Effects of Portable Sound Field FM Systems on Speech Perception in Noise

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The present investigation examined the perceptual benefits of portable, or desktop, sound field Frequency Modulation (FM) systems to more traditional body-worn FM systems. Subjects consisted of 20 adults with normal-hearing sensitivity. Speech perception was assessed by the Hearing in Noise Test (HINT) sentences, while speech spectrum noise served as the noise competition. The HINT sentences were presented to the subjects in three conditions: (1) unaided; (2) portable sound field FM system; and (3) body-worn FM with attenuating walkman-style headphones. Results indicated that the portable and body-worn FM systems significantly improved speech-recognition performance in noise compared to unaided listening conditions. However, the body-worn FM systems provided significantly better speech perception in noise scores than the portable technology. Theoretical, educational, and clinical implications of these data are discussed.

It is well accepted that the acoustical environment (e.g., noise and reverberation levels) in classrooms is a critical factor in the educational achievement of many populations of children. Such populations at risk for academic failure include children with hearing loss, language impairments, dyslexia, developmental delays, attentional deficits, English as a second language, and/or auditory processing disorders (see Crandell, Smaldino, & Flexer, 1995 for a review of past investigations). In specific, a review of previous literature indicates that commonly reported levels of classroom reverberation and/or noise can compromise not only speech perception, but also reading/spelling ability, behavior, attention, psychosocial function, on-task behaviors, concentration, and academic achievement in these populations (Crandell & Smaldino, 2000, 2001; Crandell et al., 1995 for a discussion of these studies). One well-accepted strategy for reducing the deleterious effects of reverberation and noise on such populations is the use of a body-worn Frequency Modulation (FM) amplification system. With a body-worn FM system, the teacher's voice is picked up via a FM wireless microphone located near his/her mouth (thus decreasing the speaker-listener distance), where the detrimental effects of reverberation and noise are minimal. The acoustic signal is then converted to an electrical waveform, and transmitted via a FM signal to a receiver that is worn by the child. The electrical signal is then converted back to an acoustical waveform, and conveyed to the child (or children) through headphone or earbud transducers. Due to the high signal-to-noise ratio (SNR) provided by this technology, body-worn FM amplification systems have consistently been shown to benefit speech recognition, attentional efforts, psychosocial behaviors, and academic achievement (Crandell, et al., 1995; Flexer, 1992; Lewis, 1998).

While body-worn FM systems have been available for a number of years, several companies have recently made portable (also called desktop or toteable) FM amplification systems commercially available. In contrast to the more traditional body-worn FM system, portable sound field systems have a FM receiver and loudspeaker entirely built into a small container that is placed on the child's desk. Some companies encapsulate the FM receiver and loudspeaker into a container that resembles a stack of books that can be placed on the child's desk. With portable sound field systems, the child does not have to wear a body-worn FM receiver, nor do they have cords leading to headphones. It is reasonable to assume that portable systems may provide several important advantages over traditional body-worn FM systems. First, some children may find that portable sound field systems will be less visible than body-worn FM systems. Consequently, portable sound field devices may be more accepted by students, particularly students in middle schools and high schools, as these devices may cause less negative stigma. In addition, portable sound field FM systems may prove to be more durable than body-worn units as there are no cords to carry the signal to the ear. Damaged cords are often a major cause of malfunction of body-worn FM systems (Crandell & Smaldino, 2000, 2001).

Despite the potential advantages of portable sound field technologies, there remains limited empirical data demonstrating the effectiveness of such systems in educational settings. Foster, Brackett & Maxon (1997) studied the effectiveness of a small personal sound field FM systems on improving speech recognition in a classroom environment. Subjects consisted of 10 children with normal hearing and 10 children with cochlear implants. The sound field FM amplification system consisted of the Audio Enhancement Omni Petite, which is a portable, battery-operated, speaker/receiver system that was placed on the student's desk. It should be noted, however, that the Omni Petite is usually not considered a "desktop" unit, as its size is considerably larger than desktop systems. Speech stimuli consisted of isophonemic word lists presented via monitored live voice at a level of 65 dB SPL. Results indicated that the personal sound field FM system significantly improved speech recognition for both groups of children. With the personal FM system, phoneme recognition for children with normal hearing increased from 73% to 93%. For children with cochlear implants, phoneme recognition improved from 44% to 65%. While such results are encouraging, placement of a portable sound field system, such as the Omni Petite, on a child's desk may not be practical as such a sound field system would take up a large amount of the child's desk space, thus potentially eliminating many activities that the child could perform on that surface.

