# Personal FM systems for children with autism spectrum disorders (ASD) and/or attention-deficit hyperactivity disorder (ADHD): An initial investigation

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## ARTICLE INFO

## ABSTRACT

The goal of this initial investigation was to examine the potential benefit of a frequency modulation (FM) system for 11 children diagnosed with autism spectrum disorders (ASD), attention-deficit hyperactivity disorder (ADHD), or both disorders through measures of speech recognition performance in noise, observed classroom behavior, and teacher-rated educational risk and listening behaviors. Use of the FM system resulted in significant average improvements in speech recognition in noise for the children with ASD and ADHD as well as large effect sizes. When compared to typically functioning peers, children with ASD and ADHD had significantly poorer average speech recognition performance in noise without the FM system but comparable average performance when the FM system was used. Similarly, classroom observations yielded a significant increase in on-task behaviors and large effect sizes when the FM system was in use during two separate trial periods. Although teacher ratings on questionnaires showed no significant improvement in the average level of educational risk of participants, they did indicate significant improvement in average listening behaviors during two trial periods with the FM system. Given the significantly better speech recognition in noise, increased on-task behaviors, and improved teacher ratings of listening behaviors with the FM system, these devices may be a viable option for children who have ASD and ADHD in the classroom. However, an individual evaluation including audiological testing and a functional evaluation in the child's primary learning environment will be necessary to determine the benefit of an FM system for a particular student.

**Learning Outcomes**: 1. The reader will be able to *describe* the potential benefit of FM systems for children with ASD and/or ADHD. 2. The reader will be able to *identify* on-task versus off-task listening behaviors in children with ASD and/or ADHD. 3. The reader will be able to *explain* the components of a successful pre-fit education program that may be necessary prior to fitting an FM system in children with ASD.

## 1. Introduction

Autism spectrum disorder (ASD), as defined from an educational perspective, is a developmental disability that adversely affects a child's educational performance, verbal and nonverbal communication, and social interactions with others

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(Individuals with Disabilities Education Act, 2004). From a clinical perspective, children who are diagnosed with ASD exhibit six or more deficits in the areas of social interaction; communication; and restrictive, repetitive, and stereotyped patterns of behavior (American Psychiatric Association, 2000). Furthermore, children who have ASD, which may include those diagnosed with autism, Asperger's disorder, or a pervasive developmental disorder-not otherwise specified, are often resistant to environmental change, unwilling to adjust to changes in daily routines, and tend to display abnormal responses to sensory input. Children with Asperger's disorder may also show comorbid symptoms of an attention-deficit/hyperactivity disorder (ADHD; American Psychiatric Association [APA], 2000).

The presence of ADHD alone may also adversely affect educational performance due to limited or heightened alertness with respect to the educational environment (Individuals with Disabilities Education Act, 2004). Clinically, children who are diagnosed with ADHD exhibit six or more specific maladaptive symptoms, under the categories of inattention, hyperactivity-impulsivity, or both for at least 6 months (APA, 2000). Specific clinical characteristics that may influence performance in a classroom setting include distractibility, disorganization, listening difficulties, inattention to tasks, and limited or heightened alertness. When children exhibit several of these clinical characteristics, which directly impact their educational performance, they may qualify for special education services for ADHD under the eligibility category of "other health impairment" (OHI; Individuals with Disabilities Education Act, 2004).

In the United States, there is an increasing prevalence of school-aged children who are diagnosed as having ASD or ADHD (Centers for Disease Control and Prevention [CDC], 2012; Pastor & Reuben, 2008); however, this may be related to increased exposure to and broadened definitions of these disorders over the past few years. More specifically, the CDC (2012) estimates that an average of 1 in 88 children in the United States has an ASD, and approximately 9.5% of school-aged children have ADHD (CDC, 2011). As a result, when combined, these populations constitute a large percentage of school-aged children who may require special education support or private schooling. In fact, the CDC (2009) estimates that, on average, 87% of children who have ASD receive special education support in public schools.

## 1.1. Auditory processing deficits

Despite the differences in the primary characteristics used to define ASD and ADHD, the evidence, as described below, suggests that both populations are highly influenced by sensory information from the environment, including auditory stimuli. Processing of auditory information is absolutely essential to functioning and learning in the classroom; yet, children with ASD and ADHD exhibit abnormal behavioral performance on auditory-based tasks, especially in the presence of background noise (e.g., Alcántara, Weisblatt, Moore, & Bolton, 2004; Corbett & Constantine, 2006; Gomez & Condon, 1999; Tomchek & Dunn, 2007). For example, according to profiles completed by 400 parents of children with ASD, 58–79% of the respondents indicated distractibility or inability to function in noisy environments, unresponsiveness to discriminative auditory stimuli, and difficulty attending to auditory information (Tomchek & Dunn, 2007). Furthermore, the most significant predictor of educational performance in children with ASD is their level of difficulty with auditory filtering, which is the ability to hear speech stimuli, complete tasks, and function in the presence of background noise (Ashburner, Rodger, & Ziviani, 2008). The validity of these parent reports is supported by research showing significantly poorer sentence recognition of children with ASD as compared to performance of typically functioning peers when in the presence of three types of background noise: single-talker noise, speech-shaped noise with temporal dips (i.e., quiet periods), and speech-shaped noise with temporal and spectral dips (i.e., pitch changes) (Alcántara et al., 2004). Sentence recognition requires a child to repeat, write, or point to an associated picture related to open-set words or sentences that they hear through a loudspeaker or earphones while background noise is presented from the same or a separate loudspeaker or earphone. On average, the children with ASD had sentence thresholds in noise that were 2–3.5 dB worse than the typically functioning peers (Alcántara et al., 2004). This finding suggests that children with ASD, as compared to peers, require a significantly louder signal from the talker in order to repeat what the talker says in the presence of the background noise.

Similar to the pediatric ASD population, children with ADHD exhibit high levels of inattention, difficulty with auditory filtering, and significantly poorer speech recognition performance in noisy test conditions (Gomez & Condon, 1999; Mangeot, Miller, McGrath-Clarke, Simon, & Hagerman, 2001). On the parent questionnaire used in the aforementioned studies on children with ASD, children with ADHD showed the same significant auditory deficits for filtering and sensitivity (Mangeot et al., 2001). In addition, Gomez and Condon (1999) report significantly poorer speech recognition in noise composite scores on a screening test for auditory processing disorders for children who have ADHD and learning disabilities as compared to neurotypical children or children with ADHD and no learning disabilities. The composite scores represented combined performance for subtests containing dichotic monosyllabic words, words in the presence of multi-talker babble at a +9 signal-to-noise ratio, and low-pass filtered words. In a study that included both populations, the groups of children with ASD and ADHD showed similarly degraded performance on a test of auditory attention, even in a quiet environment, as compared to performance of a typically developing group (Corbett & Constantine, 2006). Overall, studies of children with ASD and ADHD suggest similar abnormal auditory listening behaviors as well as significantly poorer speech recognition as compared to typically functioning peers. However, the exact origin or mechanisms responsible for these auditory deficits is unknown.

The measurable auditory deficits in children with ASD and ADHD as compared to typically developing peers likely stem from a combination of numerous factors including coexisting disabilities, such as language disorders, learning disabilities,

intellectual disability, poor inhibitory control (i.e., difficulty modulating sensory stimuli), and attention deficits (Alcántara et al., 2004; Corbett & Constantine, 2006; Gomez & Condon, 1999; Tomchek & Dunn, 2007). The auditory deficits may also be related to the way sound is processed throughout the auditory systems of children with ASD and ADHD. Specifically, there is evidence to suggest the presence of abnormal physiological encoding of auditory stimuli in quiet and noisy listening conditions from the level of the brainstem all the way up to the cortex (Barry, Clarke, McCarthy, & Selikowitz, 2002; Russo, Nicol, Trommer, Zecker, & Kraus, 2009; Russo, Zecker, Trommer, Chen, & Kraus, 2009). Continued research into the exact variables or mechanisms contributing to the degraded auditory-based performance of children with ASD and ADHD may provide some insight into potential intervention strategies for these populations. However, this research will only partially address barriers related to auditory processing. The second important area of auditory processing relates to difficulties caused by external factors, such as poor classroom acoustics and noisy listening environments.

