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DEVELOPMENT OF A PROTOCOL FOR FITTING OPEN FIT PERSONAL FM SYSTEMS

by

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THESIS APPROVAL PAGE

This is to certify that the thesis prepared by Jaclyn Bewick entitled Development of a Protocol for Fitting Open Fit Personal FM Systems has been approved by the thesis committee as satisfactorily completing the thesis requirement for the degree, Doctor of Audiology (Au.D.).

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ABSTRACT

Development of a Protocol for Fitting Open Fit Personal FM Systems

Jaclyn Bewick

The aim of this study was to develop a protocol that can be used for audiological purposes in a clinical setting in order to measure the benefits of open fit personal frequency modulated (FM) systems. A total of 17 normal hearing and typically developing children (six females and 11 males), ages 8 to 17 years old, underwent real ear measurements (REMs), the Hearing in Noise Test (HINT), and several questionnaires such as the Listening Inventory For Education-United Kingdom version (LIFE-UK), the LIFE-UK student version, and a follow-up questionnaire in order to evaluate their perceived benefits with the FM system. Each test or task was timed to evaluate if the proposed protocol was clinically feasible. Results indicated that the established protocol should be considered when fitting open fit personal FM systems in the clinical setting. The time restrictions of the clinical setting were appropriately met with this protocol. Output verification measurements confirmed that the FM system was functioning appropriately for each participant. Improvements in speech perception were observed in competing noise with use of the FM system; therefore, speech-in-noise testing was considered an appropriate measure for evaluating the potential benefits of an FM system. Even though the responses from the follow-up questionnaires were not statistically significant, the results indicated that participants perceived benefits in using the FM under noisy conditions. The results from this pilot study indicated that future studies should include a larger sample size in order to assist in confirmation of these results.

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LIST OF ABBREVIATIONS

AAA: American Academy of Audiology

ADD: Attention Deficit Disorder

ADHD: Attention Deficit Hyperactivity Disorder

ANOVA: Analysis of Variance

ANSI: American National Standards Institute

APD: Auditory Processing Disorder

ASD: Autism Spectrum Disorder

ASHA: American Speech-Language-Hearing Association

BKB: Bamford-Kowal-Bench

CAEP: Cortical Auditory Evoked Potential

CHAPS: Children's Auditory Performance Scale

DAI: Direct Audio Input

dB: Decibel

dB HL: Decibel of Hearing Level

dB SL: Decibel of Sensation Level

dB SNR: Decibel of Signal-to-Noise Ratio

dB SPL: Decibel of Sound Pressure Level

DSL: Desired Sensation Level

ESL: English as a Second Language

FCC: Federal Communications Commission

FM: Frequency Modulated

HATS: Head and Torso Simulators

HINT: Hearing in Noise Test

HINT-C: Hearing in Noise Test for Children

IRB: Institutional Review Board

IRI: Informal Reading Inventory

LCW: Lexically Controlled Word List

LIFE-UK: Listening Inventory For Education-United Kingdom Version

PBK: Phonetically Balanced Kindergarten

PAT: Progressive Achievement Test

RASTI: Rapid Speech Transmission Index

RTS: Reception Threshold for Sentence

SIFTER: Screening Instrument for Targeting Educational Risk

SLD: Speaker to Listener Distance

SNR: Signal-to-Noise Ratio

SRT: Speech Reception Threshold

T-Coil: Telecoil

TOPIC: Teachers Opinions re: Performance in Classroom

CHAPTER 1

INTRODUCTION

Students are presented with a variety of factors that can affect their academic success; however, an optimal acoustical environment is necessary for children to gain access to educational concepts. There are several things that can negatively affect a student's listening environment. The distance of a student from the teacher can impact a child's learning process. The greater the speaker to listener distance (SLD) levels, the poorer a student's ability to hear the desired speech signal. In addition to SLD levels, the presence of background noise is another aspect that can negatively affect a child's ability to hear in a classroom. The difference between the desired signal (e.g., the teacher) and level of competing noise is commonly referred to as the signal-to-noise ratio (SNR). When the signal is louder than the noise, the listener will have a better perception of the signal. There are multiple studies that suggest when SNRs are poor, speech intelligibility is negatively affected (Finitzo-Hieber & Tillman, 1978; Howard, Munro, & Plack, 2010; Johnson, 2000; Yacullo & Hawkins, 1987). Additionally, reverberation can further impair the listening environment. When long reverberant conditions (i.e., echo in the environment is high) occur in conjunction with competing noise and/or poor SNRs in a room, the ability to understand a speech signal (e.g., the teacher) is even more impaired (Klatte, Hellbruck, Seidel, & Leistner, 2010). Distance, competing noise, and reverberation can negatively affect all students; however, they are more detrimental for someone with hearing loss, auditory processing disorders, language disorders, reading difficulties, learning disabilities, or attention deficits (Anderson & Goldstein, 2004; Berg, Blair, & Benson,1996; Bradlow, Kraus, & Hayes, 2003; Finitzo-Hieber & Tillman, 1978;

Flexer, 1997; Geffner, Lucker, & Koch, 1996; Johnston, John, Kreisman, Hall, & Crandell, 2009; Klatte et al., 2010; Lewis, 1995; Nober & Nober, 1975; Rosenberg, 2010; Schafer et al., 2013; Smart, Purdy, & Kelly, 2010; Ziegler, Pech-Georgel, George, Alario, & Lorenzi, 2005).

Both soundfield frequency modulated (FM) systems and personal FM systems improve SNRs. Personal FM systems improve the SNR by bringing the signal (e.g., the teacher) directly to the listener's ears (e.g., student), thereby improving the SNR for the listener. There are two types of personal FM systems that can be used to overcome these acoustic issues. One of the types of personal FM systems is designed to be coupled to amplification systems such as hearing aids, cochlear implants, and bone anchored hearing aids. This type of personal FM system can be offered to individuals with hearing loss (Eiten & Lewis, 2010; Flexer, 1997; Fournier et al., 2012; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). The other type of personal FM system is one that is not coupled to amplification, but it is still a personal system. This type of FM system is an open fit device that is specifically designed for people who do not have hearing loss but need assistance in improving SNRs to access their curriculum (e.g., auditory processing disorder, attention deficit hyperactivity disorder, autism spectrum disorder, reading and/or learning disorders; Friederichs & Friederichs, 2005; Johnston et al., 2009; Schafer & Wolfe, 2010; Schafer et al., 2013; Smart et al., 2010).

Open fit personal FM systems are helpful in improving the SNR for children with normal hearing that require improved listening environments (Flexer, 1997; Friederichs & Friederichs, 2005; Johnston et al., 2009; Schafer & Wolfe, 2010; Schafer et al., 2013; Smart et al., 2010). These open fit devices are routinely fit by audiologists even though there is no set protocol to measure how the device is performing in the person’s ear (American Academy of Audiology [AAA], 2008; American Speech-Language-Hearing Association [ASHA], 2002). Furthermore, other than questionnaires, there is no uniform approach to measure patient benefit with the open fit FM system (AAA, 2008; ASHA, 2002). There have been proposed guidelines and recommendations for audiologists to consider in regards to performance measurement of a personal FM system. These guidelines and recommendations state that it is essential to consider output verification, behavioral validation, and subjective validation procedures when measuring the benefits of a personal FM system fitting (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008). Despite these guidelines and recommendations, audiologists are not routinely using these protocols.

With the development of open fit FM systems and the lack of standardization in measuring benefits, there is a need to create a protocol that audiologists could use when fitting these devices that would be manageable in time and result in both an accurate fitting and an estimate of how the individual performs with the FM system, particularly in a compromised listening environment.

CHAPTER 2

LITERATURE REVIEW

Classroom Acoustics

A classroom setting is not always an optimal environment for children to listen, learn, and understand educational concepts. The quality of the desired auditory signal may be influenced by several acoustical parameters, such as distance, background noise, and reverberation (Crandell & Smaldino, 2000; Rosenberg, 2010).

Distance. As a desired signal (e.g., speech) propagates across a classroom, the distance between the sound source and a listener may negatively impact the perception of the signal (Crandell & Bess, 1986; Leavitt & Flexer, 1991). Leavitt and Flexer (1991) analyzed speech intelligibility using Rapid Speech Transmission Index (RASTI). In order to reference a most favorable signal transmission measurement, researchers utilized a RASTI score of one. By comparing RASTI scores from various seat locations, researchers were able to identify differences in the strength of the desired signal. Head and torso simulators (HATS) located in the front seat locations obtained a RASTI score of approximately 0.8 and HATS located in the back row measured a RASTI score of approximately 0.6. When comparing the RASTI scores from the front seat locations to the back seat locations, there was a mean 45% reduction in speech intelligibility, indicating that students sitting further away from the teacher experienced greater difficulties accessing academic information presented auditorily. A similar reduction in speech perception was reported in a study conducted by Crandell and Bess (1986). Researchers conducted this study to record the effects of distance on speech perception abilities. Speech recognition scores were recorded and compared at SLDs of 6, 12, and 24 feet for all subjects. Results indicated a mean speech perception score of 89% at 6 feet SLD, 55% at 12 feet SLD, and 36% at 24 feet SLD; researchers noted a decrease in speech perception scores as the distance between the speaker and the listener increased. Even though both studies used different methods to evaluate the effect that distance has on speech understanding, similar results were observed. Leavitt and Flexer (1991) and Crandell and Bess (1986) discovered an inverse relationship between SLD levels and speech intelligibility. Overall both studies reported that as SLD levels increased, speech intelligibility scores decreased (Crandell & Bess, 1986; Leavitt & Flexer, 1991). Due to the noted degradation of speech with greater SLDs, researchers suggested that distance from a teacher can impact a child's academic learning process (Crandell & Bess, 1986; Leavitt & Flexer, 1991).

Signal-to-noise ratios. In addition to a reduction in SLDs, it is essential to have an optimal relationship between the intensity of the desired signal (e.g., the teacher) and the level of competing noise in the classroom (Crandell & Smaldino, 2000; Rosenberg, 2010). The difference between the signal and the noise is commonly referred to as the SNR. A positive SNR indicates that the desired signal is higher in intensity than the noise; whereas, a negative SNR indicates that the desired signal is lower in intensity than the competing noise. When SNRs are poor, a reduction of speech understanding can be noted. Finitzo-Hieber and Tillman (1978) recruited 12 children between the ages of 8 and 12 years old with normal hearing and age appropriate receptive language skills in order to assess the effects of competing noise stimuli (i.e., multi-talker babble). Researchers conducted a study to assess the children's overall speech perception and word discrimination abilities under four listening conditions of quiet, +12 dB SNR, +6 dB

SNR, and 0 dB SNR. Researchers found a statistically significant effect of competing noise on word discrimination scores for each of the SNR increments. It was noted that as competing noise increased in intensity, word discrimination scores across each of the SNR increments decreased in percentages. Researchers recorded word discrimination scores of 94.5%, 89.2%, 79.7%, and 60.2% for quiet, +12 dB SNR, +6 dB SNR, and 0 dB SNR respectively. Additionally a statistically significant main effect of competing noise across all SNRs was found. More specifically, researchers found a 34.3% reduction of word discrimination ability across all four SNRs. The statistically significant decrease of word discrimination scores at each individual SNR increment and across all four SNRs illustrates the negative effects of competing noise on speech understanding. Similar to Finitzo-Hieber and Tillman (1978), Yacullo and Hawkins (1987) conducted a study to assess the effects of background noise on speech understanding for 32 normal hearing children ranging in age from 8 to 10 years old. Sentences in the presence of multi-talker babble were presented at two different listening conditions of a +6 dB SNR and a +2 dB SNR. As SNR increments decreased from +6 dB to +2 dB, a statistically significant effect for sentence understanding was found with competing noise. More specifically, Yacullo and Hawkins (1987) reported a 34.9% decrease of sentence understanding in the presence of multi-talker babble across both SNRs.

Furthermore, Johnson (2000) assessed 80 normal hearing subjects ranging in age from 6 to 30 years old against multi-talker babble with a SNR of +13 dB. Testing was completed in a sound-treated audiological booth in which subjects were assessed on the number of consonants they correctly identified at four different sensation levels of 30, 40, 50, and 60 dB SL re: speech reception threshold (SRT) against multi-talker babble with a

SNR of +13 dB. The researcher found a significant reduction of mean consonant identification scores as sensation levels decreased from 50 to 30 dB SL re: SRT; researchers noted that scores decreased from 57.3% to 50.2% when sensation levels were decreased from 50 to 30 dB SL re: SRT in the presence of a +13 dB SNR. Johnson (2000) noted that competing noise significantly affected speech recognition abilities and reduced the amount of acoustic information that could be accessed at particular sensation levels. A similar reduction in speech recognition was reported in a study conducted by Howard, Munro, and Plack (2010). Howard et al. (2010) recruited 31 normal hearing children between the ages of 9 and 12 years old in order to measure speech perception abilities under SNRs representative of a typical classroom. The children were asked to repeat a list of monosyllabic consonant-vowel-consonant words at 65 dB SPL under multi-talker babble at four listening conditions: quiet, +4, 0, -4 dB SNR. Results indicated an overall reduction in word recognition abilities as the SNR became less favorable (i.e., more negative). Specifically, word recognition abilities decreased from 97-98% in quiet to 47-53% at a -4 dB SNR. Howard et al. (2010) noted that the decline in speech recognition abilities was statistically significant; therefore, finding a way to minimize noise is an important necessity for children learning in academic environment.

Wroblewski, Lewis, Valente, and Stelmachowicz (2012) recruited 48 normal hearing and typically developing children between the ages of 7 and 14 years old in order to measure the effects of noise on speech recognition abilities. Children were asked to repeat sentences from the Bamford-Kowal-Bench (BKB) sentence list under speech spectrum noises at five SNR conditions: +10, +5, 0, -5, and -10 dB SNR. Results indicated that the effect of noise on speech recognition abilities was statistically significant, in which researchers noted an overall trend amongst speech scores. As the SNR became less favorable (i.e., more negative), speech recognition scores decreased. Wroblewski et al. (2012) noted the importance of reducing the noise in a classroom in order to create a better listening environment. These studies support the fact that the presence of background noise can negatively influence the speech perception abilities of a child (Finitzo-Hieber & Tillman, 1978; Howard et al., 2010; Johnson, 2000; Wroblewski, Lewis, Valente, & Stelmachowicz, 2012; Yacullo & Hawkins, 1987).

Reverberation. Sound can be reflected, absorbed, or transmitted depending upon its interactions with the environment and its surroundings. When reflected repetitions of particular stimuli persist within a room for a particular amount of time, it can be defined as the term *reverberation* (Crandell & Smaldino, 2000; Rosenberg, 2010). It has been suggested that reverberation can affect a student's ability to understand speech and degrade the quality of a speech signal (Finitzo-Hieber & Tillman, 1978; Johnson, 2000; Klatte et al., 2010; Yacullo & Hawkins, 1987).

In order to record the effects of reverberation on speech perception abilities, Finitzo-Hieber and Tillman (1978) measured word recognition abilities of 12 children with normal hearing at 0.0 s, 0.4 s and 1.2 s of reflected sound energy. Testing was completed within two chambers (i.e., anechoic and reverberation) in order to compare word discrimination abilities of monosyllabic words under normal and reverberated sound conditions. Even though the difference in word recognition abilities between 0.0 s and 0.4 s of reverberation was not significant, researchers noted that reverberation had a statistically significant effect of understanding between reverberation times of 0.4 s and 1.2 s. Researchers concluded that the greater the reverberation, the poorer the speech understanding. In fact, Finitzo-Hieber and Tillman (1978) noted an overall 18% reduction in speech scores when comparing speech perception abilities between the 0.4 s and 1.2 s reverberant sound conditions.

Moreover, Yacullo and Hawkins (1987) found an even greater reduction in speech performance abilities when comparing sentence discrimination scores measured at reverberation times of 0.0 s and 0.8 s. Yacullo and Hawkins (1987) found a statistically significant reduction of speech performance abilities with the introduction of reverberation. In particular, a 41.1% degraded speech discrimination score was noted between measurements at 0.0 s and 0.8 s of added reverberation.

Johnson (2000) assessed 80 normal hearing subjects ranging in age from 6 to 30 years old under 1.3 s of reverberation. Testing was completed in a sound-treated audiological booth in which subjects were assessed on the number of consonants they correctly identified at four different sensation levels of 30, 40, 50 and 60 dB SL re: SRT. The researcher found a significant reduction of mean consonant identification scores as sensation level decreased from 60 to 40 dB SL and 40 to 30 dB SL re: SRT; researchers noted that scores decreased from 58.5% to 54.9% and 54.9% to 47.3% when sensation levels were decreased from 60 to 40 dB SL and 40 to 30 dB SL re: SRT respectively. Johnson (2000) noted that reverberant sound energy significantly affected speech recognition abilities and reduced the amount of acoustic information that could be accessed at various sensation levels.

Additionally, Klatte, Hellbruck, Seidel, and Leistner (2010) reported the effects of reverberation for more complex processes. A reduction in word identification, memory of words, and overall phonological processing was found when longer reverberant conditions (i.e., 1.1 s) were recorded within the classroom. Researchers noted a statistically significant reduction in word identification scores as reverberation increased from 0.49 s to 1.1 s. It was found that a 70.3% word identification score was recorded for short reverberant room conditions (i.e., 0.49 s) and a 61.7% word identification score was recorded for long reverberant room conditions (i.e., 1.1 s). Klatte et al. (2010) noted that word understanding abilities can be significantly reduced under long reverberant room conditions. These studies highlighted the negative impact that greater reverberation times can have on speech understanding abilities and/or phonological processing of children in a classroom (Finitzo-Hieber & Tillman, 1978; Johnson, 2000; Klatte et al., 2010; Yacullo & Hawkins, 1987).

