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Evaluating the efficacy of monaural vs. binaural FM fittings in children with auditory processing disorders

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EVALUATING THE EFFICACY OF MONAURAL VS. BINAURAL FM FITTINGS IN CHILDREN WITH AUDITORY PROCESSING DISORDERS

by

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Approved by:
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Abstract: The purpose of this project was to determine whether a monaural FM or binaural FM fitting strategy is more appropriate for children with Auditory Processing Disorders

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My subjects and their parents

Without your assistance, this project could not have been completed.

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ABBREVIATIONS

ALD-	Assistive Listening Device
APD -	Auditory Processing Disorder
ASHA-	American Speech-Language-Hearing Association
BASSC-	Belleville Area Special Services Cooperative
BKB-SIN -	Bamford-Kowal-Bench Speech in Noise
CAPD -	Central Auditory Processing Disorder
FLE-	Functional Listening Evaluation
MARRS-	Project Mainstream Amplification Resource Room Study
NIDCD-	National Institute on Deafness and Other Communication Disorders
SD-	Standard Deviation
SNR-	Signal-to-noise ratio
SNR-50	Signal-to-noise ratio for 50% Correct

INTRODUCTION & REVIEW OF THE LITERATURE

Auditory processing disorders (APD) have been an area of interest in the field of audiology since the 1970's when Dr. Robert Keith first tackled the subject (Wertz, Hall & Davis 2002). Controversy continues to persist over this disorder, how it should be defined, identified, and treated (ASHA, 1996 and Bellis, 1999). Some professionals question whether or not the disorder even exists (Bellis & Ferre, 1999). Over the years, this controversial topic has sparked many great debates, and a multitude of research has been conducted to further explore this intriguing area. In recent years, there has been an increased public awareness of the disorder which has resulted in an ever-increasing demand for clinical assessment and management of the disorder. Although experts disagree on the exact prevalence of the disorder, sources vary from 2-3% to 7% to 10-20%, it is undeniably a pressing problem among school aged children (Hind, 2006).

Discrepancy among experts regarding the exact prevalence of APD could result from the fact that there is no universal test battery employed when attempting to diagnose the disorder (ASHA, 2005). The tests used to confirm a diagnosis of APD seem to vary among clinicians. Some clinicians diagnose APD on the basis of self report, some use surveys from classroom teachers, some use a single test and others use an assortment of tests to make the diagnosis (Moore, 2006). This lack of consensus among professionals contributes to inadequate diagnosis of the disorder (Heine & Slone, 2008). In fact, in a 2006 survey of professionals who diagnose and treat patients with auditory processing disorders, Hind found only 1.5% of those surveyed reported being "well informed" about the subject, 20% reported being at least "quite well" informed, and 22% reported they were "adequately" informed (Hind, 2006). A large percentage

(58%) of respondents who offer to diagnose APD considered themselves to be "not well informed" (Hind, 2006). Even if there was a professional consensus on an appropriate test battery for diagnosis, it would still be difficult to pinpoint the exact prevalence of the disorder. This is because of the variability and the nature of the profiles of APD. As stated by ASHA's 2005 Working Group on Auditory Processing disorders, "Because of the variability and the nature of the profiles of (C)APD, there exists no absolute gold standard for deriving sensitivity and specificity data for tests of central auditory dysfunction" (2005). In other words, there is no way of knowing how accurate the tests are at diagnosing the disorder. Another contributing factor to the discrepancy over prevalence is the current lack of a "gold standard" for the identification of APD in children (DeBonis, 2008). Without a "gold standard" for diagnosis, it is virtually impossible to determine the exact prevalence of the disorder.

According to ASHA's Task Force on Central Auditory Processing Disorders, an appropriate assessment battery for the diagnosis of APD should include: a detailed case history, systematic observation of auditory behavior, audiology test procedures (such as pure tone thresholds, acoustic immitance measures, otoacoustic emissions and diagnostic APD tests), and speech-language pathology measures (ASHA, 1996). Diagnostic tests of APD fall into four categories. These categories include: auditory discrimination tests to assess ability to differentiate between similar sounds, auditory pattern recognition tests to asses suprasegmental speech perception, dichotic tests to assess ability to separate or integrate stimuli presented simultaneously to both ears, and monaural low-redundancy speech tests to assess ability to understand degraded speech signals (DeBonis, 2008). These tests are used to identify performance deficiencies and provide possible suggestions for remediation.

Documentation of performance deficiencies which accompany APD appear abundantly throughout the literature. However, a consensus on the exact definition of APD does not appear to exist among experts in the field (Cacace, 1998). According to ASHA's 2005 Working Group on Auditory Processing Disorders, CAPD is an "observed deficiency" in one or more of the following behaviors: sound localization and lateralization, auditory discrimination, temporal aspects of audition, auditory performance decrements with competing acoustic signals, or auditory performance decrements with degraded acoustic signals (2005). Jack Katz, a prominent researcher/clinician in the field of APD, defines auditory processing as "what we do with what we hear" (Katz, 1982). James Jerger and Frank Musiek describe APD as "a deficit in the processing of information that is specific to the auditory modality…which may be exacerbated in unfavorable environments...and may be associated with difficulty in listening, speech, understanding, language development and learning" (Santucci, 2008). Teri Bellis takes a more anatomical approach and defines APD as "a deficit in the perceptual processing of auditory information in the central nervous system" (Santucci, 2008). Perhaps Robert Keith's definition, "the inability to attend to, discriminate, recognize, or comprehend information presented auditorily even though the person has normal intelligence and hearing sensitivity" provides the best description of the disorder (Keith, 1986).

The US National Institute on Deafness and Other Communication Disorders provides a parent friendly definition of APD. According to the NIDCD "even though your child seems to "hear normally" he or she may have difficulty using those sounds for speech and language (National Institute on Deafness and Other Communication Disorders, 2004). In a 1999 JAA editorial, Teri Bellis also provided a simple definition for parents to understand. She stated that “individuals exist, who despite normal peripheral hearing sensitivity exhibit auditory difficulties, especially in challenging listening environments (Bellis, 1999).

Although experts in the field vary widely on their definition of APD, it is generally agreed upon that children with APD, despite normal hearing, typically demonstrate one or more of the following problems: poor auditory attending skills, deficits in background noise/auditory figure ground, limitations in auditory memory and retrieval, and/or delays in receptive auditory language development (Johnson, 1997). Children with APD have particular difficulty listening and maintaining attention to stimuli presented in complex listening environments (Moore, 2006 & Sloan, 1991). In addition to the tremendous difficulty understanding speech in the presence of background noise, these children also struggle understanding degraded speech signals (Chermak, 2002 & DeBonis, 2008). They seem to be easily distracted and have difficulty maintaining attention to speech stimuli (Smoski 1992). Most importantly, these deficits cannot be accounted for by hearing loss or any other factors (Beck & Bellis, 2007). In addition to these primary auditory deficits, school aged children with APD often experience difficulties in learning, speech, language, social and related functions (ASHA, 2005).