## 1.2. Classroom acoustics

Preschool, elementary, and secondary classrooms typically have poor acoustics (Knecht, Nelson, Whitelaw, & Feth, 2002) that rarely meet the guidelines set forth by the American Speech-Language-Hearing Association (ASHA, 2005a) or the American National Standards Institute (ANSI, 2010) for unoccupied noise levels (i.e., noise level in empty room), reverberation times (i.e., how much echo in a room), or signal-to-noise ratios (i.e., =intensity of teacher's voice − intensity of noise in an occupied classroom). Although ASHA and ANSI recommend that children hear the teacher's voice at a +15 dB signal-to-noise ratio, typical classrooms of school-aged children have signal-to-noise ratios ranging from −17.6 to +5 dB (Larsen & Blair, 2008; Sanders, 1965). The variable classroom conditions are likely to create a listening and learning challenge for any child and are not conducive to optimal hearing.

Even with structural modifications to improve the acoustics of a typical classroom, such as ceiling tiles, carpeting, and sound absorbing walls, most classroom noise is unavoidable. Internal classroom noise originates from the competing speech signals from children talking, books closing, papers rustling, chairs moving, students transitioning from class to class, computers, projection equipment, the hallway, and other classrooms. External noise sources may also be present from lawn equipment, nearby traffic, or playgrounds. The deleterious effects of background noise from internal and external sources are well-documented in studies on typically developing children with normal-hearing sensitivity (Jamieson, Kranjc, Yu, & Hodgetts, 2004; Neuman, Wroblewski, Hajicek, & Rubinstein, 2010). Speech recognition in noise is even more affected when a child has hearing loss (Schafer & Thibodeau, 2003; Anderson, Goldstein, Colodzin, & Iglehart, 2005) or auditory processing problems that coexist with disorders, such as ASD or ADHD (Alcántara et al., 2004). Under the Individuals with Disabilities Education Act (IDEA, 2004), the goal of successfully educating students with disabilities in the least restrictive environment or general education settings is challenging for children with ASD and ADHD because the typical classroom environments are consistently noisy and detrimental to academic performance.

## 1.3. Frequency modulation (FM) systems

One approach to address the degraded speech recognition performance in noise and auditory filtering of children with ASD and ADHD is the use of a personal frequency modulation (FM) system. Personal FM systems designed for children with normal-hearing sensitivity consist of a small receiver worn in the child's ear, which does not impede natural environmental sound, paired with a transmitter and microphone worn by the teacher. The FM system improves the signal-to-noise ratio at the child's ear by transmitting the teacher's voice directly into the child's ear at a safe and comfortable volume.

To our knowledge, there are no recent peer-reviewed, published studies designed to examine the benefits of personal FM systems for children with ASD. However there is one study on amplification in children with ASD dating back to the 1980s. In this study, 14 school-aged children who were diagnosed with ASD used body-worn FM receivers for 24 min per day for 5 weeks in order to examine the children's attention with the device (Smith, McConnell, Walter, & Miller, 1985). However, unlike traditional FM system studies, the teacher did not wear the transmitter and microphone. Instead, the child wore the transmitter, microphone, and receiver with the environmental microphone muted, which basically resulted in the use of the FM system as a hearing aid (i.e., amplification). Despite the non-traditional use of the FM system, brief trials with the device revealed less withdrawal and increased appropriate behaviors in the children when using the system.

To predict the benefits that might be achieved by children with ASD, studies on other populations may be examined. Using a more traditional FM system arrangement, two studies suggested significant benefit from soundfield (i.e. loudspeakers) or body-worn personal FM systems for children who were diagnosed with developmental disabilities or learning disabilities, respectively (Flexer, Millin, & Brown, 1990; Blake, Field, Foster, Platt, & Wertz, 1991). Flexer et al. (1990) reported significantly reduced word recognition errors when using a two-speaker soundfield FM system in nine children with developmental disabilities, ages 4–6 years, with intelligence scores of 80 and below and variable hearing thresholds. In a second study, Blake et al. (1991) included 40 children diagnosed with learning disabilities and normal-hearing sensitivity. In this study, attending behaviors substantially improved in the experimental group ($n$ = 20) using body-worn FM systems with a headset as compared to a control group ($n$ = 20) using no device.

Since the publication of these two studies, advances in FM system technology have resulted in miniaturized, ear-level FM receivers that are designed specifically for children with normal-hearing sensitivity who have listening problems. When compared to soundfield FM systems, personal, ear-level receivers may be more beneficial for children with auditory deficits

because personal receivers provide (1) a more consistent signal to each of the child's ears; (2) portability of the receivers to different classes or therapy rooms; (3) flexibility for individualized receiver programming of volume or gain; and (4) the ability to set receivers to different teacher-transmitted channels, within the same classroom, for small groups. However, there is the possibility that personal FM receivers may not be accepted by children with tactile sensitivities, which includes many children with ASD.

Two recent studies examined the benefits of personal, ear-level FM systems for children with auditory processing disorders and/or ADHD (Friederichs & Friederichs, 2005; Johnston, John, Kreisman, Hall, & Crandell, 2009). Friederichs and Friederichs (2005) examined psychoacoustic and electrophysiologic performance in 10 children, ages 7–14 years, diagnosed with auditory processing disorders and ADHD and 10 age-matched, neurotypical controls. Children in the experimental group, who were using bilateral ear-level FM receivers, showed significantly greater gains in psychoacoustic measures as well improved teacher ratings on questionnaires related to social behavior, attentiveness, and hearing profiles as compared to the age-matched, neurotypical peers. Findings also showed differences in electrophysiological responses between the two groups, suggesting abnormal processing of sound in the group of children with auditory processing disorders. In another study, Johnston et al. (2009) evaluated 10 children diagnosed with auditory processing disorders, ages 8–15 years, on measures of speech recognition in noise, teacher and child questionnaires, and psychosocial function. Following the trial with the bilateral, ear-level FM receivers, the results from the experimental group showed significantly better academic performance according to parent ratings, less difficulty hearing in the classroom according to child reports, improved psychosocial ratings, and enhanced speech recognition in noise. Overall, traditional FM system studies on children with learning disabilities, developmental disabilities, auditory processing disorders and ADHD offer positive findings regarding the benefits of personal FM systems.

## 1.4. Rationale and research questions

The presence of auditory deficits in children with ASD and ADHD combined with poor classroom acoustics are likely to cause devastating effects on children's listening abilities in the classroom. According to the aforementioned studies, auditory deficits for children with ASD and ADHD are similar, especially in noisy environments. One proposed solution to improve listening abilities in these children and to address the negative effects of typical classrooms with poor acoustics is the use of a personal FM system. Previous studies on children with learning and developmental disabilities or auditory processing disorders and ADHD offers evidence to support the present hypothesis that FM systems will provide improved speech recognition and classroom performance to most children with ASD and ADHD. In this initial, school-based investigation on children with ASD and ADHD, the following research questions were addressed:

1. Will children with ASD and ADHD tolerate and consistently use bilateral, personal FM receivers?
2. In separate groups of children with ASD or ADHD, will the use of the FM system improve individual and average speech recognition performance in background noise during two trial periods with the device?
3. For one combined group of children, are there statistically significant improvements in speech recognition in noise when using the FM system?
4. How does average speech recognition with and without the FM system for children with ASD and ADHD relate to average performance of typically functioning peers?
5. Will the use of an FM system during classroom instruction change the percentage of on-task behaviors and reduce specific maladaptive behaviors in children with ASD and ADHD?
6. How will the primary teacher rate the children with ASD and ADHD on scales used to evaluate levels educational risk and functional listening behaviors when using the FM system?

## 2. Methods

Eleven children with ASD and ADHD (i.e., experimental group) were included in five separate investigative measures: (1) speech recognition in noise, (2) classroom observations of behavior, (3) a teacher questionnaire to assess educational need, (4) a teacher questionnaire to assess listening behaviors, and (5) a social validation measures (i.e., informal questionnaires) with the teacher and each participant. In addition, 11 gender- and age-matched, typically functioning peers participated the speech recognition in noise measure in a no-FM system condition. The following sections will describe the participant groups, classrooms, equipment, and each investigative measure.

## 2.1. Participants

For descriptive purposes, the children will be categorized into three participant groups: seven children diagnosed with ASD, four children diagnosed with ADHD, and 11 gender- and age-matched, typically functioning peers. All parents signed consent forms to allow their children to participate, and all children signed assent forms prior to participation. Recruitment

documents, consent/assent forms, and all procedures for this study were approved by the Institutional Review Board at the University of North Texas.

