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# Frequency-Modulation (FM) Technology as a Method for Improving Speech Perception in Noise for Individuals with Multiple Sclerosis

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**Abstract**

Almost half of the population with multiple sclerosis (MS) complains of difficulty hearing, despite having essentially normal pure-tone thresholds. The purpose of the present investigation was to evaluate the effects of frequency-modulation (FM) technology utilization on speech perception in noise for adults with and without MS. Sentence material was presented at a constant level of 65 dBA $L_{eq}$ from a loudspeaker located at 0°azimuth. The microphone of the FM transmitter was placed 7.5 cm from this loudspeaker. Multitalker babble was presented from four loudspeakers positioned at 45°, 135°, 225°, and 315° azimuths. The starting presentation level for the babble was 55 dBA $L_{eq}$. The level of the noise was increased systematically in 1 dB steps until the subject obtained 0% key words correct on the IEEE (Institute for Electrical and Electronic Engineers) sentences. Test results revealed significant differences between the unaided and aided conditions at several signal-to-noise ratios.

**Key Words:** FM technology, hearing, multiple sclerosis, speech perception

**Abbreviations:** CID = Central Institute for the Deaf; CNS = central nervous system; EDSS = Expanded Disability Status Score; IEEE = Institute for Electrical and Electronic Engineers; MRI = magnetic resonance imaging; MS = multiple sclerosis; PTA = pure-tone average; SI = sentence intelligibility; VA = Veterans Affairs; WRS = word-recognition scores

**Sumario**

Casi la mitad de la población con esclerosis múltiple (MS) se queja de dificultad para escuchar, a pesar de tener umbrales auditivos tonales esencialmente normales. El propósito de la presente investigación fue evaluar los efectos de la utilización de la tecnología de modulación de la frecuencia (FM) en la percepción del lenguaje en ruido, en adultos con y sin MS. Un material de frases fue presentado a un nivel constante de 65 dBA $L_{eq}$ desde un altoparlante localizado a 0° de azimut. El micrófono del transmisor FM se colocó a 7.5 cm del altoparlante. Se presentó un balbuceo de hablantes múltiples desde cuatro altoparlantes colocados a 45°, 135°, 225°, y 315° de azimut. El nivel inicial de

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presentación del balbuceo fue de 55 $L_{eq}$ dBA. El nivel del ruido fue aumentado sistemáticamente in pasos de 1 dB hasta que el sujeto lograba un 0% de palabras correctas en la prueba de frases IEEE (Instituto de Ingenieros Eléctricos y Electrónicos). Los resultados revelaron diferencias entre las condiciones amplificadas y no amplificadas a varias tasas señal/ruido.

**Palabras Clave:** Tecnología FM, audición, esclerosis múltiple, lenguaje, percepción

**Abreviaturas:** CID = Instituto Central para el Sordo; CNS = sistema nervioso central; EDSS = Puntaje del Estado de Discapacidad Expandida; IEEE = Instituto para Ingenieros Eléctricos y Electrónicos; MRI = imágenes por resonancia magnética; MS = esclerosis múltiple; PTA = promedio tonal puro; SI = inteligibilidad de frases; VA = Asuntos de Veteranos; WRS = puntajes de reconocimiento de palabras

Multiple sclerosis (MS) is an inflammatory disease of the central nervous system (CNS) that affects over 400,000 Americans and almost 2.5 million individuals worldwide (National Multiple Sclerosis Society, 2004). Multiple sclerosis causes damage to myelin, the fatty coating on nerve fibers that aids in transmission of the electrochemical impulses within the nervous system, and to the nerve fibers themselves. This damage slows, distorts, or halts the transmission of the electrical impulses transmitted throughout the CNS and results in many of the symptoms associated with MS, such as fatigue, slurred speech, and blurred vision.

There is no single test that can determine whether or not an individual has MS. In fact, a diagnosis of MS is often made after ruling out other medical reasons for the symptoms. A clinical diagnosis of "definite" MS is made only when there is (1) at least two episodes or attacks, separated by at least one month or a slow, progressive course in symptoms for at least six months; (2) documented neurologic signs of lesions in more than one area of the nervous system; (3) an onset of symptoms between the ages of 10 and 59 years; and (4) an absence of other more likely neurologic explanations (Poser et al, 1983). There are four clinical courses of MS: (1) relapsing-remitting (worsening of symptoms [exacerbation or relapse] that occur with increasing frequency, along with periods of reduced symptoms [remission]); (2) primary-progressive (steady worsening of symptoms with few periods of remission); (3) secondary-progressive (begins as relapsing-remitting, but the disease worsens to a point where there is no remission in symptoms); and (4) progressive-relapsing (steady worsening of the symptoms with clear acute exacerbations, with or without improvement). Physical disability in the MS patient is often quantified using the Kurtzke Expanded Disability Status Scale (EDSS; Kurtzke, 1983). This evaluation of disability is completed during the neurological evaluation and quantifies disability by evaluating eight different functional systems (FS). These functional systems include (1) pyramidal, (2) cerebellar, (3) brainstem, (4) sensory, (5) bowel and bladder, (6) visual, (7) cerebral, and (8) other. Kurtzke EDSS scores range from 0 to 10, with higher scores indicating greater levels of disability.