SNRs and reverberation. The main premise behind researchers combining reverberation and competing sound stimuli was to simulate a typical classroom environment in order to see how understanding of words can be affected by both factors occurring simultaneously (Klatte et al., 2010). When long reverberant conditions occur in conjunction with competing noise and/or poor SNRs in a room, a more prevalent reduction of word discrimination was reported (Finitzo-Hieber & Tillman, 1978; Johnson, 2000; Klatte et al., 2010; Neuman, Wroblewski, Hajicek, & Rubinstein, 2010; Yacullo & Hawkins, 1987). In the presence of noise and reverberation, researchers have concluded a statistically significant reduction (i.e., 64.8%) in overall discrimination performance for children in an academic setting (Finitzo-Hieber & Tillman, 1978). Yacullo and Hawkins (1987) found that once reverberation and background noise were introduced into the desired signal, speech discrimination scores statistically significantly decreased from 85% to 17%.

Moreover, Johnson (2000) conducted a study in which 80 normal hearing subjects between the ages of 6 and 30 years old were assessed in quiet (i.e., no reverberation and no background noise) and a reverberant sound condition (i.e., 1.3 s) with background noise (i.e., +13 dB SNR). The researcher found that the mean consonant identification scores under combined effects of noise and reverberation were statistically significantly poorer than the scores obtained in quiet. In particular, Johnson (2000) noted a decrease across all sensation levels of 30 to 60 dB SL re: SRT when comparing the reverberation and noise condition to the quiet condition. The researcher recorded a mean consonant identification score of 56.9%, 67.4%, 71.9%, and 73.7% for sensation levels of 30, 40, 50, and 60 dB SL re: SRT respectively in the quiet condition. Speech recognition scores decreased when compared to their respected mean consonant identification scores of 45.1%, 47.0%, 49.0%, and 49.0% across sensation levels of 30, 40, 50, and 60 dB SL re: SRT respectively in the reverberation and noise condition. Results from this study showed a reduction of speech recognition abilities upon the addition of reverberation and noise at various sensation levels (Johnson, 2000).

Similarly, Neuman, Wroblewski, Hajicek, and Rubinstein (2010) conducted a study on 63 normal hearing children in order to assess the listening abilities of students amongst both reverberant and competing noise situations. Simple sentences with multi-talker babble and reverberant sound energy of 0.3 s, 0.6 s, and 0.8 s were presented to children ranging in ages of 6 to 12 years old. Researchers reported results by calculating the SNR children needed in order to obtain a speech perception performance of 50% correct (SNR-50). Neuman et al. (2010) found that as reverberation times increased from 0.3 s to 0.8 s, the SNR-50 increased for all children. More specifically, when reverberation was 0.3 s, a SNR of 2.7 dB was recorded; when reverberation was 0.6 s, a SNR of 3.4 dB was recorded; when reverberation was 0.8 s, a SNR of 4 dB was recorded. Neuman et al. (2010) concluded that in order for children to obtain at least 50% of word understanding in the presence of reverberation and background noise, a positive SNR (i.e., SNR of at least 15 dB) must be present in all conditions and an even greater SNR must be present when more noise and reverberation are noted.

Furthermore, Klatte et al. (2010) utilized a parental questionnaire that focused on questions concerning the effects of reverberant sound conditions in conjunction with indoor classroom noise on children’s overall academic performance in a classroom. For children placed in classrooms with a short reverberant sound condition (0.49 s to 0.56 s), medium reverberant sound condition (0.69 s to 0.92 s), and long reverberant sound energy (> 1.0 s) 44% of parents, 51% of parents, and 61% of parents respectively, felt that their children had poorer phonological processing abilities due to the acoustical conditions of the classrooms. Klatte et al. (2010) explained that in a school setting, children are not only identifying the words during a lesson, but also have higher integration strategies for complete comprehension; therefore, it is important to observe and study children in an atmosphere that includes both competing noise and reverberant sound energy. Collectively, all studies revealed that performance levels in the presence of reverberation and competing noise were negatively affected and therefore may impact classroom learning (Finitzo-Hieber & Tillman, 1978; Johnson, 2000; Klatte et al., 2010; Neuman et al., 2010; Yacullo & Hawkins, 1987).

Classroom Acoustics and Special Populations

Distance between speaker and listener, levels of background noise, and reverberant sound conditions affect the quality of speech stimuli for all students; however, the effects of distance, background noise, and reverberation on speech intelligibility are worse for children with hearing loss, auditory processing difficulties, language disorders, reading difficulties, learning disabilities, or attention deficits (Anderson & Goldstein, 2004; Berg et al., 1996; Bradlow et al., 2003; Finitzo-Hieber & Tillman, 1978; Flexer, 1997; Geffner et al., 1996; Johnston et al., 2009; Klatte et al., 2010; Lewis, 1995; Nober & Nober, 1975; Rosenberg, 2010; Schafer et al., 2013; Smart et al., 2010; Ziegler et al., 2005).

Hearing loss. In the presence of reverberation and multi-talker noise, children with varying degrees of sensorineural hearing loss displayed poorer word recognition abilities when compared to word recognition abilities for normal hearing individuals (Finitzo-Hieber & Tillman, 1978; Pittman, 2011). Finitzo-Hieber and Tillman (1978) measured word recognition abilities of 12 children (8 to 12 years old) with mild to moderate sensorineural hearing loss bilaterally and compared word discrimination abilities to a control group of 12 normal hearing children. Monosyllabic word discrimination abilities were established for both groups under four listening conditions of quiet, +12 dB SNR, +6 dB SNR, and 0 dB SNR and three reverberation times of 0.0 s, 0.4 s, and 1.2 s. As noise and reverberation times increased, a statistically significant reduction in word recognition abilities was found for both groups; however, a greater decrease in word recognition abilities was recorded for the hearing impaired group. In the presence of no noise or reverberation, normal hearing individuals received a 94.5 % mean word discrimination score, but the performance score decreased to a 29.7% mean word discrimination score under a 0 dB SNR and a 1.2 s reverberation time. In the presence of no noise or reverberation, hearing impaired individuals received a mean score of 87.5%, but the performance score decreased to a mean score of 15.3%. Overall the mean word discrimination scores for normal hearing individuals decreased a total of 64.8%; whereas, the mean word discrimination scores for hearing impaired individuals reduced by a total of 72.2%.

Pittman (2011) measured speech intelligibility of 30 children (8 to 12 years old) with a mild to moderately-severe hearing loss bilaterally. All hearing impaired subjects were long time hearing aid users with age appropriate cognitive and language abilities. Speech intelligibility performance of 50 normal hearing, age matched peers were recorded and used for comparison. In order to measure speech intelligibility, both groups of children were asked to categorize common nouns into three categories (i.e., people, food, and animals) presented at 50 dB SPL under two listening conditions: in quiet and in noise (i.e., steady-state broadband noise). Researchers reported a statistically significant decrease in word categorization abilities with the addition of noise for both groups; however, a greater reduction in word categorization abilities was noted for children with hearing loss. The mean word categorization score for normal hearing children in quiet was approximately 98% and was reduced to approximately 90% in the presence of noise. The mean word categorization score for children with a hearing loss in quiet was approximately 93% and was reduced to approximately 75% in the presence of noise. Researchers concluded that the effects of noise for individuals with hearing loss are even greater than those with normal hearing.

Auditory processing disorder. When noise is presented amongst individuals with auditory processing disorder (APD), speech perception abilities are worse when compared to typically developing peers (Johnston et al., 2009; Smart et al., 2010). Johnston, John, Kreisman, Hall, and Crandell (2009) measured speech perception abilities of 10 children with an APD diagnosis and 13 normal developing peers with the Hearing in Noise Test (HINT). The HINT was administered under a constant level of competing noise (i.e., 65 dB SPL) in a double-walled sound-treated booth. In order to evaluate speech perception abilities, Johnston et al. (2009) reported results of the HINT test by reception threshold for sentence (RTS) scores and SNRs. The RTS is defined as the lowest intensity level at which the participant can correctly repeat 50% of the sentence; the RTS score is calculated by averaging the presentation levels for the sentences in each list. For purposes of this study, the SNR was calculated by subtracting the level of noise (i.e., 65 dB SPL) from the RTS score obtained during HINT testing. The individuals with APD obtained a mean SNR of 6.12 dB; whereas, the individuals with age appropriate processing acquired a mean 7.97 dB SNR. When comparing speech test results between the control and experimental group, researchers explained that even though differences between groups was not statistically significant, speech perception abilities of the children with APD were lower than normal developing peers. Johnston et al. (2009) concluded that an individual with APD requires a better SNR than an individual within an age matched control group. Because of the need for a better SNR, researchers noted that speech perception abilities of individuals with APD are worse in noise than normal developing peers.

Smart, Purdy, and Kelly (2010) found a similar difference between children with APD and normal developing peers by utilizing a different testing procedure.

Smart et al. (2010) administered the Listening Inventory For Education-United Kingdom version (LIFE-UK) questionnaire to teachers for two different groups of children: 28 children with APD (mean age of 9.8 years) and 83 children with no suggested APD (mean age of 9.9 years). Researchers found statistically significant higher ratings on the LIFE-UK for children with APD in comparison to the control group. Smart et al. (2010) explained that a higher rating on the LIFE-UK is indicative of poor listening abilities in the classroom. Smart et al. (2010) concluded that the children with auditory processing deficits had greater listening difficulties in the classroom than normal developing peers.

Reading and learning/language disorders. Similarly, children with disorders associated with reading, language, and/or learning have been found to struggle even more than their respected control groups when there are less than optimal SNRs (Bradlow et al., 2003; Nober & Nober, 1975; Ziegler et al., 2005). Bradlow, Kraus, and Hayes (2003) tested children with learning disorders (n = 63) and compared the results to children with no suggested academic difficulties (n = 36) in a -8 dB SNR environment. Results revealed a statistically significant difference between the mean sentence-in-noise score for children with learning disorders to the mean sentence-in-noise score for the control group. Researchers noted a mean sentence-in-noise score ranging between 56%-65% for children with learning disorders and a mean score between 74-84% for the control group. Researchers concluded that children with learning disorders appear to struggle more in a noisy learning environment compared to their typically developing peers. Similarly, Nober and Nober (1975) recorded auditory discrimination error scores under noisy conditions for two groups: learning disorder group (n = 20) and non-learning disorder group (n = 20). Researchers found a mean auditory discrimination error score of 5.75 for individuals with a learning disorder and a mean error score of 4.7 for their respected control group. The difference in performance under competing classroom noise was not statistically significant; however, researchers found that the learning disabled group presented with more errors of auditory discrimination then the control group overall. Ziegler, Pech-Georgel, George, Alario, and Lorenzi (2005) studied the word recognition scores of 10 children with deficits specific and solely related to receptive and expressive language disorders (i.e., specific language disorders) and compared them to 10 children with no known speech perception deficits. Results indicated a statistically significant difference between typically developing peers and children with language disorders in the presence of background noise. Researchers found an 11.8% reduction in speech perception scores for individuals with language disorders when testing in competing noise. Furthermore, the researchers indicated as competing noise levels became louder than the desired signal, difference in speech deficits increased from 11.8% reductions to 14.9% reductions between the two groups. Therefore, Ziegler et al. (2005) concluded that children with specific language impairments showed greater deficits in word recognition abilities when placed in noisy environments as compared to individuals with normal language abilities.

Attention deficit hyperactivity disorder/attention deficit disorder. Geffner, Lucker, and Koch (1996) performed speech perception tests under noisy conditions in order to display the differences between 27 children with a diagnosis of attention deficit disorder (ADD) and 15 children without deficits related to attention. A statistically significant difference in speech discrimination abilities were found between groups when testing in speech-in-noise. Results showed a mean 88% (right ear) and 88% (left ear) discrimination score for the control group and a mean 54% (right ear) and 58% (left ear) discrimination score for the experimental group (Geffner et al., 1996). Researchers concluded that children with ADD displayed poorer speech discrimination scores than their respected control group under competing noise conditions.

Similarly, Schafer et al. (2013) noted the distinct difference between speech-in-noise test results in nine children with autism spectrum disorder (ASD) and/or attention deficit hyperactivity disorder (ADHD) versus a control group of 11 normal developing peers. A statistically significant difference was measured between the groups in the presence of noise. When speech-in-noise testing occurred, researchers found a -4.8 dB SNR threshold for the experimental group and a -10.1 dB SNR threshold for the control group. Schafer et al. (2013) concluded that children with ASD and/or ADHD have significantly worse speech perception abilities than their typically functioning peers.

Collectively researchers have concluded that the effects of a less than favorable classroom not only depend upon the acoustical parameters of the academic environment, but also depend upon the student’s auditory system and co-occurring deficits (Bradlow et al., 2003; Finitzo-Hieber & Tillman, 1978; Geffner et al., 1996; Johnston et al., 2009; Nober & Nober, 1975; Schafer et al., 2013; Smart et al., 2010; Ziegler et al., 2005).

Solutions to Poor Classroom Acoustics

In order to address the less than favorable listening conditions within a classroom, researchers have suggested a number of possible solutions to improve the acoustics of the academic environment. These changes range from classroom modifications, hearing aids, and soundfield amplification systems. The American National Standards Institute (ANSI) has created a set of standards for classroom acoustics that all schools are recommended to abide. According to ANSI S12.60-2010, it is recommended that unoccupied classroom noise levels should not exceed 35 dBA and unoccupied classroom reverberation times should not exceed 0.6 s in a smaller classroom (i.e., $\leq$ 10,000 ft.^{3}) or 0.7 s in a larger room (i.e., > 10,000 ft.^{3} and $\leq$ 20,000 ft.^{3}).

Classroom modifications. It has been suggested that modifying certain aspects within and surrounding the classroom can result in a more favorable learning atmosphere for all students (Beck, Tomasula, & Sexton, 2013; Berg et al., 1996; Bess, 1999; Boothroyd, 2005; Lewis, 1995; Lewis, 2008; Rosenberg, 2010). Researchers suggested that educational lessons should be taught away from busy and noisy areas such as a gymnasium, cafeteria, shared classrooms, and playgrounds. Noise and reverberation can negatively affect the learning process for all students; whether the noise and reverberation are created outside the classroom or inside the academic learning environment, a similar negative affect can be found (Berg et al., 1996; Crandell & Smaldino, 1999; Flexer, 1997; Lewis, 1995; Rosenberg, 2010). Besides competing with noises outside of the classroom, students must compete with typical sources of noise within their academic setting such as ventilation systems, projectors, computers, papers rustling, and conversations between students.

Due to the aforementioned negative effects of unwanted noise and reverberation in an academic setting, researchers have suggested implementing physical modifications within the classroom in order to eliminate extra noise and to reduce acoustical reverberation (Berg, 1993; Crandell & Smaldino, 1999; Flexer, 1997; Pakulski &

Kaderavek, 2002; Robinshaw, 2007). For instance, researchers suggested school districts use physical modifications (e.g., acoustic ceiling tiles, carpet on the floors, drapes or curtains, rubber caps or tennis balls on the bottoms of chair legs, and fiberglass panels or egg cartons on the wall) so that reverberation may be absorbed and sound reflections can be reduced. Even though modifications to certain aspects outside and inside the classroom can provide improvements for a more optimal learning environment, it is not the best or most feasible way to achieve the goal of creating a favorable listening atmosphere for students.

The lack of funding within school districts is the primary reason why modifications to the classrooms are so difficult to implement (Anderson, 2004; Rosenberg, 2010). Classroom modifications such as adding carpet to each classroom or eliminating shared classrooms, take time and money that most school districts do not have.

To bypass the issue of time and money, some researchers have suggested the idea of preferential seating to help eliminate extra noise and reverberant conditions within the classroom. By repositioning the classroom so that students are away from ventilation systems or projectors, SNRs can be increased in order to provide a more cohesive learning environment (Bess, 1999; Guardino & Antia, 2012; Hawkins, 1984; Lewis, 2008). Preferential seating is a great concept when paired with physical classroom modifications; however, when implemented alone, it is not enough to control for acoustical reverberation or competing noise (Flexer, 1997).

The lack of knowledge regarding the acoustic parameters of the academic setting amongst school personnel play a small role into why such solutions as physical modifications and preferential seating cannot be set forth. Because adults have more mature and developed auditory systems, many cannot relate nor comprehend the difficulties children encounter when trying to listen in a poor acoustical environment (Anderson, 2004; Bradley & Sato, 2004; Flexer, 2002). Sharma, Kraus, McGee and Nicol (1997) noted that a child's auditory system does not fully develop until young adulthood (e.g., 20 years old). Moreover, children have less life experiences and less knowledge of language than adults and therefore cannot fill in gaps as easily as adults when words or sentences are missed. Because of a less mature auditory system and difficulty filling in missed items during conversation, an environment in which a teacher's voice is greater than competing noise would be extremely beneficial (Anderson, 2004; Flexer, 2004). Unfortunately, because adults cannot relate to the difficulties children encounter everyday in noisy and reverberant environments, they cannot comprehend these issues. Due to this lack of understanding and ability to associate with the children, many school districts do not make classroom modifications a priority.

Hearing aids. Hearing aids are a great solution for peripheral hearing loss in general listening environments, but when addressing issues of competing noise and reverberation, a hearing aid has limited abilities in a classroom situation (Anderson & Goldstein, 2004; Berg et al., 1996; Boothroyd & Iglehart, 1998; Finitzo-Hieber & Tillman, 1978; Flexer, 1997; Lewis, 1995; Pittman, 2011). A hearing device will amplify a teacher's voice to make it loud enough for the children to respond; however, the hearing aid will also amplify all competing noise within and outside the classroom resulting in a less than favorable listening condition. In order to record the effects of noise on speech perception abilities of hearing impaired individuals, Finitzo-Hieber and Tillman (1978) measured word recognition abilities of 12 children (8 to12 years old) with a mild to moderate sensorineural hearing loss bilaterally. Speech recognition abilities of 12 normal hearing peers between the ages of 8 and 12 years old were recorded and used for correlation purposes. Monosyllabic word discrimination abilities were established with binaural hearing aids under quiet and three SNRs of +12 dB, +6 dB, and 0 dB for the hearing impaired children. The discrimination scores for hearing impaired children under the conditions of quiet, +12 dB, +6 dB, and 0 dB were 83%, 70%, 59.5%, and 39% respectively. The discrimination scores for normal hearing children under quiet and the same three SNR conditions were 94.5%, 89.2%, 79.7%, and 60.2%. Researchers concluded that even though the hearing aids provided good discrimination scores that were appropriate for the subjects' peripheral hearing loss, there were some limitations to the devices. When compared to the discrimination scores of normal hearing subjects, it was evident that the hearing aid was limited in its ability to give the hearing impaired children an optimal listening environment.