For this initial investigation, participants already diagnosed with ASD and ADHD were recruited from one self-contained, private school classroom of 9–12-year-old students with learning differences. Of the 14 children in the classroom, 11 parents signed consent forms to allow their child to participate in the study. In addition, all 11 children with parent consent signed assent forms to participate after a week-long education period about the FM system prior to initiating the experimental procedures. These 11 children, as a whole, served as the experimental group. The three parents who did not agree for their children to participate in the study did not provide details regarding their decision.

As shown in Table 1, the seven male children diagnosed with ASD ranged in age from 9 to 11 years. Representative of the general population of children with ASD, four of these children were diagnosed with at least one comorbid disability or disorder by the licensed school psychologist or a licensed private psychologist. Two children in the study were taking medication prescribed by a psychiatrist for attention problems (Participants 1 and 6), and two children had below average intelligence (Participants 1 and 7). Although two children were diagnosed with an auditory processing disorder by a licensed audiologist, the current position from ASHA (2005b) is not to diagnose an auditory processing disorder in children when they have disorders that influence multiple sensory domains, such as ASD (i.e., not auditory specific). Information about the children's diagnoses was obtained from the case history form completed by the parent, and the diagnoses were confirmed by the school administrators. Specific tests used to diagnose the children with their various disabilities or disorders were not made available to the investigators by the parents or school. Within 6 months prior to the study, all children passed school-based pure-tone hearing screenings in both ears using the State of Texas screening criteria (i.e., responded at 25 dB HL for the frequencies of 1000, 2000, and 4000 Hz). In addition, all parents reported via case history forms that their children had normal hearing according to previous audiological evaluations. Overall, the children with ASD were fairly high functioning and on the higher end of the ASD spectrum (e.g., could speak, follow directions with repetition, and comply with examiner requests). For the purposes of this study, the two children who were diagnosed with ASD as well as ADHD were included in the ASD group.

Also, shown in Table 1, two male and two female children were diagnosed with ADHD and ranged in age from 10 to 12 years. Two of these children had at least one comorbid disorder or disability that was diagnosed by the licensed school psychologist or licensed private psychologist, and all four children were taking medications prescribed by a psychiatrist for their attention difficulties or irritability. Two children had below average intelligence levels (Participant 9 and 11). Again, information about the children's diagnoses was obtained from the case history form completed by the parent, and the diagnoses were confirmed by the school administrators. Specific tests used to diagnose children with their disabilities/disorders were not provided to the investigators. These children also passed school-based hearing screenings from a school nurse within 6 months of the study, and parents reported no hearing difficulties per a past audiological evaluation.

Eleven children with typical functioning and normal-hearing sensitivity were age and gender matched to the children with ASD and/or ADHD (i.e., 9–12 years). These children served as the control group for the speech recognition in noise testing. All of these children were enrolled in various public schools. Typical functioning was determined through parent report of no disabilities, medical issues, learning differences, educational delays, past hearing problems, or suspected speech-language delays. Children passed a hearing screening in both ears using the State of Texas screening criteria and showed normal middle ear function, bilaterally.

## 2.2. FM systems

During two separate FM system trial periods and speech recognition assessments, the children with ASD and ADHD used personal, ear-level FM receivers on both ears (i.e., Phonak iSense Micro FM receivers), and the teacher used a

**Table 1**
General participant information.

| Group | Participant | Age | Gender | Diagnoses | Intelligence |
|-------|-------------|-----|--------|-----------|--------------|
| ASD | 1 | 9 | Male | ASD, anxiety disorder | <Average |
| | 2 | 10 | Male | ASD, ADHD, APD, NLD | Average |
| | 3 | 10 | Male | ASD, ADHD | Average |
| | 4 | 11 | Male | ASD | >Average |
| | 5 | 10 | Male | ASD | NA |
| | 6 | 10 | Male | ASD | >Average |
| | 7 | 11 | Male | ASD, APD | <Average |
| ADHD | 8 | 10 | Male | ADHD, APD, SLI | Average |
| | 9 | 12 | Female | ADHD | <Average |
| | 10 | 10 | Female | ADHD | >Average |
| | 11 | 10 | Male | ADHD, APD | <Average |

ASD = autism spectrum disorder; ADHD = attention-deficit hyperactivity disorder; APD = auditory processing disorder; NLD = non-verbal learning disorder; NA = not available; SLI = specific language disorder.
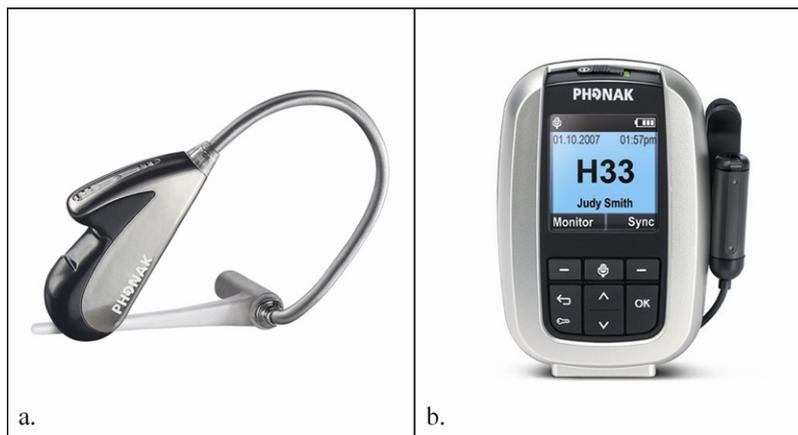
**Fig. 1.** Phonak iSense Micro FM receiver (a) and inspiro transmitter with the iLapel directional microphone (b).

**Phonak inspiro transmitter with the iLapel directional microphone** (Fig. 1). In general, the goal of an FM system is to increase the intensity of the primary signal (i.e., teacher) at the child's ear relative to the background noise in the classroom. This particular system contains Dynamic FM technology, which helps to maintain a good signal at the child's ear regardless of the ever-changing noise level in the classroom. The teacher transmitter constantly measures the noise level in the classroom. When the noise in the classroom exceeds 57 dB SPL, a relatively high noise level, the transmitter broadcasts a signal to the FM receivers to increase the gain (i.e., volume) of the child's FM receiver. While in use, the FM system maintains this adaptive-gain approach to ensure a consistently good signal-to-noise ratio in the students' ear. This type of ear-level receiver was deemed most appropriate by the first author of this article, a licensed and trained educational audiologist, given (1) the expected auditory difficulties of the children, (2) the more direct and consistent signal provided by Dynamic personal systems over soundfield systems, and (3) the necessity for different transmitting channels (i.e., more than one teacher) when children were separated into small groups for math class. This type of FM receiver does not block natural sound from entering the ear (i.e., open fitting with no earmold).

The FM receivers were set to default manufacturer settings throughout the study. The FM system functioning was verified through listening checks by the examiners on a daily basis during the trial period and before speech recognition testing. The listening checks were conducted by the examiners by holding each receiver to her ear while speaking into the transmitter microphone. In addition, using electroacoustic testing procedures suggested by the American Academy of Audiology Clinical Practice Guidelines for Remote Microphone Hearing Assistance Technologies (2008), the FM systems were verified before each of the two FM trials.

The classroom teacher or teacher's aides were given three FM transmitters for the study. When one teacher instructed the entire class, only one primary transmitter was used. All receivers were synched to the channel of the primary transmitter. However, because children in this classroom were on various academic levels, there were several days where children would be separated into two or three groups to complete math exercises. On those days, each small group teacher/aide would use a separate FM transmitter set to a different channel. The children's receivers were synched to the appropriate channel and examiners were present to assist the teacher, aides, and children in this process.

### 2.3. Private school classroom

The children's classroom was a moderate-sized, carpeted classroom with an average unoccupied noise level of the room across eight measurements around the room of 34.3 dBA ($SD$ = 0.88 dBA). The average reverberation times in seconds across eight measurements around the room were 0.4 s at 500 Hz ($SD$ = 0.08), 0.4 s at 1000 Hz ($SD$ = 0.11), 0.3 s at 2000 Hz ($SD$ = 0.09), and 0.3 s at 4000 Hz ($SD$ = 0.12). During the 45-min reading period and math class where the FM systems were used, students were most often seated at their desks. To address the distractibility of many students, the desks were placed around the perimeter of the room with students facing the wall. The students would often turn around in their seats during teacher-led instruction; however, some children would continue to face the wall at times. During instruction, the teacher was most often seated at a table near the middle-back of the room. Occasionally, children were separated into two or three groups during math led by the primary teacher or teacher's aides. Two groups were seated at a small table or on the floor in the classroom, and the third group met in the larger room adjacent to the classroom. This seating arrangement was consistent across all experimental phases of the study.