The prevalence of hearing loss as a symptom associated with MS varies, with estimates ranging from 1–86% (Mustillo, 1984). When a loss in pure-tone sensitivity does occur, it generally is considered mild in nature (Noffsinger et al, 1972). Despite this, 40% to 60% of individuals with MS having normal pure-tone thresholds complain of difficulty hearing (Musiek et al, 1989). These findings are not surprising given that MS is a disease that primarily affects the CNS. In fact, some studies have reported abnormal central auditory processing in subjects with MS, such as problems with dichotic listening tasks and auditory temporal processing (Jacobson et al, 1983; Hendler et al, 1990; Gadea et al, 2002). For example, Musiek et al (1989) reported left-ear weakness in 33% of individuals with MS on a dichotic test, suggesting that these individuals experience deficits in interhemispheric transfer. Jacobson et al (1983) also reported significant left-ear deficits on a dichotic test measure. Some investigations have reported deficits in temporal processing as well. To illustrate, Musiek et al (1989) reported that one-quarter of the subjects with MS obtained abnormal results on the Frequency Patterns Sequences Test (Musiek and Pinheiro, 1987). Additionally, Rappaport et al (1994) obtained results that suggested that a high percentage of individuals with MS had temporal-processing deficits, as assessed via a gap-detection task and a speech-perception-in-noise task. These findings suggest that demyelination within the central auditory nervous system has the potential to slow the processing of auditory information.

Since problems understanding speech in background noise are characteristic of individuals with auditory processing problems and disorders of the central auditory nervous system, one might postulate that individuals with MS also would have this type of deficit. Several studies have revealed that a high percentage (33–69%) of individuals with MS experience difficulty understanding speech when it is presented with a competing stimulus (Dayal et al, 1966; Noffsinger et al, 1972). Recently, we (Lewis et al, 2006) reported that subjects with MS performed significantly poorer on a speech-perception-in-noise task conducted in a diffuse soundfield environment compared to control subjects. Additionally, the subjects with MS reported significantly more subjective complaints about their hearing than the matched-control subjects did. These auditory complaints were significantly correlated with reduced performance on the speech-perception-in-noise task.

Numerous investigations have demonstrated that frequency modulation (FM) systems can improve speech perception in noise for individuals with both normal hearing and sensorineural hearing loss in adverse listening environments (see Crandell et al, 1995, for a review of these investigations). Specifically, past investigations have demonstrated that FM technology can improve the signal-to-noise ratio (SNR) needed for 50% word recognition by as much as 10 to 20 dB over unaided listening conditions (Hawkins, 1984; Fabry, 1994; Pittman et al, 1999; Crandell and Smaldino, 2000, 2001) and 12 to 18 dB over hearing aid alone listening conditions (Hawkins, 1984; Lewis et al, 2004) for listeners with hearing impairment. Additionally, a recent study reported that the utilization of an FM system by children with auditory processing disorders resulted in an improvement in the SNR needed for 50% word recognition by as much as 26.6 dB over the unaided listening condition (Phonak Hearing Systems, 2004). Since individuals with APD have been shown to benefit from the utilization of FM technology, it seems logical to postulate that individuals with MS would also benefit from the use of FM technology. The present investigation was initiated to evaluate FM technology as a rehabilitation option for individuals with MS. Specifically, the purpose of this investigation was to evaluate the effect of FM technology utilization on speech perception in noise for adults with and without MS.

## METHODS

### Subjects

Ten subjects with MS and ten subjects without MS were evaluated in this investigation. These study participants were recruited from the Portland VA (Veterans Affairs) Medical Center and from the Oregon Health and Sciences University in Portland, Oregon. The subjects with MS ranged in age from 40 to 56 years, with a mean age of 50 years (±6 years). Forty percent of these subjects were female, and 60% were male. The subjects without MS ranged in age from 35 to 62 years, with a mean age of 47 years (±11 years). Fifty percent of these subjects were female, and 50% were male. An independent-samples t-test revealed that there were no differences between the two groups in terms of age.

All study participants met the following inclusion and exclusion criteria: (1) age 21–65 years; (2) absence of current major disease or disorder (besides MS); (3) absence of senile dementia or other neurological conditions; (4) absence of a significant language barrier; and (5) no greater than a mild degree of hearing impairment bilaterally (as indicated by the four-frequency pure-tone average [PTA]). The subjects with MS met the following additional criteria: (1) a clinical or laboratory diagnosis of “definite MS”; (2) a diagnosis of relapsing, remitting, or primary- or secondary-progressive MS; (3) a Kurtzke EDSS score of 0 to 7.0, inclusive; (4) no history of clinical relapse or change in EDSS for three months prior to entering into the study; and (5) a recent brain magnetic resonance imaging (MRI) scan showing at least three white matter lesions on T2-weighted images consistent with MS. A neurologist and a nurse practitioner experienced in evaluating individuals with MS determined eligibility of the subjects, confirmed the diagnosis of MS, and determined the EDSS. The subjects with MS in this study had EDSS scores that ranged from 1.5 to 6.5, with a mean of 4.4 (SD = 1.7).

### Auditory Symptoms

At the time of enrollment in the study, all study participants completed a comprehensive questionnaire regarding their hearing and health history. Included in this questionnaire was a question that asked whether or not the individual noted any difficulty with his or her hearing. If the patient answered affirmatively, he or she was considered to have subjective auditory deficits.

### Amplification Systems

All subjects utilized the Phonic Ear Easy Listening FM System. This FM system is designed for individuals with normal hearing to moderate degrees of hearing impairment. The Phonic Ear PE 300T served as the FM transmitter. This FM transmitter typically is used with one of three types of microphone options: (1) a lapel microphone with omnidirectional microphone characteristics, (2) a lapel microphone with directional microphone characteristics, or (3) a boom microphone. All testing was conducted utilizing a boom microphone. The Phonic Ear PE 300R served as the FM receiver. This FM receiver may be utilized with a variety of commercially available coupling devices. All speech-perception testing was conducted using walkman-style supra-aural headphones.

### Speech Stimuli

The Institute of Electrical and Electronic Engineers (IEEE) Sentence Intelligibility (SI) test served as the speech stimuli (IEEE, 1969). This test consists of 72 lists of 10 sentences each or 720 sentences. Each sentence contains five key words, which are scored as either correct or incorrect. This sentence material has been shown to be more difficult than other sentence tests due to reduced contextual cues (Villchur, 1987; Grant and Briada, 1991). These sentences have been used in the Speech in Noise Test (SIN; Etymotic Research, 1993), the Revised SIN (Cox et al, 2001), and the QuickSIN (Killion et al, 2004) and have been used to measure SNR loss or benefit from amplification in both clinical and research applications. Despite the widespread use of these sentence materials, there has been some criticism regarding the equivalency of the sentence lists (Bentler, 2000).

