

A Study of Speech Intelligibility of Four Protective NFPA – Approved SCBA Facepieces Masks Equipped with Audio Mask Amplifiers

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Abstract

Communication among team members while using protective masks and respirators is essential in the performance of many firefighting, industrial, military and law enforcement tasks. In many situations effective communication may be life-critical. Protective masks and respirators can seriously restrict or degrade effective speech communication in the high background noise of actual working environments. While limited research has been conducted to evaluate the effectiveness of voice communications while wearing NFPA-approved Self-Contained Breathing Apparatus (SCBA) under several experimental conditions, research is lacking that considers speech intelligibility under background noise conditions that attempt to approximate working conditions. Extensive research is also not available on the impact of commercially available mask audio amplifiers that purport to enhance the speech intelligibility in communication.

This study examines the speech intelligibility performance of four different NFPA-approved SCBAs under two background noise environments. The performance of audio mask amplifiers is examined using ANSI S3.2-1989 guidelines for measuring the intelligibility of speech over communication systems using a Modified Rhyme Test as the fundamental quantitative tool. The results of the work show that speech intelligibility performance improvements are achieved for all four masks through the use of a mask amplifier and furthermore, that the most significant improvements occur under high noise conditions.

Introduction

The use of protective masks and respirators is essential in the performance of many dangerous tasks in firefighting, industry, the military and law enforcement. When using these masks, communication among team members is often important and may be life-critical.

Firefighting, industrial, military, or law enforcement situations can occur in very noisy environments. Although the protective masks used in these situations often have mechanical speech diaphragms (generally a disc made of aluminum film or metalized capton) to facilitate speech communication, however, these masks and respirators have the potential to restrict or degrade effective speech communication in the high background noise of actual working environments.

Johnson, et al. (Johnson, 2000) reviewed several experiments that examined the relationship between speech transmission accuracy while wearing respirators and several variables such as the distance between the speaker and the listener, word context, diaphragm use, and electronic amplification. This research showed decreases in speech intelligibility with increases in the distance between the speaker and the listener; an

increase in speech intelligibility with a greater word context; and little, or negative changes in intelligibility with the use of diaphragms and electronic amplification. Although the effects of noise were discussed in general in this work, research is lacking that considers speech intelligibility under various background noise conditions to more accurately gauge the impact of noise under actual working conditions. In addition, the audio amplification experiments reviewed in this article were conducted using the telephone as the communication medium. Thus the impact of the telephone signal processing, telephone diaphragm, and physical orientation of the speakers and listeners may have seriously affected the results. The impact of commercially available mask audio amplifiers, which purport to enhance the speech intelligibility in communication, therefore needs to be examined further.

This study specifically examines the speech intelligibility performance of four different NFPA-approved SCBA masks under two background noise environments. Further, the performance of audio mask amplifiers is also examined. In this study, the ANSI S3.2-1989 guidelines for measuring the intelligibility of speech over communication systems were followed using a Modified Rhyme Test as the fundamental quantitative tool (ANSI, 1989; NFPA, 1997). The results of the work show that speech intelligibility performance improvements are achieved for all four masks through the use of a mask amplifier and furthermore, that the most significant improvements occur under high noise conditions.

Methods

Four NFPA-approved SCBA masks (from different manufacturers) were tested with their matched commercially available electronic voice amplification devices. Each audio amplification device was located on the frontal area of the mask and to the side so as to not interfere with the mechanical speech diaphragm of the mask. The masks were attached to an air filled tank strapped to the wearer's back and connected to the mask by a rubber tube that was fastened directly in front of the wearer's mouth area. The regulators were positioned so that it would be impossible for a person to read the lips of the person who is wearing the mask.

Speaker Training and Testing Procedures

The Modified Rhyme Test (MRT) as defined by the ANSI S3.2-1989 guidelines was used for speech intelligibility testing. This test consists of a list of 50 words that are read in a known sentence by a speaker (or talker) and then a corresponding answer sheet is used for the listeners to indicate the key word that is spoken out of a choice of 6 words for each keyword. Within each group of 6 keywords that are used in the MRT test, only the initial or final consonant differs. The MRT test thus requires perception of consonant sounds that are difficult to transmit successfully and thus well model differences that might be critical to speech intelligibility.