Recommendations for the management of APD typically fall into two main categories: improving the quality of the acoustic signal delivered to the listener and improving the ability of the listener to make use of the delivered signal (Katz et al, 2002 & Moore, 2006). The first category employs a “bottom-up” approach to management and the latter category utilizes a “top-down” management approach (Baran, 2002). The suggested management strategy varies depending on which area the individual experiences a functional deficit. Management programs should be specifically tailored to the unique needs of each individual. In a 2002 article, Diane

Wertz confirms that “the effectiveness and precision of treatment for APD is directly related to the specificity and accuracy of the diagnosis.” Experts recommend children with a diagnosis of APD who have a functional deficit in the category of distractibility/inattention benefit from strategies such as increasing signal-to-noise ratio (SNR) (Chermak & Musiek, 1992 and Wertz et al, 2002). Children with auditory decoding deficits perform poorer as noise increases, which is why strategies that involve increasing the SNR work well with this population (Ferre, 2002). According to Douglas Beck and Teri Bellis, “improving access to the auditory signal is a key component of (C)APD intervention for many individuals” (2007). This improved access can be accomplished through the use of an assistive listening device such as an FM system (Bellis & Ferre, 1999, and Keith, 1996). Chermak points out, “whereas FM technology may not be recommended in every case of APD, it is a cornerstone of intervention with a large percentage of this population” (2002). Children who present with poor results on monaural low redundancy speech tests and dichotic speech tests will derive the most benefit from the use of personal FM system as a management strategy (ASHA, 2005, Bamiou, Campbell, & Sirimanna, 2006 and Rosenberg, 2002).

Amplification devices such as assistive listening devices (ALDs) and FM systems have been used since the 1980’s as a form of intervention with children who have auditory processing disorders (ASHA, 1996). Over the past several years, much research has been conducted documenting the benefits of FM system use. Research has shown FM systems reduce the detrimental effect of noise and distractions while improving figure-ground listening problems, listener fatigue and teacher stress (Beck, Tomasula & Sexton, 2006). This assistive listening technology significantly improves listening conditions, and is beneficial for non-hearing impaired students as well as those with hearing impairments (Johnson, 1997, Seiben et al., 2000 and Smaldino & Crandell, 2000). FM systems can be a valuable resource for any classroom, based on the findings of previous studies which have shown all children, not just those with APD require a good signal to noise ratio in order to fully understand the message that is being presented to them (Nelson & Soli, 2000). Smaldino & Crandell have suggested that even normal-hearing children require a 10 dB better signal-to-noise-ratio than adults to perform at the same level as adults (2000).

FM systems work by effectively increasing the intensity of the teacher's voice in comparison to the rest of the noise in the classroom, and by decreasing the impact of speaker-to-listener distance (Wertz et al., 2002). The FM transmitter receives the teacher's voice via the microphone, and then transmits the sound to the child's receiver (Beck et al., 2006). By overcoming the physical distance between the child and his or her teacher, the FM device allows the student to hear his/her teacher as if she were speaking at distance of only 3-6 inches (Beck et al., 2006). Decreasing the distance between the speaker and the listener allows for improvement in the perception of speech (Wertz et al., 2002). This in turn allows the student to better understand his/her teacher which leads to improvements in academic performance.

Numerous studies have revealed the positive effects of FM systems not only in academic areas such as word and sentence recognition, spelling, and reading, but in classroom behavior and attentiveness as well (Eriks-Brophy, 2000). Project Mainstream Amplification Resource Room Study (MARRS) was the first study to examine the effects of FM systems on children with academic difficulties (American Speech-Language-Hearing Association, 1991). This study specifically targeted fourth, fifth and sixth grade students who had been suffering academic deficits for 6 months or more (ASHA 1991). All of the children in this study had no more than a minimal hearing loss and all had average intelligence (ASHA 1991). FM systems with speakers that provided approximately 10 dB gain were placed in four different schools (ASHA, 1991). Students were divided into two groups (ASHA, 1991). One group was placed in an amplified classroom, and the other was placed in a classroom without an FM system (ASHA 1991). The FM system was used for three hours per day, and the students received between one and three years of FM treatment (ASHA, 1991). Results of this study revealed that students who were placed in the amplified classroom demonstrated significant improvement in Scholastic Reading Achievement scores (ASHA, 1991). These scores were equal to or greater than the scores of the students who had been placed in the unamplified classroom (ASHA, 1991).

Since this preliminary study, many other researchers have explored FM system use in classrooms. In 1991, Blake et al investigated the effects of using FM systems with learning disabled students. Children in this study ranged in age from five to ten years (Blake et al., 1991). All had at or above borderline intelligence, normal hearing, and experienced attention problems as reported by a certified special education teacher (Blake et al., 1991). The children wore the FM devices for two hours a day. The majority of the teachers reported improved attending behavior in group activities (Blake et al., 1991). Specific areas of improvement included: motivation to participate, increased eye contact, decreased response time, more appropriate verbal responses, and improved ability to follow directions (Blake et al., 1991). Overall, results from this study indicated that children who were learning disabled experienced improved attending behavior while wearing a personal FM system.

A 3-month pilot study conducted by Eriks-Brophy in 1997 investigated the potential benefits of a classroom sound field FM system for Inuit students in Quebec. Sound field FM systems were placed in three different classrooms, and speech intelligibility among age matched peers was compared in amplified vs. unamplified conditions. Results showed significant improvements in speech intelligibility scores for both normal hearing and hearing impaired students in the amplified condition (Eriks-Brophy, 2000). Results also indicated positive changes in student attending behaviors in the amplified condition (Eriks-Brophy, 2000).

Multiple studies have demonstrated that FM systems are effective at increasing signal to noise ratio, reducing the detrimental effects of reverberation in classrooms, improving attention and minimizing distractions. Specifically, FM systems have been proven to be an appropriate remediation strategy in children with auditory figure-ground, attention and distractibility problems (Johnson, 1997). FM systems directly address the inability to hear in noise, which is a common complaint among children with auditory processing disorders (Weihing, 2005). Several case studies examining children with a diagnosis of APD who use FM systems have documented improvement in not only academics, but in behavior as well (Weihing, 2005). In 1987, Stach, Loiselle and Jerger reported on 25 children suffering from auditory processing disorders who were given a trial period with FM systems (American Speech-Language-Hearing Association, 1991). The parents and teachers of the children in the study reported a significant improvement in academic achievement and behavioral performance with FM system use (ASHA, 1991). Of the 25 children involved in the study, 11 of them found their FM system trial period so beneficial they went on to be fit with the devices (ASHA, 1991).