Anderson and Goldstein (2004) conducted a study with eight children between the ages of 9 and 12 years old with mild to severe hearing loss. All subjects were long time hearing aid users with age appropriate cognitive and language abilities. Speech recognition skills were assessed within a kindergarten classroom in order to record speech perception abilities of hearing impaired students in a typical academic setting. Sentences from the HINT were performed under background noise (cafeteria and hospital sounds) with a +10 dB SNR and a 1.1 s of reverberation. Researchers stated that the average speech understanding for the subjects utilizing the hearing devices was 82.4%. Anderson and Goldstein (2004) concluded that even though subjects were receiving adequate amounts of information with the hearing aids, there was an extensive amount of room for improvement.

As previously mentioned, Pittman (2011) conducted a study with 30 children (8 to 12 years old) diagnosed with a mild to moderately-severe hearing loss bilaterally. Researchers noted that the results of the speech testing in quiet and in noise (as compared to age and gender matched normal hearing controls) indicated that children with a hearing loss experienced a significant reduction of speech perception abilities in the presence of noise. More specifically, this study showed that even when children were wearing hearing aids in the presence of noise, word recognition abilities were negatively affected.

Boothroyd and Iglehart (1998) conducted a study with 13 severe to profound hearing impaired individuals ranging in age from 15 to 17 years old. In order to measure phoneme speech perception, consonant-vowel-consonant words were presented in soundfield with multi-talker babble at a +5 dB SNR. When students were asked to write each word they heard, a group mean phoneme recognition score was calculated for individual phoneme. Researchers found a mean phoneme score of 20%, 30%, and 15% for the initial consonant, vowel, and final consonant respectively. Researchers suggested that even though some benefit was established with the use of a hearing aid, it was not enough to overcome the boundaries associated with background noise. Collectively, these studies revealed that individuals using a hearing aid as a solution in a less than optimal SNR will receive some benefit in speech perception abilities, but speech understanding will be limited (Anderson & Goldstein, 2004; Boothroyd & Iglehart, 1998; Finitzo-Hieber & Tillman, 1978; Pittman, 2011).

Soundfield FM systems. A soundfield amplification system has shown to decrease SLDs and reduce the effects of noise and reverberation in the classroom resulting in improved speech, academic, and behavioral performances for all students (Arnold & Canning, 1999; Darai, 2000; Heeney, 2004; Massie & Dillon, 2006a; Massie & Dillon, 2006b). Arnold and Canning (1999) conducted a study with 49 normal hearing students (8 to 11 years old) in a typical classroom environment. Subjects were asked to answer questions in response to reading passages of three difficulty levels (i.e., Levels 1, 2, and 3) from the Neale Analysis of Reading Ability assessment. Passages were read with and without the assistance of a soundfield system in order to evaluate the potential benefit of the amplification device. Without the use of a soundfield system, researchers found a mean score value of 3.53, 4.54, and 1.77 for Levels 1, 2, and 3 respectively. With the use of the amplification system, mean scores of 3.62, 5.02, and 2.60 were noted for Levels 1, 2, and 3 respectively. Due to these results, Arnold and Canning (1999) concluded that there were significant improvements in scores across all difficulty levels when the soundfield system was utilized.

A similar improvement in literacy scores was found in a study conducted by Darai (2000). Darai (2000) assessed the potential benefits of a soundfield system by measuring achievements in reading across 166 first grade students. The Informal Reading Inventory (IRI) was used to assess 85 normal hearing first grade students in classrooms equipped with soundfield systems and 81 normal hearing students in classrooms without amplification systems. Darai (2000) found a statistically significant difference in literacy scores between the students that utilized the soundfield system compared to those who did not use the soundfield system. In particular, the researcher noted that 28 students increased in literacy by seven reading levels when using the soundfield system; whereas, only 13 students achieved a similar level of literacy growth when the soundfield system was not used. Due to the greater number of students who achieved an increase in reading levels with use of the soundfield system, Darai (2000) suggested that the significant improvements in literacy were due to the soundfield system. Similarly, Heeney (2004) conducted a study with 636 normal hearing students ranging from first to sixth grade in order to assess the use of a soundfield amplification system. A standardized test known as the Progressive Achievement Test (PAT) was utilized to evaluate students' performances in listening comprehension, reading comprehension, reading vocabulary, and math under two conditions (i.e., with and without a soundfield system). Because percentages received by children year to year on the PAT scores do not vary, Heeney (2004) was able to utilize the past year's scores to formulate mean change comparisons. Even though results did not indicate a statistically significant change, test results did indicate an overall improvement in all four areas for those students who utilized the soundfield system. Additionally, 73% of teachers subjectively noticed that students who utilized the amplification system were more on task with their behaviors, and 75% of teachers noted that students who used the soundfield system had improvements in instructional comprehension. With the help of PAT test score comparisons and teachers' opinions, Heeney (2004) concluded that soundfield systems do provide some benefit to students.

Some researchers were curious as to what would happen to the potential benefit of a soundfield system if the majority of the students did not use English as a first language. In order to assess the benefits of a soundfield system for students who do not use English as a first language, Massie and Dillon (2006a) conducted a study with eight English as second language (ESL) classrooms. All classrooms were assessed on how the students performed when a soundfield system was present and when it was absent. An evaluation of reading, writing, and number skills were assessed in order to determine if soundfield amplification systems could help to advance the acquisition for all three academic areas. Researchers found that when amplification was used, the number of acquired literacy and numeracy skills was greater than the number of skills acquired without use of the soundfield system. In particular, when the soundfield system was not used, students only learned approximately 4.0 new skills across literacy and numeracy categories, but when the soundfield system was used, students acquired approximately 5.8 new skills across literacy, numeracy, and writing categories. Moreover, by utilizing the same eight ESL classrooms, Massie and Dillon (2006b) evaluated information from teachers about the use of the soundfield systems. Teachers were asked to rate the effect the soundfield system had on the students in their own classes using the Teachers Opinions re: Performance in Classrooms (TOPIC) rating scale; students were rated on attention, communication, and behavior in the classroom. Even though results indicated no statistically significant changes in attention, communication, and behavior with the addition of a soundfield system, teachers subjectively reported increased improvements in all areas, particularly attention.

The results from all of these studies support the idea that soundfield systems provide significant improvements in the classroom for all students (Arnold & Canning, 1999; Darai, 2000; Heeney, 2004; Massie & Dillon, 2006a; Massie & Dillon, 2006b).

Even though all children are benefiting from the improved SNRs and better SLDs, the soundfield system still has limitations for all individuals (Flexer, 1997; Flexer, 2004;

Pakulski & Kaderavek, 2002; Schafer & Wolfe, 2010). Because the teacher's voice is amplified through loudspeakers in the classroom, the strength of the signal reaching the children's ears is affected by competing noise, reverberation, and SLDs. Therefore, the signal the children are receiving does not have the most favorable SNRs. On a practicality level, soundfield systems are not the best solution for poor classroom acoustics (Flexer, 1997; Flexer, 2004; Pakulski & Kaderavek, 2002; Schafer & Wolfe, 2010). Soundfield systems are beneficial, but due to the fact that children change classrooms on a daily basis, there would have to be a soundfield system in all classrooms. Because of the funding restrictions in school districts and expenses of soundfield systems, it would be difficult to have an amplification system in every classroom (Schafer & Wolfe, 2010).

Personal FM System

Generally speaking the purpose of an FM system in a classroom is to create an optimal SNR so the child can hear the teacher's voice above any competing noises and reverberation (Eiten & Lewis, 2010; Flexer, 1997; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). Classroom modifications, preferential seating, hearing aids, and soundfield systems can minimize the negative effects of noise, reverberation, and distance, but they fail to effectively create the most optimal SNR. In order for students to gain access to auditory information with a favorable SNR, a personal FM system should be utilized. By sending the desired signal directly to the student's ear at an intensity level above extraneous noise, a student can receive the desired signal at a most favorable SNR. This will result in better speech perception and overall understanding in a classroom environment (Eiten & Lewis, 2010; Flexer, 1997; Lewis, 2008; Schafer & Wolfe, 2010).

Parts of a personal FM system. A personal FM system consists of three major components: a microphone, a transmitter, and a receiver (Eiten & Lewis, 2010; Flexer, 1997; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). Each component has a different purpose within the system and consists of different parts.

Microphone. There are three types of microphones that can be utilized: (a) a lapel microphone that is worn on the chest; (b) a collar or lavalier microphone that is worn around the neck; (c) a boom or cheek microphone that is worn on the head (Flexer, 1997; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). The microphone is worn by the speaker and captures the speaker's voice. Regardless of what type of microphone is selected, it is essential that the microphone is worn 6 inches from the mouth; however if the microphone is worn on the head it must be 1-2 inches from the mouth (Flexer, 1997; Lewis, 1995; Lewis, 2008). Because the microphone is worn close to the mouth, the negative effects of SLD and background noise are decreased (Flexer, 1997; Fournier et al., 2012; Lewis, 1995; Lewis, 2008).

Transmitter. A transmitter can be worn a variety of ways: (a) it can be coupled with a lapel, collar, or boom microphone; (b) it can be worn around the neck; (c) it can be clipped to a belt or waist (Lewis, 1995; Lewis, 2008).

The transmitter is worn by the speaker and it sends the desired signal (e.g., teacher's voice) from the microphone to the receiver. The signal is transferred by FM radio waves; in order for the receiver to receive the signal from the microphone, the transmitter and receiver must correspond to the same radio frequency or channel (Flexer, 1997; Fournier et al., 2012; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). Typically the transmission range is from 30 to over 200 feet (Flexer, 1997).

Receiver. There are three main types of receivers that are widely used today: (a) a receiver that attaches to the bottom of the hearing aid; (b) a receiver that is integrated within the hearing aid (i.e., integrated with the battery door of the hearing aid); (c) a receiver that is utilized without a hearing aid, commonly known as an ear level receiver (Eiten & Lewis, 2010; Flexer, 1997; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). It is important to note that a receiver that attaches to the bottom of a hearing aid requires an audio shoe (adaptor). In order for the receiver to work properly, the audio shoe connects to the hearing aid via the Direct Audio Input (DAI) and the receiver connects to the audio shoe. Additionally, it is essential to point out that there is another type of receiver that can be utilized; it is known at the body worn receiver. The body worn receiver is a neck loop system that can be used with or without hearing aids. Prior to use of ear level receivers, body worn systems were used to deliver sound to the ear through headphones or to the hearing aid with use of Telecoil (T-coil), DAI adaptor, and a cord. With the invention of the ear level receivers and reduced use of T-coil, body worn systems are not typically used anymore (Flexer, 1997; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010).

The receiver is worn by the listener in which it collects the transmitted signal and delivers that desired signal to the listener (Flexer, 1997; Fournier et al., 2012; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). It is essential to note that the receiver will always pick up the strongest signal transmission at its particular frequency (Flexer, 1997; Lewis, 1995). Therefore, when more than two signals are being transmitted on the same frequency channel, the receiver will respond to the stronger one or interference may occur from the device that has the same signal.

How a personal FM system works. As stated previously, an FM system works through the transmission of FM radio waves via a transmitter. Essentially the FM system is a small radio station that functions on specific frequencies assigned by the Federal Communications Commission (FCC; Flexer, 1997; Lewis, 1995; Lewis, 1998; Schafer & Wolfe, 2010).

It is important to comprehend the aspects of working with FM radio waves and the interference that may occur with FM systems (Flexer, 1997; Lewis, 1995; Schafer & Wolfe, 2010). Prior to the early 1990s, the frequencies of 72-76 MHz range were denoted for educational FM transmission purposes. In 1992, interference amongst these frequency channels became an issue due to the advancements in cell phone technology and police scanners. If a cell phone call or police scan was in the vicinity of the same region (i.e., 30 to 200 feet) and was stronger than the teacher's voice, the receiver would respond to that phone call or scan. The interference between classrooms, along with the added interference of outside sources proved to be problematic (Flexer, 1997; Lewis, 1995; Schafer & Wolfe, 2010). Because of this interference issue, the FCC created additional frequency channels for educational purposes. The use of frequencies 216-217 MHz was approved in the mid 1990s; even though these frequencies can be used for other purposes besides educational reasons, interference has been reduced. Typically other professions or cell phone calls use lower frequency channels, such as the 72-76 MHz, instead of the higher frequency channels (Flexer, 1997; Lewis, 1995).

Types of personal FM systems. There are two types of personal FM systems noted in literature. Each type of personal FM system is discussed in the following sections.

Personal FM system coupled with amplification devices. One type of FM system is designed to be coupled to amplification systems such as hearing aids, cochlear implants, or bone anchored hearing aids. This type of FM system can be offered to individuals with hearing loss who require extra assistance in listening situations (Eiten & Lewis, 2010; Flexer, 1997; Fournier et al., 2012; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). Personal FM systems proved to be very successful for individuals with various types of hearing loss (Anderson & Goldstein, 2004; Boothroyd & Iglehart, 1998; Hawkins, 1984; Tharpe, Ricketts, & Sladen, 2003).

One of the first studies to address personal FM benefit for hearing impaired individuals was conducted by Hawkins (1984). In order to conclude if an FM advantage (i.e., FM benefit) was possible, Hawkins (1984) assessed nine hearing impaired children with a mild to moderate sensorineural hearing loss ranging in ages from 8 to 14 years old. All subjects wore binaural hearing devices and had age appropriate language and cognitive abilities. Phonetically Balanced Kindergarten (PBK) words were presented to participants with a +6 and +15 dB SNR in two conditions: use of hearing aids (binaural with directional microphones) and use of hearing aids (binaural with directional microphones) with a personal FM system (binaural). For the hearing aids only condition, there was a 44% mean word recognition score at +6 dB SNR and a 64% mean word recognition score at +15 dB SNR. For the hearing aids with the FM system condition, there was a 56% mean word recognition score at +6 dB SNR and a 72% mean word recognition score at +15 dB SNR. When hearing aids were utilized in conjunction with the personal FM system, a statistically significant FM advantage was found. Results indicated that the hearing aids with the FM condition provided a 12% FM advantage at

+6 dB SNR and an 8% FM advantage at +15 dB SNR. Such results allowed Hawkins (1984) to suggest that use of a personal FM system proved to be successful for the children with hearing loss. Similar to Hawkins (1984), Boothroyd and Iglehart (1998) were curious about the potential benefits a personal FM system would provide for individuals with hearing loss. These researchers evaluated 13 severe to profound hearing impaired individuals ranging in age from 15 to 17 years old. In order to measure phoneme speech perception, consonant-vowel-consonant words were presented in a classroom with a +5 dB SNR for both the aided and aided in conjunction with an FM condition. A group mean phoneme recognition score was calculated for each phoneme segment for all participants in both conditions. Boothroyd and Iglehart (1998) initially expected the use of the hearing aids in conjunction with the FM system to eliminate the negative effects of noise. The mean phoneme recognition scores between the aided condition and aided with the FM system condition were found to be statistically significant for each phoneme position; however, the negative effects of noise was not completely eliminated as initially expected. For the aided condition, researchers found a mean phoneme score of 20%, 30%, and 15% for the initial consonant, vowel, and final consonant respectively. For the aided with FM condition, researchers found a mean phoneme score of 35%, 50%, and 25% for the initial consonant, vowel, and final consonant respectively. Despite the interference of phoneme recognition from the noise, Boothroyd and Iglehart (1998) concluded that the use of a personal FM system in conjunction with the hearing aids provided better speech perception abilities for all phoneme segments than with use of the hearing aids alone.

Similar to studies conducted by Hawkins (1984) and Boothroyd and Iglehart (1998), other researchers felt the importance to assess personal FM benefit. Anderson and Goldstein (2004) conducted a study with eight children between the ages of 9 and 12 years old with mild to severe hearing loss. All subjects were long time hearing aid users and presented with age appropriate cognitive and language abilities. Speech recognition skills were assessed within a kindergarten classroom in order to record speech perception abilities of hearing impaired students in a typical academic setting. Sentences from the HINT were performed in background noise (i.e., cafeteria and hospital sounds) with a +10 dB SNR and a 1.1 s of reverberation. In order to observe potential benefit from the FM system, subjects were tested under two conditions: with hearing aids and a combination of hearing aids with the personal FM system. Results indicated a statistically significant greater effect with use of the hearing aids and FM system than with the use of hearing aids alone. Researchers explained that the average speech understanding was 82.4% for the subjects utilizing the hearing devices and 94.4% for the subjects utilizing the hearing aids in conjunction with the FM system. Anderson and Goldstein (2004) concluded that because speech perception scores with the FM system were better on average than use of hearing aids by themselves, personal FM systems provide a more efficient and successful outcome for hearing impaired individuals in a classroom setting.