All speakers were put through a training process so that they would keep the level of their voice relatively constant at a desired decibel level (60 db or 70 db) for the actual testing. In the training, the speaker would read sentences containing the same words that were used during the actual testing process. During the actual tests, a background of pink noise either at a level of 60 db or 70 db was employed. This noise was constant in power within the frequency band of 400-4000 Hz with a tolerance of 6 decibels per octave. This was done to model the conditions in which these masks and voice amplification devices might be used. While the pink background noise was being uniformly broadcast over the field as verified by a B&K 2238 sound level meter, the speaker would read a group of fifty sentences with one sentence being read approximately every 6 seconds. The sentences would all contain the phrase "Circle the word -" where the underlined blank represents a different word used in every sentence (Appendix II contains a sample form). Each sentence had a different group of 6 words that could be chosen. However, the speaker had no influence over which word he/she would speak. The lists were randomly generated in advance according to the MRT testing protocol (using the C++ program given in Appendix I) and none of the participants had any previous knowledge as to which lists were being used during testing. The listeners all had response forms (Appendix III) that listed the 6 possible word choices for each sentence read. If the listener could not ascertain what was being said, they were instructed to guess as best that they could. As described later, blank responses were taken into

consideration while computing the final result statistics, as well as stimulus words that were read incorrectly and/or external sounds or events, which would invalidate a given sentence in the judgment of the principle investigator. All listeners were judged to be audilogically normal though not explicitly tested.

Note that for each 8CBA mask that was tested there were five talkers (as specified in the AN81 83.2-1989 standard) and for each talker there were five listeners. The experimental conditions are then defined by the background pink noise level (60 db or 70 db), the talker's speaking level (60 db or 70 db), and the status of the mask amplifier (operational or non-operational).

Subjects

The subject population consisted of 19 men and women between the ages of 18 and 51. Forty seven percent (47%) were women and 53% were men. The mean age of the test subject population was 24 yrs. and 88% were between the ages of 18 and 25 yrs. while 12% were between the ages of 28 and 51 yrs. All subjects were judged to be audilogically normal though not explicitly tested as such. No hearing defects or speech impairments were noted in any of the participants. All subjects were native born Americans without noticeable accents.

Physical Conditions

The experiment was conducted in the bottom floor of a large industrial warehouse. The room had a large tiled floor, cement block walls, and had compressed cardboard ceiling tiles. A diagram of the physical test layout is given in Figure 1. Note that the distance from the speaker to all of the listeners was 5 ft. and the background pink noise source was located off to the side of both the speaker and the listeners, not in-line with either. The talker sat facing the field containing the sound meter, listeners, and a movable soundboard, which absorbed excess noise so as not to allow for echo and distortion of the results. The acoustic field, or area in which the talker and listeners were placed, was spaced such that the listeners were in front of the talker at a distance of five feet (with a tolerance of plus 1' and negative 0').

The group of five listeners were seated in a semi-circle and spaced no more than a foot apart from each other. For each mask that the speaker used, the sound level for each speaker training session and the level of the pink noise source was measured with a calibrated B&K 2238 sound level meter using a B&K 4188 microphone and checked periodically throughout all of the experiments. Listeners did not wear masks during the experiment.

Experimental Conditions

Eight experimental sets were defined for the testing to evaluate the speech intelligibility of the SCBA Facepieces. These correspond to all possible combinations of the background noise level (60 db, 70 db), talker speaking level (60 db, 70db), and mask amplifier status (not operational, operational).

For reference purposes the resulting these Experimental Sets* are defined as

- 1: Background Noise Level 60 db; Speaking Level 60 db; Mask amplifier not operational
- 2: Background Noise Level 60 db; Speaking Level 60 db; Mask amplifier operational
- 3: Background Noise Level 70 db; Speaking Level 60 db; Mask amplifier not operational
- 4: Background Noise Level 70 db; Speaking Level 60 db; Mask amplifier operational
- 5: Background Noise Level 60 db; Speaking Level 70 db; Mask amplifier not operational
- 6: Background Noise Level 60 db; Speaking Level 70 db; Mask amplifier operational
- 7: Background Noise Level 70 db; Speaking Level 70 db; Mask amplifier not operational
- 8: Background Noise Level 70 db; Speaking Level 70 db; Mask amplifier operational

* Mask amplifier not operational: in all test cases the mask amplifier was either located or removed so as not to restrict or alter the audio characteristics of the nominal mask configuration, i.e. the speaking diaphragm was not blocked when the mask amplifier was not operational.