### 2.4. Speech recognition in noise testing

The speech recognition in noise testing was an efficacy measure and was conducted to examine the extent to which the children with ASD and ADHD would benefit from its use relative to a no-FM condition. Results from a control group in a no-FM condition were used to relate the findings from the groups with ASD and ADHD to typically functioning peers.

#### 2.4.1. Speech recognition stimuli

The speech recognition test presented sentences at a fixed level (i.e., intensity) with varying levels of background noise. A threshold in noise was obtained in dB signal-to-noise ratio (SNR-50), which represents the ratio where a child can repeat 50% of key words correctly in the presence of the background noise. For this test, lower scores (i.e., more negative) represent better performance in a condition. Speech and noise stimuli were modified from the Bamford-Kowal-Bench Speech-in-Noise Test (BKB-SIN; Etymotic Research, 2005) using Cool Edit Pro 2.1 software (Syntrillium Software, 2003). The modified version of the split track compact disc (CD) of the BKB-SIN test was created to avoid ceiling effects in the FM conditions, whereby the intensity of the sentences was decreased by 6 dB Ceiling effects, with the FM systems were expected for the standard signal-to-noise ratios on the BKB-SIN according to the first author's previous investigations with FM systems (Schafer, Wolfe, Lawless, & Stout, 2009), and an adjustment of 6 dB was suggested in the manual by the developers of the BKB-SIN (Etymotic Research, 2005). Therefore, on the modified version of the BKB-SIN used for this investigation, signal-to-noise ratios in the FM conditions ranged from +15 to −12 dB with the sentences fixed at 60 dBA. One list pair was used for each test condition. The order of BKB-SIN list pairs and order of test conditions was randomized across participants with ASD and ADHD. Typically functioning participants only completed one no-FM system test condition with two, randomly selected list pairs.

#### 2.4.2. Speech recognition test equipment

The modified BKB-SIN stimuli were recorded on CD and presented using a Sony CD-Radio-Cassette-Corder (Sony CFD-ZW755) with two detachable, single-coned loudspeakers, and additional speaker wire. The two loudspeakers, located at 0° (speech signal) and 180° (background noise) azimuth, were placed at head-level at a distance of 3 feet from the participant. This loudspeaker arrangement was chosen because it was portable and feasible for testing in a real classroom, and it simulates a preferentially seated (i.e., near the front of the room) student who is listening to a teacher in the front of the classroom with noisy classmates from behind. It is important to note, however, that this arrangement does not represent a classroom in a private or public school setting where noise sources often surround the student. The stimuli were calibrated to 60 dBA using the calibration track on the BKB-SIN split track CD and a sound level meter (Larson-Davis 824). When the FM system was in use for the speech recognition testing, the transmitter was suspended 6 in. from the loudspeaker at 0° azimuth. Care was taken to ensure that the directional microphone of the transmitter was facing in the appropriate direction during testing.

#### 2.4.3. Speech recognition test room

Speech recognition assessments for the children with ASD and ADHD were conducted in a large lunch and meeting room at their school, which was carpeted and had ceiling tiles and drapes. The average unoccupied noise level was 38.5 dBA ($SD = 0.65$ dBA) with average reverberation times in seconds for eight measurements at the location of the participant's head were 0.3 s at 500 Hz ($SD = 0.06$), 0.3 s at 1000 Hz ($SD = 0.10$), 0.2 s at 2000 Hz ($SD = 0.02$), and 0.2 s at 4000 Hz ($SD = 0.03$). Typically functioning children were tested in a similar moderate-sized, carpeted room with an average unoccupied noise level of 36.0 dBA ($SD = 0.87$ dBA) with average reverberation times in seconds of 0.4 s at 500 Hz ($SD = 0.05$), 0.3 s at 1000 Hz ($SD = 0.05$), 0.3 s at 2000 Hz ($SD = 0.06$), and 0.3 s at 4000 Hz ($SD = 0.04$). Both of these classrooms had good acoustics according to a position statement from ASHA (2005a).

### 2.5. Classroom observations

Prior to the study, the primary investigators observed participants in the private school classroom to determine typical behaviors. Following this informal observation, the most frequent observed behaviors were defined and assigned a behavior code (Table 2). Direct observation data sheets were then created by the investigators to record on-task versus off-task behaviors of the 11 participants during each 45-min observation period per session. The observation session was divided into 77, 30-s intervals, and participants with ASD and ADHD were randomly assigned to an observation sequence to control for order effects. This system allowed for seven recorded behaviors for each participant per day.

A total of four independent observers were utilized in the study, two serving as primary observers and two as reliability observers. All four observers were educated at the graduate level in speech and hearing disorders. It was not feasible to keep the observers blind to the no-FM or FM condition because the FM systems were visible; however, the observers were asked to honestly record their observations regardless of condition, given that the purpose of this study was to examine whether or not FM systems would produce any outcomes for target participants. The primary investigator made it clear to the observers that she was not sure whether or not the FM systems would be helpful to the children.

Prior to data collection, pairs of observers participated in an observation-training period. The training period required each observer pair (i.e., one primary and one secondary) to conduct observations of any three participants for 20, 30-s intervals during a different instructional period than the experimental context (i.e., not math or short reading time). These

**Table 2**
Codes assigned to off-task behaviors.

| Code | Operational definitions for codes |
|------|-----------------------------------|
| 1 | Does not follow teacher direction, but engages in distractible behaviors (e.g., does not take out or open book, doodles on paper, out of seat, blurts our answers without raising hand, or does not complete assigned work) |
| 2 | Does not respond to the teacher's questions within 5 s or teacher had to talk directly to child to get child to respond to request |
| 3 | Does not sit quietly when expected or asked, but instead, engages in other distractible behaviors (e.g., plays with anything in hands or with hands, shakes head back and forth, turns around in chair, shirt over head or face); talks to peer without permission |
| 4 | Stares at children and teacher in other small group, does not follow along with activity (e.g., behind the rest of the group) and generally appears to be distracted |
| 5 | Stares off into space; appears to have zoned out; is repeatedly redirected by teacher to follow along with activity; has head down; slouches on chair or desk; fidgety and appears restless |
| 6 | Inappropriate use of materials (e.g., plays with manipulatives, sticks it on face, stacks instead of using as instructed); plays with pens, pencils, paper, clothes, hair |
| 7 | Talks with classmate when supposed to work on activity, looks at peer to see what to do on activity |
| 8 | Displays other problem behavior (e.g., yells out, sings during instruction, curses or shouts, screams, throws objects on floor or at others, tantrums, or hits or hurts others) |

practice observations continued until observers were reliable with each other at 90% or higher for three consecutive sessions for each participant and for on-task or off-task behaviors with codes.

Once the trial periods began, each child was observed for approximately seven intervals during each observation period. The order in which the participants were observed for each period was pseudo-randomized. During the experimental observations, observers were most often seated separately but moved about the classroom to maximize visibility of the observed participant. Each observer recorded behaviors on the abovementioned direct observation data sheet. The primary observer used a stopwatch to time the 30-s observation intervals and provided the reliability observer with a nonverbal cue to signal the start of a new interval. A maximum of two observers and a minimum of one observer was present during any given observation period.

Following each observation period with two independent observers, an inter-observer reliability sheet was completed. This sheet also contained 77 intervals to record agreement (i.e., both observers recorded on-task or off-task with same code) or disagreement between the two observers for each interval to allow the investigators to report the reliability of the observations. Agreement regarding occurrence of on- or off-task behavior was computed on an interval-by-interval basis for each session of data collection. Two independent observers were present for 24 of the 32 (i.e., 75%) observation days. Reliability of the observations between the two independent observers was examined for each 30-s observation for all 24 days. To determine a percentage of observer agreement for each observation day, the number of intervals with agreement was divided by the total number of agreements plus disagreements intervals for that particular observation day. Perfect agreement (i.e., 100%) was calculated when the two observers recorded the same behaviors (i.e., off-task or on-task) as well as the same codes (i.e., 1–8). All observation days yielded reliability above 91.2%, and the average reliability across the 24 days was 98.0% ($SD$ = 2.1). On the occasion that the two observers did not agree on a behavior or code, data from the primary observer, as determined prior to the study, was used for the analyses.

