

Peer Reviewed

Review of Recent Research on Communications While Wearing a Respirator

Arthur T. Johnson, William H. Scott, and David M. Caretti

Biological Resources Engineering, University of Maryland
College Park, MD 20742, USA

Abstract

Several recent experiments meant to quantify effects of respirators on speech transmission accuracy and speed have been reviewed. Results show that word comprehension was much better when a meaningful context is supplied with the word than if the word was used by itself. Speech comprehension decreased rapidly with distance between speaker and listener for single spoken words, and use of hand signals should be considered. During face-to-face communications, the speech diaphragm improves accuracy by about 3%. When a telephone was used as the speech transmission medium, the respirator speech diaphragm was found to improve accuracy by about 5%. There was no advantage to electronic amplification of speech. Using a communications protocol to signal movement of the handset from the mouth to the ear improved accuracy to nearly the level of the no-respirator control, but did not change recognition time.

Introduction

If respirators were used only by isolated wearers, there would not be a need to communicate with others while wearing them. However, workers are often found in teams, and communication becomes necessary for social and occupational interaction. A survey of physical plant workers at the University of Maryland found communications ability to rank at the top of problems encountered while wearing respirators (Johnson and Scott, 1999). Until recently, there was limited information concerning the effect of respirator wear on speech transmission and comprehension. Because of this, a series of tests have been performed to quantify the effects of respirators on communication ability.

Just as an overall image appears when individual pixels are together taken in context, a review of several individual studies can sometimes provide the reader with perspective. For the respirator designer, this perspective can help produce a better product; for the individual training respirator users,

this perspective can guide the lessons presented; for the user himself, this perspective leads to more realistic expectations about what can be accomplished. Certainly, communications abilities can be important during emergencies when respirators are likely to be required. For these events, knowing how to react can mean the difference between life and death. Even during the performance of routine tasks, knowing about the limitations of a respirator liberates the user from self-blame, and can either lead to acceptance of these limitations or to creative processes meant to overcome them. For these reasons, this review is given.

Most of the studies reported in this review have been conducted with air-purifying full facepiece respirators. The studies, however, were meant to be generic and more or less applicable to all types of respiratory protective devices as long as these devices incorporate components (such as speech diaphragms) similar to those that were studied.

There is a large amount of similarity of communications components among military and commercial respirators. Thus, conclusions drawn from these studies should apply.

There are standard protocols that specify the testing of telephone communications (ANSI, 1989; NFPA, 1997). Procedures used in the studies to be reviewed, however, differed from these standards in at least one important aspect: listeners were not given a written list of words from which to choose the words they thought were spoken. Actual field use of respirators would not necessarily involve a small number of words known beforehand.

Task performance, in this case speed and accuracy of speech perception, is the variable of interest

for these studies. The performance rating of a given activity is the percentage performance of a person wearing a respirator compared with not wearing a respirator (Johnson *et al.*, 1992). Because the subjects serve as their own controls, the performance rating of an activity allows the effect of the respirator to be isolated from that of the individual. A 40% degradation in performance is equivalent to a task performance rating of 60%. Therefore, a task performance rating of 100 indicates no performance degradation while a 0 rating indicates complete performance degradation. Test results given as performance ratings serve to emphasize that wearer performance is probably the most important and reproducible means to assess respirator effects, and performance ratings can be used to modify task performance expectations of respirator wearers.

Effects of Distance and Context

Twenty-six subjects participated in a test to determine the effect of distance on speech comprehension while wearing a respirator mask (Coyne *et al.*, 1998). Subjects were paired, with one subject acting as the speaker and the other as the listener. Both either wore no respirators or US Army M17 full facepiece air-purifying respirators with speech diaphragms, as appropriate. The listener rode a bicycle ergometer at the low rate of 75W. The speaker held a sound level meter and was required to maintain a combined speech and background noise sound level of 70 dB using a C weighting and slow dynamic response setting.

The speaker was required to stand at six distances from the listener, beginning with the farthest distance and sequentially moving closer. The distances were 0.61, 1.22, 1.83, 2.44, 3.05, and 3.66m when wearing respirators, and 1.22, 2.44, 3.05, 6.10, 9.15, and 12.2m when not wearing respirators.

Two speech tests were performed: 1) modified rhyme test (MRT) monosyllabic single words (House *et al.*, 1965; Kreul *et al.*, 1968), and 2) the Speech Perception in Noise (SPIN) test with complete sentences (Kalikow *et al.*, 1977). Both tests were used

in a nonstandard way because the listener had to write the unknown word without referring to a list of choices.