With these considerations in mind, the purpose of the present investigation was to examine the speech-perception benefits of a commercially available portable sound field system in noisy environments for listeners with normal hearing. Speech perception was also assessed via a more traditional body-worn FM system for comparison purposes. The Hearing In Noise Test (HINT) was used as the speech stimuli, while speech spectrum noise served as the noise competition. The HINT sentences were presented to the subjects in three conditions: (1) unaided, (2) portable sound field FM system, and (3) body-worn FM with attenuating walkman-style headphones. Speech perception was assessed using an adaptive psychophysical procedure. Normal hearing subjects were utilized for this investigation as portable sound field technologies are often recommended for children with normal hearing sensitivity who exhibit speech perception or auditory processing defects (Crandell and Smaldino, 2000).

Methods

Subject Selection Criteria

Twenty subjects (5 males; 15 females) with normal-hearing sensitivity participated in this study. Subjects ranged in age from 18 – 29 years old, with a mean age of 21 years, 8 months. All of the subjects met the following criteria:
Hearing sensitivity better than or equal to 15 dB HL at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz.
English as a primary language.
Negative history of learning disability, attentional deficit, or auditory processing disorder as reported by the subject.
No significant medical problems as reported by the subject.

Speech Recognition Measures

Speech recognition was assessed using the Hearing in Noise Test (HINT) (Nilsson, Soli, & Sullivan, 1994; Nilsson, Soli, & Sumida, 1995) sentences. The HINT consists of 25 phonemically balanced lists with 10 sentences in each list. The sentences have been equated for difficulty when presented in quiet or in noise. Additionally, all HINT lists exhibit high test-retest reliability. All HINT sentences are constructed at the first grade reading level and are uniform in length (six to eight syllables each). A commercially available compact disc (CD) recording of the HINT was used. A 1000-Hz narrow-band noise, which was consistent with the root mean square (RMS) of the HINT sentences, was used as the calibration signal. The HINT was chosen as the stimulus for this study as it is representative of "everyday" running speech and is standardized for use with competing noise (Nilsson et al., 1994, 1995). In addition, the HINT can be used within an adaptive testing procedure so that difficulties associated with traditional percentage-correct speech-recognition testing procedures, such as floor/ceiling effects, could be avoided.

Noise Competition

The noise competition consisted of speech-spectrum shaped noise, available on the second channel of the HINT CD. The noise was generated by determining the average long-term spectrum of the HINT sentences, ensuring that the average SNR between the speech signal and the noise was equated across frequencies (Nilsson et al., 1994, 1995). Speech-spectrum shaped noise was used in this investigation as speech-spectrum shaped noise provides maximum masking of the signal because it has the same spectral characteristics as the speech stimuli. In addition, speech-spectrum shaped noise is representative of many real world listening environments (Nilsson et al., 1994, 1995).

Frequency Modulation (FM) Systems

The Phonic Ear Toteable sound field FM system and the Phonic Ear Easy Listener (body-worn FM system were used as the FM devices for this investigation. The Phonic Ear Toteable sound field FM system features a personal FM receiver (Model PE 300R), loudspeaker amplifier, and loudspeaker contained in a small desktop "tote bag." The totebag comes in various colors (black was used for this investigation) and contains pockets for pencils and other school items. In addition, the totebag has a wrist strap and shoulder strap for transporting the device from room to room. The Phonic Ear Toteable sound field system has a volume control which also serves as an on/off switch. The Phonic Ear Easy Listener FM System consisted of a body receiver (Model PE 300R), that was coupled to attenuated walkman-style (Model PE AT 606) headphones. For normal listeners, attenuated headphones ensure that the output of the FM system will not reach an intensity level that potentially can cause damage to the ear. The Easy Listener receiver has an on/off switch as well as a volume control. The microphone/transmitters for both FM systems are the same size and use a Phonic Ear AT513 microphone.