### 2.6. Formal and informal questionnaires

The primary classroom teacher was asked to complete two formal questionnaires: the Screening Instrument for Targeting Educational Risk (S.I.F.T.E.R.; Anderson & Matkin, 1996) and the Children's Auditory Performance Scale (C.H.A.P.S.; Smoski, Brunt, & Tannahill, 1998). The S.I.F.T.E.R., a 15-item questionnaire, assesses each child's level of educational risk as compared to neurotypical classmates on a 5-point Likert scale. The five content areas of the S.I.F.T.E.R. include: academics, attention, communication, class participation, and school behavior. Previous studies on FM systems for children with auditory processing disorders suggest that the S.I.F.T.E.R. may be sensitive for detecting benefits of FM systems following a device trial (Johnston et al., 2009).

The C.H.A.P.S., a 36-item questionnaire examines the listening difficulties of a child compared to age-matched neurotypical peers using a 7-point scale. The six listening conditions on the C.H.A.P.S. include: noise, quiet, ideal, multiple inputs (i.e., auditory, visual, tactile), auditory memory (i.e., recalling spoken information), and auditory attention. The C.H.A.P.S. is a commonly used questionnaire for identifying children with potential auditory processing disorders (Smoski & Brunt, 1992).

The primary teacher completed each questionnaire for an FM-off condition before the study and for an FM-on condition after the study. The goal of the first administration of the questionnaires was to determine if the children were "at risk" on the S.I.F.T.E.R. or C.H.A.P.S. measures and to obtain baseline ratings. The goal of the second administration of the questionnaires was to determine if the teacher observed changes in a child's level of educational risk or listening behaviors relative to the baseline ratings when the FM system was in use. Prior to the study, the primary investigator made it clear to the teacher and school administrators that she was not sure whether or not the FM systems would be helpful to the children.

Although a post-test only questionnaire would have been preferred by the investigators, which could indicate how much change was observed in behaviors following FM system use, there is no such questionnaire in existence. As a result, to

determine the amount of change that occurred, the teacher had access to the baseline questionnaires as she completed the questionnaires for the FM system condition. This methodology was used in order to (1) reduce error related to any false memories of baseline ratings and to (2) control for threats to internal validity of the ratings. First, the teacher's false memory of baseline ratings could occur because of the 2-month time period between the administration of the first and second set of questionnaires and because of the large number of questionnaires (i.e., 44) completed for the 11 participants. Second, the method of using traditional pre-post questionnaire, with no access to the baseline ratings, is subject to a major threat to internal validity: response-shift bias (Lam & Bengo, 2003). This type of bias could have occurred if the study procedures made the teacher more aware of and knowledgeable about potential at-risk listening and communication behaviors in the participants. This new knowledge could have altered the overall beliefs of the teacher regarding the children's performance at baseline as well as with the FM system, and the ratings on the second set of questionnaires would, then, reflect this shift plus any actual change in the participants. Therefore, with access to the ratings on the baseline questionnaires, the second set of questionnaires should validly represent the impressions of any positive or negative change from baseline. Overall, the methodology used in this study has fewer threats to internal validity than a more traditional pre-post questionnaire, which are subject to numerous issues (Howard, 1980).

After the study was completed (i.e., after final FM-on experimental phase), teachers and participants were asked to complete informal social validation questionnaires. The teacher questionnaire focused on ease of equipment use and perceived benefit to participants from the device. The primary teacher and the teacher's aide completed this questionnaire independently. The participant questionnaire, which consisted of mostly closed-ended questions, aimed to assess the ease of insertion of the FM receiver, comfort of the device, and perceived benefit from the FM system. One of the investigators (the second author), a licensed speech-language pathologist, administered the informal questionnaire to each participant separately. The investigator read each question aloud to participants and recorded his or her verbatim response.

## 2.7. Study procedures

### 2.7.1. Education period

Following parental consent, the children with ASD and ADHD participated in an education period about the FM systems, which consisted of five, 15–20-min lessons over one school week. The goal of this week was to acclimatize the children to the device, study procedures, and study personnel. Also, the examiners considered this education period an essential component of the child's assent to participate and determine the level of tolerance for the device. Specifically, if the child did not understand the device or study procedures or felt uncomfortable in any aspect of the study, he or she was allowed to discontinue participation in the study.

On the first day of the education period, each child received a folder containing one page to introduce study personnel with pictures and names, a simplified user instruction guide for the FM receivers, two social stories about the FM system, and an assent form for participation. Details about each lesson are provided in the Appendix. Following the lesson on Day 5, children were asked to sign the assent form if they wanted to participate in the study, and all 11 children signed the form. During this week, teachers and aides were also trained on how to use the FM transmitter, insert and remove FM receivers, and troubleshoot problems with the transmitter and receiver.

### 2.7.2. Formal teacher questionnaires

Prior to the first FM system trial, the primary classroom teacher completed the S.I.F.T.E.R. and C.H.A.P.S. questionnaires for each student regarding their performance in a no-FM system condition. She was asked to provide ratings for the child's behavior during the brief reading period and math for the whole week prior to the study (i.e., education period). Instructional activities during this week were no different than typical instruction during the reading period and math.

### 2.7.3. No-FM trial #1

The examiners completed independent classroom observations of participant behavior for 1 week (5 days total) during a brief teacher-led reading period and for math class. This time of day was selected because it was the class with the most teacher-led instruction. This trial period was ceased after 5 days because the number of on- and off-task behaviors was fairly stable across the participants.

### 2.7.4. FM trial #1

During the first FM system trial over a period of 2 weeks (8 days total), the children with ASD and ADHD used the FM system for 45 min each day during the same teacher-led reading period and for math class. Examiners were present every day of this trial period to do listening checks prior to the class and to help children put the FM receivers in their ears. If any child refused to use one or both FM receivers, he or she was not made to use the device that day, and refusal to use the FM system was recorded by the examiners. During the final 2 days of the trial period, the examiners completed speech recognition testing (i.e., BKB-SIN) in the morning before school or before the mid-morning reading period and math class. Using one BKB-SIN list pair for each condition, children were tested in a no-FM system and a FM system condition.

### 2.7.5. No-FM trial #2

Following the first FM system trial, the children did not use the device for 3 weeks. One of these weeks was the children's spring break, and during the other 2 weeks, the observers were present for 6 days to record behaviors during the same reading period and math class. This condition and duration of time was instituted to assess reversal effects from the use of FM systems with the expectation that these data would be similar to observational data during the first no-FM trial or condition. During this period of time, the teacher was also asked to stay aware of any changes in the children's behavior and academic performance.

### 2.7.6. FM trial #2

The duration of the second FM trial period was increased to 3 school weeks (13 days total). The procedures described for FM system use and the randomized speech recognition assessments in the first FM trial were identical for the second FM trial. However, during this trial, most children with ASD and ADHD could insert the FM receivers independently, and the examiners confirmed correct insertion.

### 2.7.7. Post-trial measures

Upon completion of the trial period, the primary teacher completed the S.I.F.T.E.R. and C.H.A.P.S. questionnaires for each student for the FM system condition. She was asked to consider each child's change in behavior and performance during the two FM system trials as compared to the no-FM trial periods.

At the end of the study, the 11 gender- and age-matched, typically functioning children (i.e., control group) completed two list pairs of the BKB-SIN speech recognition test in a no-FM system condition. The typically functioning children were tested to provide age-appropriate normative data for the BKB-SIN with the speech presented at 0° and noise presented at 180° azimuth. The test manual for the BKB-SIN (Etymotic Research, 2005) only provides normative data for speech and noise presented from the same loudspeaker at 0° azimuth. Because the typically functioning children did not participate in a trial period with the FM system (i.e., no acclimatization to FM), they were not tested in a FM system condition.

## 3. Results

### 3.1. Research question #1: tolerance and consistency of FM system use

Of the 11 participants, nine children participated in the study through completion whereas two participants were dropped or withdrawn from one of the experimental sessions. The classroom teacher believed the FM receivers were adding to his difficulties with concentration and behavior and requested that he discontinue the study. However, FM system use was again attempted during the second trial period, and he was able to complete the second FM system trial in its entirety. The parents of Participant 5 requested to discontinue the study after the first day of the second FM system trial. The parents did not provide an explanation for the unexpected withdrawal from the study even after repeated requests from the school and examiners. The examiners hypothesize that one parent did not want the child to wear any type of device on his ears.