Performance Ratings for word comprehension for both speech tests and varying distance appear in Fig. 1. Percentages of words heard correctly decrease with distance for both types of speech test. Comprehension of single words (MRT) is much lower and more sensitive to distance than is the comprehension of words used in predictable sentences (SPIN). Comprehension of single words is no better than about 80% for an extremely close distance of 0.61m, the same 80% comprehensibility of words in predictable sentences is 6.1m. At distances where single words are useless for communicating, speech is still intelligible a majority of the time when predictable sentences are used.

Higher levels of background noise would be expected to decrease word comprehension. As comprehension decreases, personnel may have to either 1) resort to hand signals or other nonverbal measures, 2) come closer together, or 3) resort to longer explanations concerning the idea to be communicated.

Effects of Telephone and Speech Diaphragm Amplification

Telephones do not transmit visual clues concerning meanings of spoken words. Thus, one might expect respirator wear to have little effect on speech perception.

Eleven pairs of subjects engaged in this test (Johnson *et al.*, 2000A). Members of each pair sat in different rooms linked by telephone and by computer. They each took turns acting as speakers and listeners.

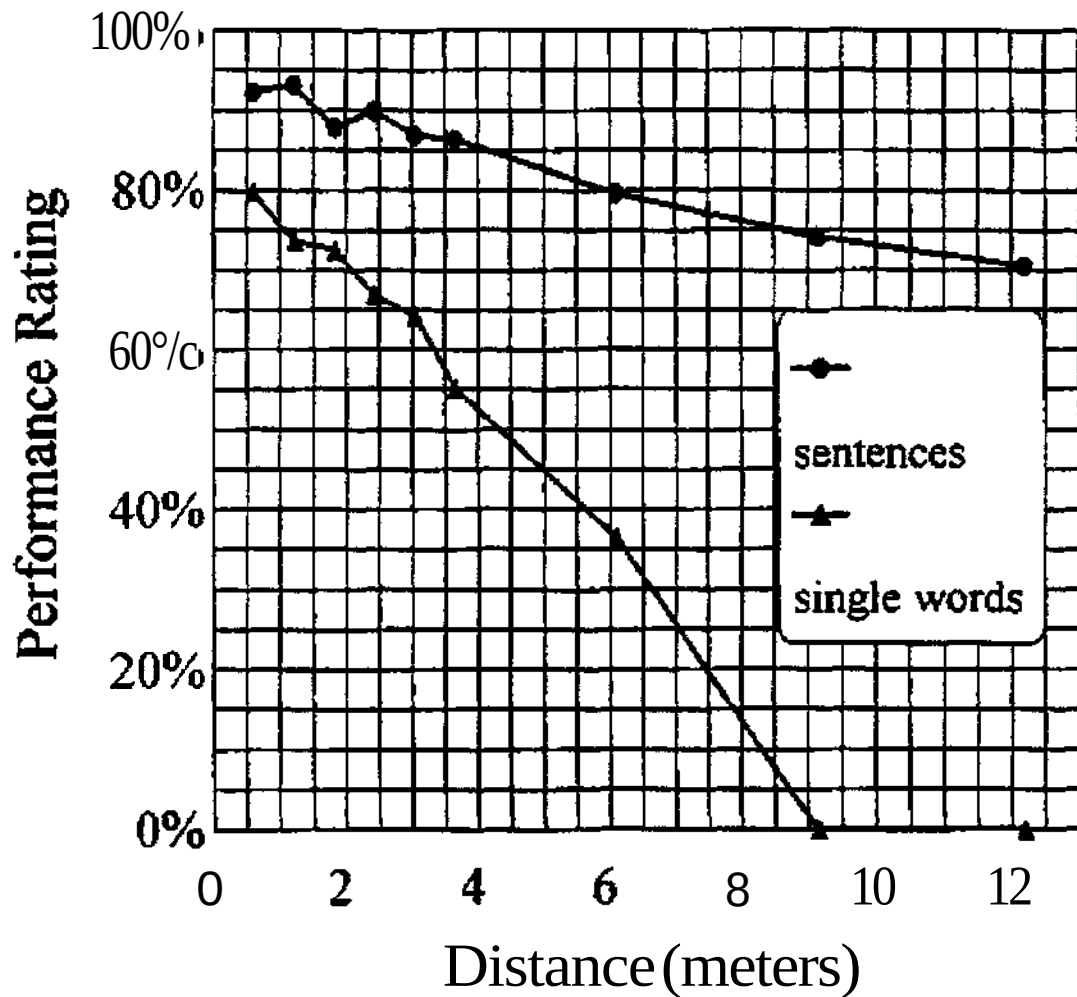


Figure 1. Plots of the **performance** ratings for speech intelligibility for the US Army M-17 respirator versus distance when predictable sentences and single words were spoken (Coyne *et al.*, 1998).

