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Multiple benefits of personal FM system use by children with auditory processing disorder (APD)

Abstract
Children with auditory processing disorders (APD) were fitted with Phonak EduLink FM devices for home and classroom use. Baseline measures of the children with APD, prior to FM use, documented significantly lower speech-perception scores, evidence of decreased academic performance, and psychosocial problems in comparison to an age- and gender-matched control group. Repeated measures during the school year demonstrated speech-perception improvement in noisy classroom environments as well as significant academic and psychosocial benefits. Compared with the control group, the children with APD showed greater speech-perception advantage with FM technology. Notably, after prolonged FM use, even unaided (no FM device) speech-perception performance was improved in the children with APD, suggesting the possibility of fundamentally enhanced auditory system function.

Sumario
Se adaptaron instrumentos Phonak EduLink FM para uso en el hogar y en el aula a niños con problemas de procesamiento auditivo (APD). Las mediciones de base en niños con APD antes del uso del FM, documentaron puntuaciones significativamente más bajas en la percepcíœn del habla, evidencias de rendimiento académico disminuido y problemas psico-sociales, en comparación con un grupo control equiparado por edad y género. Mediciones repetidas durante el año escolar demostraron mejoría en la percepción del habla en ambientes escolares ruidosos y también beneficios académicos y psico-sociales significativos. Comparados con el grupo control, los niños con APD mostraron una mayor ventaja para la percepción del habla con la tecnología FM. De manera notable, después del uso prolongado del FM, incluso en niños con APD sin auxiliar (es decir, sin FM), mejoró el rendimiento en la percepción del habla, lo que sugiere la posibilidad de una función del sistema auditivo fundamentalmente incrementada.

Key Words
Psycho-social/emotional
Pediatric
Assistive technology
Behavioral measures
Speech perception

Abbreviations
APD: Auditory processing disorder
BASC-2: Behavior assessment system for children: 2nd edition
HINT: Hearing in noise test
LIFE: Listening inventory for education
RTS: Reception threshold for sentences
SIFTER: Screening instrument for targeting educational risk

Investigations have repeatedly confirmed the significant detrimental effects of noise and reverberation on speech-perception for children listening in classroom environments (Crandell, 1991, 1992; Crandell & Smaldino, 1992; Davis et al, 1986; Finitzo-Hieber & Tillman, 1978; Kreisman et al, 2004; Olsen, 1981). In one of the most often cited of these studies, Finitzo-Hieber and Tillman (1978) noted significant negative effects of increased background noise, reverberation time, and speaker-listener distance on speech-perception both in children with hearing loss and children with normal hearing.

In 2002, the American National Standards Institute approved a standard document, ANSI S12-60–2002, specifying minimum guidelines for classroom acoustics to facilitate learning. This standard recommended maximum levels of reverberation and background noise for new and retrofitted classrooms to create a listening environment appropriate for students to learn. However, published reports of classroom acoustics describe poor listening and learning environments that rarely meet ANSI recommendation for noise (Bess & Tharpe, 1986; Crandell & Smaldino, 1995; Knecht et al, 2002), signal-to-noise ratio (SNR)

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(Crandell & Smaldino, 1995; Finitzo-Hieber, 1988; Markides, 1986), or reverberation time (Bradley, 1986; Crandell, 1992; Crandell & Smaldino, 2000, 2002). For example, a 1995 survey by Crandell and Smaldino found 32 typical classrooms with mean unoccupied noise levels of 51 dBA, well above the recommended maximum of 35 dBA in unoccupied classrooms.

In addition to the many studies documenting the impact of acoustical factors on listening by children with hearing loss, recent investigations have focused also on the difficulties experienced by children with auditory processing disorder (APD). Because the exact nature of APD differs from individual to individual, the precise role of acoustical factors in speech-perception for this population can be difficult to determine (Chermak & Musiek, 1997). However, evidence suggests that speech-perception in noise and reverberation coincides with several types of disordered auditory processing, including declines in temporal processing (Glasberg & Moore, 1989; Glasberg et al, 1987; Irwin & McAuley, 1987; Snell et al, 2002; Tyler et al, 1982), difficulty with dichotic listening (Gatehouse, 1991), difficulty with rapid speech (Konkle et al, 1977; Marston & Goetzinger, 1972; Orchik & Burgess, 1977), and diminished ability to integrate and separate binaural input (Neuman & Hochberg, 1983).

In addition to potential speech-perception difficulties, children with APD may experience diminished academic performance, particularly reading and spelling ability, and psychosocial function, including aspects of behavior, attention, and concentration (see Crandell & Smaldino, 1994, 2000; Crandell et al, 2005; for a review). Untreated APD can lead to reduced communication function in social situations resulting in negative psychosocial effects such as anxiety, loss of self esteem, and depression (Kreisman, 2007; Smaldino & Crandell, 2004).

There are few published reports of empirical data supporting the efficacy of specific classroom treatment strategies for children with APD. Recently, however, personal frequency-modulation (FM) listening technology has been proposed as an appropriate solution for the listening challenges encountered by children with APD in the classroom (ASHA, 2005). Personal FM systems use a wireless microphone to pick up a speaker's voice located near his or her mouth. The FM transmitter then converts the voice signal to an electrical waveform and transmits it using FM radio waves to a receiver worn by the listener. The receiver converts the waveform back into acoustic energy, amplifies it to an audible but safe intensity, and delivers it directly to the listener's ears via headphones, direct input to hearing aids, or other signal-delivery technology. The close proximity of the microphone to the speaker's mouth, and the direct delivery of the signal to the ears of the listener, both function to minimize the effects of noise, reverberation, and distance on the signal (Crandell et al, 2005).

Studies examining personal FM systems in the classroom confirm that this technology can significantly reduce the effects of classroom noise and reverberation and can improve the effective classroom SNR by 20 to 30 dB over unaided listening conditions (Fabry, 1994; Crandell & Smaldino, 2000, 2002), and 12 to 18 dB over listening with hearing aids (Hawkins, 1984). Recent investigations documented improvement in speech-perception performance for children utilizing personal FM systems linked with hearing aids (Anderson & Goldstein, 2004) and linked with cochlear implants (Schafer & Thibodeau, 2006).

FM technology is recommended as a potential intervention strategy for the difficulties experienced in the classroom that characterize children with APD. According to the Technical Report of the 2005 ASHA Working Group on (Central) Auditory Processing Disorders, 'The benefits of personal FM and sound-field technologies for the general population and individuals at risk for listening and learning are well documented, but little data has been published documenting the efficacy of personal FM as a management strategy for students with (C)APD (Rosenberg et al, 1999; Stach et al, 1987). For individuals with greater perceptual difficulties, such as auditory processing disorder, a body-worn or ear-level FM system should be considered initially as the accommodation strategy due to the proven signal-to-noise (S/N) enhancement capabilities of FM technology (Crandell et al, 2001).'