These sentences were stored as sound files on a computer (Apple Macintosh Centris 650). They were presented and attenuated using custom-produced software on a second computer (Hewlett Packard with a Pentium 4 processor) and a programmable attenuator (Tucker-Davis Technologies, PA4). The output of the programmable attenuator was amplified (Crown, Model CP, 660) and delivered to a loudspeaker (JBL Monitor 28) located at 0° azimuth and 1.2 m from the study participant. The reader is referred to Lilly et al (2005) for greater details regarding this experimental setup.

### Noise Competition

Uncorrelated multitalker babble served as the noise competition. Sperry et al (1997) reported that the use of speech materials has a more adverse masking effect on speech perception than other nonmeaningful noises. Additionally, this type of noise competition has been shown to be an effective masker of speech for individuals both with and without hearing loss (Souza and Turner, 1994; Snell et al, 2002). The multitalker babble was presented from four audio tracks (one for each loudspeaker) stored on two separate compact disc recordings. It was presented and attenuated using custom-produced software on a second computer (Hewlett Packard with a Pentium 4 processor) and four programmable attenuators (Tucker-Davis Technologies, PA4). The output of the programmable attenuator was amplified (Crown, Model CP, 660) and delivered to four loudspeakers (JBL Monitor 28) located at 45°, 135°, 225°, and 315° azimuths and 1.7 m away from the study participant. Again, the reader is referred to Lilly et al (2005) for greater details regarding this experimental setup.

## Procedures

Speech perception in noise was conducted in a double-walled Acoustic Systems sound-treated chamber (1.96 m [height] x 2.6 m [width] x 2.4 m [length]). The IEEE sentences were presented at a constant level of 65 dBA $L_{eq}$ from a loudspeaker (JBL Monitor 28) positioned at 0° azimuth and located 1.2 m from the study participant. The microphone of the FM transmitter was placed 7.5 cm from the high-frequency element of this loudspeaker. Uncorrelated multitalker babble was presented from four loudspeakers (JBL Monitor 28) positioned at 45°, 135°, 225°, and 315° azimuths and located 1.7 m from the study participant. All of the loudspeakers were at a height level with the subject's ears. A diagram of the loudspeaker setup used in this investigation is provided in Figure 1. The starting presentation level for the multitalker babble was 55 dBA $L_{eq}$. The level of the noise was increased systematically in 1 dB steps until the subject obtained 0% key words correct on the IEEE sentences. The subjects were provided with three IEEE sentences (15 key words) at each SNR in order to obtain a percent-correct score. To reduce the potential for order effects, the IEEE sentence lists were randomized. No sentence was repeated with a given subject in order to prevent potential learning effects. To ensure consistency of the speech and noise signals, regular calibrations were made from the location of the subject's head with the participant absent using a sound level meter (Brüel and Kjaer, Type 2238 Mediator).

Speech-perception testing was conducted both in the unaided and the aided listening condition. Prior to aided testing, the subject was allowed to adjust the volume control of the FM receiver to a level that he or she deemed to be a most intelligible listening level while listening to an IEEE word list (one that was not being used during testing) presented at a constant level of 65 dBA $L_{eq}$ from the loudspeaker located at 0° azimuth. Once a volume control setting was chosen, it was held constant throughout speech-perception testing. The subjects with MS in this investigation chose a mean volume control setting of 6 (±2), while the subjects without MS chose a mean volume control setting of 4.5 (±1). An independent-samples t-test revealed that there was not a significant difference in volume control setting between the two groups. Real-ear responses obtained for one study subject at a volume control setting of 6 are provided in Figure 2.

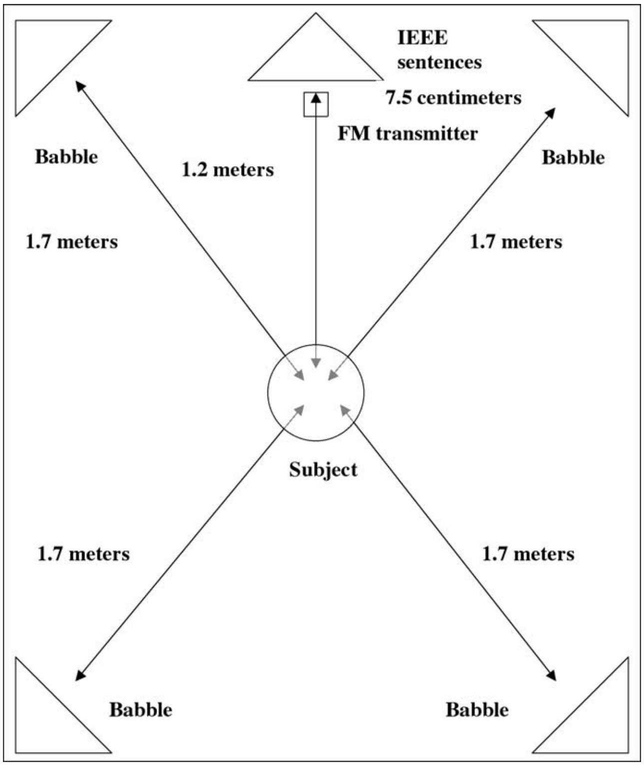


**Figure 1.** A diagram of the loudspeaker configuration used in this investigation.

## RESULTS

### Subjects

Pure-tone air-conduction and bone-conduction hearing thresholds were obtained bilaterally for both groups of subjects. Mean pure-tone thresholds for the subjects with MS were consistent with normal hearing in the lower test frequencies sloping to a mild sensorineural hearing loss bilaterally in the higher test frequencies, while mean pure-tone thresholds for the subjects without MS were consistent with normal hearing bilaterally. These results are presented in Figures 3 and 4 respectively. Word-recognition scores (WRS) were obtained bilaterally for all study participants at 25 dB above the speech reception threshold (dB HL re: ANSI standards [American National Standards Institute, 1996]) for the test ear using