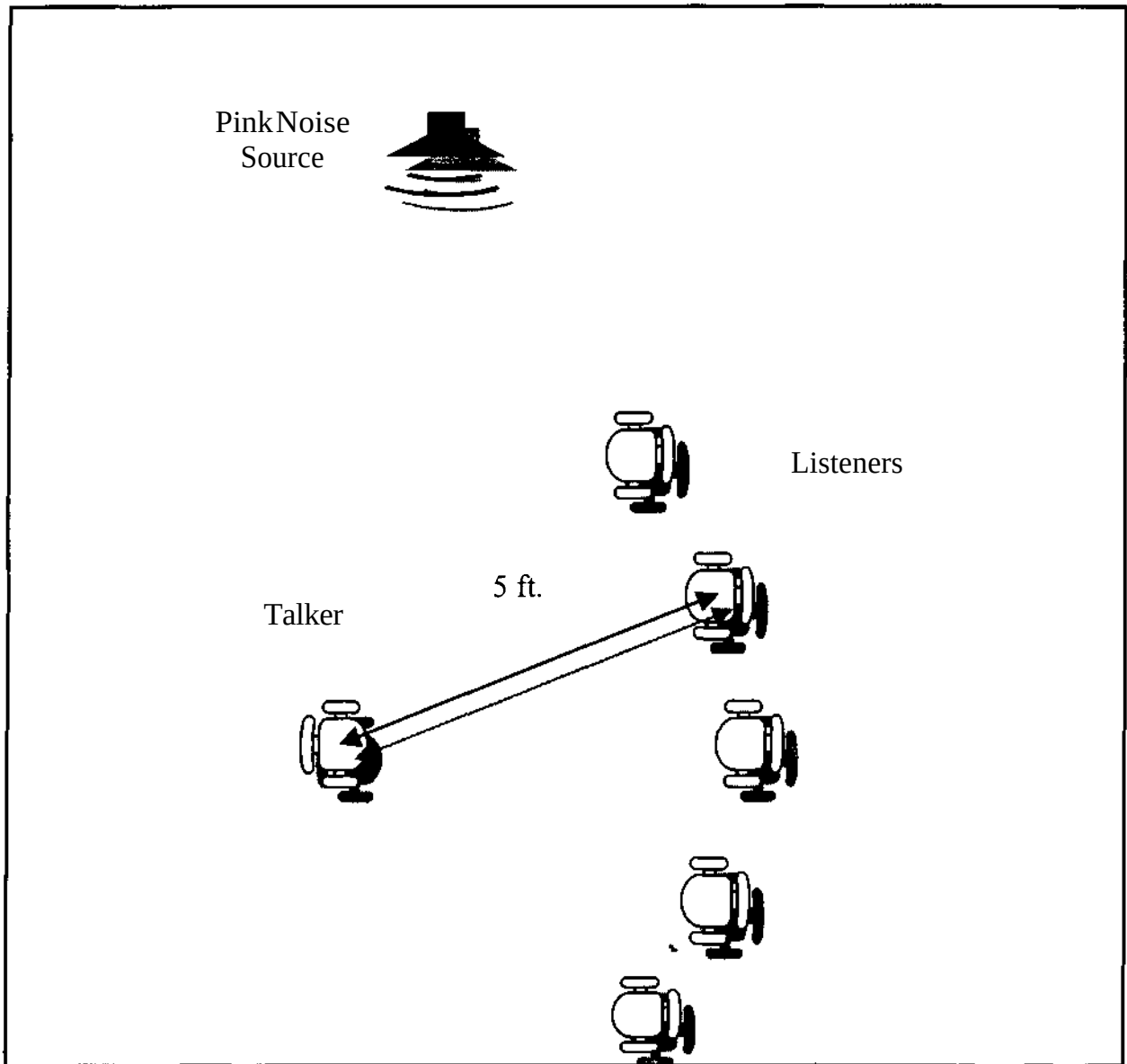


Figure 1. General Physical Layout of the Speech Experiment

Results

The full summary test scores and statistics results are contained in tables 1-4 corresponding to each one of the four SCBA masks: Mask 1 (Table 1), Mask 2 (Table 2), Mask 3 (Table 3) and Mask 4 (Table 4). As noted previously, there were five talkers for each mask and five listeners for each talker in a given experimental

condition. In Tables 1-4, the rows of the test scores and summary statistics array correspond to the talkers while the column groups correspond to the eight different experimental conditions.