Another 1987 case study observed a 7 year old boy with a diagnosis of APD who was fit with an FM device (Stach et al., 1987). Both his parents and teachers reported improvements in academic achievement and behavior (Stach et al., 1987). A similar case study published in 2007 followed an 11year old child who was diagnosed with APD at age 7 years 9 months (Sharma & Purdy, 2007). She was fit with an Easy Listener personal FM system at age eight which she wore successfully for one year. She reported that the FM device helped her with classroom listening. Anecdotal testimonies such as these provide support in favor of why FM systems are an appropriate form of treatment for children with APD.

While much research exists documenting the benefits of using FM systems with children who have auditory processing disorders, little research has been done to compare the effects of monaural vs. binaural FM fittings in this population. Based on the proven benefits of binaural summation and the hearing aid fitting principal that binaural amplification provides greater benefits than monaural amplification, it is reasonable to assume the same theory may apply to FM systems. Research is needed in this area to better serve children with APD. The current study is aimed at addressing this issue.

RESEARCH OBJECTIVE

The research objective of this study is to determine whether children with a diagnosis of APD in the area of auditory figure ground, auditory attention and or/tolerance receive significantly greater benefit from a binaural FM fitting as opposed to a monaural FM fitting.

HYPOTHESIS

Children diagnosed with APD suffering deficits in the area of auditory figure ground, auditory attention and/or tolerance will receive greater benefit from a binaural FM fitting than a from a monaural FM fitting.

METHODOLOGY

The research protocol for this study was reviewed and approved by the Institutional Review Board (IRB) and the Human Studies Committee at Washington University School of Medicine in December 2008. Before enrollment, all subjects were advised regarding their participation in this study after which written and verbal informed consent was obtained.

Subjects

Subjects consisted of 9 children with a diagnosis of CAPD in the area of auditory figure ground. Subjects ranged in age from 7-13 years with a mean age of 10.5 years (SD 1.8 years). Demographic information for subjects is summarized in Appendix A. Inclusion criteria for subjects consisted of: females and males, ages 7-17 years, with a score of 7 or lower on the Auditory Figure Ground subtest of the SCAN-C. Individuals with hearing loss, autism spectrum disorders or cognitive impairments were excluded from this study. Subjects in this study were recruited from Belleville Area Special Services Cooperative (BASSC). All participants in this study had been previously diagnosed with CAPD using the SCAN-C Test for Auditory Processing Disorders in Children as part of the test battery, and all demonstrated deficits in the auditory figure ground category. The SCAN-C is a diagnostic test for APD in children ages 5-11 years which is designed to assess the perception stage of APD (Keith, 1996). It is composed of 4 subtests (Filtered Words, Auditory Figure Ground, Competing Words & Competing Sentences) which require children to listen and repeat stimulus words or sentences.

To recruit subjects, APD files were reviewed from previous years to determine which of the children diagnosed with APD met the inclusion criteria for the study. Only subjects with a score of 7 or lower in the auditory figure ground subtest of the SCAN-C were included in this study. Seven was chosen as the cut-off point, because a score of eight or higher on this subtest is considered “normal”. Scores of seven or below are indicative of some degree of auditory figure ground deficit. SCAN-C scores for subjects ranged from 2 to 7 with a mean of 5.67 (SD=1.66).

Brief letters explaining the study were sent out to the parents of children who met the inclusion criteria. Please see Appendix B for a copy of the letter that was sent to the parents of each potential subject. Nine children (5 males and 4 females) who received recruitment letters volunteered to participate in the study. Subjects who volunteered to participate were mailed a copy of the informed consent document and contacted by phone to schedule a one hour test session. At the beginning of the test session, the examiner reviewed the informed consent with the subject and his/her parents and provided an opportunity for questions.

Equipment

All speech-in-noise testing at BASSC was performed in a double walled, acoustically treated sound suite with calibrated loudspeakers mounted on the walls. A GSI-61 clinical audiometer with 2 independent channels was used in conjunction with an Awaia Sounds 2 channel CD player which was calibrated through the GSI-61 audiometer. Two Phonak EduLink FM Receivers with a Phonak Campus S FM transmitter were used to complete the aided portion of the testing. The Phonak EduLink is a small behind the ear FM receiver developed especially for use with children who have auditory processing deficits (EduLink, n.d.). EduLinks improve speech understanding in noisy classrooms by effectively increasing SNR by up to 20-30 dB (EduLink, n.d.). EduLinks were chosen for this study, because they are flexible and can be made to fit any size ear (left or right). The FM transmitter and receivers were sent to the manufacturer to ensure they were working properly prior to testing any subjects.

Functional Listening Evaluations (FLE's) were completed in unoccupied classrooms at each child's respective school. A RadioShack Digital Sound Level Meter 33-2055 was used to calibrate the output stimuli while administering the FLE's. BKB-SIN sentence lists 1-8 were presented at random using a Bose Wave portable CD player. Two Phonak EduLink FM Receivers with a Phonak Campus S FM transmitter were used to complete the aided portion of the testing.

Tests

<u>BKB-SIN</u>

The BKB-SIN speech-in-noise test was chosen for this study to help evaluate the efficacy of monaural vs. binaural FM fittings in children with APD suffering from auditory figure ground deficits. The BKB-SIN test was chosen, because it helps demonstrate the benefits of amplification and predicts performance with amplification in noisy listening environments. The BKB-SIN Test uses the Bamford-Kowal-Bench sentences (Bench and Bamford, 1979). It is comprised of 18 List Pairs equated for difficulty. Each List Pair contains two sections (section A & B) which are composed of 8-10 sentences (totaling 18-20 sentences for each List Pair). All sentences contain three to four key words. Please refer to Appendix C for a sample List Pair. Before each sentence is presented, a male speaker says "ready" to prepare the listener. The sentences are then presented at pre-recorded SNRs that decrease in 3 dB steps ("BKB-SIN Speech-in-Noise", 2005). List Pairs 1-8 have ten sentences in each section, with one sentence at each of the following SNRs: +21, +18, +15, +12, +9, +6, +3, 0, -3, and -6 dB ("BKB-SIN Speech-in-Noise", 2005). List Pairs 1-8 can be used for all listeners, normal hearing or hearing impaired. List Pairs 9-18 are not recommended for normal hearing listeners, because they encompass a smaller range for SNRs which could result in a test floor effect ("BKB-SIN Speech-in-Noise", 2005). For the purpose of this study only List Pairs 1-8 were used.