Throughout the study, most of the children readily accepted use of the FM receivers on both ears as indicated by user compliance. Occasionally, however, the investigators noted anecdotally that one or two participants would complain about the device bothering his or her ear or about the retention of the receiver in the ear, but these children would continue to use the system after the examiners adjusted the receiver on the ear. Some children removed the FM receiver for some period of time because (1) the receiver was "bothering his or her ear(s)", (2) the receiver was "uncomfortable", or (3) the child was asked by the teacher to remove the receiver and leave the room for behavior issues. Specific details about the amount of time FM receiver(s) were removed for these participants are provided in Table 3. Children who are not listed in Table 3 did not

**Table 3**
Duration of participant removal of FM receivers.

| Participant # | FM trial 1 | | | FM trial 2 | | |
|---|---|---|---|---|---|---|
| | Removal (min) | Days | 1 or 2 FM | Removal (min) | Days | 1 or 2 FM |
| 1 | 12.5 | 2 | 2 | – | – | – |
| 2 | [*] | [*] | [*] | 41.5[*] <br> 12.0[*] <br> 10.0 | 2 1[*] <br> 1 | 2 2[*] <br> 1 |
| 4 | 16.0[*] | 1[*] | 2[*] | – | – | – |
| 6 | 13.0 <br> 34.5 | 1 <br> 1 | 2 <br> 1 | – | – | – |
| 7 | 35.0 | 1 | 1 | – | – | – |
| 8 | 11.5 | 1 | 1 | 22.5 | 2 | 2 |
| 11 | – | – | – | 27.0 | 1 | 2 |
| Total | 122.5 | 7 | 9 | 113.0 | 7 | 9 |

*Note.* – = no-FM removal during a particular trial period; FM = frequency modulation receiver.
[*] Teacher instructed child to remove FM due to poor behavior.

**Table 4**
Speech recognition in noise performance in no-FM and FM system conditions across two test sessions.

| Group | Participant # | No-FM 1 | FM 1 | No-FM 2 | FM 2 |
|---|---|---|---|---|---|
| Autism spectrum disorder | 1 | −7.0 | −11.0 | −5.0 | −10.5 |
| | 2 | 0.0 | −10.5 | −3.0 | −10.5 |
| | 3 | −1.0 | −11.0 | −2.0 | −13.0 |
| | 4 | −9.0 | −13.5 | −7.5 | −13.0 |
| | 5 | −4.5 | −7.5 | DNE | DNE |
| | 6 | −6.5 | −13.0 | −4.0 | −13.0 |
| | 7 | −4.0 | −8.5 | 0.5 | −7.5 |
| | Average | **−4.6** | **−10.7** | **−3.5** | **−11.3** |
| | SD | **3.2** | **2.3** | **2.7** | **2.2** |
| Attention-deficit hyperactivity disorder | 8 | −8.0 | −13.0 | −3.5 | −9.5 |
| | 9 | −6.5 | −8.5 | −9.5 | −12.5 |
| | 10 | −6.5 | −12.0 | −3.5 | −12.0 |
| | 11 | −5.0 | −6.0 | −4.5 | −9.5 |
| | Average | **−6.5** | **−9.9** | **−5.3** | **−10.9** |
| | SD | **1.2** | **3.2** | **2.9** | **1.6** |

*Note.* Lower scores represent better performance; values represent performance in dB signal-to-noise ratio at the 50% correct level. DNE = did not evaluate; FM = frequency modulation receiver; SD = standard deviation.

remove the FM receivers during the trial period. Overall, most of the children were able to tolerate and consistently use the FM receivers for the 280 min in FM trial 1 and 455 min in Trial 2.

### 3.2. Research question #2: individual and group speech recognition in noise results

The individual and group speech recognition in noise thresholds in dB signal-to-noise ratio at the 50% correct level following the two separate FM system trials are provided in Table 4. In this table, lower thresholds in dB (i.e., more negative) represent better performance. In other words, a lower threshold in one condition indicates that the child could repeat a greater number of scoring words when listening at a higher noise level. The two separate test sessions were conducted in order to examine the reliability of the measurements.

As shown from the individual speech recognition results in Table 4, the children's performance appears fairly stable (i.e., similar) between the two test sessions with most children showing thresholds that were ±3 dB from the same condition in the other session. When examining performance differences between conditions, all 11 participants exhibited better performance (i.e., lower thresholds) in the FM system condition as compared to the no-FM condition; however, the improvements varied across individuals and across sessions. Nonetheless, all children achieved improved speech recognition in noise of at least 3 dB in one of the two test sessions. The maximum improvement with the FM system was 11 dB for Participant 3, and the minimum improvement with the FM system was 1 dB from Participant 11.

As shown in Table 4, average performance in the two conditions and across the two sessions was similar between the two groups; however, it appears that the ASD group achieved slightly greater benefit from using the FM system. Specifically, in Session 1 the difference between the no-FM and FM system condition (i.e., FM benefit) was 6.1 dB for the ASD group and 3.4 dB for the ADHD group. In Session 2, the FM benefit was 7.8 dB for the ASD group and 5.6 for the ADHD group. The group differences are likely influenced by the small number of participants in the ADHD group and the fact that the child with the least benefit (Participant 11) was included in the ADHD group.

### 3.3. Research question #3: statistical analysis of speech recognition in noise performance

Given the small sample sizes in this initial investigation, it was not feasible to conduct separate statistical analyses of the speech recognition in noise performance for the ASD and ADHD groups. As a result, the statistical analyses included data from all participants, with the exception of Participant 5 who did not complete the second speech recognition test session. Average performance of the 10 children across the two test session is displayed in Fig. 2.

Data from the 10 children were analyzed with two-way, fully repeated measures analysis of variance (ANOVA) with the independent variables of test session (i.e., 1, 2) and listening condition (i.e., no-FM, FM). The analysis revealed no significant main effect of test session, $F(1, 40) = .23$, $p = .64$, a significant main effect of listening condition, $F(1, 40) = 59.5$, $p = .00003$, and a significant interaction effect between trial and condition, $F(2, 40) = 6.4$, $p = .03$. No main effect of test session suggests that the measurements were reliable across the two tests. The significant main effect of condition, with an average difference of 6.1 dB, suggests substantial benefit from the FM system for improving speech recognition thresholds in noise. A post-hoc analysis using the Tukey–Kramer Multiple-Comparison Test on the two-way interaction effect suggested that speech recognition with the FM system in Session 1 and in Session 2 was significantly better than performance in either no-FM system condition ($p < .05$).

The magnitude of benefit from the FM system may also be examined by calculating the effect size (i.e., $d$) and variance [Var ($d$)] between the two sets of no-FM and FM system conditions. Because this study used a repeated measures design,
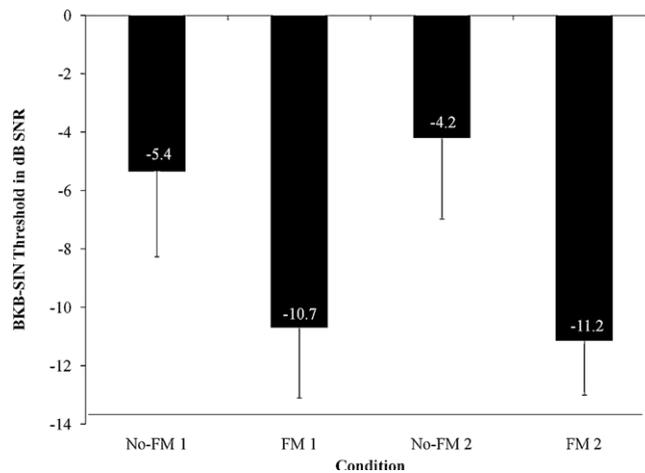
**Fig. 2.** Speech-in-noise thresholds at the 50% correct level for the no-FM system and FM system conditions. *Note.* Vertical lines represent one standard deviation; BKB-SIN = Bamford-Kowal-Bench Speech-in-Noise test; FM = frequency modulation; SNR = signal-to-noise ratio.

there is a high probability that data from the no-FM and FM system conditions are highly correlated. In order to avoid over-estimation of the effect size, modified effect size and variance formulas were used that were specifically designed for correlated measures (Dunlap, Cortina, Vaslow, & Burke, 1996). Traditional calculations of effect size, such as those proposed by Hedges and Olkin (1985), only may be used with two independent samples. Using these formulas, the magnitude of benefit measured in the first and second FM trials yielded effect sizes of 2.0 (Var ($d$) = .35) and 2.8 (Var ($d$) = .53), respectively. These effects are considered large according to Cohen (1988).

### 3.4. Research question #4: comparison of speech recognition in children with ASD and ADHD versus typically functioning peers

Planned comparisons of speech recognition in noise thresholds between the 11 typically developing peers and the 11 children with ASD and ADHD were performed using $t$-tests. Given the similar speech recognition performance for the ASD and ADHD groups across the two FM system trials, thresholds across the two BKB-SIN list pairs for each condition were averaged prior to analysis. Again, only one set of no-FM and FM system thresholds was available for Participant 5. Average speech recognition performance of the ASD and ADHD groups and the typically developing peers are shown in Fig. 3.