Miniaturized personal FM devices are now commercially available for classroom use. One of these, the Phonak EduLink system, consists of a compact and lightweight behind-the-ear FM device measuring 3.5 inches in length. A flexible receiver tube allows the device to be bent and hung over the ear with the end of the receiver tube in the concha and the battery door behind the pinna. In this configuration, the EduLink earpiece is minimally visible, does not occlude the ear, allows the wearer access to environmental sound in addition to the FM signal, and permits students to converse with classmates without removing the device. The EduLink system was developed as a complement to auditory rehabilitation training particularly for student populations, such as children with APD, attention deficit hyperactivity disorder (ADHD), and learning disabilities. These student populations generally have normal hearing sensitivity yet problems listening in the classroom. The EduLink system is also designed to be easy to use and acceptable for classroom use by older, more image-conscious students who are less accepting of bulkier personal or desktop soundfield FM configurations.

Despite the anticipated benefits of FM systems for children with APD, there no formal investigations of the potential value of this technology as a treatment strategy. The present study evaluates the potential benefits in speech-perception and psychosocial function of a new personal FM system, the Phonak EduLink, when used in mainstream classroom environments by children with auditory processing disorder.

Methods

Subjects

Subjects were recruited on a volunteer basis in response to community advertisement through fliers and word-of-mouth. Potential subjects were screened using the criteria mentioned below and placed in the appropriate group for participation in the study. All subjects were reported to be on grade level by the parent. The Institutional Review Board of the Health Science Center for the University of Florida approved this investigation.

Ten children (eight male, two female) with a positive diagnosis of APD were recruited as subjects to complete a trial of FM use in the classroom. Subjects ranged in age from 8 years, 2 months to 15 years, 7 months with a mean age of 11 years, 8 months. All subjects, evaluated at the University of Florida Speech and Hearing Center, were screened and met the following selection criteria: normal hearing sensitivity, normal middle-ear function (type A tympanograms), and evidence of APD as defined by performance more than two standard deviations below the mean for at least one ear on two different measures of auditory processing (ASHA, 2005). A clinical test battery was used for the diagnosis of APD which included, but was not limited to, the following measures: auditory figure ground performance (e.g. Goldman-Fristoe-Woodcock test of auditory discrimination and synthetic sentence identification), dichotic listening (e.g. staggered spondaic words and dichotic digits double pairs), screening for phonemic awareness deficits (e.g. test of auditory analysis skills and phonemic synthesis test), and auditory sequencing performance (e.g. duration pattern sequence and pitch pattern sequence). See Table 1 for a summary of the deficit areas for the group. Ideally, an additional group of children with APD would have been included in the study to explore maturational effects without the use of the FM system; however, no interested participants were located for inclusion in this group.

Thirteen children (nine male and four female) were recruited as a control group. Children in this group ranged in age from 8 years, 2 months to 13 years, 2 months with a mean age of 10 years, 6 months. All subjects in the control group were screened and met the following criteria: normal hearing sensitivity, normal middle-ear function, and normal auditory processing function, as defined by the criteria for the APD group. Subjects for the control group were recruited from a North Florida K-12 school that included students from a geographically and socio-economically diverse population.

FM system

Following a diagnosis of APD, subjects in the experimental group were fitted binaurally with Phonak EduLink FM systems. Binaural listening is consistent with goals set forth in the Technical Report of the 2005 ASHA Working Group on (Central) Auditory Processing Disorders regarding the fitting of assistive listening devices for children with APD (ASHA, 2005). Subjects from the control group were fitted with the FM system for use in the lab setting during one visit for evaluation of speech perception only. Use of the FM system by the control group was limited to this one visit.

System specifications

The Phonak EduLink is a non-occluding, ear-level style FM receiver appropriate for use in the classroom by children with mild hearing loss, as well as children with disorders such as APD. Subjects were also provided with a Campus S FM transmitter with the Miniboom microphone (worn on the face and over the ear). When worn, the microphone was situated approximately 1 to 1.5 inches from the mouth of the speaker. The microphone has directional capabilities, but for the purpose of this study, was left in an omnidirectional mode. The initial fitting did not include real-ear measures; however, at the beginning of the study, electroacoustic evaluation of the system was conducted to verify that the output level of the FM receivers was in line with manufacturer specifications. The FM receivers have a manufacturer reported volume control range of 14 dB and are pre-set at a maximum volume consistent with safe use for normal-hearing children. Parents and subjects were instructed to keep the volume set at maximum unless the listening situation warranted an adjustment.

Wearing schedule and monitoring

Regular use was defined as use of the FM system in school for all lecture-based classroom situations on a daily basis. Home use was not required but encouraged to increase familiarity with the FM system. Home use also provided opportunities for use of the system with family members and multiple media devices such as music players, the television, and the computer. Use of the FM system was monitored via parent report on follow-up visits to the research lab.

Fitting

Subjects and parents from the APD group were instructed in the use of the FM system at the initial fitting. Prior to the beginning data collection for this study, an initial electroacoustic response of one of the FM devices was obtained. From this response, the researchers established that a safe volume setting of maximum gain (turning the volume wheel to the maximum point) would be used consistently among participants. Participants were instructed to use the devices with the volume at this setting. Listening checks were completed by the researchers prior to and during the fitting process to ensure sound quality and equipment function. Students and parents in the APD group were instructed on how to check the function of the system and ensure communication between the transmitter and receiver. The researchers taught the participants how to change the batteries and encouraged participants to change the batteries once every two weeks to ensure use of a fresh battery at all times. Batteries were provided to the participants by the researchers. The researchers sent letters to the teachers of the subjects explaining how to best use the FM system, provided some

Table 1. Patterns of auditory processing findings for children with auditory processing disorders (APD)

Subject	*Age (year; month)*	*Gender*	*Auditory figure ground*	*Dichotic listening*	*Phonemic awareness*	*Auditory sequencing*
1	11;8	F	+	+	*	+
2	10;0	M	–	+	–	+
3	11;7	F	+	–	–	–
4	14;10	M	–	+	+	+
5	8;2	M	+	+	+	*
6	11;5	M	+	+	*	+
7	11;11	M	+	+	+	*
8	15;7	M	+	+	+	–
9	10;4	M	+	+	+	*
10	11;0	M	+	+	+	–

Note: Interpretation of symbols: * = did not test; + = abnormal findings; – = findings within normal limits.

troubleshooting tips, and indicated the availability of an in-service education, if desired by the teachers or administration. None of the teachers took advantage of the offer for an in-service on use of the FM system.

Data collection schedule

Speech-perception and psychosocial measures were administered prior to fitting with the EduLink system and during the school year after a period of at least five months of the FM system use in the classroom. Speech-perception (HINT), and selected academic (SIFTER, LIFE) and psychosocial (BASC-2) measures were repeated at the return visit. For the APD group in which pre-fit and post-fit measures were completed, none of the initial responses were available for review by any participants when completing follow-up measures.