Procedures

Prior to participation in the study, each subject underwent an audiologic evaluation. Pure-tone air conduction thresholds were assessed in a double-walled IAC sound treated booth using a GSI-16 clinical audiometer. All pure tones were output to TDH-49 headphones mounted in MX-41/AR supra-aural cushions. Pure-tone thresholds were obtained for octave frequencies between 250 and 8000 Hz. In addition, 3000 and 6000 Hz was tested. An otologic examination was performed in order to rule out any abnormalities of the auricle and external auditory meatus. The HINT sentences were presented to the subjects in three conditions: (1) unaided, (2) portable sound field FM system, and (3) body-worn FM with attenuating walkman-style headphones. Prior to each FM condition, the subject set the volume of the FM system to their most comfortable loudness (MCL) while listening to HINT sentences through a loudspeaker at 65 dB SPL. There was limited variability with both FM systems as subjects consistently set the devices between 7 and 7-1/2 on the volume control dial.

An adaptive procedure was utilized when administering the HINT sentences in noise. This procedure resulted in a Reception Threshold for Sentences (RTS) or 50 percent correct performance level. As noted previously, the adaptive procedure was used in order to avoid the inherent difficulties of traditional percentage-correct speech-recognition testing procedures, such as poor test/retest reliability and floor/ceiling effects. In all conditions, the speech-spectrum noise was presented simultaneously with the speech stimuli at a level of 60 dB SPL. The following procedure, as recommended by Nilsson et al. (1994) was used to assess the RTS:

1. The first sentence was presented at an audible level and raised in 4 dB steps until it was correctly identified.
2. The following sentence was presented at a level 2 dB lower than the previous sentence.
3. If the sentence was correctly identified, then the presentation level was again dropped by 2 dB. If, however, the sentence was not correctly identified, then the next sentence was presented at a level that was 2 dB higher.

This procedure was repeated for twenty sentences (two HINT lists). The level that each sentence was presented was noted. The level of the twenty-first sentence was calculated based upon the accuracy of the subject's response to the twentieth sentence. The first four sentences were considered practice and levels of those sentences were not used in calculating the RTS. The RTS was calculated as the average level of the fifth to the twenty-first sentence, regardless of whether the sentence was completed correctly or incorrectly.

All of the speech stimuli were presented through a compact disk player, routed through channel one of the GSI-16 clinical audiometer, and presented through a high-quality GSI laboratory loudspeaker. The loudspeaker was situated at 0 degrees azimuth and 1 meter from the subject's head (at a height of 5 feet) to simulate teacher position. The competing noise was routed through the second channel of the audiometer and presented to a second loudspeaker, located at 180 degrees azimuth and 1 meter from the subject's head. The portable sound field system was placed at a distance of 1 foot from the listener to simulate a desktop position. Calibration of the acoustic signal (speech and noise) was conducted with a Type I sound level meter coupled to a one-third-octave band filter and fitted with a precision sound-field microphone. The signal was calibrated using a 1000 Hz calibration tone from the HINT compact disk prior to testing each subject. The Phonic Ear AT513 transmitter/microphone was fixed at a distance of three inches from the front speaker. The order of all the conditions was randomized. Practice trials were given to each subject to familiarize them with each listening condition. In addition to this, each subject was given breaks between conditions to ensure attentiveness.