Functional Listening Evaluation

Modified Functional Listening Evaluations (FLEs) were completed at 4 of the subjects' schools. The FLE was developed by Cheryl DeConde Johnson and P. Von Almen. The purpose of the FLE is to determine how listening abilities are affected in an individual's natural listening environment (Johnson, 2001). According to Johnson, "it is designed to simulate listening ability in situations that are more representative of actual listening conditions than can often be replicated in sound booth assessment" (Johnson, 2001). This test is often used in the field of educational audiology to help demonstrate the benefit of FM usage in the classroom (Kooper, 2007). FLE's are administered in a student's unoccupied classroom, or a classroom that most approximately matches its size, ambient noise level, and floor and wall surfaces (Johnson, 2001). Multi-talker babble noise and speech stimuli (word or sentence material) are presented at a distance of three feet away from the student (Johnson, 2001). The volume of the CD player is adjusted using a sound level meter so that the multi-talker noise averages 60-70 dB SPL at the student's ear (Johnson, 2001). Test stimuli is presented in both quiet and noise at distances varying between 3-15 feet (Johnson, 2001). Typical protocol involves presentation of 8 different sets of stimuli in both quiet and noise, using an auditory only and an auditory+visual mode at close (3 ft) and far (12-15 ft) distances (Johnson, 2001). For the purpose of this study, a modified version of the FLE omitting Auditory + Visual conditions and far distances (12-15 ft) was completed.

Procedure

The following testing was performed for each subject in either the Belleville Area Special Services Cooperative building or in an unoccupied classroom in the student's respective school.

Sound Booth Testing

Five subjects (3 males & 2 females) completed testing in the BASSC sound suite. Subjects were placed in a sound proof booth and tested in three different listening conditions: no FM system, monaural FM system and binaural FM system. Subjects were positioned in the booth between two loud speakers at 90 degrees azimuth. BKB-SIN split track stimuli was presented via loud speakers at 50 dB. One speaker delivered sentences (right speaker) while the other speaker delivered multi-talker babble (left speaker). Three BKB-SIN List Pairs consisting of twenty sentences each were administered in each listening condition. Lists 1 through 8 were presented to subjects at random. Subjects were asked to ignore the background noise and repeat each sentence. Correctly repeated key words were then recorded on the score sheet.

Three BKB-SIN sentence lists were first presented to the children in the no FM listening condition. After these lists were completed, each subject was fit with a Phonak EduLink FM receiver in their right ear. The Phonak Campus S FM transmitter was placed in front of the speaker where the sentences were being presented, and three more lists were administered. After these three lists were administered the subject was fit with a second Phonak EduLink FM receiver and the process was repeated.

Classroom Testing

A modified version of the Functional Listening Evaluation (FLE) was completed at 4 (2 males & 2 females) of the subjects' schools. The modified FLE's were completed using BKB-SIN sentences in unoccupied classrooms in each subject's school. A CD player was placed on a table 3 feet away from the student. A sound level meter was used to calibrate the output so that the multi-talker noise and sentences averaged 70 dB SPL (on an A weighted scale) at the student's ear. BKB-SIN sentences were presented via the CD player in the same three listening conditions as above. These subjects were given the same instructions as the subjects who completed testing in the BASSC sound booth. A similar testing protocol was also followed, with the exception of the number of List Pairs administered. Due to time constraints and subject fatigue, only two BKB-SIN List Pairs were presented to each subject during classroom testing.

RESULTS

The first step in determining the results of the BKB-SIN is to calculate the SNR-50 Score (signal-to-noise ratio for 50% correct). This number is calculated by adding the number of correct words for each list then subtracting the total correct from 23.5 to obtain the SNR-50. This step is repeated for both lists of a List Pair (A & B). The two scores are then averaged together to obtain the List Pair Score. The raw data for all subjects are reported in Appendix D.

BKB-SIN SNR-50 mean data for subjects tested in the BASSC sound booth is illustrated in Figure 1. A score of -7.5 dB indicates the subject repeated all key words correctly. In other words, an SNR-50 of -7.5 dB represents a perfect score on the BKB-SIN. The higher the SNR-50 Score, the more key words missed, and the more the subject struggled in background noise.

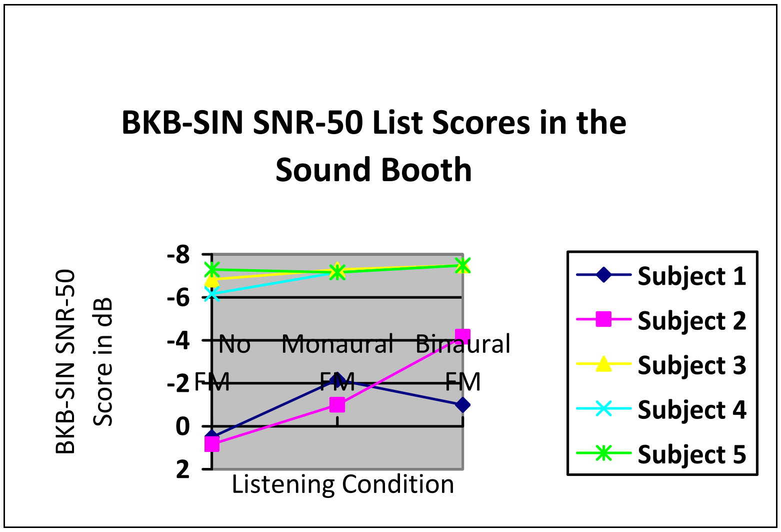

Figure 1: BKB-SIN SNR-50 Sound Booth Scores

Figure 2 illustrates group mean SNR-50 data for subjects tested in unoccupied classrooms. All subjects' performance on the BKB-SIN improved with the addition of an assistive listening device (ALD).

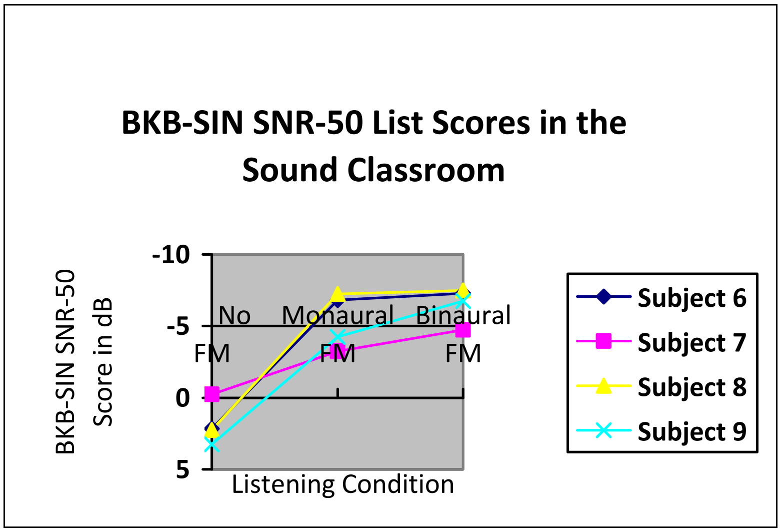

Figure 2: BKB-SIN SNR-50 Classroom Scores

Figure 3 illustrates mean SNR-50 scores of all 9 subjects combined. Pink lines represent subjects tested in the sound booth and blue lines represent subjects tested in the classroom.