Academic performance

Academic performance was assessed using the screening instrument for targeting educational risk (SIFTER; Anderson, 1989) and the listening inventory for education (LIFE; Anderson & Smaldino, 1998). The SIFTER and LIFE are rating instruments commonly used to evaluate learning difficulties and success of classroom interventions for children with auditory disorders. The SIFTER provides rating scales for the teacher to assess a student's performance in five areas: academics, attention, communication, class participation, and school behavior. In the present study, the SIFTER was provided to the teachers and parents of the students in the APD and control groups. Due to the extremely low rate of return from the teachers, only the parent data for the SIFTER was available for analysis. The LIFE, which was developed as an extension of the SIFTER, provides self-report scales for children to provide direct input on the listening problems they are experiencing. Previous research has demonstrated the efficacy of the SIFTER and LIFE in pre-test/post-test designs for evaluating intervention using classroom listening devices (see Crandell et al, 2005 for a review).

Speech perception

EQUIPMENT AND SOUND BOOTH ARRANGEMENT

The HINT was administered in a double-walled sound-treated booth using a five-speaker array surrounding the seated participant. The participant was seated in the center of the sound booth. One speaker (Tannoy System 600, single coned), located at 0 degrees azimuth, 1 metre from the subject, was used to deliver the sentences. Four speakers (Definitive BP-2X bipolar, double coned) located at 45, 135, 225, and 315 degrees azimuth (in the corners of the booth), 1 metre from the participant, were used to deliver the noise competition. This speaker array simulated listening to a single talker within a diffuse noise field typically encountered in everyday listening environments.

STIMULI

Speech perception assessment was conducted using the hearing in noise test (HINT; Nilsson et al, 1994) in quiet and noise conditions. The HINT consists of 25 lists of 10 phonemically balanced sentences spoken by a male voice and recorded to CD with speech spectrum noise matched to the long-term spectrum of the sentences serving as noise competition.

For this investigation, the noise competition track provided on the HINT test disc was recorded to the right and left channel of two CDs. To control for the possible confound of co-modulation masking release (Grose & Hall, 1992), the noise tracks were uncorrelated by shifting the starting point of each noise track fractionally so that, if all four tracks were started simultaneously, the four CD channels would produce noise signals identical in spectral content but out of phase. Each CD channel was routed separately through one channel of a Crown D-75A amplifier to a Definitive BP-2X bipolar speaker. Each speaker was calibrated at the level of the amplifier to produce a noise signal at 59 dBA, measured at the head of a subject seated in the booth. Thus, when all four speakers were driven simultaneously, the noise competition at the center of the room was 65 dB SPL. Signal and noise levels were calibrated monthly using a Quest 2700 type II sound level meter with octave band filter, utilizing a frequency-modulated 1000 Hz calibration tone modified from the HINT test CD.

PROCEDURE

Reception thresholds for sentences (RTS) in noise were obtained using an adaptive procedure. The HINT measures a speech-in-noise threshold at the 50% correct performance level. The HINT competition noise was held steady at 65 dB SPL. The presentation level of the sentences was varied based upon whether the subject was able to repeat each sentence correctly and in full. Thresholds in quiet were obtained using the same procedure without noise competition.

Twenty-four HINT lists were paired (list 1 with list 2, list 3 with list 4, etc.) and randomly selected for each of the two presentation conditions, for a total of twenty HINT lists per subject. No list was repeated for any test session. Adaptive-threshold testing was conducted by varying the presentation level of sentences in 2-dB steps based upon whether the previous sentence was repeated correctly nor not. After completion, an RTS in dB SPL was calculated by averaging the presentation level of the fifth through twenty-first sentences. A signal-to-noise ratio (SNR) was calculated by subtracting the level of the noise (65 dB SPL) from the RTS. The SNR indicates the difference in intensity between a stimulus voice and a typical level of diffuse environmental noise that is required by the subject to correctly perceive speech.

The aided conditions of testing were completed with the microphone transmitter assembly placed at 0 degrees azimuth to the speaker delivering the speech material. The microphone was placed approximately 3 inches from the diaphragm of the speaker to simulate the distance from the mouth of a teacher utilizing the microphone/transmitter system. In the aided conditions, subjects wore the EduLink receivers binaurally. In the unaided conditions, all FM system equipment was powered off and subjects wore no receivers.

Psychosocial function

Psychosocial function was evaluated using the behavior assessment system for children: second edition (BASC-2; Reynolds & Kamphaus, 2004). Administration procedures, as outlined in the respective test manuals, were followed for both student and parent questionnaires. The BASC-2 uses a series of questions to create a profile of adaptive and maladaptive behaviors and emotions for children and adolescents. Each administration of the BASC-2 can include forms completed independently by the student and by a parent. The BASC-2 was standardized on a group of 3400 children and 4800 parents (Reynolds & Kamphaus, 2004). The parent rating scale (PRS) is used to measure positive and negative behaviors in home and community settings in 14 sub-categories including adaptability, anxiety, depression, functional communication, and withdrawal. The student self-report of personality (SRP) provides insight into the child's own feelings and thoughts. It includes 16 sub-categories of attitudes and emotions including attitude toward school, locus of control, interpersonal relations, and self esteem. Educational psychologists commonly use the BASC-2 to classify students as at risk for difficulties relating to psychosocial function in the categories discussed above according to the Individuals with Disabilities Education Act (IDEA). Scores obtained via the BASC-2 questionnaires can be classified as average, at-risk, or clinically significant. Scale scores in the at-risk range are between one and two standard deviations from the mean, while scores in the clinically significant range are two standard deviations or more away from the mean (Reynolds & Kamphaus, 2004). Prior investigations have demonstrated the validity of this instrument for use with children who have hearing loss or other communication disorders (Kreisman et al, 2004; Kreisman, 2007; Redmond, 2002). Most notably, Kreisman et al (2007) reported that, in comparison to an age and gender matched control group, a group of children with a diagnosis of APD experience significant emotional and social difficulties.

Results

Academic performance

Group measures

Academic performance was measured using the SIFTER and LIFE questionnaires, which indicate degree of academic risk. The SIFTER was originally intended to be completed by parents and teachers; however, only data was available from parents due to the extremely low rate of response from the students' teachers. The LIFE questionnaire was completed by the students. The above mentioned measures were completed by the students and parents in the APD group at the pre-fit and post-fit evaluations. The same measures were obtained in one visit from the students and parents of the control group. Comparisons of these findings for the APD and control groups are reported in the following section. Figure 1 and Table 2 display mean SIFTER scores for the APD group at pre-fit and post-fit evaluations as well as the mean scores for the control group. Figure 2 and Table 3 display the results of the LIFE questionnaire for the APD group at pre-fit and post-fit evaluation as well as results for the control group.