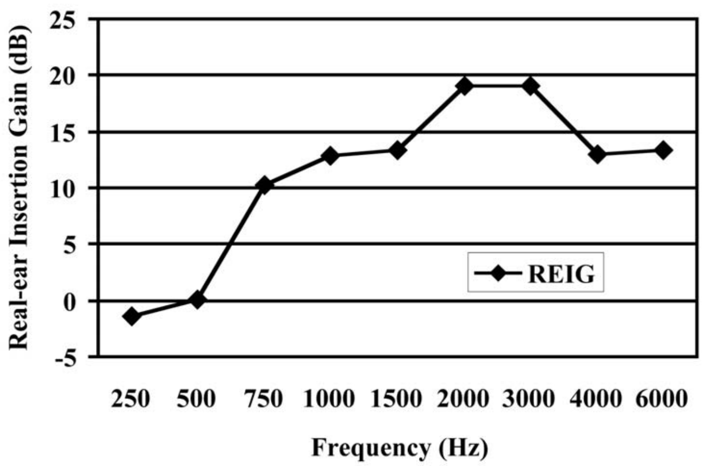


**Figure 2.** Real-ear insertion gain (REIG) obtained for one subject at a volume control setting of 6 using an 80 dB SPL input of composite noise.

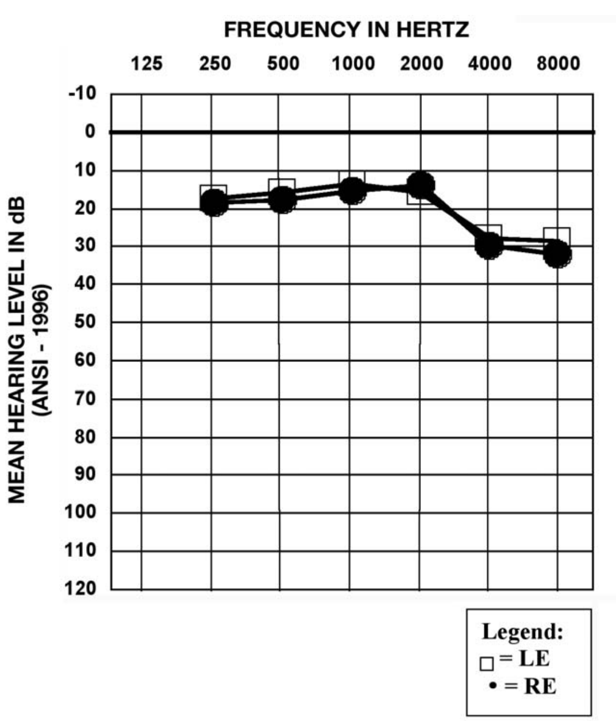


**Figure 3.** Mean pure-tone thresholds obtained for the right and left ears in the subjects with MS.

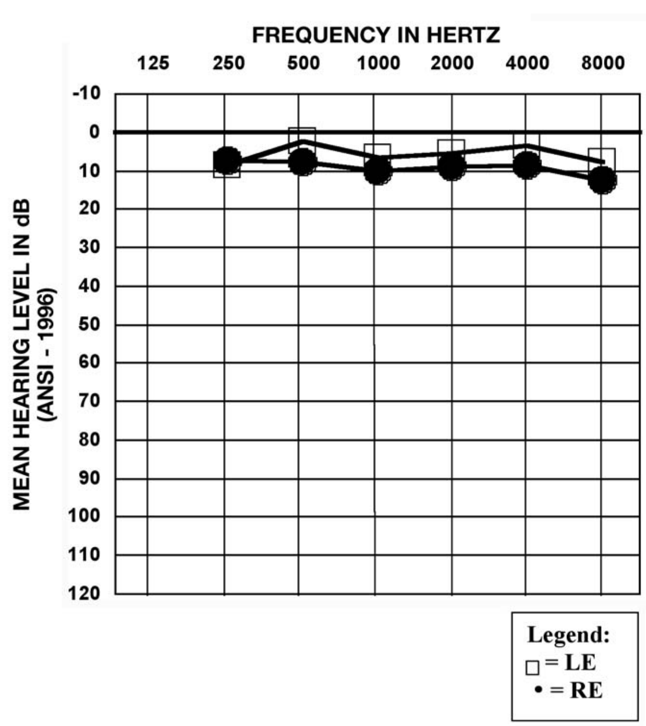


**Figure 4.** Mean pure-tone thresholds obtained for the right and left ears in the subjects without MS.

recorded Central Institute for the Deaf (CID) W-22 word lists (VA disk 1.1 [Wilson and Preece, 1990]). For the subjects with MS, test results revealed mean WRS (±1 standard deviation [SD]) of 96% (±3%) and 93% (±5%) for the right and left ears respectively. Mean WRS (±1 SD) for the subjects without MS were 97% (±4%) and 96% (±2%) for the right and left ears respectively. Independent samples t-tests revealed that there was not a significant difference ($p > 0.05$) between the right and left ears in terms of the four-frequency PTA and word-recognition scores in quiet for either group of subjects. Independent-samples t-tests also revealed that there were no significant differences between the two experimental groups in regard to PTA or WRS in each ear.

### Auditory Symptoms

Complaints of subjective auditory deficits in this sample of MS subjects are as follows: 10% reported "no," 70% reported "yes," and 20% reported "unsure." The subjects without MS reported the following: 70% reported "no," 20% reported "yes," and 10% reported "unsure." These results are presented in Figure 5. A Fisher's Exact Test revealed that there was a statistically significant difference ($p < 0.05$) in subjective complaints of auditory symptoms between the two groups.