A similar outcome in speech perception was reported in a study conducted by Tharpe, Ricketts, and Sladen (2003). Researchers conducted this study to record the effects of a personal FM system on speech perception abilities in a less than ideal listening environment. Fourteen children (5 to 11 years old) with a minimal to mild sensorineural hearing loss were evaluated with the HINT for children (HINT-C), the

Screening Instrument for Targeting Educational Risk (SIFTER), and a self-questionnaire for children. Testing occurred in a double-walled sound-treated audiological booth with five loudspeakers positioned at different azimuths in order to create a classroom-like setting. Speech perception abilities for all subjects were tested with the HINT-C prior to receiving an FM system (i.e., no FM) and after a six week trial with personal FM devices. There was a statistically significant difference between the FM and no FM conditions. In particular, results indicated an 8.3 dB SNR advantage when subjects wore the FM system in comparison to no FM system. Additionally, the SIFTER results indicated no overall improvements after the trial with the FM systems; it is important to note that even though no statistical significance was noted across the SIFTER categories, teachers subjectively noted some improvements in the academic performance with use of the FM system. When the children were asked about the use of the personal FM, 74% of the children responded that they liked the amplification system because they could hear the teacher better. Also, 90% of the students noted that it was easy and/or very easy to hear the teacher's voice with the FM system. Tharpe et al. (2003) concluded that because of the noted improvements in academic performance across SIFTER categories and the significantly better speech perception abilities across HINT scores, use of a personal FM system for even minimal to mild hearing impaired individuals can be beneficial.

Even though all of these studies used different methods and tests to conclude results, they support the idea that a personal FM system is beneficial for individuals with various degrees of hearing loss (Anderson & Goldstein, 2004; Boothroyd & Iglehart, 1998; Hawkins, 1984; Tharpe et al., 2003).

Personal FM system without amplification systems. The other type of FM system is utilized without additional amplification devices for those individuals who do not have hearing loss. Research has shown that this type of FM system is beneficial for children who have normal hearing (Mukari, Umat, & Razak, 2011). Mukari, Umat, and Razak (2011) recruited 22 normal hearing and typically developing children between the ages of 8 and 9 years old in order to assess the benefits of a binaural, open fit personal FM system. All speech-in-noise testing was completed in a sound-treated audiological booth under two FM conditions (i.e., no FM and FM) with competing noise (i.e., multi-talker babble) at a fixed 65 dB SPL. Researchers found a statistically significant difference between RTS scores and SNRs when testing was completed with and without the FM system. Researchers recorded an average RTS score of 60.5 dB SPL for the no FM condition and a 51.4 dB SPL for the FM condition. A SNR of -4.45 dB was calculated for the no FM condition and a -13.56 dB SNR was measured for the FM condition. Overall, results indicated a mean FM benefit of 9.1 dB when binaural, open fit personal FM systems were utilized in noisy conditions. Results suggested that use of an FM system provides significant benefit in noisy conditions for even normal hearing and typically developing children.

As mentioned previously, the open fit personal FM system is most beneficial for individuals with normal hearing who have APD, ADHD, ASD, and reading and/or learning disorders (Flexer, 1997; Friederichs & Friederichs, 2005; Johnston et al., 2009; Schafer & Wolfe, 2010; Schafer et al., 2013; Smart et al., 2010).

APD. In order to show the potential benefits of an FM system for individuals with APD, Johnston et al. (2009) conducted a study on 10 normal hearing children between the ages of 8 and 13 years old with an APD diagnosis. In order to establish a baseline measurement for speech perception abilities, the HINT was administered to the APD group at the initial fitting of the FM system. Speech perception abilities were measured at the initial fitting (pre-fit) and after a five month FM trial period (post-fit); HINT testing was completed under two listening conditions (i.e., in quiet and in noise) and two FM conditions (i.e., with the FM system and without the FM system). Speech perception abilities of 13 normal hearing and typically developing age matched peers were measured under the same listening and FM conditions only for an initial fit and used for comparison against HINT results for the APD group pre-and post-fit measurements. When the FM system was not used during the pre-fit evaluations, the APD group had statistically significant lower speech perception abilities in comparison to the control group; however, after the five month trial with the FM system, the speech perception differences were no longer present between the two groups. Overall, no differences in HINT results were found in quiet for the no FM and FM conditions across: (a) pre-fitting versus post-fitting HINT results of the APD group; (b) pre-fitting HINT results of the APD group versus the HINT results of the control group; (c) post-fitting HINT results of the APD group versus the HINT results of the control group. When the FM system was utilized under noisy conditions, a statistically significant improvement in speech perception abilities for the APD group was noted for pre- and post- fitting evaluations compared to the control group. For example, Johnston et al. (2009) noted that the APD group post-fit evaluation yielded an 11.91 dB FM benefit; whereas, the control group speech perception evaluations only yielded an 8.24 dB FM benefit. Johnston et al. (2009) concluded that the FM system provided the children with APD a greater advantage in speech perception abilities under noisy conditions in comparison to the control group. Researchers suggested that such noted improvements of speech perception for individuals with APD were a direct reflection of FM use. Furthermore, researchers utilized the SIFTER and LIFE questionnaire results in order to validate any changes that may have occurred. It was found that after the five month FM trial, the children with APD showed improvements in academics and communication categories, according to their teachers. Similarly, according to students' perceptions of the FM system, the LIFE scores indicated improvements in almost all situations examined. Johnston et al. (2009) used results from the HINT, SIFTER, and LIFE questionnaires in order to indicate the overall benefit students with APD receive when use of a personal FM system is utilized.

A similar outcome of FM benefit was noted in a study conducted by Smart et al. (2010). Smart et al. (2010) conducted a study in order to measure the potential benefit of a personal FM system for children who have been diagnosed with APD. Initially, 29 normal hearing children (7-12 years old) with a diagnosis of APD were evaluated in a double-walled sound-treated audiological booth; however, only 22 children completed the study. Because APD is typically a co-occurring disorder, majority of the children who were tested presented with other deficits (i.e., Asperger's Syndrome, ADD/ADHD, and learning and/or language disorders). In order to objectively measure the potential benefit of a personal FM, researchers utilized the Lexically Controlled Word List (LCW). Words from the LCW were presented at 70 dB SPL with a 0 dB SNR prior to the FM trial (no FM) and after the five month FM trial (with the FM). Researchers found a statistically significant improvement in LCW scores between the post-FM trial and pre-FM trial conditions when presented in noise. In order to have a more subjective outlook on results, researchers utilized the LIFE-UK questionnaire. This questionnaire was administered to all of the participants' teachers prior to the FM fitting and after the completion of the trial. Researchers noted that according to the teachers' responses post-FM fit of the LIFE-UK, 79% of the children were considered to have a successful and/or highly successful FM fitting trial. Additionally, a parent questionnaire, modified from the LIFE-UK, was used in order to evaluate if parents and teachers observed similar benefits. When the averaged LIFE-UK ratings between parents and teachers were compared post-FM, Smart et al. (2010) found a statistically significant positive correlation. Researchers concluded that even though the FM was only worn during school, parents and teachers observed similar findings in the classroom and at home. The improvements on the LCW word lists, LIFE-UK ratings, and parent questionnaire following an FM fitting trial allowed researchers to conclude that personal FM systems are both beneficial and effective for children with APD in a classroom-like setting.

One interesting study conducted by Friederichs and Friederichs (2005) not only used teacher questionnaires to measure potential benefit of a personal FM system, but utilized cortical auditory evoked potential (CAEP) responses. For correlation purposes, researchers used 10 children diagnosed with attention and learning disorders in conjunction with a suspected APD diagnosis as the experimental group and 10 aged matched children with no suspected APD or co-occurring deficits as the control group. All children ranged in age from 7 to 14 years old and had normal hearing. Researchers analyzed responses from the teacher questionnaire for all children and noted positive changes across social behavior, attentiveness, and hearing profile. As the children wore the FM devices, the severity of symptoms associated with all three categories began to decrease and continued to decrease throughout the year. This consistent and significant decrease in social, attention, and listening symptoms were not noted for the control group. Therefore, researchers concluded that the positive changes across social behavior, attentiveness, and listening abilities were due to the use of the FM system. Additionally, researchers measured P2/P3 disruption patterns for CAEPs across the control and experimental groups in order to note if differences have occurred with use of a personal FM system. Differences between the P2/P3 patterns of distribution were noted between the individuals who utilized the FM system and the control group. It was found that the amplitude of P2 was increased for both infrequent and frequent tonebursts across the experimental group after 6 months and 12 months of FM use. This spike in amplitude of the P2 was not observed for the control group over the 12 month trial. Because the control group did not display a "distinct pattern of detection" or increase in P2 amplitude, researchers suggested that the changes in the experimental group were beyond the normal maturational changes. Friederichs and Friederichs (2005) concluded that the FM system was beneficial as an intervention for the children with suspected APD and co-occurring deficits.

The results from Friederichs and Friederichs (2005), Johnston et al. (2009), and Smart et al. (2010) suggest that regardless of choice for testing procedure, use of a personal FM system results in a beneficial intervention option for children diagnosed with APD. Therefore all three studies support the idea that a personal FM system provides children with auditory processing deficits benefits in a classroom setting.

Attention, learning and language disorders. Researchers have proposed a solution for improving overall listening skills in an academic setting for individuals with attention, learning, or language disorders; they have noted that use of a personal FM system proves to be successful at eliminating extraneous background noise and thus aids in providing better speech perception, social behavior, and academic performances (Purdy, Smart, Baily, & Sharma, 2009; Schafer et al., 2013).

Schafer et al. (2013) conducted a study in order to examine the potential benefits of a personal FM system in children diagnosed with ASD, ADHD, or both. Nine children with a diagnosis of ASD and/or ADHD were evaluated and rated on the basis of speech-in-noise assessments, the SIFTER, and Children's Auditory Performance Scale (CHAPS) questionnaire. For purposes of this review, only results from the speech testing will be discussed. All children from the experimental group participated in two mini-trials in which speech-in-noise testing was observed with and without use of binaural FM devices. Two trial periods were utilized for test-retest reliability purposes. In order to determine if there was a difference in speech-in-noise test results between the no FM and FM condition, Schafer et al. (2013) utilized a mean SNR threshold and an FM benefit score (i.e., the difference between the no FM and FM condition). An analysis of speech-in-noise assessments found a 6.1 dB and 7.8 dB FM benefit for individuals with ASD across trial one and trial two respectively. An analysis of speech-in-noise assessments for ADHD participants found a 3.4 dB and 5.6 dB FM benefit across trial one and trial two respectively. For trial one, the average performance of speech-in-noise testing via SNR thresholds across all nine subjects was -5.4 dB SNR and -10.7 dB SNR for no FM and FM condition respectively. For trial two, the average performance of speech-in-noise testing via SNR thresholds across all nine subjects was -4.2 dB SNR and -11.2 dB SNR for no FM and FM condition respectively. It is important to note that a lower (i.e., more negative) speech-in-noise score indicates a better performance in noise. Researchers found that speech perception abilities via FM benefit and SNR thresholds were statistically significantly better with use of the FM system in comparison to no FM use. Collectively, the speech-in-noise testing results with the FM system across all trials and participants indicated a significant improvement in speech perception by 5.9 dB compared to the speech-in-noise testing results without the FM system. Overall, it was noted that all children displayed better (i.e. lower) speech perception thresholds after use of the FM system.

Moreover, Schafer et al. (2013) utilized a control group of 11 normal hearing and typically developing children in order to provide more information about the benefits of an FM system. Speech-in-noise thresholds were established for the control group under the no FM condition and compared these results to the no FM and FM speech-in-noise thresholds of the experimental group. Researchers found a statistically significant difference between groups under the no FM condition; speech in noise testing yielded a -4.8 dB SNR for the experimental group and a -10.1 dB SNR for the control group without use of the FM system. Schafer et al. (2013) explained that as expected, children with ASD and ADHD performed worse than typically developing peers under noise with no FM system. When comparing speech perception abilities between the control group without an FM system and the experimental group with the FM system, researchers found that there was no statistically significant difference between speech perception abilities of the two groups. Speech-in-noise testing yielded a -10.6 dB SNR for the experimental group and a -10.1 dB SNR for the control group. Researchers concluded that use of an

FM system for ASD and ADHD children increases their speech recognition abilities to a similar performance level of typically developing peers in noisy environments.

Purdy, Smart, Baily, and Sharma (2009) conducted a study that measured FM benefit for children with reading disorders. The benefit of an FM system was based upon the results from the LIFE-UK prior to and after a 6 week trial with personal FM systems for children with reading delays. For purposes of this study, Purdy et al. (2009) noted that identification of a reading disorder was characterized by the fact that the child's individual reading levels were delayed by at least 18 months. Researchers believed that use of an FM system would improve both the teachers' and children's perceptions of listening abilities while in a classroom setting. Thirty-eight children (6-11 years old) with diagnosed reading disorders participated in answering questions from the LIFE-UK prior to and after the trial with the FM system. Researchers calculated that ninety-two percent of children (n = 35) regarded the FM system with positive comments and beneficial statements. A control group with typically developing peers of similar ages was used for correlation purposes and analysis of benefit; the control group had normal hearing and did not utilize an FM system for the trial period. When listening in more difficult situations, the experimental group had statistically significantly better ratings on the LIFE-UK than those individuals who did not utilize the FM system (i.e., control group). Due to the significant improvements and perceived benefit of the FM system from the children, researchers noted that use of this amplification system can help individuals with reading delays in a classroom-like setting. In order to assess the FM benefit from a teacher's perspective, the LIFE-UK was completed by teachers for both the control and experimental groups pre- and post- fit. Prior to utilization of an FM system, the teachers did not perceive a difference in the control and experimental group; however, after the 6 week trial period, teachers perceived a significant difference between the individuals that used the FM system and the control group. In fact, listening abilities on the LIFE-UK were rated as better by all teachers for the experimental group post-FM fit. Due to the significant improvements in listening abilities as noted by the teachers, researchers concluded that a six week trial with FM systems for individuals with reading delays is beneficial.

Collectively, these studies support the idea of using an FM system as a solution for improving overall listening abilities in a classroom for individuals with an attention, learning, or language disorder (Purdy et al., 2009; Schafer et al., 2013).

Fitting Protocol

Even though personal FM systems have provided children with benefits, no standards for evaluating such improvements have been developed. According to ASHA "Guidelines for Fitting and Monitoring FM Systems" (2002), ANSI has not developed a set protocol that can be widely used for measuring benefits of a personal FM fitting. The American Academy of Audiology "Clinical Practice Guidelines: Remote Microphone Hearing Assistance Technologies for Children and Youth from Birth to 21 Years" (2008) also noted that there is no standard approach for measuring the benefits of a personal FM system. Even though no set protocol has been established, several organizations and researchers proposed guidelines for individuals to consider in regards to performance measurement of an FM system. It is essential to consider output verification, behavioral validation, and subjective validation procedures when measuring the benefits of a personal FM fitting (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008).

Output verification measurements. It is essential for audiologists to have a way to confirm that the FM system is performing correctly. The purpose of utilizing output verification measurements is to ensure that the FM system is functioning accordingly (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008). By utilizing electroacoustic analysis with either a 2 cc coupler or real ear protocol, the performance of a personal FM system can be tested.

Electroacoustic analysis using a 2 cc coupler. In order to confirm that fitting goals of the FM system were met, an assessment of the functional gain is necessary (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008). Utilizing a 2 cc coupler approach is an ideal way to test the functional gain of a personal FM system when coupled with a hearing aid.

One of the first guidelines for verification with a 2 cc coupler was provided by ASHA (2002). When fitting a personal FM system with a hearing device, it was recommended that the output of the personal FM microphone be 10 dB higher (i.e., louder) than the output of the hearing aid microphone. In order to ensure this +10 dB FM advantage, the output of the FM microphone was measured with an 80 dB SPL input level and the output of the hearing aid microphone was measured with a 65 dB SPL input level in the test box. The differences of input measurements allowed for the output of the FM to be 10 dB louder than the output of the hearing aid. If the advantage was not 10 dB, then adjustments were conducted (ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008). The ASHA (2002) guidelines were the most noted and current electroacoustic protocols available; however, as technology advanced for both hearing aids and FM systems, this approach became more difficult to implement (AAA, 2008; Eiten & Lewis, 2010). With hearing aids and FM systems incorporating more complex signal processing platforms and with the invention of the ear level FM receiver, the FM advantage approach was not appropriate for all FM system electroacoustic analyses.

Due to the advances in signal processing, AAA (2008) developed a new electroacoustic analysis approach: the transparency approach to FM verification. When an FM receiver is coupled to the hearing aid, a 65 dB SPL input level is delivered to both the hearing aid microphone and the FM microphone. If the FM level has been set to a +10 dB SNR advantage, the output of the FM system should not be different from the hearing aid output by more than +/- 2 dB (AAA, 2008; Eiten & Lewis, 2010; Lewis, 2008). If the output of the two amplification systems differs by +/- 2 dB, adjustments are made. When utilizing an open fit device, a 2 cc coupler verification approach cannot be completed; a 2 cc coupler cannot account for the acoustic properties of an open fit device (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008).

Electroacoustic analysis using real ear measurements. If there is no 2 cc coupler and test box, real ear verification can be utilized to confirm the performance and setting for the personal FM system (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008). When utilizing an ear level FM system, electroacoustic analysis cannot be completed with a 2 cc coupler; this ear level receiver requires the use of a probe tube method due to its open fit concept. Eiten & Lewis (2010) explained that a 2 cc coupler cannot account for the acoustics in an open fit and therefore a real ear method is more appropriate. When utilizing a real ear method approach, it is important to make sure that the functional gain settings are appropriate for use. For instance, real ear measurements can be used to ensure that maximum output gains are not set too loud (ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008).

Behavioral validation methods. In order to assess the benefits the patient is receiving from the FM system, it is important to use behavioral validation methods. Speech-in-noise testing is one of the most common ways to confirm speech perception performances with an FM system (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008). Many researchers utilize this method of validation for a number of reasons: (a) can be conducted in a sound-treated audiological booth with specific speech-in-noise tests in order to simulate a typical classroom learning environment; (b) easy comparison of speech performances with the presence and absence of an FM system; (c) provides the validation needed to confirm the benefits and functioning of the FM system (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008).