Group comparisons

Regarding academic performance, a t-test comparison of SIFTER scores revealed that, at the pre-fit evaluation, parents of students in the APD group rated their children significantly poorer ($p < .05$) in the domain of academics compared to control group peers, as illustrated in Figure 1. There was no longer a significant difference between the control group and APD group at the post-fit evaluation for the APD group in the academic domain. The SIFTER scoring system classifies responses for each domain into the following categories: pass, marginal, or fail. For the control group all responses fell within the 'pass' range. Although no statistically significant changes were noted

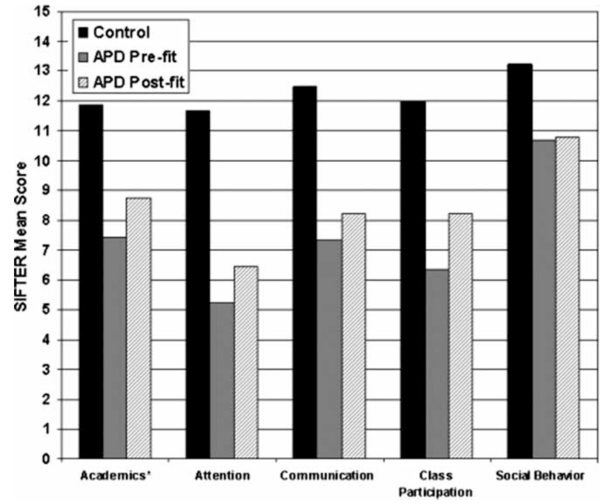

Figure 1. Comparison of APD pre-fit and post-fit to control mean scores from the screening instrument for targeting educational risk (SIFTER). Significant difference was found between the pre-fit APD evaluation and the control mean score for the academic domain (*$p < .05$). Data are summarized numerically in Table 2.

in paired t-test comparisons of pre-fit to post-fit evaluations for the APD group, mean scores for the following domains improved from the 'fail' range to the 'marginal' range: academics, communication, and class participation. In other words, a greater educational risk was seen at the APD pre-fit evaluation than at the post-fit evaluation. Results of the LIFE self-report evaluation revealed that students in the APD group initially experienced higher levels of difficulty in every situation surveyed, as summarized in Table 3. Significant differences ($p < .05$) were noted for several situations. Significant improvement was seen from the pre-fit to post-fit evaluation for the APD group for questions 1, 3, and 5, which relate to the following classroom situations: teacher talking in front of room, teacher talking with back turned, and other students making noise. In regards to the situation with other students making noise, the post-fit results for the APD group yielded significant improvement over the control group results. For question 6, results from the post-fit evaluation for the APD group showed increased risk for problems in the classroom situation with a student answering during a discussion. For question 9, although the mean result improved slightly, pre-fit and post-fit evaluations for the APD group showed greater risk than the control group for problems with word recognition during a test or directions.

Speech perception

Pre-fit measures

At pre-fit, the APD group performed with a reception threshold for sentences (RTS) of 31.57 dB SPL (SD = 4.77) when listening in quiet in the unaided (without FM system) condition. When listening in noise in the unaided condition, a signal-to-noise ratio (SNR) of 6.12 dB (SD = 2.80) was obtained. When using the FM system in the quiet condition, the APD group performed with an RTS of 27.95 dB SPL (SD = 2.24) yielding a benefit of 3.62 dB (SD = 4.63) from use of the FM system. Also, when

Table 2. Mean scores for the screening instrument for targeting educational risk (SIFTER) questionnaire

	Control group	*APD group (before FM use)*	*APD group (after FM use)*
SIFTER domain	*Mean score (SD)*	*Mean score (SD)*	*Mean score (SD)*
Academics*	11.85 (1.57)	7.44 (3.13)	8.78 (2.64)
Attention	11.69 (2.32)	5.22 (1.20)	6.44 (1.88)
Communication	12.46 (1.98)	7.33 (2.65)	8.22 (2.59)
Class participation	12.00 (2.04)	6.33 (3.04)	8.22 (2.11)
Social behavior	13.23 (2.20)	10.67 (1.66)	10.78 (2.28)

Note: Significant differences ($p < 0.05$) between groups indicated as follows: *APD post-fit. SD = standard deviation.

using the FM system in the noise condition, the APD group had a mean SNR of −4.22 dB (SD = 2.72) yielding a benefit of 10.34 dB (SD = 2.85) from using the FM system. In other words, when the FM system was used in the noise condition, the increase in desired signal over the background noise necessary for speech understanding was 10.34 dB less than what was needed when no FM system was used. This reflects improved speech understanding with use of the FM system in the presence of background noise for the APD group. Refer to Table 4 for a summary of RTS and SNR values.

Post-fit measures

At the post-fit evaluation, the APD group performed with an RTS of 27.77 dB SPL (SD = 4.40) when listening in quiet in the unaided (without FM system) condition. When listening in noise in the unaided condition, a signal-to-noise ratio (SNR) of 6.82 dB (SD = 1.16) was obtained. When using the FM system in the quiet condition, the APD group performed with an RTS of 25.75 dB SPL (SD = 2.40) yielding a benefit of 2.02 dB (SD = 3.55) from use of the FM system. Also, when using the FM system in the noise condition, the APD group had a mean SNR of −5.09 dB (SD = 2.76) yielding a benefit of 11.91 dB (SD = 2.75) from using the FM system. As was seen in the pre-fit measures, at the post-fit evaluation the increase in desired signal over background noise necessary for speech understanding was 11.91 dB less than the increase needed when no FM system was used. These results indicate that the benefit received with FM use for the APD group was maintained through the study period.

Control group

A mean RTS of 24.79 dB SPL (SD = 2.81) was obtained for the control group when listening in quiet in the unaided (without FM system) condition. When listening in noise in the unaided condition, an SNR of 7.97 dB (SD = 2.40) was obtained. When using the FM system in the quiet condition, the control group performed with an RTS of 24.07 dB SPL (SD = 2.41) yielding a benefit of 0.73 dB (SD = 3.32) from use of the FM system. Also, when using the FM system in the noise condition, the control group had a mean SNR of −0.27 dB (SD = 2.96) yielding a benefit of 8.24 dB (SD = 2.73) from using the FM system. Similar to results for the APD group at pre-fit and post-fit evaluations, the increase in desired signal over background noise necessary for speech understanding for the control group was 8.24 dB less than the increase needed when no FM system was used. These results indicate that the benefit received with FM use

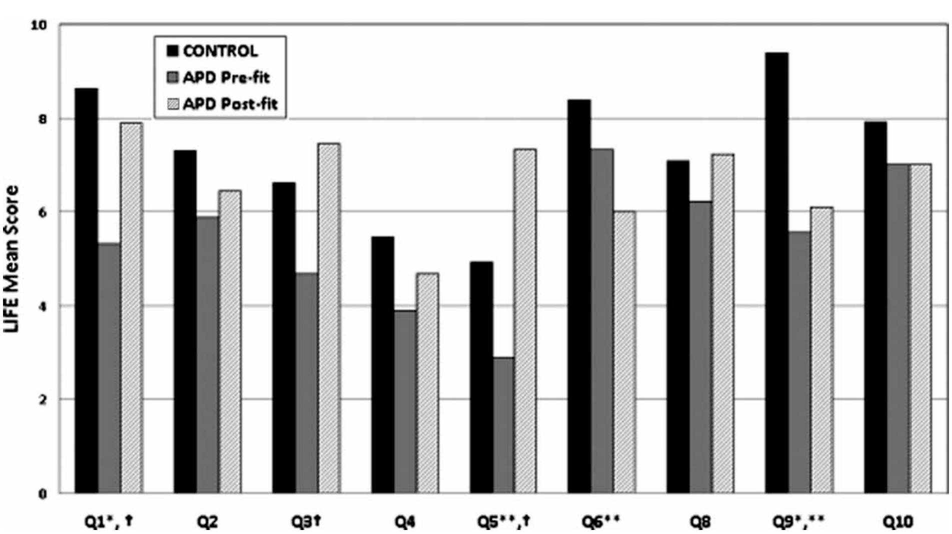

Figure 2. Comparison of APD pre-fit and post-fit to control mean scores from the listening inventory for education (LIFE) questionnaire. Significant differences denoted for the different questions as follows ($p < .05$): *APD pre-fit vs. Control, **APD post-fit vs. Control, †APD pre-fit vs. APD post-fit. Data are summarized numerically in Table 3.