A particular test score is defined by three integer values: C, N, and B. For a given MRT stimulus/response test, C is the number of correct responses provided by a listener, N is the number of possible correct answers, and B is the number of blank responses. While the base MRT test consists of 50 possible stimuli/responses, environmental conditions or talker (or listener) problems occasionally required the invalidation of a specific stimulus. For example, an unusually large background noise from an external source or an incorrect selection of the proper word as a stimulus resulted in the invalidation of a specific item on a test. Thus the value of N deviated from, but is always less than, the value of 50.

Subjects also did not uniformly provide a response to valid stimuli even though they were instructed to always provide their best estimate as to what word was spoken by the talker. This generally occurred because of lapses in attention or temporary confusion on the part of individual listeners. The value of B, which is always greater than or equal to zero, represents the number of these blank responses in a given test. The assumption was made that the listener could not choose among the possible responses in this situation and thus that all possible choices of stimuli were equally likely; therefore $B/6$ is the expected number of correct responses for this situation.

The adjusted test (ratio) score is defined to be $R = (C+B/6)/(N+B)$. This represents the ratio of correct responses ($C+B/6$), adjusted for invalid stimuli/responses and blank responses, to the total number of valid stimuli ($N+B$).

For each mask and each experimental condition (*i.e.* noise level, speaking level, mask amplifier status), the mean and standard deviation of the adjusted test ratio scores is computed over all talkers and listeners (25 data points for each experimental set). In addition, the difference between values of the corresponding adjusted test ratio scores for the experimental conditions 1 and 2; 3 and 4; 5 and 6; and 7 and 8 are computed along with their mean and standard deviation values. Note that the computation of these difference statistics were done between groups and not between individuals. The mean and standard deviation of the differences are then used to compute 90% and 95% confidence intervals. These statistics are summarized in the tables 1-4.

Table 1. Statistics of Ratio Score (R) for Mask 1 — for Experimental Set (1 through 8)

	1	2	3	4	5	6	7	8
Mean of R	60%	84%	28%	61%	75%	87%	47%	70%
Std. Dev. of R	11%	7%	9%	15%	11%	5%	14%	10%
Compared sets		2-1		4-3	✓	6-5		8-7
Mean of diff.		25%		33%		13%		23%
Std Dev of Diff		11%		16%		9%		13%
Confidence Interval 1	90% low 90% high	21% 28%		27% 38%		10% 16%		19% 27%
Confidence Interval 2	95% low 95% high	20% 29%		26% 39%		9% 16%		18% 28%

Table 2. Statistics of Ratio Score (R) for Mask 2 — for Experimental Set (1 through 8)

	1	2	3	4	5	6	7	8
Mean of R	49%	77%	22%	53%	73%	88%	45%	73%
Std. Dev. of R	12%	9%	8%	15%	10%	7%	11%	12%
Compared sets		2-1		4-3		6-5		8-7
Mean of diff.		28%		32%		14%		28%
Std Dev of Diff		16%		17%		8%		13%
Confidence Interval 1	90% low 90% high	23% 34%		26% 37%		12% 17%		24% 32%
Confidence Interval 2	95% low 95% high	22% 35%		25% 38%		11% 18%		23% 33%

Table 3. Statistics of Ratio Score (R) for Mask 3 — for Experimental Set (1 through 8)

	1	2	3	4	5	6	7	8
Mean of R	73%	88%	45%	72%	84%	91%	66%	81%
Std. Dev. of R	9%	7%	15%	12%	6%	4%	9%	9%
Compared sets		2-1		4-3		6-5		8-7
Mean of diff.		15%		26%		8%		16%
Std Dev of Diff		8%		15%		8%		11%
Confidence Interval 1	90% low 90% high	12% 17%		21% 31%		5% 10%		12% 19%
Confidence Interval 2	95% low 95% high	11% 18%		21% 32%		5% 11%		12% 20%

Table 4. Statistics of Ratio Score (R) for Mask 4 — for Experimental Set (1 through 8)

	1	2	3	4	5	6	7	8
Mean of R	65%	84%	35%	66%	78%	94%	63%	84%
Std. Dev. of R	9%	12%	14%	18%	8%	3%	11%	7%
Compared sets		2-1		4-3		6-5		8-7
Mean of Diff.		19%		32%		16%		20%
Std Dev of Diff		11%		14%		8%		12%
Confidence Interval 1	90% low 90% high	15% 22%		27% 37%		13% 18%		16% 24%
Confidence Interval 2	95% low 95% high	14% 23%		26% 38%		13% 19%		15% 25%

As one specific example of the interpretation of these results, consider the Mask 3 summary statistics. We observe that, in our sample of 25 differences between ratio test scores for experimental conditions 1 and 2, the average difference in speech intelligibility is 15% with a population standard deviation of 8%. We can then be 95% confident that the population mean is in the interval of:

$$[15\% - 1.96 \times 8\%/5, 15\% + 1.96 \times 8\%/5] = [11.86\%, 18.14\%]$$

Conclusions

Several immediate conclusions can be drawn from the summary statistical data in Tables 1-4. The first set of two conclusions (1 & 2 below) can be viewed as consistency tests in the sense that the results would be expected.

