Behind-the-Ear FM Systems: Effects on Speech Perception in Noise

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The present investigation examined the perceptual benefits of behind the ear (BTE) 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 four conditions: (1) unaided; (2) monaural BTE-FM; (3) binaural BTE-FM; and (4) body-worn FM with attenuating walkman-style headphones. Results indicated that the BTE and body-worn FM systems significantly improved speech-recognition performance in noise compared to unaided listening conditions. However, no significant differences in speech perception were noted between either the BTE or body-worn FM systems. Theoretical, educational, and clinical implications of these data are discussed.

Key Words: **Frequency Modulation (FM)**
Speech Perception
Hearing In Noise Test
Behind the ear (BTE)

Introduction

It is well recognized that the acoustical environment in classrooms is a critical variable in the educational achievement of many populations of children with normal hearing (see Crandell, Smaldino, & Flexer, 1995 for a review of past investigations). Such populations at risk for academic failure include children with language, reading, attentional, learning and/or auditory processing disorders. One 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 or 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. As a result of the high signal-to-noise ratio (SNR) provided by this technology, body-worn FM amplification systems consistently have been shown to benefit both speech recognition and academic achievement (Crandell et al., 1995; Flexer, 1992; Lewis, 1998).

While body-worn FM systems have been available for many years, several companies have recently made ear-level, or behind-the-ear (BTE), FM amplification systems commercially available. In contrast to the traditional body-worn FM receiver, these systems have the FM receiver built into a BTE shell that is then coupled to an earmold for the listener. With BTE 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 BTE FM systems may provide several important advantages over traditional body-worn FM systems. First, BTE FM systems will be less visible than body-worn FM systems. Consequently, BTE devices may be more accepted by students, particularly students in middle schools and high schools, as these devices may result in a less negative stigma. In addition, BTE 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 frequently a cause of malfunction of body-worn FM systems (Crandell & Smaldino, 2000, 2001). Unfortunately, despite the commercial availability and potential advantages of BTE FM technologies, there remains a paucity of empirical data demonstrating the effectiveness of such systems in the educational setting.

With these considerations in mind, the purpose of the present investigation was to examine the speech-perception benefits of a commercially available BTE FM system (Phonic Ear Sprite® BTE FM) in noisy environments for listeners with normal hearing. Speech perception was also assessed via a more traditional body-worn FM system (Phonic Ear Easy Listener®) for comparison purposes. The Hearing In Noise Test (HINT) was used as the speech stimuli with speech spectrum noise as the noise competition. The HINT sentences were presented to the subjects in four conditions: (1) unaided; (2) monaural BTE-FM; (3) binaural BTE-FM; and (4) 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 BTE FM systems are often recommended for children with normal hearing sensitivity who exhibit speech perception or auditory processing deficits (Crandell & Smaldino, 2001).

Methods

Subject Selection Criteria

Twenty subjects (2 males; 18 females) with normal hearing sensitivity participated in this study. Subjects ranged in age from 18 – 29 years old, with a mean age of 22 years, 6 months. All of the subjects met the following criteria:

1. Hearing sensitivity better than or equal to 15 dB HL at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz.
2. English as a primary language.
3. Negative history of learning disability, attentional deficit, or auditory processing disorder as reported by the subject.
4. No significant medical problems.

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. All HINT sentences are constructed at the first grade reading level and are uniform in length (six to eight syllables each). The sentence lists have been equated for difficulty when presented in quiet or in noise. Additionally, all HINT lists have been shown to exhibit high test-retest reliability (Nilsson et al., 1994, 1995).

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: (1) representative of "everyday" running speech, (2) standardized for use with competing noise, and (3) used within an adaptive testing procedure (Nilsson et al., 1994, 1995).

Noise Competition

The noise competition consisted of speech-spectrum shaped noise, available on the second channel of the commercially available 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 (Crandell, 1991; Nilsson et al., 1994, 1995).