Table 3. Mean scores for listening inventory for education (LIFE) questionnaire

LIFE question	Control group	APD group (before FM use)	APD group (after FM use)
	Mean score (SD)	Mean score (SD)	Mean score (SD)
Q1*	8.62 (1.98)	5.23 (2.89)	7.89 (2.14)
Q2	7.31 (2.06)	5.15 (2.94)	6.44 (2.56)
Q3†	6.62 (2.63)	4.77 (3.00)	7.44 (1.59)
Q4	5.46 (4.18)	4.00 (2.97)	4.67 (2.69)
Q5**,†	4.92 (2.78)	3.00 (2.83)	7.33 (2.18)
Q6**	8.38 (2.23)	6.77 (3.66)	6.00 (1.73)
Q8	7.08 (2.93)	6.00 (3.00)	7.22 (1.79)
Q9*,**	9.38 (1.56)	5.75 (3.11)	6.11 (2.21)
Q10	7.92 (2.14)	6.92 (2.99)	7.00 (3.16)

Note: Significant differences ($p < 0.05$) between groups indicated as follows: *APD pre-fit vs. Control, **APD post-fit vs. Control, †APD pre-fit vs. APD post-fit. SD = standard deviation.

in the noise condition was notable for participants in the APD group at pre-fit and post-fit evaluations as well as for the participants in the control group.

Group comparisons

Comparisons between the pre-fit and post-fit measures for the APD group were obtained using the Wilcoxon signed ranks test. Comparisons of the control group to the APD pre-fit and post-fit measures were obtained using a t-test for difference between means. For the unaided condition in quiet, the performance of the APD group did not change significantly from pre-fit to post-fit evaluation. Also, for the unaided condition in quiet, the performance of the APD group at pre-fit was significantly worse than the performance of the control group ($t = 4.416$, $p < .001$). Performance of the APD group improved from pre-fit (RTS of 31.57 dB SPL) to post-fit (RTS of 27.77 dB SPL) evaluations. At the post-fit evaluation, a significant difference was no longer noted between the APD group and control group performance. Refer to Figure 3 for a summary of results in the quiet condition.

For the unaided condition in noise, the performance of the APD group did not change significantly from pre-fit to post-fit evaluation. Also, for the unaided condition in noise, comparison of the performance of the APD group at pre-fit and post-fit evaluations to the control group did not yield any statistically significant differences. Refer to Figure 4 for a summary of results in the noise condition.

For the aided condition in quiet, the performance of the APD group did not change significantly from pre-fit to post-fit evaluation. At pre-fit, the APD group performed significantly worse than the control group ($t = 3.665$, $p = .001$). Although, the difference was not a significant improvement, the performance of the APD group showed improvement from pre-fit (RTS of 27.95 dB SPL) to post-fit (RTS of 25.75 dB SPL) evaluations. As was seen in the unaided condition in quiet, at the post-fit

Table 4. Mean scores for the hearing in noise test (HINT) in unaided and aided listening conditions (reported in dB SPL)

HINT condition			Control group	APD group (before FM use)	APD group (after FM use)
			HINT result (SD)	HINT result (SD)	HINT result (SD)
Unaided					
	Quiet	RTS*	24.79 (2.81)	31.57 (4.77)	27.77 (4.40)
	Noise	RTS	72.97	71.12	71.82
		SNR	7.97 (2.40)	6.12 (2.80)	6.82 (1.16)
Aided					
	Quiet	RTS*	24.07 (2.41)	27.95 (2.24)	25.75 (2.40)
	Noise	RTS	64.73	60.78	59.91
		SNR*,**,†	−0.27 (2.96)	−4.22 (2.72)	−5.09 (2.76)
Benefit (unaided RTS vs. aided RTS)					
	Quiet		0.73 (3.32)	3.62 (4.63)	2.02 (3.55)
	Noise**		8.24 (2.73)	10.34 (2.85)	11.91 (2.75)

Note: Significant differences ($p < 0.05$) between groups indicated as follows: *APD pre-fit vs. Control, **APD post-fit vs. Control. RTS = reception threshold for sentences; SNR = signal to noise ratio; SD = standard deviation.

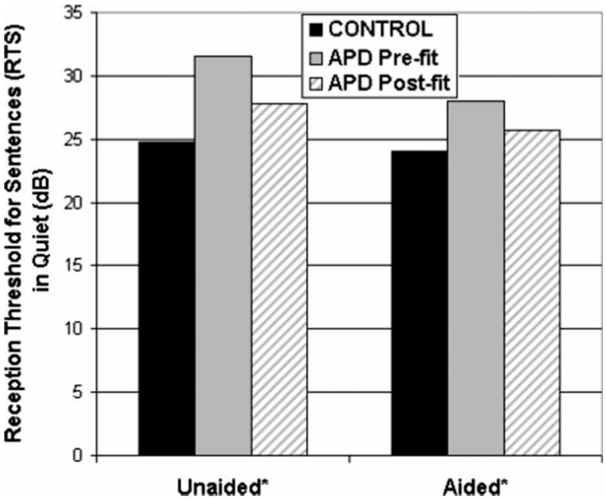

Figure 3. Scores from hearing in noise test (HINT) for the quiet condition indicate improved performance after EduLink FM device use for the APD group. Significant difference between pre-fit performance of APD group and control group is indicated by asterisk ($p < .05$). Data are summarized numerically in Table 4.

evaluation, a significant difference was no longer noted between the APD group and control group performance in the aided condition in noise.