1. The speech intelligibility at the higher talker speaking level was always greater than at the lower talker speaking levels. Based on the tabulated data (and assuming a normal distribution), the average improvement is $14.81 \pm 5.45\%$ at a confidence level of 99%.

In particular, independent of the type of mask, for a specified background noise level (60 db or 70 db) and status of the mask amplifier (operational or non-operational) the mean ratio test values for a 70 db speaking level were always greater than the mean ratio test values for a 60 db speaking level.

As an example, observe that for Mask 3 the mean ratio value for experimental set 5 (Background Noise Level 60 db; Speaking Level 70 db; Mask amplifier not operational) is 84% while the mean ratio value for experimental set 1 (Background Noise Level 60 db; Speaking Level 60 db; Mask amplifier not operational) is 73%.

2. The speech intelligibility at the lower background noise level was always greater than at the higher background noise level. Based on the tabulated data (and assuming a normal distribution), the average improvement is $21.2 \pm 5.28\%$ at a confidence level of 99%.

In particular, independent of the type of mask, for a specified speaking level (60 db or 70 db) and status of the mask amplifier (operational or non-operational) the mean ratio test values for a 60 db background noise level were always greater than the mean ratio test values for a 70 db background noise level.

As an example, observe that for Mask 4 the mean ratio value for experimental set 2 (Background Noise Level 60 db; Speaking Level 60 db; Mask amplifier operational) is 84% while the mean ratio value for experimental set 4 (Background Noise Level 70 db; Speaking Level 60 db; Mask amplifier operational) is 66%.

The following four conclusions (3, 4, 5 & 6 below) are more interesting in the sense that the results are not obvious:

3. The speech intelligibility with the mask amplifier present and operational was better than with the mask amplifier not present.

In particular, independent of the type of mask, for a specified background noise level (60 db or 70 db) and speaking level (60 db or 70 db) the mean ratio test values with mask amplifier operational were always greater than the mean ratio test values with mask amplifier not operational. Based on the tabulated data (and assuming a normal distribution), the average improvement is $21.75 \pm 5.7\%$ at a confidence level of 99%.

As an example, observe that for Mask 1 the mean ratio value for experimental set 2 (Background Noise Level 60 db; Speaking Level 60 db; Mask amplifier operational) is 84% while the value for experimental set 1 (Background Noise Level 60 db; Speaking Level 60 db; Mask amplifier not operational) is 60%. For Mask 2, the mean ratio value for experimental set 6 (Background Noise Level 60 db; Speaking Level 70 db; Mask amplifier operational) is 88% while the value for experimental set 5 (Background Noise Level 60 db; Speaking Level 70 db; Mask amplifier not operational) is 73%.

4. There was a greater improvement in speech intelligibility with the use of the mask amplifier when the background noise was high as compared to the lower background noise case. Based on the tabulated data (and assuming a normal distribution), the average improvement for the high noise case is $26.25 \pm 4.16\%$ at a confidence level of 90% while the average improvement for the low noise case is $17.25 \pm 4.37\%$ at the same confidence level.

In particular, independent of the type of mask, the mean of the difference between the test ratio values (for a specified speaking level) for the mask amplifier operational case and the mask amplifier non-operational case was greater in the higher background noise (70 db) case than the lower background noise case (60 db).

As an example, observe that for Mask 1 the mean of the difference between experimental sets 1 and 2 (without and with audio amplifier operational, 60 db background noise, speaking level 60 db) is 25% while the mean of the difference between experimental sets 3 and 4 is 33% (without and with audio amplifier operational, 70 db background noise, speaking level 60 db). The magnitude of this example result is typical, in a relative sense, for all the masks that were tested.

5. The improvement noted in conclusion 4 was greater, in an absolute sense, in the lower speaking level case as compared to the higher speaking level. However, in a relative sense, the improvements were approximately the same. This is also generally independent of mask type.