### Speech Perception in Noise

The mean percent of key words correct at each SNR for both the unaided and aided listening conditions obtained by both groups of subjects are presented in Figure 6. From this figure, it is apparent that both the subjects with MS and the subjects without MS obtained better performance with the FM system at certain SNR. A three-way analysis of variance (ANOVA) with repeated measures revealed a significant ($p < 0.01$) main effect for aided versus unaided ($F_{1,18} = 39.35$) and for SNR ($F_{26,468} = 346.28$) and a significant interaction effect for aided x SNR ($F_{26,468} = 13.09$). The main effect for group was not significant. Post hoc analyses revealed that there was a significant difference between the unaided and aided listening conditions with subjects obtaining better scores in the aided listening condition. Post hoc analyses also revealed significant differences in key words correct between many of the SNR levels.

The mean percent of key words correct (±1 SD) at each SNR for both the unaided and aided listening conditions obtained by the subjects with MS are presented in Figure 7. This figure illustrates that, at some signal-to-noise ratios, there is a difference in speech perception in noise between the unaided and the aided listening condition, with the aided condition being better than the unaided listening condition at these signal-to-noise ratios. A two-way ANOVA with repeated measures on both factors was conducted. Both main effects and the interaction were

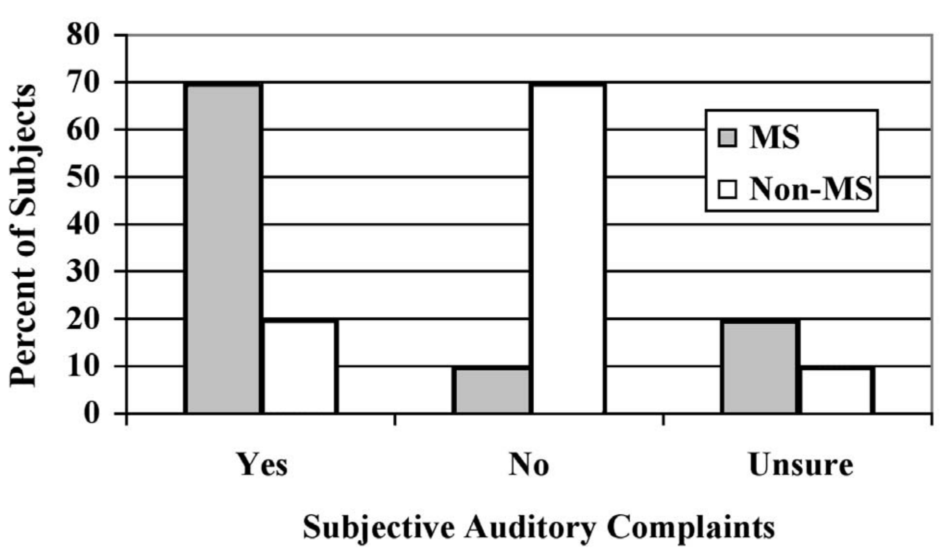


**Figure 5.** Subjective auditory complaints reported by both groups of subjects.

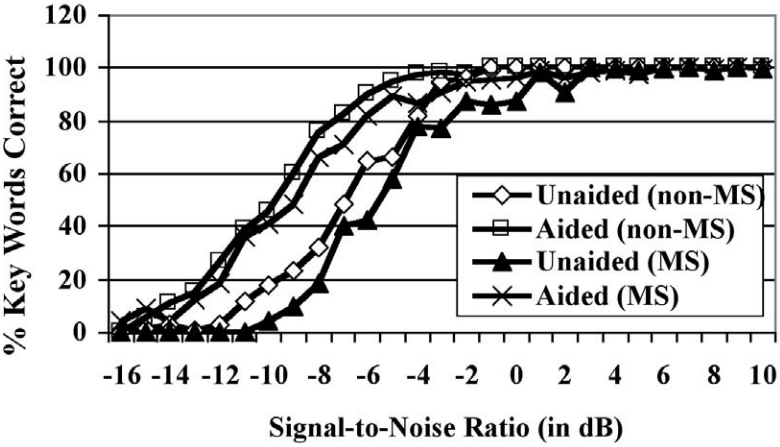


**Figure 6.** Mean percent of key words correct at each SNR for subjects with and without MS in both the unaided and aided listening conditions.

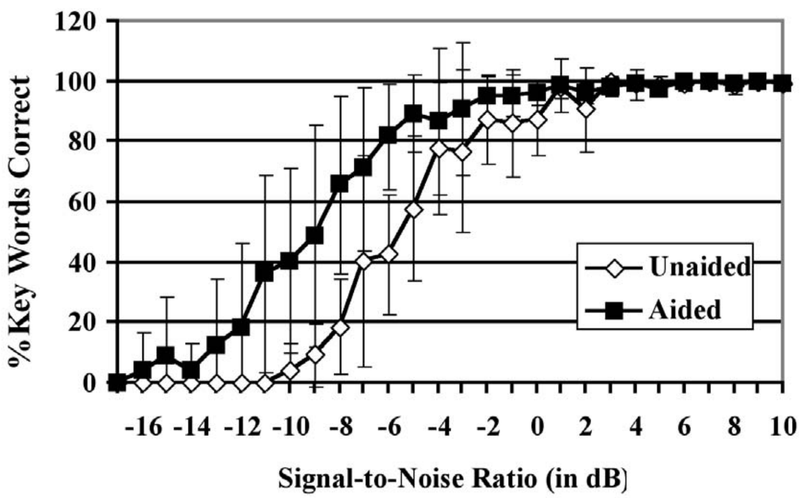


**Figure 7.** Mean percent of key words correct (±1 SD) at each SNR for subjects with MS in both the unaided and aided listening conditions.

significant at $p < 0.01$ (aided versus unaided: $F_{1,9} = 15.40$; SNR: $F_{26,234} = 171.82$; aided x SNR: $F_{26,234} = 5.91$). Since the main interest of this investigation was to determine if the aided versus the unaided conditions differed at the various SNR levels, an analysis of simple effects was performed. It was determined that significant differences existed at the following SNR: -6 dB, -7 dB, -8 dB, -9 dB, -10 dB, and -11 dB. Detailed information regarding the differences obtained at these signal-to-noise ratios is provided in Table 1.