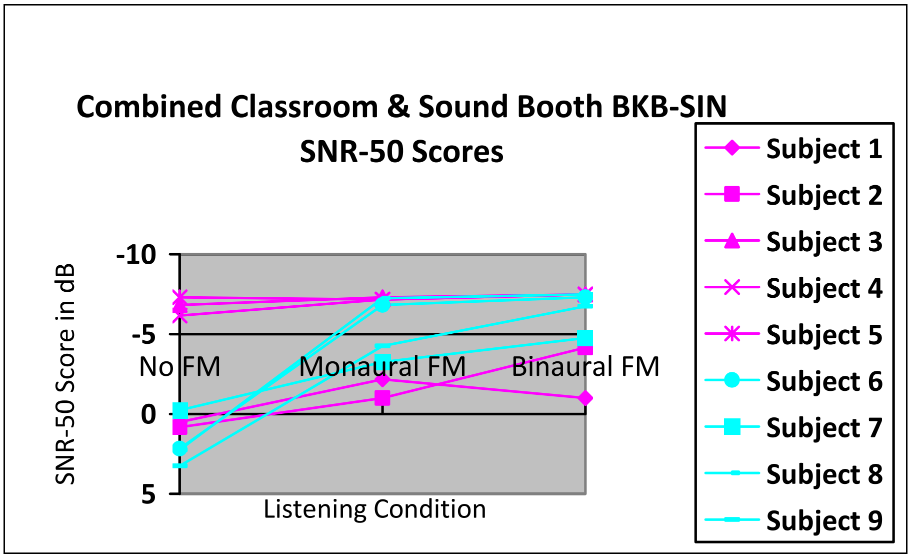

Figure 3: Combined Sound booth & Classroom BKB-SIN SNR-50 Scores

A repeated measures analysis of variance (ANOVA) using "FM Signal" and "Listening Environment" as conditions was performed to determine if BKB-SIN SNR-50 scores improved significantly from one condition to the next. ANOVA was calculated at a 95% confidence interval (alpha level=0.05). No statistically significant differences were observed between listening environments (classroom or sound booth) overall (p=0.24). Significant changes were observed in the FM signal condition overall (p=0.000046). A statistically significant difference was found between the unaided (No FM listening condition) and the aided listening conditions (monaural or binaural listening conditions) (p=0.0000126); however no significant differences were observed between the monaural and binaural listening conditions (p=0.29). Figure 4 illustrates a main effects plot for mean scores in each FM listening condition. This figure demonstrates how the mean response (test score) increases as the FM signal increases from 0 to 1 to 2.

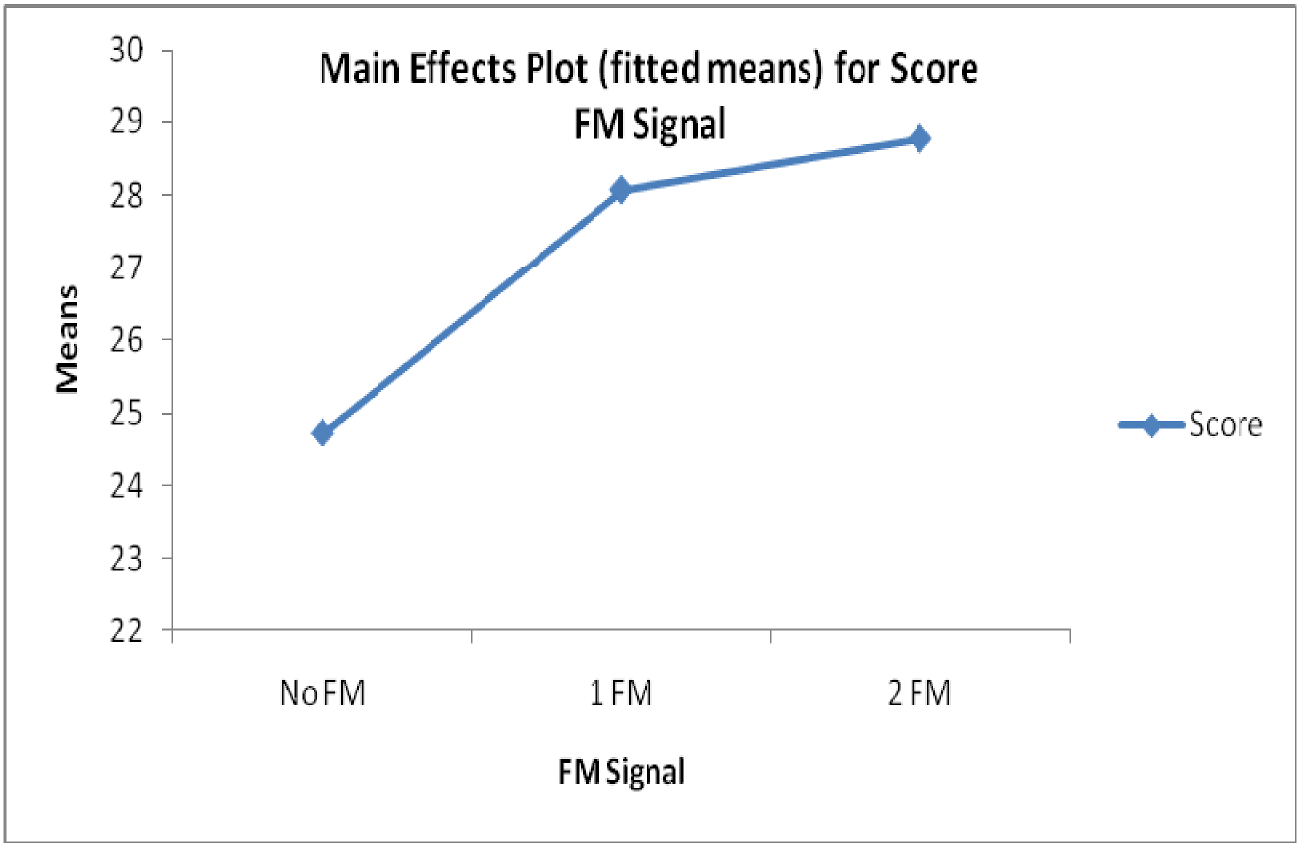

Figure 4: Main Effects Plot for subject mean scores across FM listening conditions

In addition to the statistically significant main effect found for FM system, a significant interaction effect was also detected between FM system and setting status (p=0.00039). Figure 5 illustrates an interaction plot for subject mean scores in each listening environment.