As an example, observe that for Mask 2, the difference between experimental sets 1 and 2 (without and with audio amplifier operational, 60 db background noise, speaking level 60 db) is 28% while the difference between experimental sets 3 and 4 (without and with audio amplifier operational, 70 db background noise, speaking level 60 db) is 32%. However, for the same mask, the difference between experimental sets 5 and 6 (without and with audio amplifier operational, 60 db background noise, speaking level 70 db) is 14% while the difference between experimental sets 7 and 8 (without and with audio amplifier operational, 70 db background noise, speaking level 70 db) is 28%.

6. The standard deviations of the ratio test scores did not show significant patterns; however, the mean of the standard deviation values was approximately 10%, reasonably independent of the type of mask. The range of values among all masks is from 3% to 18% (both limits occurred in the Mask 4 tests), while the standard deviation of these values is approximately 3.4 — a relatively low value implying consistent test results.

The first two conclusions can be viewed primarily as consistency checks on the experimental methodology; however, the quantitative data on the speech intelligibility improvements possible between the two speaking levels and the two background noise levels yield potentially valuable information.

The next four observations provide interesting new results in the framework of performance measurement of speech intelligibility for SCBA facepieces with (and without) audio mask amplifiers. First, and most importantly, under all defined experimental conditions there was a clear (statistically significant) increase in the speech intelligibility with the use of the audio mask amplifier. The 99% confidence interval for this increase was 16% - 26% representing a substantive magnitude comparable to the increases in intelligibility that occurred in connection with the first observations of experimental **consistency**, *i.e.* with a speaking level difference of 10db or a background noise level difference of 10db. The data indicate (conclusion 4) that the overall increases in speech intelligibility occur at an average value of 17% for the low background noise case and at an average value of 26% for the high background noise case. This seems to result from the fact that at lower noise levels there were a greater number of correct responses and that less of an improvement was possible while at the higher noise levels the audio mask amplifiers had a more significant effect in raising the speech levels "above the noise level." Conclusions 5 and 6 are more difficult to interpret though one might interpret conclusion 5 as implying that relative measure of improvement are more natural to examine in this context than absolute measures.

Summary

This study investigated the speech intelligibility performance of four NFPA-approved respirators under two background noise conditions and two speaking levels. ANSI S3.2-1989 guidelines for measuring the intelligibility of speech over communication systems were followed. For each of the four masks, the performance with and without audio mask amplifiers was obtained and the results studied in a statistical framework.

The primary result of the work show is that there is a statistically significant (at the 99% confidence level) speech intelligibility performance improvement with the use of a mask amplifier on NFPA-approved SCBA masks. Furthermore, the most significant improvement in speech intelligibility (at a 90% confidence level) occurs when the mask amplifier is used in a high background noise condition.

This research can be extended in a number of directions. First, the subject population can be broadened in terms of diversity, *i.e.* in terms of non-native American speakers. A broader diversity of test subjects could better represent the full population of individuals engaged in firefighting, law enforcement and military tasks

that use SCBA facepieces. Second, additional types of NFPA-approved SCBA facepieces can be studied. In terms of speech intelligibility there were significant differences that were found between the four masks examined in the study. Further research directed at isolating the underlying factors that might explain these differences would be important. Third, speech intelligibility tests with both talkers and listeners both using SCBA facepieces would be important. Finally, a fourth possible important direction of research would be to develop, and use as the basis for speech intelligibility testing such as described in this paper, more detailed and representative models of the acoustic environments and psychological conditions faced by firefighters, law enforcement personnel and the military in the use of these masks. Speech intelligibility tests using pink background noise and given under minimal psychological stress conditions can provide useful data that represents one dimension of actual use. However, other aspects of actual acoustic noise, e.g. time-varying characteristics, as well as the subjects psychological state, e.g. being in high stress conditions, can also be equally important to characterize the full value of audio mask amplifiers.