When reviewing literature regarding behavioral validation of personal FM systems for hearing impaired individuals, normal hearing individuals, or individuals with other deficits, similar speech-in-noise tests were utilized (Anderson & Goldstein, 2004; Boothroyd & Iglehart, 1998; Hawkins, 1984; Johnston et al., 2009; Smart et al., 2010; Tharpe et al., 2003). One of the most common used speech-in-noise tests to validate FM speech perception benefits is the HINT (AAA, 2008; Anderson & Goldstein, 2004; ASHA, 2002; Eiten & Lewis, 2010; Johnston et al., 2009; Lewis, 2008; Tharpe et al., 2003). The HINT consists of 25 lists of phonetically balanced sentences with 10 sentences per list. Speech spectrum noise is presented in conjunction with the sentences in order to simulate listening in a classroom-like setting. Researchers concluded that use of the HINT provides the validation that is needed to ensure the functioning of the personal FM system (Anderson & Goldstein, 2004; Johnston et al., 2009; Tharpe et al., 2003).

It is essential to consider not only the developmental age of a child when choosing a validation measure, but is important to consider the level of language and any deficit each child may possess. Because the HINT is comprised of sentences, there are going to be times that such a test is not appropriate for the participants (Eiten & Lewis, 2010; Lewis, 2008). In order to effectively test children with APD and other co-occurring deficits, Smart et al. (2010) used the LCW word list in conjunction with a 0 dB SNR. While testing children with a mild to moderate sensorineural hearing loss, Hawkins (1984) decided to use the PBK word list with a +6 and +15 dB SNR as an assessment for speech-in-noise testing. Moreover, Boothroyd and Iglehart (1998) used consonant-vowel-consonant words to measure phoneme speech perception with a +5 dB SNR for individuals with hearing impairment. By using speech-in-noise tests that were appropriate for each participant group, researchers were able to conclude functional validation of FM use (Boothroyd & Iglehart, 1998; Hawkins, 1984; Smart et al., 2010).

Subjective validation methods. After the functional settings and behavioral validation of the FM system has been evaluated, it is essential to ensure that the personal FM system is subjectively providing benefit for each participant (Eiten & Lewis, 2010; Lewis, 2010). Subjective validation tools are utilized to demonstrate to parents, teachers, and participants the speech perception and listening benefits that are perceived with use of an FM system (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Johnson, 2010; Lewis, 2008; Lewis, 2010). There are a variety of tools that can be used to examine the perceived benefits of an FM system. One of the most common forms of subjective validation is a questionnaire which can be administered to parents, teachers, or the participant (self-questionnaire). Researchers typically use questionnaires as a validation tool because they can receive rating scores of perceived benefits both pre-and post-FM fittings (Johnson, 2010; Lewis, 2010). There are several common questionnaires utilized amongst the researchers who have established speech perception benefit with personal FM systems (Friederichs & Friederichs, 2005; Johnston et al., 2009; Purdy et al., 2009; Schafer et al., 2013; Smart et al., 2010; Tharpe et al., 2003).

SIFTER. The SIFTER is a questionnaire typically given to teachers in order to measure five areas of performance: academic, attention, communication, classroom participation, and school behavior (Johnston et al., 2009; Schafer et al., 2013; Tharpe et al., 2003). The SIFTER provides a rating scale for 15 questions related to the assessment and improvements perceived by the teacher across all five areas of school performance. In order to record perceived benefits of FM use, researchers utilize the SIFTER to demonstrate to teachers, parents, and participants the benefits the child receives across academic, attention, communication, participation, and behavioral categories (Johnston et al., 2009; Schafer et al., 2013; Tharpe et al., 2003).

LIFE. LIFE is another questionnaire typically given to students and teachers in order to evaluate classroom listening situations (Johnston et al., 2009; Purdy et al., 2009; Smart et al., 2010). There are two versions (i.e., United Kingdom version and United States version). The LIFE-UK is brief questionnaire that is administered to primary teachers; it allows teachers to rate students on a five-point scale regarding several listening and behavioral abilities (Purdy et al., 2009; Smart et al., 2010). Johnston et al. (2009) used the student and teacher/parent version. The student version consists of 15 statements; children respond to each statement by choosing one of the five-point rating scale items. The teacher version consists of 13 statements in which adults respond to each statement by checking one of the five-point rating scale items. In order to evaluate learning difficulties or benefits of an FM system, researchers utilize the LIFE-UK for subjective validation purposes (Johnston et al., 2009; Purdy et al., 2009; Smart et al., 2010). Moreover, some researchers have adapted the LIFE-UK in order to create a questionnaire to administer to parents (Smart et al., 2010).

Time. According to Dennis and Gonzenbach (2011), audiological appointment times can vary from 30 minutes to 90 minutes depending upon the complexity of the service and preparation time needed for that particular appointment. Dennis and Gonzenbach (2011) further explained that time is affected by the amount of direct patient care (i.e., preparation and appointment services).

Purpose of this Study

With the development of the open fit FM systems, there is a need to create a protocol for children receiving these devices in order to evaluate the benefits in a clinical setting. The aim of this study is to develop a protocol that can be used in clinical practice to verify and validate open fit personal FM systems that considers the demands of the clinical setting.

CHAPTER 3

METHODS AND MATERIALS

Participants

Seventeen typically developing children between the ages of 8 and 17 years old participated in this study. The participants consisted of six females and 11 males with a mean age of 13.8 years (*SD* = 2.32). To be included in the study, participants needed to have normal hearing, normal middle ear status, and no reported history of learning, language, or listening difficulties. Prior to proceeding with testing, hearing status was confirmed on the date of testing by performing hearing screenings at 15 dB HL across all octaves of 250-8000 Hz bilaterally (Appendix A). Middle ear status was also confirmed on the day of testing by performing tympanometry (Appendix A). Participants were required to have Jerger Type A tympanograms in order to proceed with this study (Shanks & Shohet, 2009). Anyone who failed the hearing screening and/or tympanometry testing was referred to an audiologist for more comprehensive diagnostic testing. Parents/guardians completed a comprehensive case history form prior to the test session (Appendix B). Primary teachers were asked to complete the LIFE-UK questionnaire (Appendix C). Attached to each questionnaire was a cover letter explaining to the teachers the purpose of the study and directions on how to complete the LIFE-UK questionnaire (Appendix D).

Each participant was recruited on a volunteer basis through word of mouth or flyer (Appendix E). Parents/guardians were required to sign a consent form prior to participation (Appendix F). All children completed assent forms at the start of the test session (Appendix G). Recruitment, consent forms, assent forms, and all procedures were approved by the Institutional Review Board (IRB) at Towson University before testing commenced (Appendix H).

Following the hearing screening and tympanometry testing, a timer was used to log the time it took to complete each portion of the fitting session. The log was kept for the following tasks: Completion of the LIFE-UK student questionnaire (timed), verification of the FM system (timed), speech perception testing in all conditions (timed), and completion of the follow-up questionnaire (timed). Additionally, a timer was used to log the time it took to complete preparation tasks (i.e., calibration of probe tube, test box, and HINT CD; inputting data into the Verifit; set-up of the audiological booth). All times were recorded separately and then averaged together to estimate how long a fitting appointment may take clinically using this protocol.

FM System and Output Verification Measurements

The Oticon Amigo Star FM ear level devices were used as the open fit receivers for this study. Participants were fit with two ear level receivers on the day of testing. Prior to testing, REMs were conducted in order to confirm the performance and settings for each personal ear level device. Prior to conducting REMs, the probe tube microphone and Audioscan Verifit test box were calibrated. In order to ensure that maximum output gains were not set too loud, the Desired Sensation Level (DSL) v.5.0 prescription formula targets and the recommended 105 dB SPL uncomfortable loudness levels were selected and inputted into the Verifit prior to measurements (AAA, 2008; Fuglholt & Angelo, 2013).

Verification began with evaluating the response of the FM signal at the level of each participant's ears (AAA, 2008; Fuglholt & Angelo, 2013). The FM microphone and transmitter (i.e., the Amigo T30 transmitter) were placed inside the Audioscan Verifit test box with the reference microphone enabled. A test signal was played to the FM microphone and transmitter in the test box. A real ear response with each of the FM receivers was evaluated by the probe tube in the participant's ears. The probe tube measured the response of the amplified signal (AAA, 2008; Fuglholt & Angelo, 2013).

The predicated uncomfortable loudness levels were used to ensure that maximum output gains were not set too loud (AAA, 2008). A real ear saturation frequency response was measured by the FM microphone inside the test box with an 85 dB SPL pure tone input signal across all frequencies; the FM receiver was set at maximum volume during this pure tone sweep. If the response curve fell below the predicted uncomfortable loudness levels, then no adjustments were needed. If the response curve was measured above the predicted uncomfortable loudness levels, re-adjustments occurred and a new real ear saturation frequency response was re-measured.

The DSL v.5.0 prescription formula targets were used to ensure that gain was set appropriately for each participant. The frequency response curves were measured with a chest level FM microphone of 84 dB SPL input level and calibrated speech signal. Frequency response curves were evaluated at the highest and lowest volume setting in order to illustrate a full range of gain across all frequencies. Selection of the volume setting that best matched the DSL v.5.0 targets was chosen. Only evaluation of frequency responses between 1000-4000 Hz were taken into consideration due to the predicted attenuation of the low frequency gains from the receivers. Finally, an informal listening check occurred prior to speech perception testing (AAA, 2008; Fuglholt & Angelo, 2013).

Behavioral Validation

All speech perception testing was administered in a double-walled sound-treated audiological booth. The HINT (Nilsson, Soli, & Sullivan, 1994) was administered in soundfield in both quiet and noise and with and without the use of the Amigo Star receivers. Due to the typical arrangement of speakers in the audiological test suite, only two speakers were utilized for testing. The primary speech signal was presented to the participant at a 0° azimuth and the competing noise was presented from behind at 180° azimuth. The competing speech spectrum noise was presented at a fixed level of 65 dB HL during the noise conditions. The sentences were presented at a +5 dB SNR to begin testing for all listening conditions. A GSI-61 audiometer coupled to a Sony CD player provided the speech signal and competing noise stimuli for testing purposes. The participant was positioned in the center of the room at a distance of 4.5 feet from the front and back loudspeakers. The microphone/transmitter of the FM system was placed 6 inches from the front loudspeaker in order to represent the typical distance from the microphone to mouth of the speaker (Flexer, 1997; Lewis, 1995; Lewis, 2008). A routine listening check was performed prior to testing each participant to ensure that the FM microphone was positioned towards the loudspeaker for testing and to ensure that accurate sound quality was assessed.

The HINT was used in this study as a measure of speech perception for sentences and was presented in quiet and noise with and without use of an FM system. The HINT consists of 25 lists of sentences with 10 sentences and five words to each sentence. The sentences are phonetically balanced and the competing noise is strategically matched to the speech spectrum of the sentences. The language level of the sentences is approximately a first-grade reading level (Nilsson et al., 1994). Prior to testing under each condition, four sentences were used in order to ensure familiarity of each listening task for all participants. Participants were asked to correctly repeat two lists (containing 10 sentences each) of sentences in quiet and in noise without the FM system; the same procedure occured in quiet and in noise with the FM system. The noise (i.e., competing noise and quiet) and FM (i.e., no FM and FM) conditions were randomized for each participant and test lists were randomized. Breaks were given as needed for each participant.

A reception threshold for sentences (RTS) was obtained for each noise and FM condition per participant. An RTS is defined as the lowest intensity level at which the participant can correctly repeat 50% of the stimuli. In order to obtain the RTS, speech intensity levels were adjusted in 2 dB steps depending upon responses. A correct response was defined as an accurate repetition of at least three key words in each sentence. An incorrect response was defined by substituting or missing at least three key words (i.e., only two correct) in each sentence. A correct sentence response decreased the speech intensity level by 2 dB steps and an incorrect response increased the speech intensity level by 2 dB steps; this process continued until each list was completed for each listening condition. The RTS was calculated by averaging the presentation levels of the sentences that were presented across each listening condition. In order to measure the FM benefit, the differences between the mean RTS scores with the FM and without the FM system was calculated for each noise condition (i.e. competing noise and quiet). Additionally, the RTS was expressed as a SNR. The SNR was calculated by subtracting the fixed competing noise level (i.e., 65 dB HL) from the RTS score. An RTS score and

SNR was found for each participant and a mean RTS score and SNR was found for the entire group. This is the routine protocol and scoring method for the HINT (Nilsson et al., 1994).

Subjective Validation

Prior to testing, each participant completed the LIFE-UK student version questionnaire which asked about hearing in 13 different listening environments (Appendix I). After the speech perception testing, students completed a follow-up questionnaire regarding individual experiences in hearing conditions with the FM and without the FM system (Appendix J). This follow-up questionnaire contained two open ended questions and four questions that required the participants to rate their responses along a five-point rating scale modified from the LIFE-UK student version.

Both questionnaires were administered verbally with the researcher reading each question for the student and recording all responses while the child looked at the questionnaire (or read along).

Statistical Analysis

Various statistical analyses were performed to evaluate the data sets. Descriptive statistics for total scores and responses from all tests were performed on Microsoft Excel 2007 in order to evaluate the means and standard deviations. A two-way repeated measures analysis of variance (ANOVA) was performed in order to identify if there were differences between the RTS scores measured for the participants across the noise (i.e., competing noise and quiet) and FM (i.e., no FM and FM) conditions. Dependent sample t-tests were performed in order to identify if the group mean HINT results (i.e., RTS scores and SNRs) in noise without the FM system were different from the group mean

HINT results (i.e. RTS scores and SNRs) in noise with the FM system. An independent samples t-test was performed in order to identify speech perception differences between the group of participants that stated ‘Yes’ and the group of participants that stated ‘No’ to the open ended follow-up questions (i.e., Questions 1 and 2). In order indicate if there was a correlation between the teachers’ perceptions of their student’s listening abilities and each participant’s perception about their own listening abilities, Spearman Correlation Coefficients were calculated. Certain questions from the LIFE-UK were paired from certain questions from the LIFE-UK student version that seemed to best correspond to each other for analytical purposes. Lastly, a Spearman Correlation Coefficient was calculated in order to identify if there was a relationship between the FM benefit and the responses to the follow-up questionnaires. All inferential statistics were performed on IBM SPSS Statistics version 21.

CHAPTER 4

RESULTS

A total of 17 children (6 females, 11 males) between the ages of 8 and 17 years old (*M* = 13.82, *SD* = 2.32) participated in this study. Prior to testing, a hearing screening was conducted for each participant and confirmed a normal hearing status for all participants at 15 dB HL across all octaves of 250-8000 Hz bilaterally. During tympanometric testing, a normal middle ear status was confirmed for all participants by indication of Jerger Type A tympanograms bilaterally. There was no history of learning, language, or listening difficulties described by the parents/guardians on the comprehensive case history forms for any participant. All participants were considered to be typically developing children as indicated by the information presented on the case history forms. All 17 children had normal hearing, normal middle ear status, and no history of learning, language, or listening disorders; therefore, they met the criteria to participate in this study. Data for all 17 participants was analyzed using Microsoft Excel 2007 and IBM SPSS Statistics version 21.

Time

Time was recorded for each participant and each test. Table 1 illustrates the group mean time it took to complete each individual portion of the protocol. Additionally, the mean time for the entire protocol was calculated. On average, it took 28 minutes to perform the entire protocol.

The total time displayed in Table 1 represents the average amount of time it took to complete the preparation (i.e., calibration of probe tube, test box, and HINT CD;

inputting data into the Verifit; set-up of the audiological booth), LIFE-UK student version, REMs, all four conditions of the HINT, and the child follow-up questionnaire.

Table 1

Mean Times for Protocol

	Time (minutes)	
	Mean	SD
Appointment Preparation	6.28	0.35
LIFE-UK	2.16	0.01
REMs	7.19	0.08
HINT	10.07	0.04
Follow-up questionnaire	1.49	0.02
Total	27.91	3.59

Note. The mean values represent whole group data. The total represents the entire time it took to complete the session. SD = standard deviation.

Output Verification Measurements

Real ear verification measurements were conducted and used to confirm the performance and settings for the personal ear level devices for each participant. The real ear saturation frequency response of the FM system was measured for each participant. Because the real ear saturation frequency response curve for each participant was always below the predicted uncomfortable loudness levels, no adjustments to maximum output gains were needed. In order to best match the DSL v.5.0 prescription formula targets across the 1000-4000 Hz range, the FM system for all participants had to be set to volume 4.

Behavioral Validation Measurements

The HINT test was performed in quiet and in noise both with and without the FM system. Table 2 reveals the means and standard deviations of the RTS scores and SNRs across all listening conditions. Overall, the participants received the best (i.e., lowest) mean RTS scores and SNRs in the quiet conditions, regardless of FM usage. It is important to note that participants received the same mean HINT results (i.e., RTS scores and SNRs) in the quiet condition with and without the FM system. When under the influence of competing noise, participants received a better (i.e., lower) mean RTS score and SNR *with* the use of the FM system than *without* use of the FM system. The overall FM benefit was calculated across both conditions as shown in Table 3.

Table 2

Mean Scores for HINT Results Across the No FM and FM Listening Conditions

	Quiet		Competing Noise	
	RTS (SD)	SNR (SD)	RTS (SD)	SNR (SD)
No FM	46 (0)	-19 (0)	54.8 (1.01)	-10.2 (1.01)
FM	46 (0)	-19 (0)	48.5 (0.60)	-16.5 (0.60)

Note. The average HINT thresholds expressed in mean RTS scores and SNRs across the noise (i.e., competing noise and quiet) and FM (i.e., no FM and FM) conditions. SD = standard deviation. RTS is measured in dB HL. SNR is measured in dB SNR.

Table 3

Mean FM Benefit in Both Test Conditions

	Quiet	Competing Noise
Benefit (No FM RTS-FM RTS)	0 dB HL	6.3 dB HL

Note. The mean benefit for each condition of the HINT testing.

A two-way repeated measures ANOVA was performed to assess whether there were differences amongst the participants' RTS scores with competing noise versus quiet and FM (i.e., no FM or FM) conditions. The dependent variable for this task was the RTS scores and the independent variables were the noise and FM conditions. The results indicated a statistically significant main effect for noise, $F(1, 16) = 1033.07$, $p < .001$ and for the FM condition, $F(1, 16) = 633.63$, $p < .001$. There was a statistically significant interaction observed between noise and FM condition, $F(1, 16) = 633.63$, $p < .001$.