For the aided condition in noise, superior performance was noted in both the pre-fit and post-fit evaluations of the APD group over the control group. This finding is further discussed below. Significant differences were found between performance

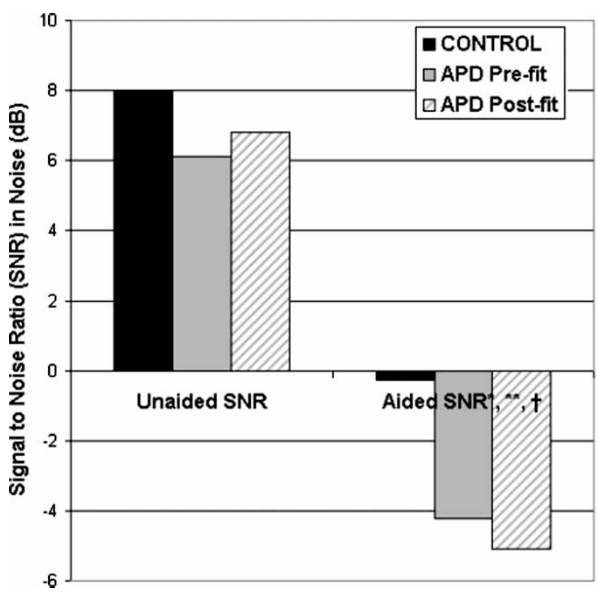

Figure 4. Scores from hearing in noise test (HINT) in the noise condition indicated significantly improved performance in the aided condition for the APD group after EduLink FM device use. Significant differences between groups indicated as follows ($p < .05$): *APD pre-fit vs. Control, **APD post-fit vs. Control, †APD pre-fit vs. APD post-fit. Data are summarized numerically in Table 4.

of the APD group at pre-fit and post-fit evaluations ($z = -2.244$, $p = .025$) indicating significant improvement in performance. At both the pre-fit and post-fit evaluations, the APD group performed significantly better than the control group in the aided condition in noise (pre-fit: $t = 3.950$, $p = .002$; post-fit: $t = 4.293$, $p < .001$). A number of factors may influence the trend seen where the APD group continuously performed better than the control group when using the FM system in the noise condition. For additional discussion of this phenomenon, refer to the discussion section below.

Psychosocial function

Group measures

Psychosocial function of all participants was evaluated using the BASC-2 student and parent forms. These measures were completed by the students and parents in the APD group at the pre-fit and post-fit evaluations. Psychosocial measures were obtained in one visit from the students and parents of the control group. The scoring of the BASC-2 results in classifications for various psychosocial domains that are either within normal limits or considered one of the following: 'at-risk' or 'clinically significant.' For the purpose of data analysis, these results were translated to be either normal or abnormal findings. Comparisons of these findings for the APD and control groups are reported in the following section. One-sided significance is reported for all psychosocial measures with $p < .05$.

Group comparisons

For the student form, McNemar comparisons were made between the pre-fit and post-fit evaluations. A significant decrease from pre-fit to post-fit was noted in the number of students rating themselves outside of the normal range on two BASC-2 scales: locus of control ($p = .0315$), and depression ($p = .0315$). A chi square test revealed that, in comparison to the control group, significantly more of the participants in the APD group at the pre-fit evaluation were found to be outside of the normal range on the following student report BASC-2 scales: locus of control ($\chi^2 = 4.887$, $p = .037$), anxiety ($\chi^2 = 4.727$, $p = .048$), depression ($\chi^2 = 7.800$, $p = .007$), attention problems ($\chi^2 = 7.800$, $p = .007$), and interpersonal relationships ($\chi^2 = 4.887$, $p = .037$). Refer to Figure 5 for a display of the student report results for the APD pre-fit evaluation and the control group. Also, for the student report form, a chi square test revealed that, in comparison to the control group, significantly more of the participants in the APD group at the post-fit evaluation were still found to be outside of the normal range on only the attention problems scale ($\chi^2 = 4.727$, $p = .048$). Refer to Figure 6 for a display of the student report results for the APD post-fit evaluation and the control group. When considered together, all of these student report comparisons reflect improvements in psychosocial function for the APD group, specifically in areas related to the following BASC-2 scales: locus of control, anxiety, depression, and interpersonal relationships.

For the parent form, McNemar comparisons were made between the pre-fit and post-fit evaluations. No statistically significant decrease from pre-fit to post-fit was noted in the number of parents rating their children outside of the normal range for the various BASC-2 scales. A chi square test revealed that, in comparison to the control group, significantly more of the participants in the APD group at the pre-fit evaluation were

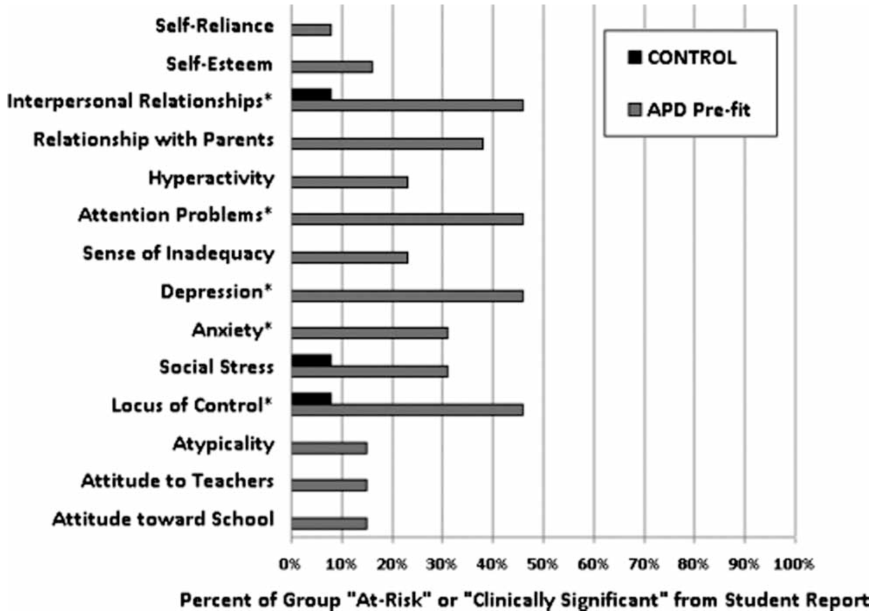

Figure 5. Comparison of percentage of students found to be either 'at risk' or 'clinically significant' (responses collapsed to indicate one abnormal score) on student reports of the BASC-2. Results displayed for control group and APD pre-fit (*$p < .05$).

rated outside of the normal range by their parents on the following parent report BASC-2 scales: attention problems ($\chi^2 = 10.400$, $p = .002$), leadership ($\chi^2 = 4.887$, $p = .037$), and functional communication ($\chi^2 = 6.500$, $p = .015$). Refer to Figure 7 for a display of the parent report results for the APD pre-fit evaluation and the control group. Also, for the parent report form, a chi square test revealed that, in comparison to the control group, significantly more of the participants in the APD group at the post-fit evaluation were still rated by their parents to be outside of the normal range on only the attention problems scale ($\chi^2 = 4.887$, $p = .037$). Refer to Figure 8 for a display of the parent report results for the APD post-fit evaluation and the control group. In summary, parents of the children with APD perceived improvements in psychosocial function following use of an FM system, in the areas related to the following BASC-2 scales: leadership and functional communication. In general, a trend was