References

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Appendix I

C++ Program to Generate MRT Stimulus Form

```
#include <iostream>
#include <string>
#include <fstream>

using namespace std;

int main()
{
    ofstream fout;
    fout.open("words.txt");
    if (fout.fail() == true) {cout <<"File Open Failure!!!"; exit(1);}

    string words [50] [6] = {
        {"went", "sent", "bent", "dent", "tent", "rent"},
        {"hold", "cold", "told", "fold", "sold", "gold"},
        {"pat", "pad", "pan", "path", "pack", "pass"},
        {"lane", "lay", "late", "lake", "lace", "lame"},
        {"kit", "bit", "fit", "hit", "wit", "sit"},
        {"must", "bust", "gust", "rust", "dust", "just"},
        {"teak", "team", "teal", "teach", "tear", "tease"},
        {"din", "dill", "dim", "dig", "dip", "did"},
        {"bed", "led", "fed", "red", "wed", "shed"},
        {"pin", "sin", "tin", "fin", "din", "win"},
        {"dug", "dung", "duck", "dud", "dub", "dun"},
        {"sum", "sun", "sung", "sup", "sub", "sud"},
        {"seep", "seen", "seethe", "seek", "seem", "seed"},
        {"not", "tot", "got", "pot", "hot", "lot"},
        {"vest", "test", "rest", "best", "west", "nest"},
        {"pig", "pill", "pin", "pip", "pit", "pick"},
        {"back", "bath", "bad", "bass", "bat", "ban"},
        {"way", "may", "say", "pay", "day", "gay"},
        {"pig", "big", "dig", "wig", "rig", "fig"},
        {"pale", "pace", "page", "pane", "pay", "pave"},
        {"cane", "case", "cape", "cake", "came", "cave"},
        {"shop", "mop", "cop", "hop", "pop"},
        {"coil", "oil", "soil", "toil", "boil", "foil"},
        {"tan", "tang", "tap", "tack", "tam", "tab"},
        {"fit", "fib", "fizz", "fill", "fig", "fin"},
        {"same", "name", "game", "tame", "came", "fame"},
        {"peel", "reel", "feel", "eel", "keel", "heel"},
        {"hark", "dark", "mark", "bark", "park", "lark"},
        {"heave", "hear", "heat", "heal", "heap", "heath"},
        {"cup", "cut", "cud", "cuff", "cuss", "cub"},
        {"thaw", "law", "raw", "paw", "jaw", "saw"},
        {"pen", "hen", "men", "then", "den", "ten"},
        {"puff", "puck", "pub", "pus", "pup", "pun"},
        {"bean", "beach", "beat", "beak", "bead", "beam"},
        {"heat", "neat", "feat", "seat", "meat", "beat"},
        {"dip", "sip", "hip", "tip", "lip", "rip"},
        {"kill", "kin", "kit", "kick", "king", "kid"},
        {"hang", "sang", "bang", "rang", "fang", "gang"},
        {"took", "cook", "look", "hook", "shook", "book"},
        {"mass", "math", "map", "mat", "man", "mad"},
        {"ray", "raze", "rate", "rave", "rake", "race"},
        {"save", "same", "sale", "sane", "sake", "safe"},
        {"fill", "kill", "will", "hill", "till", "bill"},
        {"sill", "sick", "sip", "sing", "sit", "sin"},
        {"bale", "gale", "sale", "tale", "pale", "male"},
        {"wick", "sick", "kick", "lick", "pick", "tick"},
        {"peace", "peas", "peak", "peach", "peat", "peal"},
        {"bun", "bus", "but", "bug", "buck", "buff"},
        {"sag", "sat", "sass", "sack", "sad", "sap"},
        {"fun", "sun", "bun", "gun", "run", "nun"}
    };
}
```

```

for (int times = 0; times < 50; times++)
{
    fout << "MODIFIED RHYME TEST" << endl<< endl << endl;

    fout << "Set _____" << endl << endl;
    fout << "Talker: _____ Amplifier on: YES / NO" << endl;
    fout << "Mask _____" << endl << endl;
    fout << "Noise Level _____ Date _____ Time _____" << endl << endl;

    fout << "Read the following sentences one at a time" << endl;
    fout << " * Do not repeat sentences or words." << endl;
    fout << " * Speak clearly." << endl;
    fout << " * Maintain the constant volume level that you learned in" << endl;
    fout << " training" << endl;
    fout << " * Do not raise or lower your voice as the noise level" << endl;
    fout << " changes." << endl;
    fout << " * Be careful to go in proper order" << endl;
    fout << " * Read a sentence about every 6 seconds" << endl << endl
    << endl;

    for (int i = 0; i < 25; i++)
    {
        int r = rand() % 6;
        fout << 2*i+1 << '\t' << "Circle the word "
        << words[2*i][r] << ".";
        r = rand() % 6;
        fout << '\t' << '\t' << 2*i+2 << '\t' << "Circle the word "
        << words[2*i+1][r] << "." << endl;
    }
}

fout.close();
return 0;
}