A two-tailed dependent samples t-test was completed in order to determine if there were differences between the group mean RTS scores with the FM system and without the FM system. There was a statistically significant difference between RTS scores in noise with and without the FM system, $t(16) = 25.17$, $p < .001$, 95% CI [5.72, 6.77]. The Bonferroni correction factor (.05/2 = .025) was used for all significant values noted in the two series dependent samples t-test. The difference between the RTS scores in noise across both FM conditions can be seen in Figure 1. A t-score could not be calculated for the quiet condition because the difference between the standard deviations was 0. Due to these ceiling effects and potential abnormal distributions, a Wilcoxon Signed Rank Test was conducted to assess the difference between the mean RTS scores for the quiet condition with and without the FM system. Results indicated that the difference between the mean RTS score in quiet *with* the FM system ($Mdn = 0$) was not statistically significant from the mean RTS score in quiet *without* the FM system ($Mdn = 0$), $p = 1.000$.

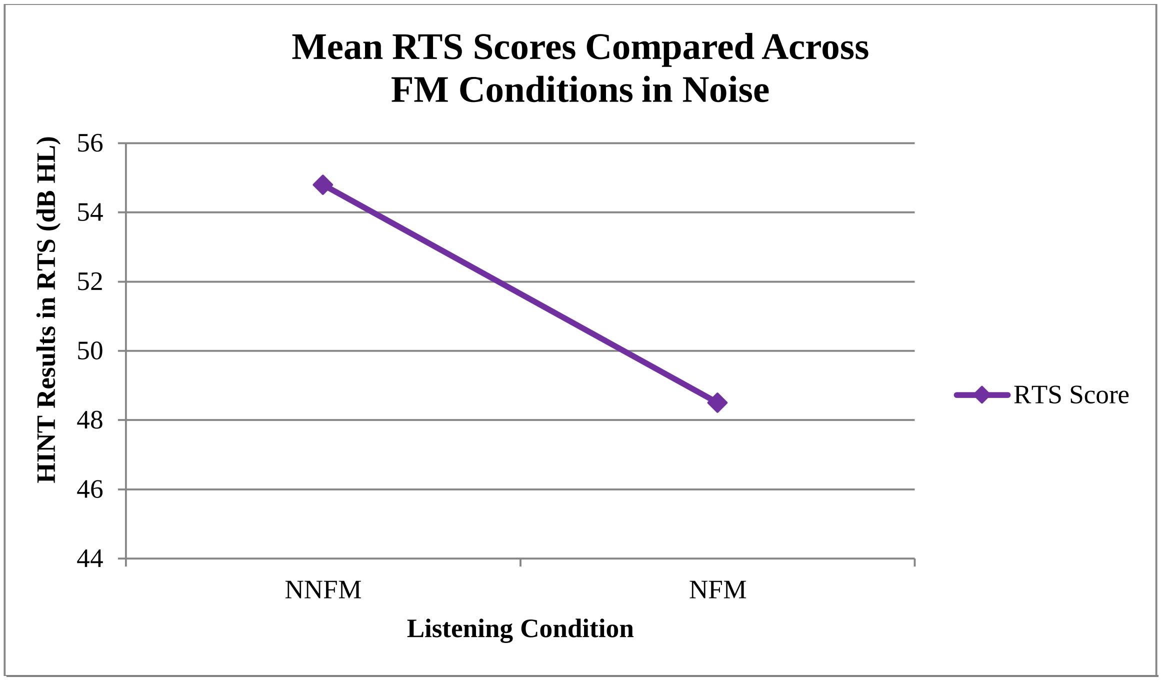


Figure 1. The average RTS scores measured across the competing noise condition without an FM system (NNFM) and competing noise with an FM system (NFM). The group mean RTS score with the FM system was better (i.e., lower) than the group mean RTS score without the FM system. The lower the RTS score, the better the performance in noise.

A two-tailed dependent samples t-test was completed in order to determine if there were differences between the group mean SNRs with the FM system and without the FM system. There was a statistically significant difference between the SNRs in noise with and without the FM system, $t(16) = 25.17$, $p < .001$, 95% CI [5.72, 6.77]. The difference between the SNRs in noise across both FM conditions can be seen in Figure 2. The Bonferroni correction factor (.05/2 = .025) was used for all significant values noted in the two series dependent samples t-test. The Wilcoxon Signed Rank Test indicated that the difference between the mean SNR in quiet *with* the FM system (*Mdn* = 0) was not statistically significant from the mean SNR in quiet *without* the FM system (*Mdn* = 0), $p = 1.000$.

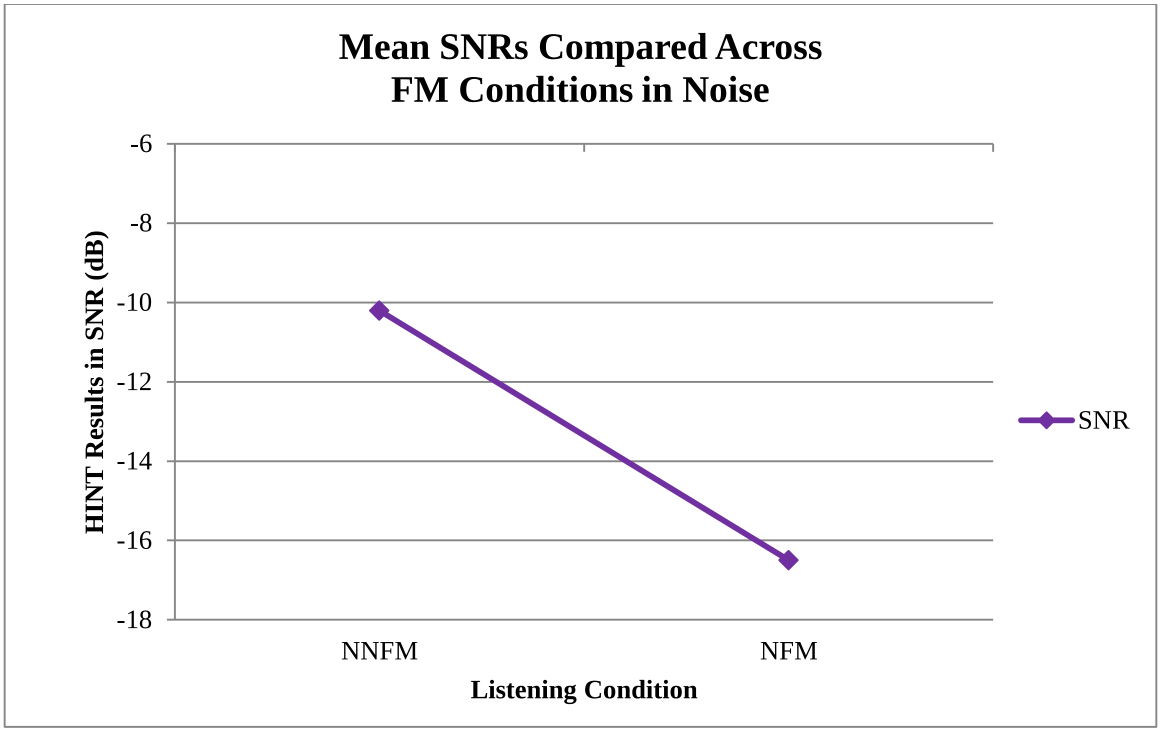


Figure 2. The average SNRs measured across the competing noise condition without an FM system (NNFM) and competing noise with an FM system (NFM). The group mean SNR with the FM system was better (i.e., lower) than the group mean SNR without the FM system. The lower (i.e., more negative) the SNR, the better the performance in noise.

Subjective Validation Measurements

LIFE-UK and LIFE-UK student version. Only four LIFE-UK questionnaires were returned; therefore, only responses from these four LIFE-UK questionnaires could be used for statistical analysis. The LIFE-UK was administered to primary teachers in order to obtain a better understanding on how the teachers perceive their students' listening abilities in school. A five-point rating scale from "very good" (1) to "very poor" (5) was provided to the teachers in order to answer the questions. Of the four teachers who responded, all four rated their students' overall listening behaviors as "very good" across the 13 different listening environments. Additionally, all four teachers rated the overall noise levels in the class while working in groups and during whole class teaching as "very good".

The LIFE-UK student version was administered to each participant in order to obtain a better understanding of how the participants perceive their hearing abilities across 13 different listening environments. A five-point rating scale from “always easy” (1) to “always difficult” (5) was provided to participants in order to answer the questions. All participants (n = 17) reported a rating of “always easy” in regards to how well they can hear the teacher’s words when in quiet (i.e., no noise from outside the classroom, the teacher is talking, and the teacher is giving a test). On average, 12 participants reported a rating of “always easy”, four participants reported a rating of “mostly easy”, and one participant reported a rating of “sometimes difficult” in regards to how well they can hear the teacher’s words when there is noise from one source inside the classroom (i.e., the overhead protector is on, the teacher is moving around the room, and someone is giving an answer). On average, seven participants reported a rating of “always easy”, eight participants reported a rating of “mostly easy”, and two participants reported a rating of “sometimes difficult” in regards to how well they can hear the teacher’s words when there is noise from multiple sources (i.e., outside traffic, children making noise outside the classroom, all children moving around the room, and all children whispering). On average, three participants reported a rating of “always easy”, seven participants reported a rating of “mostly easy”, six participants reported a rating of “sometimes difficult”, and one participant reported a rating of “mostly difficult” in regards to how well they can hear the teacher’s words when they are working in groups or in an assembly.

Spearman Correlation Coefficients were calculated in order to determine if the teachers’ responses on the LIFE-UK were associated with the participants’ responses on the LIFE-UK student version. Specifically, three separate Spearman Correlation

Coefficients were calculated in order to determine if there was a relationship between responses. Certain questions from the LIFE-UK and LIFE-UK student version that seemed to best correspond to each other were paired together for correlation analyses (Appendix K). Overall, there were no statistically significant correlations noted between the paired responses from the questionnaires, as summarized in Table 4.

Table 4

Relationship Between Responses from the LIFE-UK and LIFE-UK Student Version

	SLIFE 3		SLIFE 12		SLIFE 7	
	CC	Sig.	CC	Sig.	CC	Sig.
LIFE-UK	.94	.06	-.24	.76	.58	.43

Note. SLIFE 3 = LIFE-UK student version Question 3. SLIFE 12 = LIFE-UK student version Question 12. SLIFE 7 = LIFE-UK student version Question 7. CC = Correlation Coefficient. Sig. = two tailed significance value, $p < .05$.

Follow-up questions. The follow-up questionnaire administered after the testing required students to provide an open ended response to Question 1 (i.e., Do you like listening with the personal FM system?) and Question 2 (i.e., Do you think a device like that would help you listen in the classroom?). Ninety-four percent of the participants (n = 16) reported that they liked listening with the personal FM system. The one participant that reported he or she did not like listening with the personal FM system made comments about the physical discomfort of the device. Eighty-eighty percent of the participants (n = 15) reported that they thought a device like the FM system would help them listen in the classroom. The two participants that did not think a device like the FM system would be useful in the academic environment made comments about the device being uncomfortable.

An independent samples t-test was performed to assess whether the FM benefit of the participants who stated 'Yes' to Questions 1 and 2 of the follow-up questionnaire was different from the FM benefit of the participants who stated 'No' to Questions 1 and 2 of the follow-up questionnaire. Results indicated, on average, that those who replied 'Yes' to Question 1 on the follow-up questionnaire yielded a better (i.e., higher) FM benefit score than those that replied 'No' to Question 1 on the follow-up questionnaire, as shown in Figure 3. However, this difference was not statistically significant, $t(15) = 0.63$, $p = .55$, 95% CI [-1.61, 2.97]. Those who replied 'Yes' to Question 2 on the follow-up questionnaire yielded a better (i.e., higher) FM benefit score than those that replied 'No' to Question 2 on the follow-up questionnaire, as shown in Figure 3. However, this difference was not statistically significant, $t(15) = 1.70$, $p = .11$, 95% CI [-0.32, 2.79].

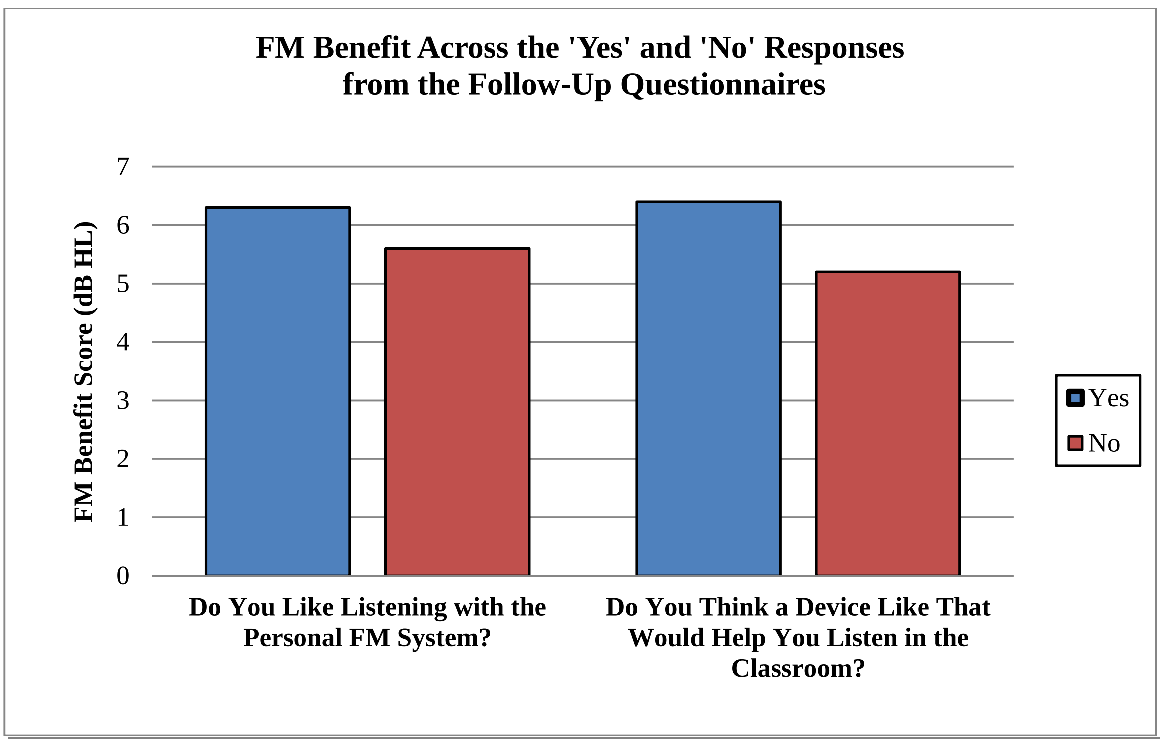


Figure 3. Participants' responses to Questions 1 and 2 of the follow-up questionnaire in relation to the group mean FM benefit.

A five-point rating scale from “always easy” (1) to “always difficult” (5) was provided to participants in order to answer Questions 3 through 6 on the follow-up questionnaire. One participant reported a rating of “always easy”, 13 participants reported a rating of “sometimes difficult”, and three participants reported a rating of “mostly difficult” in regards to how easy it was to understand the sentences *without* the FM system in noise. Five participants reported a rating of “always easy”, 10 participants reported a rating of “mostly easy”, and two participants reported a rating of “sometimes difficult” in regards to how easy it was to understand the sentences *with* the FM system in noise.

Seven participants reported a rating of “always easy”, eight participants reported a rating of “mostly easy”, and two participants reported a rating of “sometimes difficult” in regards to how easy it was to understand the sentences *without* the FM system in quiet. Fourteen participants reported a rating of “always easy” and three participants reported a rating of “mostly easy” in regards to how easy it was to understand the sentences *with* the FM system in quiet. The mean responses for Questions 3 through 6 on the follow-up questionnaire can be seen in Figure 4.

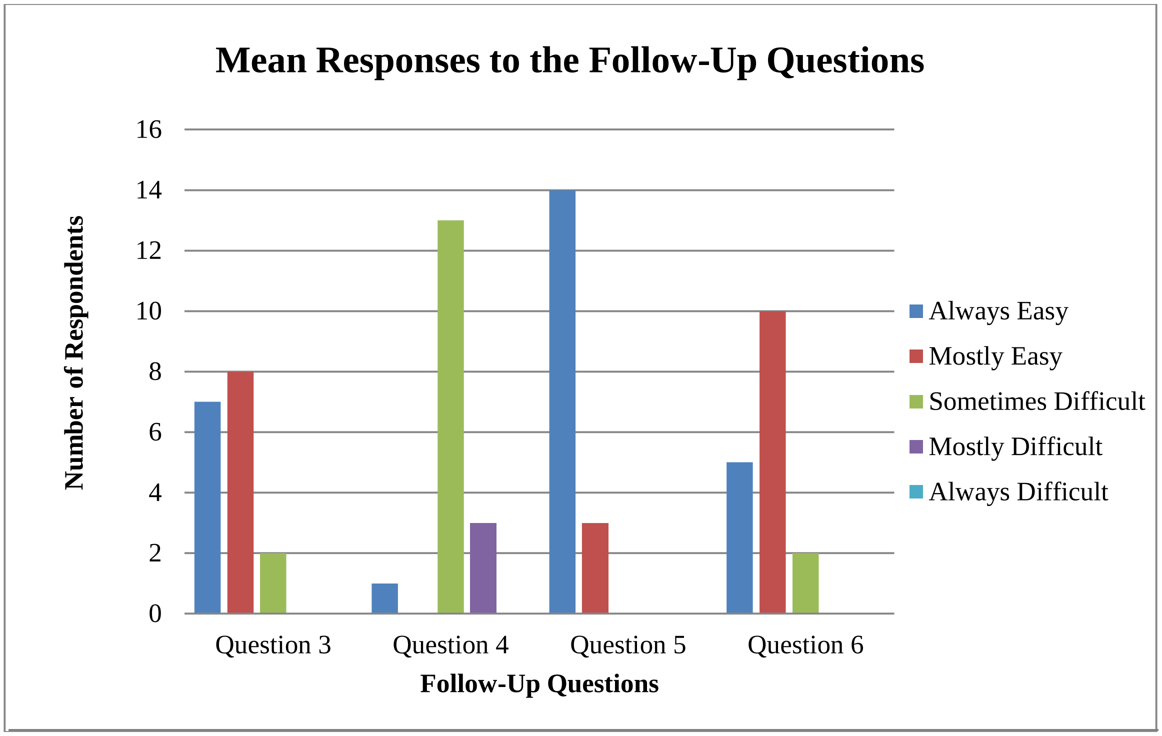


Figure 4. Participants' responses to Questions 3 through 6 of the follow-up questionnaire. Question 3: How easy was it to understand the sentences in quiet *without* the FM system?; Question 4: How easy was it to understand the sentences in noise *without* the FM system?; Question 5: How easy was it to understand the sentences in quiet *with* the FM system?; Question 6: How easy was it to understand the sentences in noise *with* the FM system?