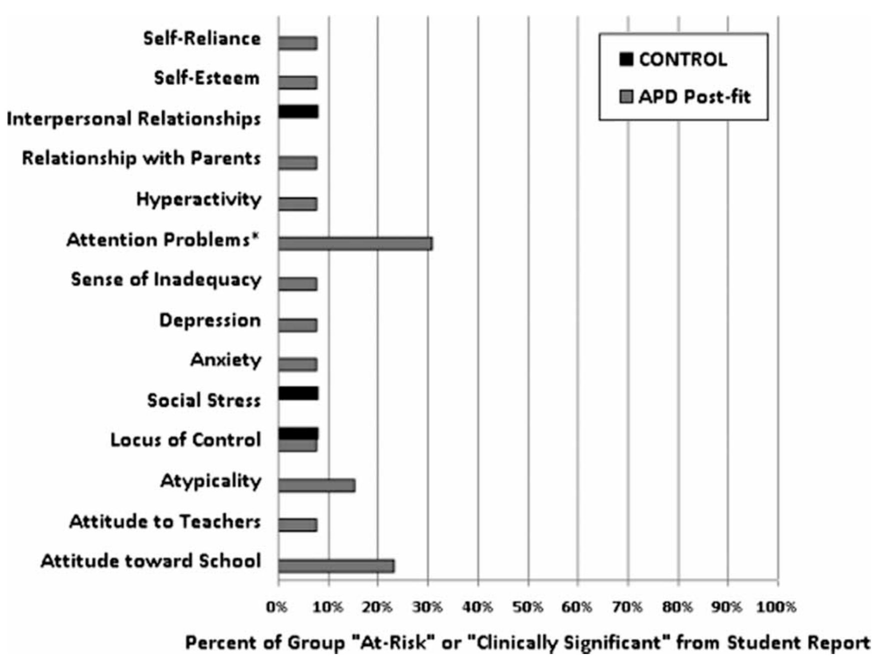

Figure 6. Comparison of percentage of students found to be either 'at risk' or 'clinically significant' (responses collapsed to indicate one abnormal score) on student reports of the BASC-2. Results displayed for control group and APD post-fit (*$p < .05$).

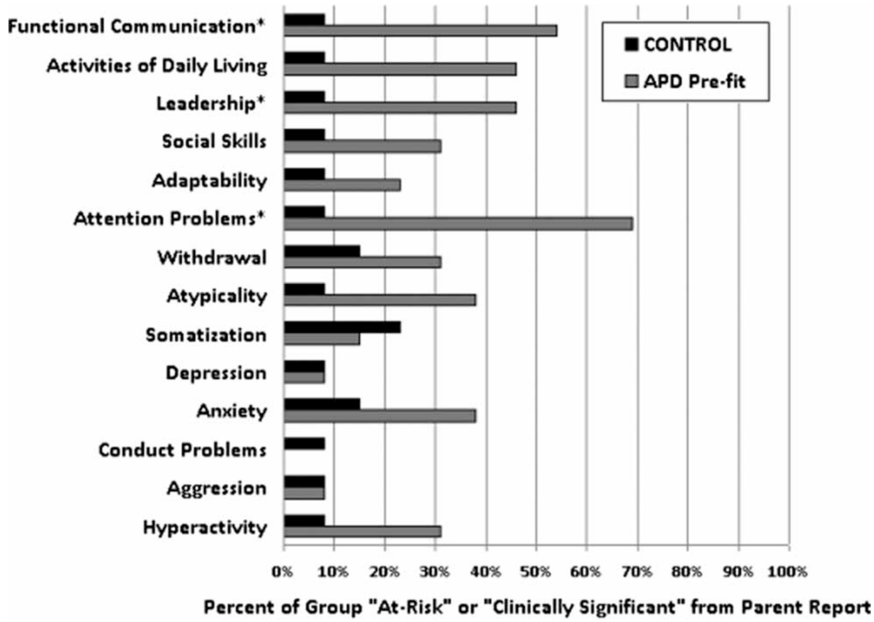

Figure 7. Comparison of percentage of students found to be either 'at risk' or 'clinically significant' (responses collapsed to indicate one abnormal score) on parent reports of the BASC-2. Results displayed for control group and APD pre-fit (*p <.05).

noted where parents tended to rate students' psychosocial status lower than did the students themselves on analogous self-report scales.

Discussion

In school-aged children, APD negatively impacts speech-perception (Chermak & Musiek, 1997), academic performance, and on-task behavior (Crandell & Smaldino, 1994, 2000), and emotional and psychological health (Crandell, 1999; Kreisman, 2007; Smaldino & Crandell, 2004). The present investigation evaluated, for a group of children with APD, the potential benefits of a miniaturized ear-level FM system on speech-perception, academic performance, and psychosocial status. Measurements of each domain were taken prior to fitting and after long-term use of the system. In addition, scores for the APD group on each

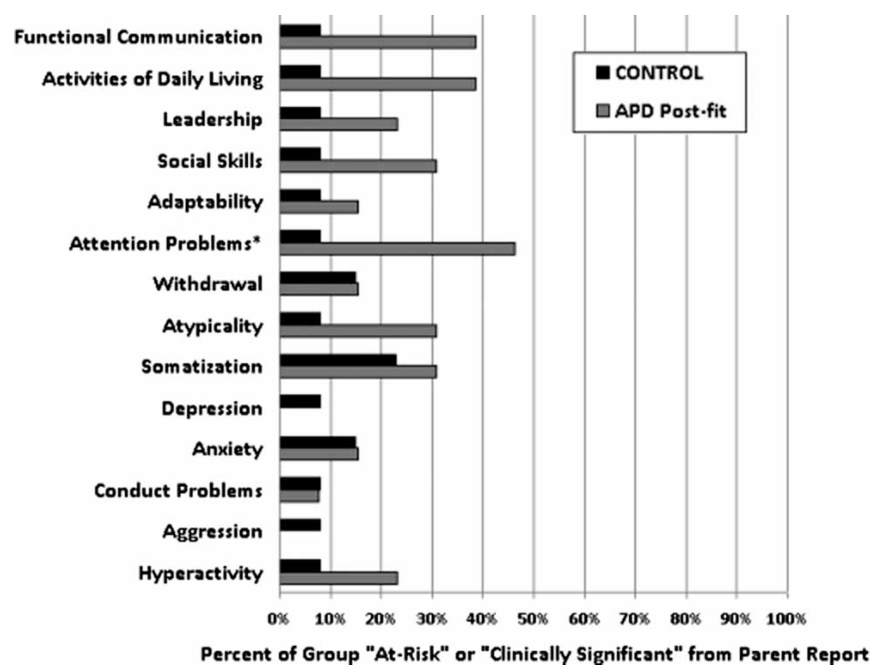

Figure 8. Comparison of percentage of students found to be either 'at risk' or 'clinically significant' (responses collapsed to indicate one abnormal score) on parent reports of the BASC-2. Results displayed for control group and APD post-fit (*p <.05).

outcome measure were compared to an age- and gender-matched control group of children with normal hearing and without APD. Although changes in outcome measures over the relatively short duration of the study could have occurred in the control group, the research design did not include repeated evaluations of these participants. Control group participants did not participate in any form of long-term treatment (i.e. use of FM device for extended period) and were evaluated with use of the FM system during a single test session.

We anticipated that children with APD would demonstrate poorer speech-perception, poorer performance in the classroom, and diminished psychological and emotional health compared to peers with normal auditory function. Certainly these disadvantages were evident in the baseline findings for in the present study. Prior to use of the FM system, scores on two inventories of academic performance, the SIFTER and LIFE, were significantly poorer for the APD group than for control-group peers, suggesting that both parents and students themselves perceived listening difficulty in typical classroom situations. Significantly more students in the APD group rated themselves outside of the normal range in multiple psychosocial domains including interpersonal relationships, depression, and anxiety compared to control-group peers. Similarly, parents of students in the APD group were significantly more likely than control group parents to rate their children outside of the normal range in psychological domains including leadership, attention, and functional communication.