First, a comparison of the typically developing group in the no-FM condition to the ASD and ADHD groups in the no-FM system condition showed significantly poorer performance for the ASD and ADHD groups [$t(20)$ = 6.1, $p$ = .00005], which suggests substantially poorer speech recognition in noise. Using traditional calculations of effect size (Hedges & Olkin, 1985), a comparison of these two conditions yields an effect size of 2.5 (Var ($d$) = .33), which represents a large effect (Cohen, 1988).
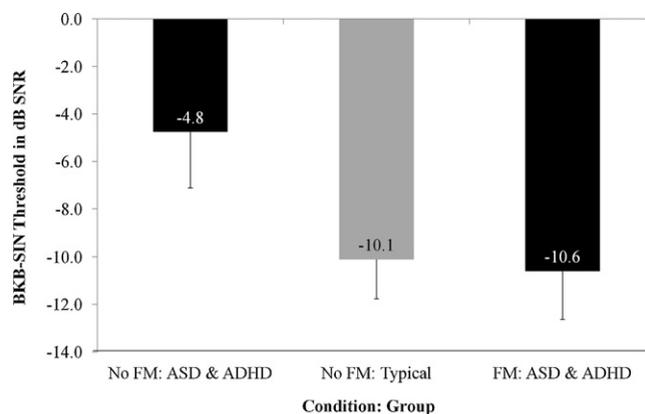


**Fig. 3.** Average speech-in-noise thresholds across the conditions and two groups of listeners. *Note.* Vertical lines represent one standard deviation; BKB-SIN = Bamford-Kowal-Bench Speech-in-Noise test; FM = frequency modulation; SNR = signal-to-noise ratio.
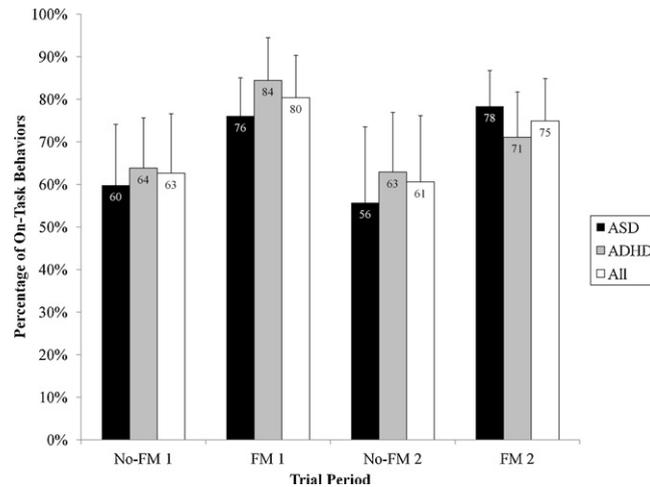
**Fig. 4.** Average percentage of on-task behaviors for participants diagnosed with autism spectrum disorders (ASD), attention-deficit hyperactivity disorder (ADHD), all participants combined.

Second, when comparing performance of the typically developing group in the no-FM system condition to performance of the ASD and ADHD groups in the FM system condition, no significant differences were detected between groups [$t(20) = -.63$, $p = .54$]. Therefore, the children with ASD and ADHD performed similarly to their peers when using the FM system.

### 3.5. Research question #5: observed on-task behaviors without and with FM system

Observers recorded on and off-task behaviors of each participant over 32 observation periods across the same number of days. The following results provide analyses of (1) the average percentage of observed on-task behaviors in separate ASD and ADHD groups for each trial period, (2) the average on-task behaviors across all participants for each trial period, and (3) the frequency of the codes assigned to off-task behaviors for no-FM and FM trials.

#### 3.5.1. Average on-task behaviors

The percentage of on-task behaviors were calculated for each child by (1) summing the on-task behaviors during a particular trial period (i.e., no-FM trial; FM trial) and (2) by dividing the on-task behaviors by the total number of observed behaviors during the same trial period. Results for each child were then combined and averaged across the separate groups of children with ASD ($n = 7$) or ADHD ($n = 4$). The average percentage of on-task behaviors for the ASD group, ADHD group, and for all participants combined is shown in Fig. 4.

The average on-task behavior in the two no-FM trials and in the groups of participants with ASD and ADHD was similar and ranged from 56% to 64%. Performance in the FM conditions across groups was also fairly similar and ranged from 76% to 84%, with the exception of the second FM trial of the ADHD group. This condition yielded a lower average on-task behavior at 71%. One of the four children in the ADHD group, in particular, had uncharacteristic behavioral problems during this phase trial period of the study, which may have influenced the group mean. On more than one day, this child was removed from the classroom by the teacher for unacceptable behavior. When omitting this participant's data from the analysis, the average on-task behaviors for the ADHD group in the second FM trial increased to 75%, which is more characteristic of data in the other FM trials.

**Table 5**
Effect sizes ($d$) and variance (Var ($d$)) of on-task behaviors between conditions.

| Group | n | Condition comparison | d | Var ($d$) |
|---|---|---|---|---|
| Autism spectrum disorder | 6 | No-FM$_1$ versus FM$_1$ | 1.1 | 0.2 |
| | 6 | No-FM$_1$ versus FM$_2$ | 1.3 | 0.4 |
| | 6 | No-FM$_2$ versus FM$_1$ | 0.8 | 0.2 |
| | 5 | No-FM$_2$ versus FM$_2$ | 1.0 | 0.2 |
| Attention-deficit hyperactivity disorder | 4 | No-FM$_1$ versus FM$_1$ | 1.6 | 0.5 |
| | 4 | No-FM$_1$ versus FM$_2$ | 0.6 | 0.1 |
| | 4 | No-FM$_2$ versus FM$_1$ | 1.7 | 0.9 |
| | 4 | No-FM$_2$ versus FM$_2$ | 0.6 | 0.2 |

*Note.* FM = frequency modulation system in use.

When comparing the performance in the no-FM and FM conditions, use of the FM system improved average on-task behaviors in the first and second trial periods by 16% and 23%, respectively, in the ASD group and by 21% and 8%, respectively, in the ADHD group. Overall, the large improvements in average on-task behavior for each group over the two separate trial periods suggest that the FM system is an effective assistive technology for enhancing desired classroom behavior.

The magnitude of benefit from the FM system was examined by calculating the effect size (Dunlap et al., 1996) between the FM-off and FM-on conditions in each group (Table 5). For the children with ASD, effect sizes between the no-FM and FM system trials conditions yielded large effects (Cohen, 1988) across all four comparisons. Effect sizes were also large for data from the ADHD group for comparisons to the first FM-on phase, and effect sizes calculated with the second FM-on phase resulted in medium effect sizes. Overall, the medium and large effect sizes across the two groups support the effectiveness of the FM system for improving on-task classroom behaviors.

### 3.5.2. Statistical analysis of on-task behaviors across participants

Separate group analyses of FM effectiveness were not feasible given the small sample size and within-group variability for the children with ADHD; therefore, data from the two groups were combined to allow for statistical comparison between conditions and trials of the study. Average on-task data for the combined groups is shown in Fig. 4. A two-way, repeated measures ANOVA was conducted to examine the within-subject factors of condition (i.e., FM-off and FM-on) and trial period (1 and 2). Given the repeated measures in this study, this type of ANOVA was deemed most appropriate for the data. However, this analysis requires complete data from all participants; therefore, the two participants (i.e., 2 and 5) who did not complete all four trial periods were excluded from this group analysis.

The repeated measures ANOVA revealed a significant main effect of condition [$F(1, 36) = 32.5$, $p = .0005$], no significant main effect of trial period [$F(1, 36) = 59.5$, $p = .22$], and no interaction effect between condition and trial period [$F(1, 36) = 59.5$, $p = .44$]. A post-hoc analysis using the Tukey–Kramer Multiple-Comparison Test suggested on-task behaviors were significantly higher in both FM trial periods as compared to both no-FM trial periods ($p < .05$).