A Spearman Correlation Coefficient was calculated to assess if there was a relationship between the mean FM benefit in noise and the responses to the follow-up questionnaire. A Bonferroni correction factor (.05/4 = .0125) was used for all significant levels. Results indicated no statistically significant correlations between the FM benefit and the perceptual responses from the children noted on follow-up questionnaire, as summarized in Table 5.

Table 5

Relationship Between FM Benefit and Responses from the Follow-Up Questionnaire

	Question 3		Question 4		Question 5		Question 6	
	CC	Sig.	CC	Sig.	CC	Sig.	CC	Sig.
Benefit in Noise	.11	.68	.17	.52	-.32	.22	.11	.68

Note. CC = Correlation Coefficient. Sig. = two-tailed significance value.

CHAPTER 5

DISCUSSION

With the development of open fit personal FM systems and the lack of standardization in measuring the benefits, there is a need to create a protocol that audiologists could realistically use to accurately verify and validate the fittings of these devices. The main purpose of this study was to create a protocol, specifically for open fit personal FM systems, that would be manageable in time and result in both an accurate fitting and an estimate of how a person may perform with an FM system in a compromised listening environment.

Time

Even though it has been suggested to consider verification and validation procedures when measuring the benefits of an open fit personal FM system, audiologists are not routinely following such proposed recommendations (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008). Therefore, one of the goals for this study was to create a protocol that could be used clinically that included output verification, behavioral validation, and subjective validation procedures and would not significantly increase a fitting appointment. Dennis and Gonzenbach (2011) explained that the total amount of time for a particular procedure consists of the time it takes to complete each service (i.e., verification and validation procedures) in conjunction with the time it takes to prepare for the appointment. When taking into consideration the amount of time it took to prepare for and complete all verification and validation procedures, the entire protocol for this study took approximately 28 minutes. Typically an audiological appointment can vary from 30 to 90 minutes depending on the complexity of the service (Dennis & Gonzenbach, 2011).

The time it took to prepare for and complete the protocol established for this study was measured below the lowest time interval as noted by Dennis and Gonzenbach (2011). Therefore, the amount of time necessary to complete this protocol should be considered feasible for clinical practice and could easily be implemented into an FM fitting appointment.

Output Verification

In order to confirm the performance and settings of the personal ear level devices for each participant, an assessment of functional gain is necessary (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Lewis, 2008; Mukari et al., 2011). In order to accurately confirm that gain settings are appropriately established for each individual patient, researchers have shown that the FM system should be set at a volume level that best matches the manufacturer’s target levels and prescription formulas (Fuglholt & Angelo, 2013; Mukari et al., 2011). Similarly to what researchers have illustrated in literature, functional gain settings in the present study were established at a volume control that best matched prescription formula target levels. In particular, the volume control of the FM receivers were set at a level that best matched the targets of the DSL v.5.0 prescription formula, the formula that is recommended for use with children (AAA, 2008). Therefore, the ear level devices were routinely set to volume 4 to match this target.

Behavioral Validation

The present study revealed that use of an open fit personal FM system significantly improved speech perception abilities in competing noise conditions as indicated by the HINT test results. Specifically, comparison of the mean RTS score and SNR *with* the FM system in noise to the RTS score and SNR *without* the FM system in noise revealed significant differences across the two HINT measurements. The improvements across speech perception abilities in noise yielded a 6.3 dB FM benefit after initial use of the open fit personal FM devices. The results noted in the present study are similar to literature, which has found significant differences across speech perception abilities with and without the use of an FM system under noisy conditions (Johnston et al., 2009; Mukari et al., 2011). Specifically, Johnston et al. (2009) measured speech perception improvements to yield an 8.24 dB FM advantage. Similarly, Mukari et al. (2011) measured speech perception improvements to yield an FM benefit of 9.1 dB. Overall, the speech perception results from the present study suggest that the open fit personal FM system is responsible for the noted improvements across speech perception abilities in noisy conditions.

As expected, the present study found no significant differences between speech perception scores in quiet when comparing HINT results across FM and no FM conditions. Overall, the speech perception results yielded a 0 dB FM benefit across the FM conditions. Because the purpose of an FM system is to create an optimal SNR in situations with competing noise, it was expected that no difference in HINT results would be measured in quiet environments for this study (Eiten & Lewis, 2010; Flexer, 1997; Johnston et al., 2009; Lewis, 1995; Lewis, 2008; Schafer & Wolfe, 2010). Similar results across quiet conditions can be found within literature (Johnston et al., 2009). Johnston et al. (2009) found that regardless of FM usage, the HINT results amongst normal hearing and typically developing children when performed in quiet are not significantly different. Specially, they only found a 0.72 dB FM benefit when measuring speech perception abilities across quiet conditions with and without an FM system (Johnston et al., 2009).

Overall, as expected, speech perception abilities did not change in quiet conditions with the use of the FM system. The differences observed between quiet and noise with and without the FM system would be an excellent counseling tool for parents and schools to discuss the subjective benefit the child is receiving in a controlled environment.

It is essential to remember that the purpose of this study was not to simulate the competing noise levels in a typical classroom but rather estimate how each participant performed in a compromised listening environment with the FM system. This study used a speaker configuration that most audiology test suites with speaker arrays have set-up. This will, hopefully, help audiologists more easily implement this type of testing into their practice.

Subjective Validation

Researchers have used follow-up questionnaires to evaluate the subjective benefits the participants receive from the FM system (AAA, 2008; ASHA, 2002; Eiten & Lewis, 2010; Schafer et al., 2013). Schafer et al. (2013) utilized open ended questions in a follow-up questionnaire for participants in order to validate the benefits of an FM system under noisy conditions. Even though improvements in speech perception abilities were not statistically significant, 90% of the participants in the study reported that it was at least “easy” to hear the teacher’s voice in noise *with* the FM system. Of the 10% of participants that did not like the FM system, comments regarding the physical discomfort of the device were noted. In comparison to the findings measured throughout literature, the current study found similar results regarding the responses to the open ended follow-up questionnaires.

Results from this study indicated that individuals who responded in a positive manner (i.e., ‘Yes’) to Questions 1 and 2 of the follow-up questionnaire yielded a better FM benefit than those participants who responded to the same questions in a negative manner (i.e., ‘No’). Even though differences between the FM benefits were not statistically significant, a vast majority of children responded “Yes” to both open ended questions. In particular, 94 % of the participants (n = 16) noted that they liked listening with the personal FM system and 88% (n = 15) of the participants noted that they thought a device like the FM system would be useful in a classroom. Those that responded ‘No’ to the open ended questions found the FM system to be uncomfortable. Overall, even though statistically significant values were not found, the use of open ended questions for follow-up questionnaires can be considered clinically valuable in validating an FM fitting for school-aged participants.

In order to indicate if participants in the current study benefited from use of the FM system in noisy conditions, participants were asked to rate their experiences along a five-point rating scale modified from the LIFE-UK student version. Overall when participants were asked how easy it was to understand sentences in noise with and without the FM system, the number of participants that stated it was “sometimes difficult” (n = 13) and “mostly difficult” (n = 3) decreased *with* use of the FM system. Specifically, two participants reported a rating of “sometimes difficult” and none of the participants reported a rating of “mostly difficult” when the FM system was used in noise. Additionally, the number of participants that stated it was “always easy” (n = 0) and “mostly easy” (n = 1) to understand the sentences increased *with* use of the FM system. Specifically, five participants reported a rating of “always easy” and 10 participants reported a rating of “mostly easy” when the FM system was used in noise. Overall, even though there were no statistically significant correlations between the measured speech perception abilities and the responses from the questionnaires, the use of rating scale questionnaires across the noisy conditions can be considered clinically valuable in validating an FM fitting for school-aged participants.

It is essential to note that the present study found variable and inconsistent responses on the rating scale follow-up questions across the quiet condition. Statistical analysis of the behavioral validation results indicated that there was no difference across the FM conditions in quiet; however, the subjective validation responses illustrated that there was a difference in responses across the quiet condition with and without the FM system.

Future Directions

Since this is a pilot study, additional testing with a larger sample size is needed to confirm these results. A larger sample size would give the data more power in order to assist in confirmation of the results. Due to the small sample size, the correlation analyses have been affected and therefore it is recommended that a larger sample is used. Due to the low return rate of the LIFE-UK questionnaires, the correlation analyses performed should be considered with caution. Therefore, for future protocol testing, a better return system of the LIFE-UK questionnaires should be implemented along with a larger sample size. The participants could receive the questionnaire prior to their test session and be required to bring it in, completed, to their session. It would be helpful to use the information from the LIFE-UK in order to see if the teachers’ and students’ responses about the students' listening abilities are associated; this information would provide more evidence that the child may benefit from a personal FM system. This is especially important for FM fittings that involve children who are not typically developing (e.g., APD or other learning disabilities). It is suggested that teachers be contacted directly by the researchers, with parental consent, in order to ensure completion of each participant's LIFE-UK teacher questionnaire.

Conclusion

Based on the results from this study, the established protocol consisting of REMs, HINT measurements, and all questionnaires should be considered for fitting an open fit personal FM system. The time management demands of the clinical setting were taken into consideration and resulted in an appropriate protocol for clinical practice (i.e., 30 minute appointments are considered reasonable for FM fittings). Additionally, this protocol resulted in best practice approach to FM fittings that took into account the time demands of clinical practice. Real ear verification measurements confirmed that the functional gain settings were appropriately established for each patient; therefore, it was considered that output verification measurements confirmed appropriate functionality and performance of the FM system at the level of each participant's ears. The use of HINT for evaluating speech perception benefits in noise with the FM system was considered an appropriate measure to subjectively evaluate performance. The language level of the HINT sentences is approximately a first grade-reading level and results yielded significant improvements in speech perception with the FM system in noisy conditions. Therefore, this test could be used clinically to evaluate a patient's behavioral response with the FM system.

Even though the responses from the follow-up questionnaires were not statistically significant, both open ended and rating scale questions can be considered clinically useful in validating the benefits of an FM system in noisy conditions for children with the modifications previously in place. In order to confirm the results from this study, future studies should include a larger sample size and a long term FM trial following this fitting protocol for children with APD or other learning difficulties.

APPENDICES

APPENDIX A

HEARING AND MIDDLE EAR SCREENING FORM

TOWSON UNIVERSITY

Hearing Screening

Participant:________________________ Date:______________

Otoscopic Examination: Right: _____________________ Left: _________________________

Tympanometry: Right: _____________________ Left: _________________________

Pure Tone Air Conduction Screening:

Frequencies	250 Hz 500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz 8000 Hz
Right Ear						
Left Ear						

Pass Criterion: Responses at 15 dB HL (twice) across frequency ranges. A check mark indicates normal response and 'x' means no response.

Overall Results:

Pass________

Refer for Medical Evaluation:_____

*If medical contraindication is present, it is recommended to consult a primary care physician.

Refer for Complete Diagnostic Audiological Evaluation_______

*If there is a need for an audiological evaluation, it is recommended that you consult the Speech, Language, and Hearing Center at Towson University or another audiologist of your choice for a full diagnostic hearing examination. The pure tone air conduction screening is used indicate a refer/pass and does not measure the participants true thresholds. The contact information for the Speech, Language and Hearing Center at Towson University is noted below.

Towson Speech, Language and Hearing Center
One Olympic Place, Room 200
Towson, MD 21204
410-704-3095

Thank you for your participation! If there are any questions, please contact the Principal Investigator, Jennifer Smart, Ph.D. JSmart@towson.edu or co-investigator, Jackie Bewick, B.S. at JBewic1@students.towson.edu

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

APPENDIX B

COMPREHENSIVE CASE HISTORY FORM

Jennifer L. Smart, Ph.D., CCC-A, FAAA
Hearing and Listening Lab
8000 York Road
Towson, MD 21252

CHILD CASE HISTORY FORM

Child's Name:____

Date of birth:_________________________Age: _________

Home Address: ____

Home phone: ______________________Parent Work or Cell phone: ______________________

Parent/Guardian names:____

School & Teacher:_____________________________________Current Grade: ___________

Name of person filling out this form and relationship to participant:

____

I. BIRTH HISTORY

A. Pregnancy and Delivery:

1. Was pregnancy full term? Yes _____ No_____

    a. What was the birth weight? _____lbs. ____oz

    b. Were there any feeding problems? Yes _____ No _____

    c. Was the baby's activity level: Average _____Overactive _____ Underactive _____

2. Were there any complications during the pregnancy *or* delivery? *Yes _____ No _____

    *If yes, please ____

    ____

3. Please describe the neonatal period (CHECK ALL THAT APPLY)

Normal ____ Cyanotic (blue)____ Jaundiced_____ Neonatal Intensive Care Unit_____

Other complications? If yes, please describe:

II. DEVELOPMENTAL HISTORY

Development:

1. Motor Development: Normal _____ Delayed _____
2. Speech/Language Development: Normal _____ Delayed _____
   a. Child's primary (first) language? ____
   b. Is the child fluent in any other languages? If so, please specify ________________

III. MEDICAL HISTORY

A. Major Childhood Illnesses:

	Age
1. Mumps	____
2. Measles	____
3. Chicken Pox	____
4. Seizures	____
5. Other	____

*Comments:____ ________

Allergies (medications, foods, seasonal, etc.) *Yes _____ No _____

If yes, please explain:____
____

B. Otological history

1. Universal Newborn Hearing Screening Pass____ Failed_____

   If failed, please explain if audiological measures were completed and outcomes:
   ____
   ____

2.	Yes	No	How many?	Which ear(s)?	Age(s)
Ear infections:	____	____	__________	___________	___________
Ears draining:	____	____	__________	___________	___________
Chronic colds:	____	____	__________	___________	___________

Has the child had the following?

	Yes	No	Age(s)
Pressure Equalization (P.E.) Tubes?	____	____	______

If yes, which ear(s): ____________________

C. Other diagnoses:

Has your child been diagnosed with any of the following disorders or difficulties? If yes, please note specific diagnosis and date of diagnosis. Thank you.

Hearing loss: Yes____ No ____
comments:____________________________________

Dyslexia: Yes ____ No ____
comments:____________________________________

Reading disorder: Yes ____ No ____
comments:____________________________________

Learning disability: Yes ____ No ____
comments:____________________________________

ADD/ADHD: Yes ____ No ____
comments:____________________________________

Language Disorder: Yes ____ No ____
comments:____________________________________

Autism Spectrum Disorder: Yes ____ No ____
comments:_______________________________

Asperger Syndrome: Yes ____ No ____
comments:______________________________

Anxiety Disorder: Yes ____ No ____ comments:____________________________

Other:____

IV. EDUCATIONAL AND EMOTIONAL HISTORY

1. Have there been any problems in school? Yes___ No___
   If yes, please explain briefly:
   ____
   ____
   ____

2. Has the child ever received special help or been in a special class in school? Yes___ No___
   If yes, please explain briefly:
   ____
   ____

3. Has the child exhibited any social and/or emotional problems? Yes___ No___
   If yes, please explain briefly:
   ____
   ____

APPENDIX C

LIFE-UK

L.I.F.E[1]. UK
Listening Inventory for Education
Teacher Appraisal of Listening

Name________________________________ Date______________________

School ________________________________ Teacher___________________

I_____________________________________(parent/guardian) give permission to complete this survey about my child and support the study.

Instructions: Read the statement below and then circle the score that best describes the behavior of the child. You should make a judgment as to whether or not the following behaviors are a cause for concern or not.

		Rating				
		Very good ←		*Satisfactory*		*Very Poor* →
1.	Following class directions					
2.	Following individual directions					
3.	Overall attention span					
4.	On task behavior					
5.	Rate of learning (speed of following instruction)					
6.	Involvement in class discussions (volunteers more, makes appropriate contributions)					
7.	Contributes when working in a group					
8.	Paying attention to multimedia (e.g. video, OHP)					
9.	Willingness to answer questions					
10.	Answering questions in an appropriate and relevant manner					
11	Amount of repair behavior (this refers to asking questions, to teacher or peer, in order to clarify what is required					
12.*	Overall noise levels in the class while working in groups					
13.*	Noise levels in the class during whole class teaching					

Additional Comments:

[1] Based on LIFE by Karen Anderson and Joseph Smaldino 1997
* Only appropriate for classroom soundfield amplification systems

APPENDIX D

COVER LETTER FOR TEACHERS

TOWSON UNIVERSITY

Jennifer L. Smart, Ph.D., CCC-A, FAAA
Hearing and Listening Lab
8000 York Road
Towson, MD 21252

Teachers:

Your student has recently participated in a graduate thesis project for Towson University. The purpose of the study is to develop a feasible clinical protocol to fit personal FM systems (listening devices). The study is evaluating three different aspects of the personal FM system fittings: (1) objective setting of the devices, (2) questionnaires, (3) listening in noise testing. It is hoped that the results from this study will have beneficial effects in the development of an accurate protocol for fitting open fit FM systems (listening devices) that can be used in clinical practice around the country.