Despite the significant difference reported at the aforementioned SNR for the subjects with MS, this benefit with the FM

**Table 1. Summary of Signal-to-Noise Ratios (SNR) That Were Statistically Significant for the Subjects with MS**

| SNR | Mean % Key Words Correct in the Unaided Condition | Mean % Key Words Correct in the Aided Condition | Mean Difference in % Key Words Correct between the Two Conditions |
|---|---|---|---|
| -6 dB | 42.6 | 81.9 | 39.3 |
| -7 dB | 40.3 | 71 | 30.7 |
| -8 dB | 18.5 | 65.8 | 47.3 |
| -9 dB | 9.3 | 48.5 | 39.2 |
| -10 dB | 4.4 | 40.6 | 36.2 |
| -11 dB | 0 | 36.3 | 36.3 |

system did not occur for all study participants. To illustrate this point, the benefit obtained with the FM system (aided minus unaided) at each SNR for each subject is reported in Figure 8.

A two-way ANOVA with repeated measures on both factors also was conducted for the subjects without MS. Both main effects and the interaction were significant at $p < 0.01$ (aided versus unaided: $F_{1,9} = 34.07$; SNR: $F_{26,234} = 176.21$; aided x SNR: $F_{26,234} = 8.18$). Since the main interest of this investigation was to determine if the aided versus the unaided conditions differed at the various SNR levels, an analysis of simple effects was performed. It was determined that significant differences existed at the following SNR: -5 dB, -6 dB, -7 dB, -8 dB, and -9 dB. Detailed information regarding the differences obtained at these signal-to-noise ratios is provided in Table 2.

## DISCUSSION

To our knowledge, this is the first study assessing the effects of FM technology on speech perception in noise among people with MS. Our results suggest that, at particular signal-to-noise ratios, there is a significant difference in speech perception in noise for the subjects with MS between the unaided listening condition and the condition with the FM system. At each of these signal-to-noise ratios, the group with MS performed better with the use of the FM system. On average, these subjects obtained a 38% improvement in key words correct at these signal-to-noise ratios with the utilization of FM technology. Stated otherwise, these subjects obtained an average improvement of 3.5 dB SNR with the use of the FM system. This improvement in speech perception in noise with the use of the FM system is consistent with results of prior studies in other subject populations demonstrating that FM technology can significantly improve the SNR needed for 50% word recognition (Hawkins, 1984; Fabry, 1994; Pittman et al, 1999; Crandell and Smaldino, 2000, 2001; Lewis et al, 2004; Phonak Hearing Systems, 2004). Additionally, Hawkins (1984) reported that the children with sensorineural hearing impairment obtained an average improvement

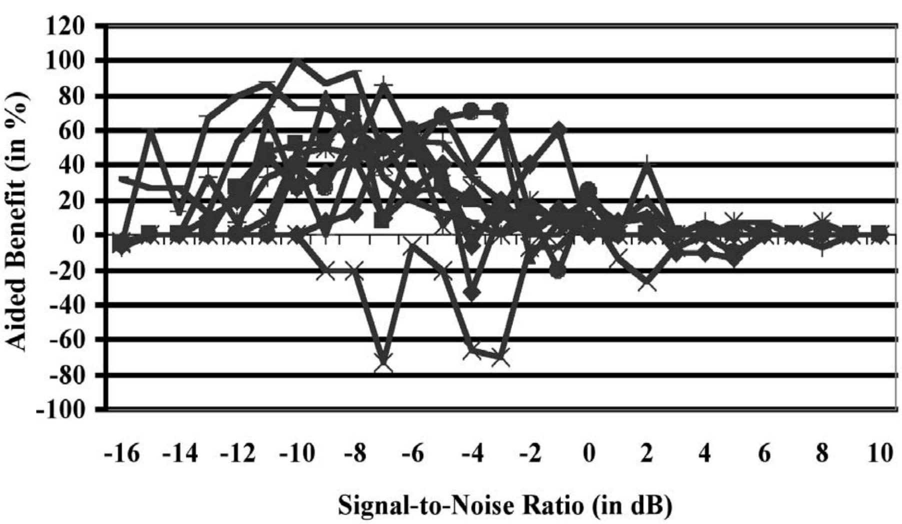


**Figure 8.** Aided benefit obtained at each SNR for each subject for the group with MS.

**Table 2. Summary of Signal-to-Noise Ratios (SNR) That Were Statistically Significant for the Subjects without MS**

| SNR | Mean % Key Words Correct in the Unaided Condition | Mean % Key Words Correct in the Aided Condition | Mean Difference in % Key Words Correct between the Two Conditions |
|---|---|---|---|
| -5 dB | 66 | 95.3 | 29.3 |
| -6 dB | 68 | 90.7 | 22.7 |
| -7 dB | 47.9 | 82.6 | 34.7 |
| -8 dB | 34.1 | 75.9 | 41.8 |
| -9 dB | 24.7 | 63.3 | 38.6 |

in word-recognition performance of 32% with the utilization of FM technology over hearing aids alone at a +6 dB SNR.

To help put these findings into context, the data obtained from this investigation are plotted in Figure 9 alongside data reported in Lewis et al (2006). Two groups of subjects were evaluated in the Lewis et al (2006) study using the same methods described in the present investigation: (1) individuals with MS and (2) individuals without MS. The MS-patient group was composed of 23 subjects that had a mean age of 51 years (±7 years). The control group consisted of 30 subjects that had a mean age of 51 years (±11 years). A one-way analysis of variance (ANOVA) revealed that there was not a significant difference ($p > 0.05$) between these two subject groups in terms of age, education level, WRS for the right and left ear, or between the four-frequency pure-tone averages in the right and the left ear. From Figure 9, it is apparent that the subjects in the present investigation performed similarly to a larger group of individuals with MS in the unaided listening condition. When the subjects with MS in the present study utilized FM technology, they outperformed the control subjects in the Lewis et al (2006) study. This suggests that the utilization of FM technology can help overcome the communication difficulties experienced by this population in difficult listening situations.