MRT words appeared in random order on the computer screen of the **speaker**, and each word was transmitted by telephone from the speaker to the **listener**, who would attempt to repeat the word. If the word was judged to be correctly identified, the listener typed the word into her/his computer. The computer thus scored both accuracy and speed of response.

Among other equipment, subjects wore US Army M40 full facepiece air-purifying respirators with and without an electronic speech amplifier and speaker clamped to the outside of the respirator speech diaphragm. There was a no-respirator control condition. Subjects also wore hoods.

Performance rating for the M40 with standard speech diaphragm (no amplifier) was 94%; performance rating with the amplifier/speaker was 89%. There was no statistical significance between these two conditions. Using a telephone with a respirator therefore reduced single word comprehension by about 10% compared to the telephone with no respirator.

Why was there no speech intelligibility advantage with the amplifier and speaker mounted on the respirator? It was noticed that the telephone handset was not long enough for the receiver to cover the ear when the transmitter was located near the speech diaphragm. Subjects tended to hold the handset to

their ears so that they could hear, and didn't move the handset transmitter to the speech diaphragm to speak.

It took twice as long to identify the words wearing the respirator compared to the control. Performance ratings of speed of response were 52% and 51% with the standard diaphragm and

amplifier/speaker. In addition, words that were identified incorrectly took longer to be agreed upon.

Of the incorrect words, 46% involved the letter "P" either at the beginning or at the end of the word. This was potentially attributed to the high frequency content of the spoken sound of *p* that is not transmitted well by the respirator.

Value of Speech Diaphragm and Telephone Protocol

If the speech amplifier has no value for improving either speed or accuracy of single word comprehension, does a respirator even need a speech diaphragm? Also if the configuration of the amplifier/speaker did not allow it to be used to full advantage, could there be an improvement if a protocol were followed that required the subject to move the handset to her/his mouth during speaking and to the ear when listening?

Twelve pairs of subjects performed a test (Johnson *et al.*, 2000B) similar to the telephone study described previously. The protocol and methods of this study were identical to those of the previous test. However, subjects wore several different kinds of commercial respirators, including several full facepiece air-purifying respirators with and without speech diaphragms, a half-facepiece air-purifying respirator without speech diaphragm, and a loose-fitting powered air-purifying respirator.

Two replications were performed. In the first, subjects held the telephone handset in any way they wished; they were not given any instructions about its use with the respirator. In the second replication, subjects were instructed to place the transmitter of the handset in front of the speech diaphragm when speaking, and to place the receiver over their ears

when listening. They were to signal the transition from speaking to listening by saying the word "over" into their phones.

The communications protocol improved comprehension accuracy for all respirators without any concomitant decrease in recognition time. Without the protocol, accuracy performance ratings varied from 84% to 93% for the different respirators. With the protocol, performance ratings varied from 91% to 98%; in other words, the protocol improved word comprehension to levels nearly the same as with the no respirator control condition. The time to recognize words remained at about twice that of the control, both with and without the protocol. Thus, respirator use with the communications protocol would be expected to slow word comprehension, requiring twice as much time, but not to reduce the ability to comprehend words.

Among the respirator types tested, the full-facepiece air-purifying respirator without a speech diaphragm gave the lowest performance rating. Comparing results with this respirator against similar respirators with speech diaphragms indicates that a speech diaphragm can improve word comprehension accuracy by about 5%, but with no advantage for recognition time.

Value of Speech Diaphragm During Face-to-Face Communications

Based on the results of Johnson *et al.* (2000B), respirators with speech diaphragms offer about a 5% advantage to speech intelligibility accuracy over those without such devices during telephone communications. What is the impact of a speech diaphragm during face-to-face communications?

This question was addressed in a study recently completed by Caretti (2000). Eight subject pairs were seated opposite each other at a distance of 10 feet.

The listener was positioned before a touch screen computer monitor that was used to record her/his responses. Each stimulus MRT word was presented verbally using the carrier phrase "The first (or second, third, etc.) word is _____," with the numerical order increasing with each successive stimulus word. Listeners selected the word that was perceived to be spoken from a list of six response words presented on the computer monitor by pressing a button on the touch screen that

corresponded to the perceived word. The listener then provided a thumbs-up hand signal to the speaker to cue her/him to proceed to the next word. The speaker presented a total of 50 stimulus words for each test. Speakers were instructed not to use any visual signals (hand signals) to communicate with the listener, not to repeat any of the words, and to keep their voice level between 65 and 70 dBA throughout the trial. A sound level meter was positioned within the speaker's view to keep them aware of the loudness of their voice. Background noise levels were also measured throughout each MRT test. Each speaker presented two word lists to the listener before the speaker and listener switched positions.