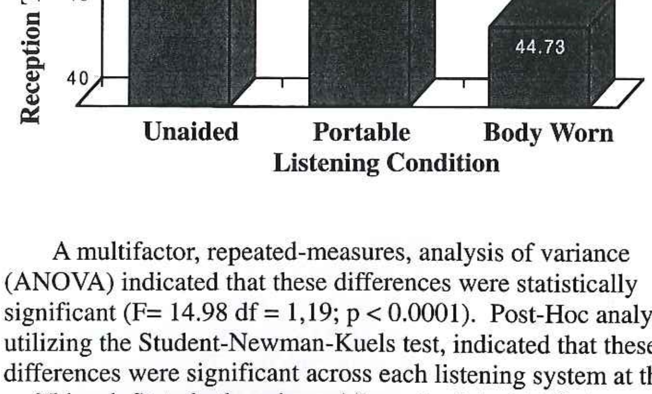
Statistical Analysis

In order to assess utilization of FM systems and communication benefit, a repeated measures analysis of variance (ANOVA) procedure was conducted to examine differences between type of FM system and speech-recognition abilities in noise. Post-hoc analyses were conducted using the Student-Neuman-Keuls procedure. All analyses were conducted at the $p < 0.05$ level of significance.

Results

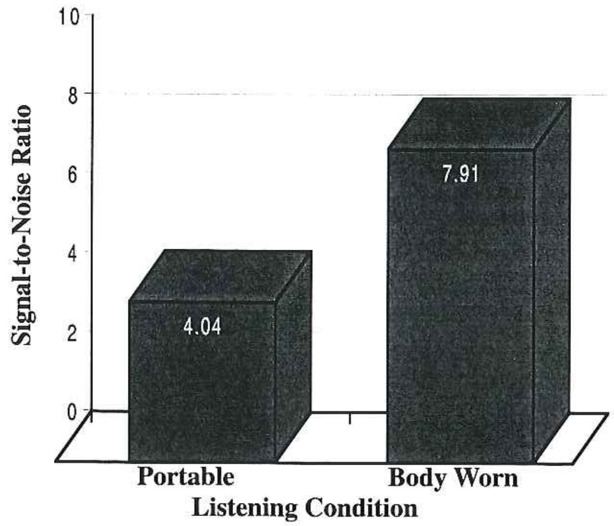
Mean RTSs (in dB SPL) as a function of listening condition (unaided, portable sound field FM, body-worn FM) are presented in Figure 1. Recall that the lower the RTS the better the speech-recognition performance. In addition, improvements in recognition scores, compared to the unaided listening condition, are found in Figure 2. Overall, these findings illustrate several trends. First, subjects obtained better speech-recognition when using either the portable or body-worn FM systems compared to unaided listening conditions. Specifically, the following RTSs were obtained for each listening condition: portable sound field FM (RTS = 48.59 dB SPL; s.d. = 2.55), body-worn FM (RTS = 44.73 dB SPL; s.d. = 3.25), unaided (RTS = 52.63 dB SPL; s.d. = 3.49).

Figure 1: Mean RTSs (in dB SPL) as a function of listening condition (unaided, portable sound field FM, body-worn FM).



A multifactor, repeated-measures, analysis of variance (ANOVA) indicated that these differences were statistically significant ($F= 14.98$ $df = 1,19$; $p < 0.0001$). Post-Hoc analyses, utilizing the Student-Newman-Kuels test, indicated that these differences were significant across each listening system at the $p < .05$ level. Stated otherwise, while each of the FM fitting configurations improved speech-recognition performance over unaided listening conditions, the body-worn FM system augmented speech recognition more than the portable FM system.

Figure 2. Mean improvements in SNR, compared to the unaided listening condition, for the portable sound field FM and body-worn FM.



Discussion

The present investigation examined the perceptual benefits of a portable sound field FM system compared to a more traditional body-worn FM system. Subjects consisted of 20 adults with normal hearing sensitivity. Speech perception was assessed by the HINT sentences, while speech spectrum noise served as the noise competition. In summary, results from this investigation demonstrated that both the portable and body-worn FM systems significantly improved speech-recognition performance in noise compared to unaided listening conditions. However, the body-worn FM systems provided significantly better speech perception in noise scores than the portable technology. These results from this investigation are discussed below.