The subjects with MS and the subjects without MS in the present investigation obtained similar results with the FM system. This suggests that the improvements noted with the FM system may be a result of having a remote microphone located near the speaker's mouth, where the effects of reverberation, distance, and noise are minimal. However, this simple approach may be enough to alleviate some of the communication problems experienced by individuals with MS.

### Limitations of the Study

Despite the significant findings reported in this investigation, there are several study limitations that may have influenced the results that were obtained. First, there is recognized diversity between individuals in regard to the symptoms associated with MS, depending on the sites and amount of damage in the CNS (National Multiple Sclerosis Society, 2004). Additionally, the symptoms associated with MS can fluctuate from day to day in the same individual. This within-subject and between-subject variability may have affected the results obtained in this investigation by either underestimating or overestimating the benefits of FM technology experienced by this population.

A relatively small number of subjects with MS were evaluated in this study. As the symptoms associated with MS are highly variable between individuals, this small sample size may have exaggerated or minimized the speech-perception benefits of FM technology that are reported. Additionally, because of the number of comparisons that were made, the reader should interpret the results with some caution. Since this study was conducted as a pilot investigation, the authors plan to conduct a future investigation regarding the effects of FM technology on speech perception in noise in a larger sample of subjects. The final results of that investigation may add to our knowledge regarding the auditory characteristics of the general MS population and the potential benefits of FM technology for these individuals.

In this testing paradigm, large standard

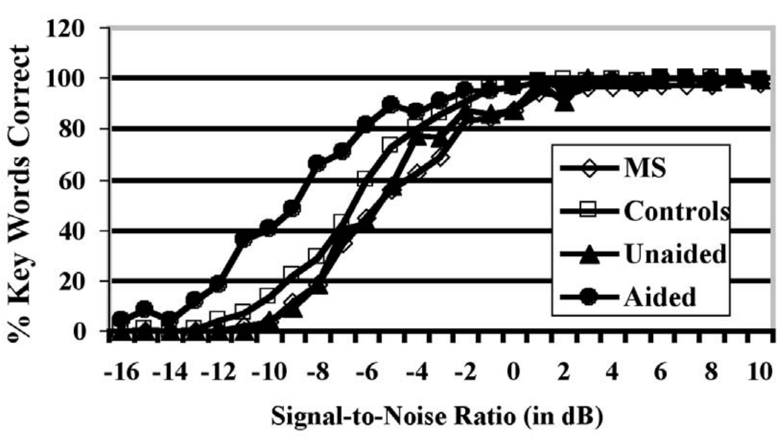


**Figure 9.** Comparison of present data to data presented in Lewis et al (2006).

deviations were obtained at certain signal-to-noise ratios. For these subjects, the standard deviations ranged from 0% to 37%. This finding suggests that the average scores are quite variable across signal-to-noise ratios. This finding corresponds with results obtained by Bentler (2000). In that investigation, Bentler also showed large standard deviations across IEEE sentence lists for both subjects with normal hearing and hearing impairment (0% to 37%). The large standard deviations obtained with this test material may have minimized the differences between the two experimental conditions.

A major criticism of tests that use the IEEE sentences (e.g., the SIN test and the QuickSIN) is the lack of equivalency between some of the IEEE sentence lists. Bentler (2000) reported that there was a significant difference between some of the sentence lists for subjects with normal hearing at the 53 dB SPL and 83 dB SPL presentation levels. At the 53 dB SPL presentation level, the following sentence lists were considered to be equivalent: (1) Lists 1 and 2; (2) Lists 5 and 6; and (3) Lists 3, 4, and 8. At the 83 dB SPL presentation level, the following sentence lists were considered to be equivalent: (1) Lists 1, 2, and 9; (2) Lists 3, 4, and 5; and (3) Lists 6 and 8. Since subjects in this investigation randomly received sentences from Lists 1 through 19 for the unaided listening conditions and Lists 1 through 17 for the aided listening conditions, it cannot be ruled out that this lack of list equivalency did not have an effect on the test results. This lack of list equivalency may have minimized or exaggerated the differences between the two experimental conditions depending on which lists were administered.

Finally, one cannot assume that the findings in this investigation are comparable to "real-world" performance with FM technology. Although attempts were made to simulate a "real-world" environment by utilizing uncorrelated multitalker babble presented from multiple locations, the conditions utilized in this study are still not typical of "real-world" listening environments. In "real-world" listening environments, the desired speech signal is not always presented at 0° azimuth, and noise does not always emanate from a static location or from the rear and sides of the listener. Therefore, various modifications of the speech and noise presentations may alter speech-perception results (Ricketts, 2000). Additionally, as mentioned earlier, the FM transmitter was located 7.5 cm from the primary loudspeaker. This distance represents an ideal placement for the FM transmitter, thereby minimizing the effects of noise, reverberation, and distance on the speech signal. Unfortunately, this placement may not occur in a "real-world" listening environment. At this time, we do not know what the effects of microphone distance would have on speech-perception performance in noise. A future investigation is planned by the authors to assess the subjective benefits obtained by individuals with MS (with standardized questionnaires) while using FM technology in their everyday listening environments. This subjective information should provide greater information regarding the benefits of FM technology in "real-world" listening environments.

## Summary

Many individuals with MS experience communication difficulty, especially in situations with background noise. Frequency modulation technology may be a viable means for improving speech perception in noise for people with MS. Further research is warranted to assess the auditory rehabilitation potential of FM technology in a larger sample of MS subjects and in real-world listening situations.

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## REFERENCES

American National Standards Institute (ANSI). (1996) *Specification for Audiometers*. New York: American Institute of Physics.