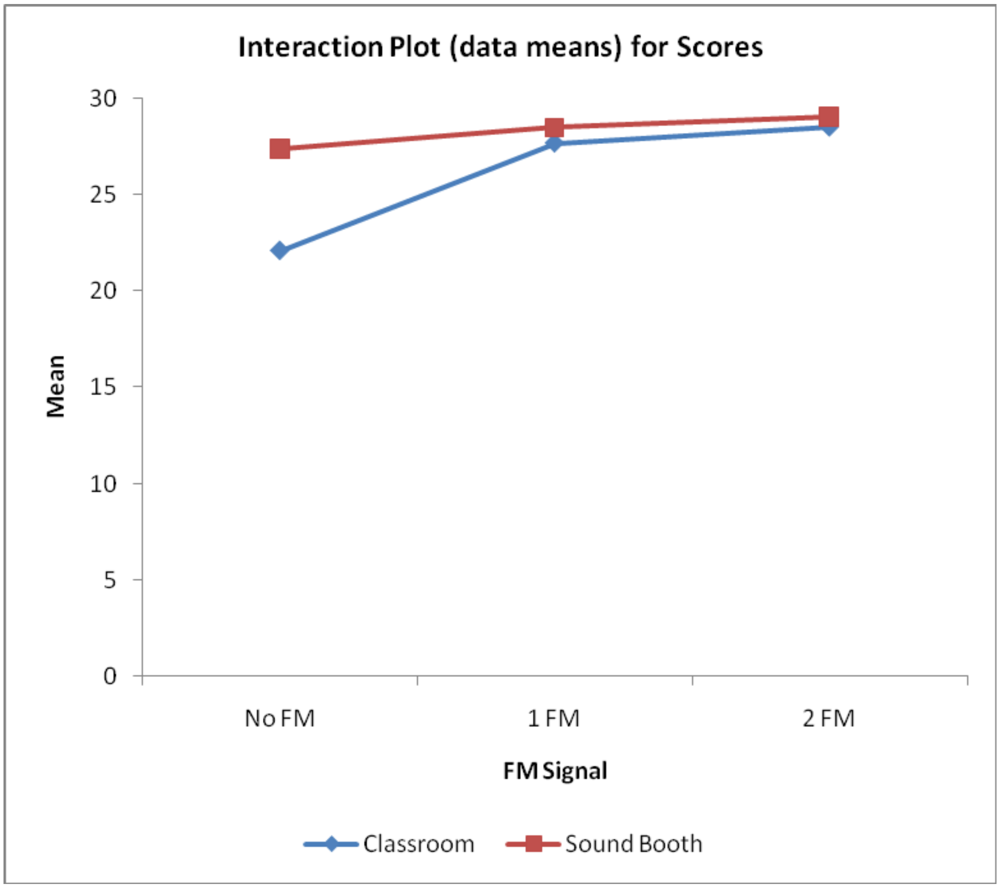

Figure 5: Interaction plot for mean scores of subjects across listening environments

Follow up tests were performed to test for significant differences in listening conditions between the classroom environment and the sound booth environment. No significant differences were revealed between the 1 FM sound booth condition and the 1 FM classroom condition (p= 0.39) or between the 2 FM sound booth condition and the 2 FM classroom condition (p= 0.57). A statistically significant difference was found between the No FM sound booth condition and the No FM classroom condition (p= 0.053).

After each testing session was completed, students were asked to subjectively report which, if any, listening condition was easiest for them. Six of the nine subjects indicated the No

FM listening condition was much more difficult than either of the aided listening conditions. The other three subjects (Subject, #3, #4, #5) reported no difference in difficulty among the three listening conditions. Subjects #2, #8 and #9 stated listening became much easier for them after they were fit with an FM system. They did not notice a significant difference between the monaural or binaural FM condition. Subjects #1 & #7 reported the monaural FM listening condition was easier than the binaural FM listening condition. Subject #6 reported the binaural FM listening condition was easiest. Table #1 illustrates these subjective opinions.

No difference in ease of listening condition	Either aided listening condition easiest	Monaural FM condition easiest	Binaural FM condition easiest
Subject #3, #4 & #5	Subject #2, #8, #9	Subject #1 & #7	Subject #6

Table 1: Subjective Reports on Ease of Listening Conditions

DISCUSSION

Current and previous research involving FM systems and children diagnosed with APD has focused on which population of APD children can most benefit from an FM system, and the actual benefits that FM systems can provide. To date little to no research examining appropriate FM fitting strategies for children who struggle with this disorder exists. This study was carried out to try and determine which FM fitting strategy, monaural or binaural, is most appropriate for children diagnosed with APD who suffer deficits in noisy listening environments. It was hypothesized that a binaural FM fitting strategy would provide the most benefit for this population of children. Statistical analysis did not support this hypothesis. No significant differences were observed between the monaural and binaural FM fittings in either setting ($p=0.29$); however, the presence of an FM signal overall was found to be significant (p=0.000046). Significant differences were also observed between the unaided (no FM) listening condition and the aided (monaural & binaural) listening conditions (p=0.0000126).

Testing conducted in the sound booth varied greatly among the 5 subjects assessed. Three of the 5 subjects tested performed well in all three listening conditions, one performed best in the monaural listening condition and another performed best in the binaural listening condition. It is difficult to determine why Subjects #3, #4 and #5 had such good SNR-50 scores. It is possible that if these children had been tested in an unoccupied classroom their results may have been different. Perhaps their auditory figure ground deficits are only exacerbated in noisy active classrooms, and therefore were not observable in the quiet sound booth. Another plausible explanation for such elevated performance is these children simply grew out of their APD sometime between when they were diagnosed and the time of this study. It is also unclear why subject #1 performed best in the monaural FM condition. Overall, these sound booth findings suggest that perhaps there shouldn't be a standard FM fitting recommendation for all children, but rather FM fittings should be determined on a case by case basis.

Unlike the sound booth setting, an observable trend was noted amongst subjects in the unoccupied classroom setting. In this situation, all five subjects showed improvement from the No FM listening condition to the Monaural/Binaural FM listening conditions. These results correspond with previous research on this topic, and suggest children with APD benefit from some type of assistive listening device (ALD) in the classroom.

When the repeated measures ANOVA was performed, no significant differences were found between settings (sound booth and classroom) overall (p=0.24); however, significant differences were found between the unaided (no FM) listening condition and the aided (monaural

& binaural) listening conditions. These findings support previous research which has documented the benefits of utilizing FM systems as a form of remediation for children with auditory processing disorders.

