM

Association of Workplace Chronic and Acute Stressors With Employee Weight Status: Data From Worksites in Turmoil

In a previously published article in *Journal of Occupational and Environmental Medicine*,[1] the first name of coauthor Su was misspelled. Dr. Su's name should have appeared as Su Haiyan. The editors regret the error.

REFERENCE

1. Fernandez ID, Su H, Winters PC, Liang H. Association of workplace chronic and acute stressors with employee weight status: data from worksites in turmoil. *J Occup Environ Med*. 52(suppl 1):S34–S41.

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