Bentler R. (2000) List equivalency and test-retest reliability of the speech in noise test. *Am J Audiol* 9:84–100.

Crandell C, Smaldino J. (2000) Room acoustics and amplification. In: Valente M, Roeser R, Hosford-Dunn H, eds. *Audiology: Treatment Strategies.* New York: Thieme.

Crandell C, Smaldino J. (2001) Improving classroom acoustics: utilizing hearing-assistive technology and communication strategies in the educational setting. *Volta Rev* 101(5):47–62.

Crandell C, Smaldino J, Flexer C. (1995) *Sound Field Amplification. Theory and Practical Application.* San Diego: Singular Publishing Company.

Cox RM, Gray GA, Alexander GC. (2001) Evaluation of a revised Speech in Noise (RSIN) test. *J Am Acad Audiol* 12(8):423–432.

Dayal V, Tarantino L, Swisher L. (1966) Neuro-otologic studies in multiple sclerosis. *Laryngoscope* 76:975–979.

Etymotic Research. (1993) *The SIN Test.* CD. Elk Grove Village, IL: Etymotic Research.

Fabry D. (1994) Noise reduction with FM systems in FM/EM mode. *Ear Hear* 15:82–86.

Gadea M, Marti-Bonmati L, Arana E, Espert R, Casanova V, Pascual A. (2002) Dichotic listening and corpus callosum magnetic resonance imaging in relapsing-remitting multiple sclerosis with emphasis on sex differences. *Neuropsychology* 16(2):275–281.

Grant K, Briada L. (1991) Evaluating the articulation index for auditory-visual input. *J Acoust Soc Am* 89(6):2952–2960.

Hawkins D. (1984) Comparisons of speech recognition in noise by mildly-to-moderately hearing-impaired children using hearing aids and FM systems. *J Speech Hear Disord* 49:409–418.

Hendler T, Squires N, Emmerich D. (1990) Psychophysical measures of central auditory dysfunction in multiple sclerosis: neurophysiological and neuroanatomical correlates. *Ear Hear* 11(6):403–416.

Institute of Electronic and Electrical Engineers (IEEE). (1969) *IEEE Recommended Practice for Speech Quality Measures*. New York: IEEE.

Jacobson J, Deppe U, Murray T. (1983) Dichotic paradigms in multiple sclerosis. *Ear Hear* 4(6):311–317.

Killion M, Niquette P, Gudmundsen G, Revit L, Banerjee S. (2004) Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. *J Acoust Soc Am* 116(4):2395–2405.

Lewis MS, Crandell C, Valente M, Horn J. (2004) Speech perception in noise: directional microphones versus frequency modulation (FM) systems. *J Am Acad Audiol* 15(6):424–437.

Lewis MS, Lilly D, Hutter M, Bourdette D, Saunders J, Fausti S. (2006) Some effects of multiple sclerosis on speech perception in noise: a preliminary look. *J Rehabil Res Dev* 43(1):91–98.

Lilly D, Hutter M, Levitt H, Kusumoto A, Lewis MS. (2005) Development of a sound-field system and materials for the measurement of speech intelligibility in multi-talker babble.

Kurtzke J. (1983) Rating neurologic impairment in multiple sclerosis: an expanded disability status scale (EDSS). *Neurology* 33(11):1444–1452.

Musiek F, Gollegly K, Kibble K, Reeves A. (1989) Electrophysiologic and behavioral auditory findings in multiple sclerosis. *Am J Otol* 10:343–350.

Musiek F, Pinheiro M. (1987) Frequency patterns in cochlear, brainstem, and cerebral lesions. *Audiology* 26(2):79–88.

Mustillo P. (1984) Auditory deficits in multiple sclerosis: a review. *Audiology* 23(2):145–164.

National Multiple Sclerosis Society. About MS. www.nationalmssociety.org/about%20ms.asp (accessed July 22, 2004).

Noffsinger D, Olsen W, Carhart R, Hart C, Sahgal V. (1972) Auditory and vestibular aberrations in multiple sclerosis. *Acta Otolaryngol Suppl* 303(Suppl.):5–63.

Phonak Hearing Systems. (2004) EduLink: improves speech understanding in noisy classrooms. *Field Study News* (May). http://www.phonak.com/com_professional_educationalresources_fieldstudynews_may04.pdf (accessed September 24, 2004).

Pittman A, Lewis D, Hoover B, Stelmachowicz P. (1999) Recognition performance for four combinations of FM system and hearing aid microphone signals in adverse listening conditions. *Ear Hear* 20:279–289.

Poser C, Pary D, Scheinberg L, McDonald I, Davis F, Ebers G, Johnson K, Sibley W, Silberberg D, Tourtellotte W. (1983) New diagnostic criteria for multiple sclerosis: guidelines for research protocols. *Ann Neurol* 13(3):227–237.

Rappaport JM, Gulliver JM, Phillips DP, VanDorpe RA, Maxner CE, Bhan V. (1994) Auditory temporal resolution in multiple sclerosis. *J Otolaryngol* 23(5):307–324.

Ricketts T. (2000) Impact of noise source configuration on directional hearing aid benefit and performance. *Ear Hear* 21:194–205.

Snell K, Mapes F, Hickman E, Frisnia D. (2002) Word recognition in competing babble and the effects of age, temporal processing, and absolute sensitivity. *J Acoust Soc Am* 112(2):720–727.

Souza P, Turner C. (1994) Masking of speech in young and elderly listeners with hearing loss. *J Speech Hear Res* 37(3):655–661.

Sperry J, Wiley T, Chial M. (1997) Word recognition performance in various background competitors. *J Am Acad Audiol* 11(2):71–80.

Villchur E. (1987) Multichannel compression processing for profound deafness. *J Rehabil Res Dev* 24:135–148.

Wilson R, Preece J. (1990) Development of a compact disc for speech audiometry. *Audiol Today* 2:24–26.