Despite these multiple disadvantages for students in the APD group at baseline and the modest sample size in the study, students with APD demonstrated clear benefit from EduLink FM system utilization in nearly every domain that was evaluated. As expected, speech-perception scores for speech-in-quiet and speech-in-noise conditions were significantly improved for students in the APD group when fit binaurally with the EduLink FM system. The benefit of FM technology in speech-perception was maintained throughout the study period. For the APD group, improvements in speech-perception scores were documented in the quiet condition with and, importantly, without use of the FM system. The improvement in speech-perception in quiet (specifically, 3.8 dB improvement in unaided listening threshold and 2.2 dB improvement in aided listening threshold), after prolonged use of the FM system, suggests that enhanced hearing with the FM system contributed to improved auditory perception abilities. This improvement may reflect fundamental changes in the auditory system of the children with APD. Of course, it is possible, albeit unlikely, that the improvement in speech-perception was secondary to auditory system maturation for students in the APD group during the relatively brief examination period, and was not related to FM use. The possibility of development-related changes in speech perception could be further investigated with the inclusion of a second group of children with APD who did not use the FM system.

Additionally, speech-perception benefit from FM use was greater in a group of children with APD than a control group, and benefit improved significantly over time for the APD group. Speech-perception benefit from FM use was significantly greater for the children with APD than for age- and gender-matched children without a diagnosis of APD. That is, when using the FM system for speech-perception in noise, the improvement in performance gained by use of the FM system was greater for children with APD than for those without APD. This is an interesting finding in light of the similarity between groups for the speech-perception in noise scores in the unaided condition. We do not have a ready explanation for this finding. Also, the children with APD showed, from the pre-fit to post-fit evaluation, a significant improvement in speech perception in noise with use of the FM system. The same effect was not observed in the unaided condition. Further examination of the potential benefit of FM use by students with APD is warranted to verify, and better define, long-term changes in speech perception.

Children with APD showed improved academic status after the use of FM technology for approximately five months. Comparisons of LIFE scores pre- versus post-utilization of the FM system indicated benefits in nearly every domain examined. Specifically, the children with APD moved from the 'fail' range to the 'marginal' range on the SIFTER in the academics and communication categories. Outcome for the LIFE inventory improved significantly in the following situations: teacher talking in front of room, teacher talking with back turned, and other students making noise. Improvement in outcome for the LIFE inventory included two conditions that would be expected to be most difficult for a child with hearing loss or APD, namely, listening to the teacher when his/her back is turned and listening when other students are making noise. Notably, improvement in the latter category was so stark that children in the APD group reported a significant advantage compared to the control group after use of the EduLink FM system. This finding is similar to anecdotal reports that, in certain situations, some children with hearing loss who are using an FM system may actually perceive speech better than peers who do not have a hearing loss and do not have the benefit of an FM device. The significant improvements across multiple listening situations as measured by the LIFE are very encouraging from the standpoint of measuring fitting outcomes in a real-world environment. These consistently-reported improvements suggest that the speech-perception benefits of personal FM technology measured in the laboratory were also evident in the classroom listening environments of the students using the EduLink FM devices.

We found improved psychosocial status in children with APD after the use of FM technology for five months. Multiple benefits in psychosocial health were noted for the children in the APD group after use of the FM system. In particular, parents rated their children as less at risk for problems related to leadership and functional communication. More importantly, the children rated themselves as less at risk for problems related to locus of control, depression, anxiety, and interpersonal relationships. In other words, prior to use of an FM system, the group of children with APD was at risk for problems in several psychosocial domains that can have potentially detrimental effects on academic status as well as overall health. After use of the FM system, despite the small size of this group of children with APD, significant improvements were found in almost all identified areas of concern for potentially serious psychosocial problems.

We found potential long-term benefits of FM use in the areas of academic, emotional, and psychosocial status, as well as speech-perception abilities. Implementation of a similar protocol by clinical and educational audiologists is recommended for populations of children with APD. Fitting protocol guidelines are published in technical documents produced by the American Speech Language and Hearing Association (ASHA, 2005) as well as the American Academy of Audiology (in press). As noted in the ASHA Technical Report on (Central) Auditory Processing Disorders (2005), the selection, fitting, and management of an assistive listening device as well as training involved, is a process for which all steps must be included to ensure appropriate and effective management of children with APD. As with any sound output devices used by children, transducers used with an FM system should have a limited output as a protective measure against noise induced hearing loss (i.e. limited output headphones). An ear-level device, such as the one used in this study, has a volume control with a limited output. In fitting any hearing instrument or device with a child, clinicians should instruct the parent and teacher to perform a listening check on the device routinely.

Consistent with published guidelines, we recommend, binaural fitting for personal FM use for children with APD (ASHA, 2005). The present study does not provide data for establishing the duration of time necessary for an adequate trial period of FM use. However, in order to monitor the success of a trial with an FM system, at minimum, the audiologist should use measures to routinely screen the child's academic status and verify speech-perception status. The SIFTER (Anderson, 1989) and LIFE (Anderson & Smaldino, 1998) were effective tools for monitoring the degree of risk for problems relating to academics in the group of participants in this study. The LIFE is available in forms to be completed by the student or the teacher. The SIFTER can be completed by the teacher as well. Parent completion of the SIFTER yielded informative results regarding academic status of the children in this particular investigation. Parent feedback along with teacher reports can contribute significantly to an informed decision regarding duration of FM system use for a child with APD. However, it is critical for the audiologist to verify the speech-perception abilities of the child with APD in order to accurately assess the benefit received with the FM system when listening in noise. Notably, in the present study, eight out of the ten children with APD displayed specific deficits in auditory figure-ground (speech-in-noise) processing, but significant improvements for the entire group were found with use of the FM system. In other words, children demonstrating auditory deficits consistent with APD, even without specific problems with listening in noise, may still derive benefit from an improved signal-to-noise ratio in the classroom environment. We recommend children with APD be evaluated annually with multiple measures to monitor status of auditory processing abilities. This is especially true for children receiving intervention. While the HINT is an appropriate tool for evaluating the speech-perception improvement gained with use of an FM system, other appropriate clinical measures of auditory figure-ground or speech-in-noise processing can be used when re-evaluating the status of a child's auditory processing abilities.

The findings of our study justify the support of educators for the implementation of an intervention, such as the ear-level FM system for children with APD. Intervention with FM technology has the potential to reduce the need for ESE (exceptional student or special education) or other special services in the schools, thereby reducing costs and burden to the school system and teachers. Use of an ear-level FM system for children with APD does not disrupt classroom instruction in a regular classroom. Implementation of this form of intervention is cost effective in light of the potential for reduction of risk for academic failure and improvement of psychosocial function in children with APD subsequently reducing the need for additional academic and social services.

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