In order to gain a better understanding of each child's listening abilities in school, it would be beneficial if you could complete a short questionnaire (attached). The Listening Inventory for Education-United Kingdom Version (LIFE-UK) questionnaire allows you to rate the student's overall behaviors in the classroom across 13 different listening environments. This survey should take a few minutes and only requires you to place a checkmark or circle in the rating box that you feel best describes your student's listening abilities and overall behaviors in the academic setting.

Acknowledgement of parental consent and support of the study is included at the top of the questionnaire. Also, prepaid envelopes have been provided in order to return your survey. Your participation will not impact the participation of the child in this study. Participants will not be penalized if the survey is not completed. However, it would be appreciated if you could take a few minutes to help us with this thesis project. If you have any questions regarding this study please contact the Principal Investigator, Jennifer Smart, Ph.D. JSmart@towson.edu or co-investigator, Jackie Bewick, B.S. at Jbewic1@students.towson.edu.

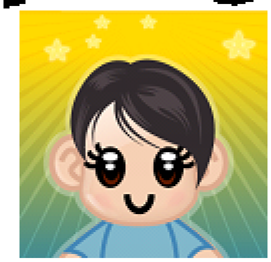
Thank you in advance for your time.

APPENDIX E

RECRUITMENT FLYER

TOWSON UNIVERSITY

LOOKING FOR



Typically Developing **CHILDREN** with normal hearing between the ages of **6 to 17** to participate in a research study about listening in noise.

Purpose of the Study:

The purpose of this study is to develop a protocol for fitting open fit FM systems (listening devices) that can be used in clinical practice.

Procedures for the Study:

Participants will receive a free hearing screening and will listen to some sentences in noise that they need to repeat back to the tester. The participants will try on listening ear pieces (custom to their ears) and repeat more sentences back to the tester. The entire study consists of one session of approximately 1.5 hours and all testing will be completed at the Institute for Wellbeing (IWB) or Dr. Smart's laboratory in Van Bokkelen Hall at Towson University.

Thank you in advance for your time!

If there are any questions, please contact the Principal Investigator, Jennifer Smart, Ph.D. JSmart@towson.edu or co-investigator, Jackie Bewick, B.S. at JBewic1@students.towson.edu

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

APPENDIX F

INFORMED CONSENT FORM

TOWSON UNIVERSITY

Informed Consent Form

Study Title: Development of a Protocol for Fitting
Open Fit Personal FM Systems

Co-investigator:
Jackie Bewick
Jbewic1@students.towson.edu

Principal Investigator:
Jennifer L. Smart, Ph.D.
Assistant Professor
Towson University
Department of Audiology, Speech-Language Pathology, and Deaf Studies
8000 York Road
Towson, MD 21252-0001
JSmart@towson.edu
(410) 704-3105

Purpose of the Study:
The purpose of this study is to develop a feasible clinical protocol to fit personal FM systems (listening devices). The study will evaluate three different aspects of the personal FM system fittings: (1) objective setting of the devices, (2) questionnaires, (3) listening in noise testing.

Procedures:
Your child will undergo a free hearing screening. Following the hearing screening your child will be fit with two ear level open fit FM systems (listening devices). Measurements will be completed to ensure that the listening devices are appropriately set to your child's ears. Your child will also be given two questionnaires at two different times throughout testing to evaluate both listening in the school environment and the listening devices. The questionnaires will be administered orally. Your child will also be required to listen to some sentences in quiet and in noise in soundfield. Your child will be required to repeat back the sentences they hear. The entire study consists of one session of approximately 1.5 hours and all testing will be completed at the Institute for Wellbeing (IWB) or Dr. Smart's laboratory in Van Bokkelen Hall at Towson University.

Risks/Discomfort:
There are no established risks for your child if you and your child choose to undergo this study. All tests utilized in this study are a part of routine clinical practice. If your child does not pass the hearing screening, they will be referred to the appropriate professional for a comprehensive evaluation. You or your child may choose to withdraw from the study at any point in time without penalty.

Benefits:
It is hoped that the results from this study will have beneficial effects in the development of an accurate protocol for fitting open fit FM systems (listening devices) that can be used in clinical practice around the country.

<u>Compensation:</u>
All participants will receive free parking.

Confidentiality
All information and data collected during the study period will be kept strictly confidential. In order to preserve confidentiality, a number will be assigned to your child prior to the beginning of the test session. This number will be used, instead of a name, to identify your child throughout the entire study including data analysis. Your child's responses to questionnaires and speech stimuli testing will be recorded on paper and transferred to electronic data files (paper and electronic files will be locked in filing cabinet when not in use) for a period of 3 years.

_____ I have read and understood the information on this form.

_____ I have had the information on this form explained to me.

______________________________ ____________
Parent/Guardian Signature Date

______________________________ ____________
Witness to Consent Procedures Date

______________________________ ____________
Principal Investigator Date

If you have any questions regarding this study please contact the Principal Investigator, Jennifer Smart, Ph.D. JSmart@towson.edu or co-investigator, Jackie Bewick, B.S. at JBewic1@students.towson.edu. You can also contact the Institutional Review Board Chairperson, Dr. Debi Gartland, Office of University Research Services, 8000 York Road, Towson University, Towson, Maryland 21252; phone (410) 704-2236.

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

APPENDIX G

INFORMED ASSENT FORM

TOWSON UNIVERSITY

INFORMED ASSENT FORM

Project title: Development of a Protocol for Fitting Open Fit Personal FM Systems

Co-investigator:
Jackie Bewick
Jbewic1@students.towson.edu

Principal Investigator:
Jennifer L. Smart, Ph.D.
Assistant Professor
Towson University
Department of Audiology, Speech-Language
Pathology, and Deaf Studies
8000 York Road
Towson, MD 21252-0001
JSmart@towson.edu
(410) 704-3105

Information Sheet for Participants

(To be read aloud to each participant)

Purpose of study

You are participating in this study in order to help us gather information about listening in noise.

What tests does the study involve?

We will play a series of listening games. First of all, you will have a short activity in which you will hear beeps through earphones. You will have to press a button or tell me when you hear the beeps. Then you will try on listening ear pieces and listen to sentences in quiet and in noise. You will tell me what words you hear. Finally you will be asked some questions out loud about listening in school and with the listening devices. These activities will help us to learn more about your ability to hear in noise with and without the listening devices.

You can ask for a break at any time you need one.

Visits

You will come to see us one time at the Institute for Wellbeing (IWB) or to Dr. Smart's laboratory at Towson University to complete the tasks I described. Your visit will last about 1.5 hours.

Child Assent Form

(To be read aloud to the child and signed by researcher if child agrees to participate)

Title of Project: Development of a Protocol for Fitting Open Fit Personal FM Systems

Principal Investigator: Jennifer Smart, Ph.D.
Co investigator: Jackie Bewick, B.S.

If you are happy to do this study, I will need you to write your name on this piece of paper.
First, I will ask you some questions, just to make sure that you are happy to do this. Say 'yes' if you agree with what I am saying. If you do not agree with the statement, tell me 'no.'

- I have had the information sheet read out loud to me.
- I understand that you want to find out about my listening and how I hear sounds.
- I understand that I can decide to stop at any time.
- I understand that some of my answers will be used in a report, but that people reading the report will not know that the answers are mine, because my name will not be written on it.
- I understand that my answers will be kept for a long time in a safe place.
- I have had a chance to ask questions.

If you would like to do this, please write your name and I will sign below.

.... Child's Name	.... Researcher's Signature
Today's date:..	

If you have any questions regarding this study please contact the Principal Investigator, Jennifer Smart, Ph.D. JSmart@towson.edu or co-investigator, Jackie Bewick, B.S. at JBewic1@students.towson.edu. You can also contact The Institutional Review Board Chairperson, Dr. Debi Gartland, Office of University Research Services, 8000 York Road, Towson University, Towson, Maryland 21252; phone (410) 704-2236.

THIS PROJECT HAS BEEN REVIEWED BY THE INSTITUTIONAL REVIEW BOARD FOR THE PROTECTION OF HUMAN PARTICIPANTS AT TOWSON UNIVERSITY.

APPENDIX H

IRB APPROVAL

TOWSON UNIVERSITY

APPROVAL NUMBER: 14-A055

To: Jennifer Smart
8000 York Road
Towson MD 21252

From: Institutional Review Board for the Proctection of Human Subjects Justin Buckingham, Member

Date: Thursday, January 09, 2014

RE: Application for Approval of Research Involving the Use of Human Participants

APPROVED
JAN 16 2014
TOWSON IRB

Office of Sponsored Programs
& Research

Towson University
8000 York Road
Towson, MD 21252-0001

t. 410 704-2236
f. 410 704-4494

Thank you for submitting an Application for Approval of Research Involving the Use of Human Participants to the Institutional Review Board for the Protection of Human Participants (IRB) at Towson University. The IRB hereby approves your proposal titled:

Development of a Protocol for Fitting Open Fit Personal FM Systems

If you should encounter any new risks, reactions, or injuries while conducting your research, please notify the IRB. Should your research extend beyond one year in duration, or should there be substantive changes in your research protocol, you will need to submit another application for approval at that time.
We wish you every success in your research project. If you have any questions, please call me at (410) 704-2236.

CC: 3 Co-PI's
File

Date: Thursday, January 09, 2014

NOTICE OF APPROVAL

TO: Jennifer Smart **DEPT:** ASLD

PROJECT TITLE: *Development of a Protocol for Fitting Open Fit Personal FM Systems*

SPONSORING AGENCY:

APPROVAL NUMBER: 14-A055

The Institutional Review Board for the Protection of Human Participants has approved the project described above. Approval was based on the descriptive material and procedures you submitted for review. Should any changes be made in your procedures, or if you should encounter any new risks, reactions, injuries, or deaths of persons as participants, you must notify the Board.

A consent form: [✓] is [ ] is not required of each participant

Assent: [✓] is [ ] is not required of each participant

This protocol was first approved on: 09-Jan-2014

This research will be reviewed every year from the date of first approval.

Amy L Taylor for

Justin Buckingham, Member

Towson University Institutional Review Board

APPENDIX I

LIFE-UK STUDENT VERSION

L.I.F.E[1]. UK Student Version
Listening Inventory for Education
Student Version

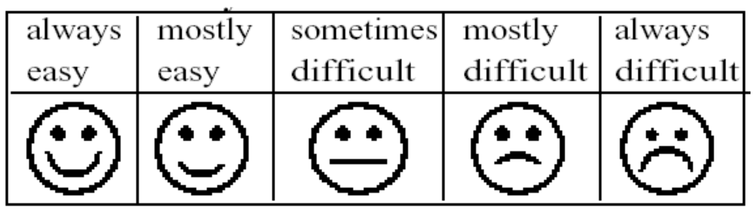
Name________________________________ Date______________________

School ______________________________ Teacher____________________

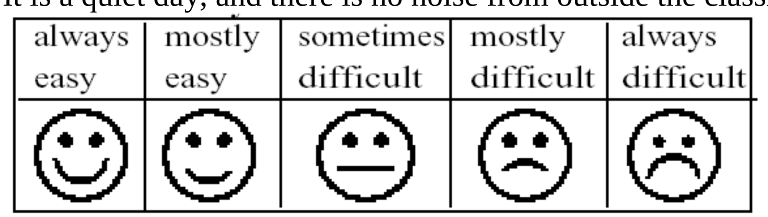
Instructions: You are going to be asked some questions about how well you can hear in school. For each of the 13 listening scenarios, you will be shown 5 choices with 5 corresponding faces. The sad face means the hearing is always difficult to hear. The happy face means that it is always easy to hear. The face in the middle means that it is sometimes difficult to hear. After listening to each question, you are going to rate how well you can hear in school for that particular scenario. Any questions?

How well can you hear the teacher's words when:

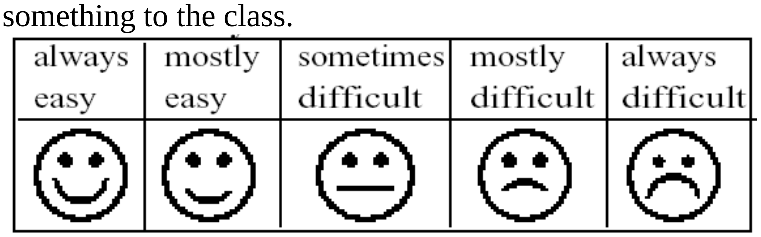
1. There is traffic outside the classroom.



2. It is a quiet day, and there is no noise from outside the classroom.



3. The class has just finished an activity and is tidying up. The teacher says something to the class.



4. The teacher is talking but you cannot see her face.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

5. The teacher is talking but there are children making a noise outside your classroom.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

6. The teacher is talking. Some other children in the class are tidying up their things, moving pencils, paper, chairs, walking around, and whispering.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

7. The teacher has asked a question to the whole class. Someone is giving an answer.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

8. The teacher is talking to the class and the overhead projector is on.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

9. The teacher is talking and moving around the room.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

10. The teacher is giving a test to the class.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

11. There are two teachers in the class. They are both talking. One of the teachers is talking to you from the front of the class. You need to listen to this teacher

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

12. You are all working in groups.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

13. You are in assembly.

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

APPENDIX J

FOLLOW-UP QUESTIONNAIRE

Post-Child Questionnaire

Name____________________________________ Date________________________

School ___________________________________ Teacher_____________________

Instructions: You are going to be asked some questions about how well you heard with the FM system and without the FM system. For some questions, you will be shown five choices with five corresponding faces. The sad face means the hearing is always difficult to hear. The happy face means that it is always easy to hear. The face in the middle means that it is sometimes difficult to hear. After listening to each question, you are going to rate how well you heard for that particular scenario. For some questions, you will be required to supply a short, well thought out answer without choices. Any questions?

1. Did you like listening with the personal FM system?

2. Do you think that a device like that would help you listen in the classroom?

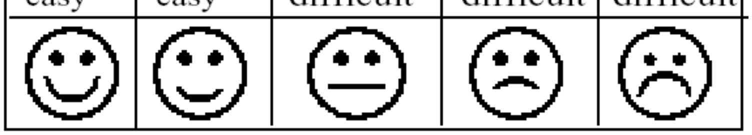
<u>Without the FM system</u>

1. How easy was it to understand the sentences when in quiet?

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

2. How easy was it to understand the sentences when in noise?

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult



<u>With the FM system</u>

3. How easy was it to understand the sentences when in quiet?

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

4. How easy was it to understand the sentences when in noise?

always easy	mostly easy	sometimes difficult	mostly difficult	always difficult

*Graphics for this questionnaire taken from LIFE-UK, student version (Canning, 1999)

APPENDIX K

QUESTIONNAIRE RESPONSES FOR CORRELATION ANALYSES

LIFE –UK
Following class directions
(Question 1)

LIFE-UK student
The class have just finished an activity and are tidying up. The teacher says something to the class **(Question 3)**

LIFE –UK
Overall noise levels in the class while working in groups **(Question 12)**

LIFE-UK student
You are all working in groups **(Question 12)**

LIFE –UK
Noise levels in the class during whole class teaching **(Question 13)**

LIFE-UK student
The teacher has asked a question to the whole class. Someone is giving an answer **(Question 7)**

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CURRICULUM VITA

Jaclyn Bewick

Education

Towson University: *Towson, MD* *August 2011 - Present*

- Doctor of Audiology Candidate *Anticipated Completion May 2015*

Bloomsburg University: *Bloomsburg, PA* *August 2007 – May 2011*

- Bachelor of Science in Audiology and Speech Pathology

Clinical Experiences

AC Tinnitus, Hyperacusis, and Balance Center**:** *York, PA*
February 2014-May 2014

Student Intern

- Performed and interpreted adult and pediatric diagnostic audiological evaluations. Conducted adult and pediatric hearing aid evaluations, fittings and troubleshooting. Assisted and interpreted comprehensive vestibular evaluations using videonystagmography and bi-thermal caloric air irrigation.

White Oak Assessment Center: *Baltimore, MD*
August 2013 – December 2013

Student Intern

- Performed and interpreted pediatric diagnostic audiological evaluations as part of the Child Find and Infants and Toddlers Program. Participated in Individualized Education Plan (IEP) meetings. Conducted hearing aid and FM troubleshooting to ensure FM systems were functioning appropriately.

ENTAA Care Audiology: *Glen Burnie, MD*
February 2013 - July 2013

Student Intern

- Performed and interpreted adult and pediatric diagnostic audiological evaluations. Performed and interpreted comprehensive vestibular evaluations using electronystagmography and bi-thermal caloric air irrigation. Conducted canalith repositioning procedures. Conducted adult hearing aid evaluations, fittings and troubleshooting. Explained and demonstrated use of assistive listening devices in conjunction with hearing aids. Performed and interpreted adult otoneurologic auditory brainstem response testing. Completed diagnostic audiological, electrophysiological, and vestibular reports

Towson University Speech, Language and Hearing Center: *Towson, MD*
February 2012 – December 2013

Audiology Student Clinician

- Performed and interpreted adult and pediatric diagnostic audiological evaluations. Administered comprehensive adult and pediatric auditory processing test batteries. Conducted adult and pediatric hearing aid evaluations, fittings and troubleshooting. Completed audiological and auditory processing reports

Professional Development / Continuing Education

Towson University Student Academy of Audiology
September 2011-Present
Student Academy of Audiology
Fall 2012-Present
Special Olympics Healthy Hearing Volunteer: *Towson, MD*
Summer 2013
Oticon Audiology Camp: *Keystone, CO*
Summer 2013
American Academy of Audiology Conference: *Boston, MA*
Spring 2012
American Academy of Audiology Conference: Orlando, FL
Spring 2014
Hear Now and Forever Conference: *Wilkes-Barre, PA*
Fall 2009