Further statistical analysis was performed to see if there was a significant difference between the sound booth and the classroom at each of the three listening conditions (i.e. No FM sound booth vs. no FM classroom, monaural sound booth vs. monaural classroom, and binaural sound booth vs. binaural classroom) This analysis revealed a statistically significant difference between the classroom and sound booth in the No FM listening condition ($p=0.053$). No significant differences were found between the sound booth and classroom in the monaural or binaural FM listening conditions (p-values were 0.39 and 0.57 for 1 FM and 2 FMs, respectively). What this result suggests is that when students do not have an FM system on, their performance in the classroom is significantly worse than their performance in the booth. However, once they are fit with an FM system (monaural or binaural) the listening environment no longer has an impact on performance. These results could explain why subjects #3, #4, & #5 performed so well without an FM system in the sound booth.

Overall results indicated that as the FM signal increases from a monaural signal to a binaural signal subjects' mean responses do not improve significantly. Results of this study imply binaural FM fittings do not provide significantly more benefit to children with auditory figure ground difficulties than monaural FM fittings. Statistical analysis refutes the previously stated hypothesis "Children diagnosed with APD suffering deficits in the area of auditory figure ground, auditory attention and/or tolerance will receive greater benefit from a binaural FM fitting than a from a monaural FM fitting."

These findings suggest the decision whether or not to fit a child with an FM system should not be made based on scores obtained in the sound booth alone.   Both performance in the sound booth *and* performance in the classroom should be analyzed before deciding whether or not a child could significantly benefit from an FM system. If sound booth scores only were used as the determining factor in this decision, it is conceivable that many children who could benefit from an FM system may be missed. Before deciding whether or not to fit a child with an FM system, an FLE should be completed in the child's classroom to measure performance ability.

Subjective Reports

Subjective reports from patients are an essential component of the fitting process, regardless of the device being fit. Without these reports, it would be very difficult for an audiologist to attain a comfortable fitting strategy for their patient. For this reason, it is important to take into consideration what information your patients have to offer. That being said, there were three subjective reports which were of particular interest in this study.

Subject #6 reported the binaural FM condition was easier for him than either of the other two conditions. His SNR-50 scores appear to validate this statement. After the No FM listening condition was administered he stated, "That was really hard. I scratched my head, because I didn't know what the man was saying." As the SNR increased he became noticeably more restless. This restlessness appeared to fade away with the addition of an ALD. In addition, his articulation skills improved dramatically with the addition of the FM system. It is also interesting to note that during the monaural FM listening condition, he plugged his non FM ear and reported it was easier for him to hear the sentences that way. Figure #6 illustrates the BKB-SIN List Pair results for Subject #6.

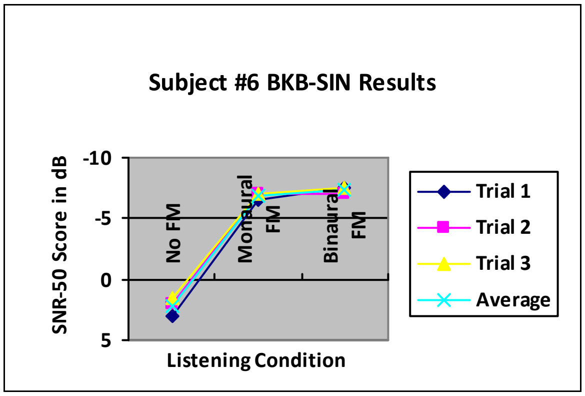

Figure 6: BKB-SIN SNR-50 List Pair Scores for Subject #6

Two of the six subjects (Subject #1 & Subject #7) who reported benefit from an FM system indicated it was easier to hear with the FM receiver in only one ear as opposed to having an FM receiver in both ears. Subject #1 reported it was much more difficult to hear in the binaural FM listening condition, and her SNR-50 scores confirmed this statement as illustrated in Figure #7.

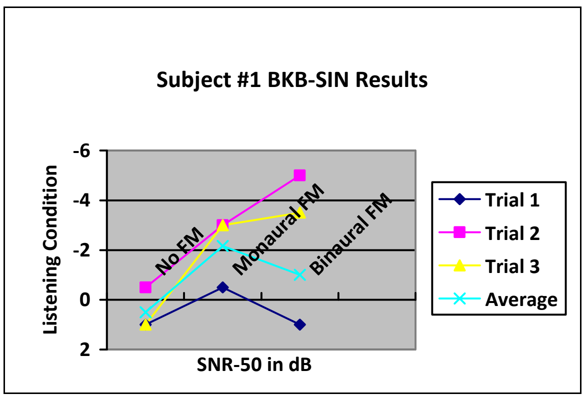

Figure 7: BKB-SIN SNR-50 List Pair Scores for Subject #1

While the vast majority of subjects interviewed demonstrated results consistent with their perceptual ease of listening, one subject's perceptions did not match up with his data results. Subject #7 reported the monaural FM condition was easier than the binaural FM condition;

however his SNR-50 score results did not appear to support this statement. As depicted in Figure #8, he performed better with two FM receivers than he did with a single FM receiver in all three trials.

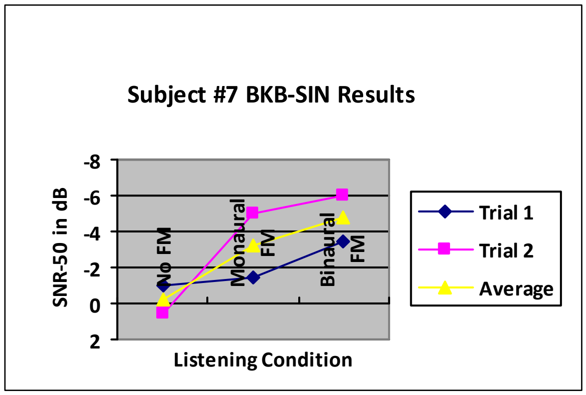

Figure 8: BKB-SIN SNR-50 list scores for Subject #7

Overall, these subjective reports suggest that conceivably FM fittings should be considered on an individual basis for each child. Children are unique; therefore it makes sense that not every child will benefit from the same FM fitting strategy. Based on these subjective reports, each child's auditory processing strengths and weaknesses should be analyzed, and their subjective opinions should be considered before deciding whether to fit the child monaurally or binaurally with an FM system.

Study Limitations

Although diligent efforts were made to control for extraneous variables which could have impacted the results of this study, there were some limitations that should be acknowledged.

Perhaps the most obvious limitation of the present study was the relatively small sample size of subjects we were able to recruit. The original aim of the study was to enlist no fewer than 20 participants to be tested across the three different listening conditions. This goal was not achieved. Although improvements were observed when comparing the binaural FM fitting with the monaural FM fitting listening conditions, the small sample size of subjects in this study made it difficult to obtain statistically significant results across settings. Future research could benefit from a larger subject pool.