Subject pairs completed MRT test trials during wear of several different military full facepiece air-purifying respirators with and without speech

diaphragms. A total of seven respirators with speech diaphragms and seven without speech diaphragms were assessed. Percentage of words correctly identified was calculated using the equation:

$$\% \text{ correct} = (\text{number correct} - [\text{number incorrect}/5]) * 2$$

This equation was used to correct the word score for chance or guessing made possible by the multiple-choice form of the answer sheet (Van Cott and Kinkade, 1972). The results of this investigation showed that MRT scores averaged about 91% for respirators with speech diaphragms and 88% for those without a speech diaphragm. These findings indicate that a speech diaphragm improves speech intelligibility accuracy by roughly 3% during face-to-face communications.

Conclusions

Depending on the communications medium, those responsible for respirator programs may wish to establish training in communications procedures. If communication takes place face-to-face, then important messages should probably be spoken as redundant words. If greater distances are involved,

hand signals should be used. If the telephone is to be used, then a communications protocol should be established. If a significant amount of communication is required among wearers, then extra time must be allowed for words to be understood.

References

- ANSI Standard S3.2-1989, "Method for Measuring the Intelligibility of Speech Over Communication Systems," Acoustical Society of America, New York, NY (1989).
- Caretti, D.M., "Human Factors Evaluation of Various Domestic and Foreign Military Respirators," U.S. Army Edgewood Chemical Biological Center, Aberdeen Proving Ground, MD, Feb 2000, UNCLASSIFIED Draft Report (2000).
- Coyne, K.M., A.T. Johnson, G.H. Yeni-Komshian, and C.R. Dooly, "Respirator Performance Ratings for Speech Intelligibility," *Amer. Ind. Hyg. Assoc. J.* 59:257-260 (1998).
- House, A.S., C.E. Williams, M.H.L. Hecker, and K.D. Kryter, "Articulation - Testing Method: Consonantal Differentiation with a Closed-Response Set," *J. Acoust. Soc. Am.* 61:1337-1351 (1965).
- Johnson, A.T., and W.H. Scott, "Survey of Physical Plant Respirator Wearers at the University of Maryland," unpublished observations (1999).
- Johnson, A.T., W.H. Scott, C.G. Lausted, K.M. Coyne, M. S. Sahota, M. M. Johnson, G. Yeni-Komshian, and D.M. Caretti, "Communication Using a Telephone While Wearing a Respirator," *Am. Ind. Hyg. Assoc. J.* 61:264-267(2000A).
- Johnson, A.T., W.H. Scott, K.M. Coyne, F.C.S. Koh, and J. Rebar, "Telephone Communications with Several Commercial Respirators," *Am. Ind. Hyg. Assoc. J.* (submitted) (2000B).

Johnson, A.T., R.A. Weiss, and C. Grove, "Respirator Performance Rating Table for Mask Design," *Amer. Ind. Hyg. Assoc. J.* 53:193-202 (1992).

Kalikow, D.N., K.N. Stevens, and L.L. Elliott, "Development of a Test of Speech Intelligibility in Noise Using Sentence Materials with Controlled Word Predictability," *J. Acoust. Soc. Am.* 61:1337-1351 (1977).

Kreul, E.J., J.C. Nixon, K.D. Kryter, D.W. Bell, and J.S. Lang, "A Proposed Clinical Test of Speech Discrimination," *J. Speech Hearing Res.* 11:536-552 (1968).

NFPA Standard 1981, "Open-Circuit Self-Contained Breathing Apparatus for the Fire Service," National Fire Protection Association, Quincy, MA (1997).

Van Cott, H.P., and R.G. Kinkade, eds., "Human Engineering Guide to Equipment Design," American Institutes for Research, Washington, DC, 1972.

ISRP Back Issues

Complete back issues for the years 1983-1990 have been reprinted and bound in five volumes. The five-volume set is available for \$400 (U.S.), including packing and mailing.

Other individual back issues are also available upon request. Individual journals cost \$45.00 (U.S.) per issue for up to four issues. Reprints of individual journal articles are available for a charge of \$40.00 per article.

Mail your orders with payment to:

Dr. James S. Johnson
Lawrence Livermore National Laboratory
PO Box 808, L-379
Livermore, CA 94551
925-422-5165
925-422-5176 FAX