Frequency Modulation (FM) Systems

The Phonic Ear Sprite [BTE FM system] and the Phonic Ear Easy Listener [body-worn FM system] were used as the FM devices for this investigation. The Phonic Ear Sprite BTE FM is a digitally programmable hearing aid with an FM receiver built into a BTE style casing. The Sprite can be fit to individuals with normal hearing and hearing impairment and is programmed via a hand-held programmer (Phonic Ear Model PE 801). To fit the Sprite, hearing threshold levels are entered from 250-6000 Hz. Both linear and non-linear prescriptive formulae are then available for selection protocols. Linear protocols include Desired Sensation Level (DSL), National Acoustic Laboratory Revised Protocol (NAL-RP) and Prescription of Gain/Output II (POGO II). Non-linear (WDRC) protocols include DSL i/o (input/output), NALw (the superscript, w, signifies the formula is for WDRC) and POGOw. If the DSL or DSL i/o protocols are selected, the programmer screen then requests additional assessment data, including age, speech spectrum, transducer used to obtain audiometric data, Upper Level of Comfort (ULC) and Real Ear Coupler Difference (RECD). Upper Level of Comfort and RECD information can be entered manually or pre-programmed averages can be used. An "Adjust" screen then allows the programmer to change the hearing instrument settings via subjective patient comments. Parameters that can be adjusted include Gain (in dB at 1kHz), Maximum Power Output (MPO) in dB SPL, Low Frequency Tone, and High Frequency Tone. Wide Dynamic Range Compression (WDRC), which activates a fixed 2:1 compression with a threshold of 60 dB SPL, is also an available option. The BTE Sprite also has a volume control that can be deactivated using the programmer. The Sprite has a Microphone/Frequency Modulation/Off (M/FM/O) switch, so that it can be used as a hearing aid as well as an FM system.

The Phonic Ear Easy Listener FM System consists of a body receiver that was coupled to attenuated walkman-style Phonic Ear 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.

Earmolds

The Phonic Ear Sprite BTE FM systems were coupled to the subject via Comply® (sound tube adapters connected to open-style Comply canal tips. The canal tips are available in three different tip sizes (standard, short, and slim) and five different venting options #0 through #4 (0, 1, 2, 3 or 4 vent grooves). The various sizes and venting options control feedback and occlusion for hearing aid or BTE-FM demonstrations, or when used as a loaner earmold. To reduce maximally the occlusion effect (and since many FM fittings for individuals with normal hearing incorporate open or free field earmolds), #4 ear standard tips (the largest vent available) were used.

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 were tested. An otologic examination was performed in order to rule out any abnormalities of the auricle, external auditory meatus, and associated outer ear structures.

The HINT sentences were presented to the subjects in four conditions: (1) unaided; (2) monaural BTE-FM; (3) binaural BTE-FM; and (4) body-worn FM with attenuating walkman-style headphones. For the monaural BTE-FM condition, subjects were randomly assigned to be tested with the system on the right ear or the left ear (ten subjects for each ear). Prior to the testing of each BTE-FM aided condition, the Sprite BTE-FM system was programmed by inputting the subject's pure-tone thresholds using the Phonic Ear PE 801 programmer. The data was entered via company protocol for fitting individuals with normal hearing (DSL I/O, with WDRC off and AGC-O on). For both UCL and RECD information, the "averages" option on the programmer was used. 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. For the binaural BTE FM condition, the subject followed the same procedure until the second FM receiver was comfortable and balanced with the first receiver. Interestingly, there was relatively minimal variation in volume control settings for all subjects.

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. The adaptive procedure was used in order to avoid the inherent difficulties of traditional percentage-correct speech-recognition testing procedures. In all conditions, the speech-spectrum noise was presented simultaneously with the speech stimuli at a level of 60 dB SPL. Sixty dB SPL is representative of many occupied classroom environments (Crandell & Smaldino, 2000, 2001). The following procedure, 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.
4. This procedure was repeated for twenty sentences (two HINT lists). The level at which 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 speech-perception testing was conducted in a sound-treated IAC room. All of the speech stimuli were presented through a compact disk player, routed through channel one of a clinical audiometer (GSI-16), and presented through a high-quality GSI loudspeaker. The loudspeaker was positioned at 0 degrees azimuth and 1 meter from the subject's head (at a height of 5 feet) to simulate teacher position. The Phonic Ear AT513 transmitter/microphone was fixed at a distance of three inches from the front speaker to simulate normal FM microphone position (Crandell et al., 1995). 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. 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 the 1000 Hz calibration tone from the HINT compact disk prior tc testing each subject.

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

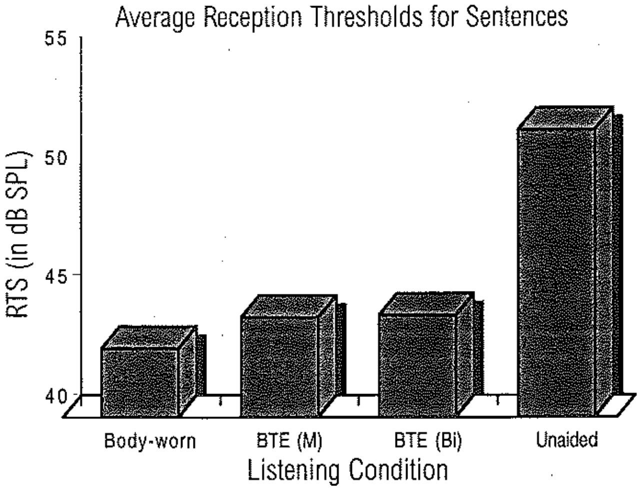
In order to assess utilization of FM systems and communication benefit, a repeated measures analysis of variance (ANOVA) procedure was conducted to examine differences between type of FM system and speech-recognition abilities in noise. Post-hoc analyses were conducted using the Student-Neuman-Keuls 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, binaural BTE FM, monaural BTE FM, body-worn FM) are presented in Figure 1. Recall that the lower the RTS the better the speech-recognition performance. Overall, these findings illustrate several trends. First, subjects obtained better speech-recognition scores when using either the binaural BTE, monaural BTE, or body-worn FM systems compared to unaided listening conditions. Specifically, the following RTSs were obtained for each listening condition: binaural BTE FM (RTS = 44.23 dB SPL; s.d. = 2.55), monaural BTE (RTS = 44.19 dB SPL; s.d. = 2.72), body-worn FM (RTS = 42.88 dB SPL; s.d. = 3.25), unaided (RTS = 52.08 dB SPL; s.d. = 3.49).