First, this study indicated that both FM systems (portable and body worn) significantly improved speech-recognition performance in noise compared to unaided listening conditions. Specifically, the mean HINT threshold for the unaided condition was 52.63 dB SPL, while HINT thresholds for the portable and body-worn FM listening conditions were 48.59 dB SPL, and 44.73 dB SPL, respectively. This resulted in an improvement of 4.04 dB in SNR for the portable FM system and 7.91 dB in SNR for the body-worn FM system over unaided listening conditions. It should be noted that although these performance differences may initially appear inconsequential, it is well recognized that relatively small changes in SNR can equate to large differences in percentage correct scores. For example, Nilsson, et al. (1994) indicated that a 1-dB change in SNR for the HINT sentences equates to a change of approximately 10% in percentage-correct scores. Thus, these data strongly suggest that either portable or body-worn FM systems can significantly improve speech recognition for listeners with normal hearing in noisy environments, such as classroom settings.

A second finding of this investigation was that the body-worn FM listening system significantly improved speech perception compared to the portable unit. Specifically, the body-worn unit provided an improvement of approximately 4 dB in SNR compared to the portable sound field system. These findings were not necessarily surprising as the transducer for the body-worn (headphones) system is considerably closer to the ear than the loudspeaker of the portable unit, thus offering a greater SNR (less noise and reverberation) to the listener. In addition, the Walkman-style headphones offer a minimal degree of attenuation of background noise. Overall, these data suggest that children with normal hearing who are at risk for listening deficits in the classroom could utilize either of these systems for SNR improvement. However, for those children with more significant perceptual difficulties (such as children with hearing loss and severe auditory processing disorders), body-worn, or ear level, FM systems should be considered as an initial strategy due to their greater enhancement in SNR. Of course, audiological counseling is always required to determine the most appropriate FM system for a particular child. That is, the child, parent, and teacher need to be involved in the decision-making process when an FM system is recommended. If cosmetics are a major concern, as is often the case for older school age children, the portable system (or an ear level system) may be a more appropriate choice. Clearly, providing a choice between several styles of FM systems empowers the child to select which system he or she would prefer to use. Such empowerment should lead to increased acceptance and use of the FM system by the child.

Future research with portable sound field FM technology will need to focus on the efficacy of portable sound field technology in actual classroom settings across different companies and populations of children - particularly children with hearing impairment and/or cochlear implants. An evaluation of the specific student's auditory performance in the classroom, prior to and following portable sound field FM utilization, will be a critical component in determining the efficacy of the procedure. The most widely used efficacy material is a report inventory called the Screening Instrument for Targeting Educational Risk (S.I.F.T.E.R.) (Anderson, 1989). This inventory, designed to be filled out by the teacher, has items that focus on the teacher's observations on classroom performances, which are related to good listening skills. The areas sampled by the S.I.F.T.E.R. include academic, attention, communication, class participation and school behavior. A pre-school version of the S.I.F.T.E.R. has recently been reported (Anderson & Matkin, 1996). Recently, Anderson and Smaldino have developed a self-report inventory that could be used by school-aged children and can be used as a direct index of student change as the result of sound field FM equipment. This inventory, The Listening Inventory for Education (L.I.F.E), includes pictures of common classroom situations that could provide a listening challenge to the student. The student indicates how much difficulty he or she may experience in each of the listening environments. The L.I.F.E. has been successfully used as an efficacy measure with sound reinforcement systems, modifications of classroom acoustics, classroom FM systems and digital hearing aids (Anderson & Smaldino, 1998). Finally, future research will need to examine whether portable sound field FM systems are more cost effective in terms of use and repair. As noted previously, it is reasonable to assume that portable sound field FM systems may prove to be more durable than body-worn units since no cords are needed to carry the signal to the ear. Such an assumption will certainly need to be verified via empirical research before widespread utilization of portable sound field technology in educational settings can be expected.

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