Another considerable limitation of this study was due to scheduling conflicts, not all children were able to be tested in both listening environments (sound suite and classroom). The group of subjects tested in the sound suite at BASSC was different than the group of subjects who completed testing at his/her respective school. This could have affected the results of the study. It is plausible that the subjects tested in the sound booth who performed well across all three listening conditions, including the no FM condition, could have performed poorly in the no FM listening condition if tested in the classroom. Because we were unable to assess the same subjects in each listening environment, it is difficult to draw comparisons between the two. It would have been interesting to observe whether or not there was a difference in performance within individual subjects when tested in a sound booth vs. being tested in their natural listening environment (classroom).

A third limitation of this study was the variation in speaker set up between the sound booth and the classroom. In the sound booth, subjects were positioned in front of the loud speakers at 45 degrees azimuth. In the classroom, subjects were positioned in front of the speakers at 0 degrees azimuth. The speakers were set up differently in the classroom, because they were connected to a CD player and could not be detached. This speaker set up may have inadvertently caused a more challenging listening condition. This could have attributed to the differences which were observed between the sound booth and classroom in the No FM listening condition, and may have impacted the results of the study. Future research should employ the same speaker positions for both the sound booth and the classroom.

Future Research

As mentioned previously, future research exploring the topic of monaural versus binaural FM fittings in children should focus on incorporating a larger number of test subjects in the study. Small sample sizes can sometimes influence test results; therefore a larger sample size would strengthen the statistical significance of the study. In addition to recruiting a larger number of participants, another suggestion for future research would be to test every subject in both the sound booth and the classroom. Evaluating the same children in both listening environments would enable researchers to determine if children's struggles in background noise are exacerbated in their "real world" listening environment vs. in a sound treated booth. This would be especially beneficial to audiologists who are contemplating whether or not to fit a child with an FM system. It would also be a valuable tool to audiologists who need to provide the school system with justification of why an FM system/assistive listening device (ALD) is essential for a particular student.

Another area for future research brought about by this study would be to test "normal" children using the BKB-SIN in the classroom and observe whether or not they benefit from an FM fitting. If "normal" children performed well on the BKB-SIN sentences without the assistance of an FM system it could illustrate to teachers, administrators and parents just how much children with APD struggle in noisy listening conditions in comparison to “normal” kids.

CONCLUSION

Previous studies have documented the benefits of using FM systems as a remediation strategy for children with auditory processing disorders who experience difficulty listening in background noise. This study was designed to supplement past and current research, and to explore the best possible FM fitting strategy for these children. Findings indicate there is not a significant difference between monaural FM fittings and binaural FM fittings; however FM systems, regardless of fitting strategy, were found to significantly benefit subjects in a classroom setting. Future research with a larger population is needed to further investigate monaural vs. binaural FM fittings in children with APD.

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APPENDIX A

Demographic Data for 9 Subjects with Auditory Processing Disorders

Subject ID	Sex	Age	Score on Auditory Figure Ground Section of SCAN-C
Subject 1	Female	11	6
Subject 2	Female	11	6
Subject 3	Male	11	7
Subject 4	Male	12	6
Subject 5	Male	11	7
Subject 6	Male	7	4
Subject 7	Male	9	7
Subject 8	Female	9	6
Subject 9	Female	13	2

APPENDIX B

2411 Pathways Crossing

Belleville, IL 62221

Belleville Area Special Services Cooperative

Phone (618) 355-4700

Date

Dear ____________,

I am currently supervising a graduate student from Washington University who is completing her Capstone Project in the area of auditory processing disorders. Specifically, Kristen Haider is conducting a study to determine if a binaural FM fitting provides more benefit than a monaural FM fitting for students who have difficulty listening in noisy conditions. We are looking for students who would like to participate in this study. Your < son,daughter > came to mind as a possible subject.

The study would involve one testing session at the BASSC office after school hours. In addition, one testing session would be conducted at your child's school. There would be no cost to you or your family to participate in the study. All information will be kept confidential. The study involves little to no risk for your child.

If you are interested in having your child participate in this study please contact me at (618) 355-4778 or at kim.ott@bassc-sped.org as soon as possible. Thank you for your consideration.

Kimberly K. Ott, Au.D.

Educational Audiologist

Kristen Haider

Graduate Student, Washington University

APPENDIX C

Sample of BKB-SIN Sentences-List Pair 1

List 1A

1. They are looking at the clock.
2. The car engine is running.
3. Children like strawberries.
4. They are buying some bread.
5. The green tomatoes are small.
6. He played with his train.
7. The bag fell to the ground.
8. The boy did a handstand.
9. The water boiled quickly.
10. The man is painting a sign.

List 1B

1. The dog made an angry noise.
2. They followed the path.
3. Someone is crossing the road.
4. The mailman brought a letter.
5. The milk was by the front door.
6. The candy shop was empty.
7. The lady stayed for lunch.
8. The policeman knows the way.
9. The little girl was happy.
10. They are coming for Christmas.

APPENDIX D

BKB-SIN SNR-50 Results for all Nine Subjects

BKB-SIN SNR-50 Results in Sound Field

Subject	No FM	No FM List Average	Monaural FM	Monaural List Average	Binaural FM	Binaural List Average
Subject # 1	1 -.5 1	.5	-.5 -3 -3	-2.16	1 -.5 -3.5	-1
Subject # 2	3 0 -.5	.83	-1 -1.5 -.5	-1	-2 -3 -7.5	-4.16
Subject # 3	-6.5 -7.5 -7.5	-6.83	-7.5 -7 -7.5	-7.3	-7.5 -7.5 -7.5	-7.5
Subject # 4	-6 -7 -5.5	-6.16	-7.5 -7.5 -6.5	-7.16	-7.5 -7.5 -7.5	-7.5
Subject # 5	-7.5 -7.5 -7	-7.3	-7 -7.5 -7	-7.16	-7.5 -7.5 -7.5	-7.5

BKB-SIN SNR-50 Results in Classroom

Subject	No FM	No FM List Average	Monaural FM	Monaural List Average	Binaural FM	Binaural List Average
Subject # 6	3 2 1.5	2.16	-6.5 -7 -7	-6.83	-7.5 -7 -7.5	-7.3
Subject # 7	-1 .5	-.25	-1.5 -5	-3.25	-3.5 -6	-4.75
Subject # 8	1.5 3.0	2.25	-7.5 -7	-7.25	-7.5 -7.5	-7.5
Subject # 9	4.5 2.0	3.25	-4.5 -4.0	-4.25	-7.5 -6.0	-6.75