A multifactor, repeated-measures, analysis of variance (ANOVA) indicated that these differences were statistically significant ($F= 11.59$ $df = 1,19$; $p < 0.0001$). Post-Hoc analyses, utilizing the Newman-Kuels test, indicated that these differences were significant across FM system at the $p < .05$ level. Stated otherwise, while each of the FM fitting configurations improved speech-recognition performance over unaided listening condi-

Figure 1. Mean RTS (in dBSPL) as a function of listening condition (unaided, binaural BTE FM, nonaural BTE FM, body-worn FM).



tions, none of the FM systems augmented speech recognition more than another. That is, no statistical differences were noted between the binaural BTE, monaural BTE, or body-worn FM systems in improving speech recognition.

Discussion

The present investigation examined the perceptual benefits of a newly available BTE and more traditional body-worn Frequency-Modulation (FM) system on listeners with normal hearing sensitivity. Speech perception was assessed by the HINT sentences and speech spectrum noise served as the noise competition. In summary, results from this investigation demonstrated that both the BTE and body-worn FM systems significantly improved speech-recognition performance in noise when compared to unaided listening conditions. Moreover, results showed no significant differences in speech recognition between the various FM listening conditions (monaural BTE, binaural BTE, and body worn). These results are discussed below.

First, this study indicated that both FM systems (BTE 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 52.08 dB SPL, while HINT thresholds for the binaural BTE, monaural BTE, and body-worn FM listening conditions were 44.23 dB SPL, 44.19 dB SPL, and 42.88 dB SPL, respectively. These data suggest that any of the FM configurations examined in this investigation can improve the SNR in noisy environments by approximately 8 to 9 dB. 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. Certainly, these data strongly suggest that either BTE 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 no significant differences were noted between either the binaural BTE, monaural BTE, and body-worn FM listening conditions. These data could suggest that children at risk for listening deficits in the classroom could utilize any of these systems or configurations for SNR improvement. However, further research would need to be done in order to verify the efficacy of these amplification devices in these populations. Since speech-recognition scores were equivalent across the various systems, these results stress the need for extensive audiological counseling 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 BTE FM system may be a more appropriate choice. Conversely, if the child has attentional or cognitive deficits, the parents and teachers may prefer the more traditional body-worn FM system that has a lesser chance of being lost. Clearly, providing a choice between the two 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.

The finding that no difference in speech recognition was present between the monaural and binaural BTE FM conditions was somewhat surprising as binaural advantages in speech recognition (such as binaural squelch) are well recognized (see Moore, 1997). At present, the reason for this finding remains uncertain. One possibility for these findings is that a single BTE FM system improved the SNR significantly to overcome binaural advantages in speech recognition. However, a more logical explanation for these findings is that the type (speech spectrum noise) and configuration of speech and noise presentation (speech at 0 degrees/noise presented at 180 degrees) was not sufficiently challenging to evaluate the true advantages of wearing two BTE FM systems over one. To support this hypothesis, Crandell, Valente, Lewis, and Enriott (2001) recently reported a significant improvement in speech-recognition scores in listeners with hearing loss using two Phonak Microlink FM systems as compared to one. In that investigation, noise was presented from numerous sources (45, 135, 225 and 315 degrees) while speech was presented at 0 degrees. Results indicated that individuals using two FM systems achieved SNRs 3 to 4 dB higher than those using just monaural systems. Additional research needs to be conducted in this area.

While the present study has demonstrated speech recognition benefits with BTE FM systems, future research with BTE FM technology will need to focus on the efficacy of BTE technology in actual classroom settings across different companies and populations of children. As noted, the authors are currently examining BTE FM use in individuals with hearing loss. An evaluation of the specific student's auditory performance in the classroom, prior to and following BTE 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 which could be used by school-aged children. 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 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 BTE FM systems are more cost effective in terms of use and repair. As noted previously, it is reasonable to assume that BTE 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 BTE technology in educational settings can be expected.

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