```

Appendix II

Sample MRT Stimulus Form

MODIFIED RHYME TEST

Set _____

Talker: _____ Amplifier on: YES / NO Mask _____

Noise Level _____ Date _____ Time _____

Read the following sentences one at a time

- * Do not repeat sentences or words.
- * Speak clearly.
- * Maintain the constant volume level that you learned in training
- * Do not raise or lower your voice as the noise level changes.
- * Be careful to go in proper order
- * Read a sentence about every 6 seconds

- | | | | |
|----|------------------------|----|-----------------------|
| 1 | Circle the word rent. | 2 | Circle the word gold. |
| 3 | Circle the word pack. | 4 | Circle the word lace. |
| 5 | Circle the word sit. | 6 | Circle the word dust. |
| 7 | Circle the word teak. | 8 | Circle the word din. |
| 9 | Circle the word wed. | 10 | Circle the word tin. |
| 11 | Circle the word dun. | 12 | Circle the word sud. |
| 13 | Circle the word seen. | 14 | Circle the word pot. |
| 15 | Circle the word test. | 16 | Circle the word pick. |
| 17 | Circle the word bath. | 18 | Circle the word say. |
| 19 | Circle the word wig. | 20 | Circle the word pale. |
| 21 | Circle the word cake. | 22 | Circle the word shop. |
| 23 | Circle the word soil. | 24 | Circle the word tack. |
| 25 | Circle the word fig. | 26 | Circle the word came. |
| 27 | Circle the word eel. | 28 | Circle the word mark. |
| 29 | Circle the word heat. | 30 | Circle the word cub. |
| 31 | Circle the word saw. | 32 | Circle the word pen. |
| 33 | Circle the word pun. | 34 | Circle the word bean. |
| 35 | Circle the word seat. | 36 | Circle the word lip. |
| 37 | Circle the word kid. | 38 | Circle the word sang. |
| 39 | Circle the word cook. | 40 | Circle the word mass. |
| 41 | Circle the word race. | 42 | Circle the word sane. |
| 43 | Circle the word will. | 44 | Circle the word sing. |
| 45 | Circle the word tale. | 46 | Circle the word kick. |
| 47 | Circle the word peach. | 48 | Circle the word bus. |
| 49 | Circle the word sap. | 50 | Circle the word run. |

Appendix III

MRT Response Form

MODIFIED RHYME TEST

Listener _____ Position _____ Set _____

Talker _____ Amplifier on: YES / NO Mask _____

Noise Level _____ Date _____ Time _____

1				14				27				40	
went dent	sent tent	bent rent		not pot	tot hot	got lot		peel eel	reel keel	feel heel	mass mat	math man	map mad
2			15			28			41				
hold fold	cold sold	told gold		vest best	test west	rest nest		hark bark	dark park	mark lark	ray rave	raze rake	rate race
3			16			29			42				
pat path	pad pack	pan pass		pig pip	pill pit	pin pick		heave heal	hear heap	heat heath	save sane	same sake	sale safe
4			17			30			43				
lane lake	lay lace	late lame		back bass	bath bat	bad ban		cup cuff	cut cuss	cud cub	fill hill	kill till	will bill
5			18			31			44				
kit hit	bit wit	fit sit		way pay	may day	say gay		thaw paw	law jaw	raw saw	sill sing	sick sit	sip sin
6			19			32			45				
must rust	bust dust	gust just		pig wig	big rig	dig fig		pen then	hen den	men ten	bale tale	gale pale	sale male
7			20			33			46				
teak teach	team tear	teal tease		pale pane	pace pay	page pave		puff pus	puck pup	pub pun	wick lick	sick pick	kick tick
8			21			34			47				
din dig	dill dip	dim did		cane cake	case came	cape cave		bean beak	beach bead	beat beam	peace peach	peas peat	peak peal
9			22			35			48				
bed red	led wed	fed shed		shop top	mop hop	cop pop		heat seat	neat meat	feat beat	bun bug	bus buck	but buff
10			23			36			49				
pin fin	sin din	tin win		coil toil	oil boil	soil foil		dip tip	sip lip	hip rip	sag sack	sat sad	sass sap
11			24			37			50				
dug dud	dung dub	duck dun		tan tack	tang tam	tap tab		kill kick	kin king	kit kid	fun gun	sun run	bun nun
12			25			38							
sum sup	sun sub	sung sud		fit fill	fib fig	fizz fin		hang rang	sang fang	bang gang			
13			26			39							
seep seek	seen seem	seethe seed		same tame	name came	game fame		took hook	cook shook	look book			

Scorer _____

Score _____