### 3.5.3. Statistical analysis of off-task codes across participants

As explained in the methods section, observers recorded a code (Table 2) to define any off-task behaviors. To examine changes in specific behaviors across no-FM and FM trials of the study, an average percentage across participants was calculated for each code in each trial. Data were combined across the two no-FM and two FM trial periods because there was no effect of trial period in the previous analysis of on-task behaviors. To determine the percentage of observations where a specific code occurred in the no-FM trials relative to the total number observations, the following steps were taken: (1) the number of times a particular code occurred was summed for each participant in the two no-FM trial periods; (2) the sums for Step 1 were each divided by the total number of observed behaviors for that particular participant in the no-FM trial periods to yield a percentage per code; and (3) the individual percentages were averaged across nine participants for each code. Data from participants 3 and 7 were incomplete and were, therefore, excluded from these analyses. The same three steps were repeated for the FM trial periods. These calculations yielded an average percentage for each code in the no-FM and FM trial periods (Fig. 5). Paired $t$-tests between no-FM and FM system trial periods were conducted for each code in order to determine any significant change in a particular behavior. Results of these analyses reveal a significant decrease in the occurrence of Code 1 (Does not follow teacher direction, but engages in distractible behaviors) ($t[8] = 2.7$, $p = .01$) and Code 3 (Does not sit quietly when expected or asked, but instead, engages in other distractible behaviors) ($t[8] = 2.1$, $p = .03$) when using the FM system. The remainder of the $t$-tests did not yield significant increases or decreases in specific codes ($p > .05$).
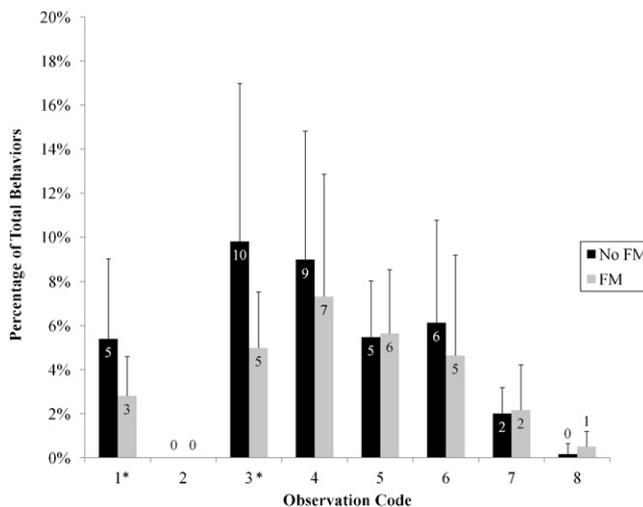


Fig. 5. Average percentage of off-task behavior codes in device conditions.

**Table 6**
Number of children in each risk category for the teacher-rated content areas on the screening instrument for targeting educational risk. (S.I.F.T.E.R.)

| Content Area | Condition | Pass | Marginal risk | Fail |
|---|---|---|---|---|
| Academics | No-FM | 4 | 3 | 4 |
| | FM | 4 | 3 | 4 |
| Attention | No-FM | 5 | 0 | 6 |
| | FM | 5 | 1 | 5 |
| Communication | No-FM | 5 | 2 | 4 |
| | FM | 6 | 1 | 4 |
| Class participation | No-FM | 5 | 2 | 4 |
| | FM | 6 | 1 | 4 |
| Social behavior | No-FM | 5 | 2 | 4 |
| | FM | 5 | 2 | 4 |

*Note.* FM = frequency modulation system.

The effect sizes (Dunlap et al., 1996) between the no-FM and FM system conditions were 0.66 (Var $(d)$ = .11) for Code 1 and 0.82 (Var $(d)$ = .19) Code 3, which are both considered large effects (Cohen, 1988).

### 3.6. Research question #6: formal and informal questionnaires

#### 3.6.1. Formal questionnaire results

The primary classroom teacher completed two formal questionnaires, the S.I.F.T.E.R. and C.H.A.P.S., for all 11 participants in order to rate their performance and behaviors in a no-FM system and a FM system condition. As stated previously, two participants completed only one FM system trial. For these children, the teacher based her comments on the single FM system trial. Ratings for the remainder of the children were based on teacher observations across the two FM system trials.

The S.I.F.T.E.R. questionnaire yields two types of data: (1) the number of children with pass, fail, or marginal risk ratings in each content area and (2) the sum of the responses in each content area. As shown in Table 6, approximately half of the children passed and half of the children failed in each content area on the S.I.F.T.E.R. in the no-FM and FM system conditions, with a few children in the marginal-pass category. Overall, use of the FM system does not appear to improve or worsen teacher ratings across the five content areas, but one child with ASD did show some improvement in several areas (details in Section 4.4). The sums of the teacher ratings in each separate content area were compared for the no-FM system and FM system ratings (i.e., pre versus post ratings) using planned nonparametric tests with the Wilcoxon Signed-Rank Test for Difference in Medians. These five analyses yielded no significant differences in the teacher ratings from the no-FM to the FM system conditions (i.e., $p$ > .05) for all comparisons.

The C.H.A.P.S. questionnaire also yields two types of data: (1) the number of children with pass or fail ratings for each listening condition and (2) the sum of the ratings in each separate C.H.A.P.S. listening condition. As shown in Table 7, the majority of children were placed in the at-risk category with and without the FM system on the C.H.A.P.S. for each of the six listening conditions. Most of the children either improved in one or more conditions ($n$ = 4) or remained in the at-risk

**Table 7**
Number of children in each risk category for the Children's Auditory Performance Scale. (C.H.A.P.S.)

| Listening condition | FM condition | Pass | At risk | Effect size (variance) |
|---|---|---|---|---|
| Noise | No-FM | 2 | 9 | .40 (.02) |
| | FM | 1 | 10 | |
| Quiet | No-FM | 2 | 9 | .38 (.01) |
| | FM | 4 | 7 | |
| Ideal | No-FM | 2 | 9 | .34 (.01) |
| | FM | 3 | 8 | |
| Multiple | No-FM | 2 | 9 | .18 (.01) |
| | FM | 3 | 8 | |
| Memory | No-FM | 1 | 10 | .41 (.05) |
| | FM | 2 | 9 | |
| Attention | No-FM | 2 | 9 | .28 (.02) |
| | FM | 1 | 10 | |

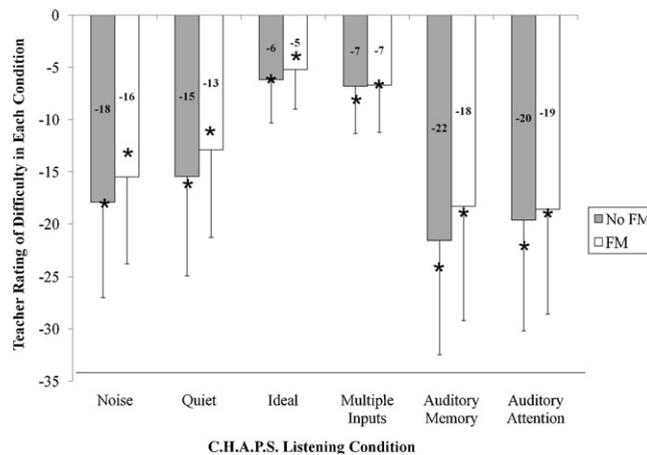*Note.* FM = frequency modulation system.

**Fig. 6.** Sum of no-FM and FM system teacher ratings on the Children's Auditory Performance Scale (C.H.A.P.S.). *Note.* Vertical lines represent one standard deviation; asterisks indicate median values; FM = frequency modulation.

category across conditions, with one child showing worse performance in several conditions (details in Section 4.4). The sums of the teacher ratings in the no-FM system and FM system conditions are shown in Fig. 6. For each of the C.H.A.P.S. listening conditions, the sum of ratings in the no-FM system and FM system conditions were compared with planned comparisons using the Wilcoxon Signed-Rank Test for Difference in Medians. The analyses revealed significantly less listening difficulty (i.e., significant FM benefit) when using the FM system in the following listening conditions: noise ($z = 2.1$, $p = .04$, two-tailed), quiet ($z = 2.7$, $p = .07$, two-tailed), ideal ($z = 2.2$, $p = .03$, two-tailed), auditory memory sequencing ($z = 2.0$, $p = .04$, two-tailed), and auditory attention span ($z = 2.0$, $p = .05$, two-tailed). The only listening condition that did not produce significant differences between the no-FM system and FM system conditions was multiple inputs ($z = 1.8$, $p = .07$, two-tailed).

Given the small sample size, large variability in ratings, and the potential for increased error from the six separate Wilcoxon analyses, effect sizes between teacher ratings in the no-FM and FM system conditions were also calculated using the same approach as described in Section 3.3 (Dunlap et al., 1996). Table 7 provides the effect sizes and variances for each listening condition on the C.H.A.P.S. The strength of the effect sizes for the noise, quiet, ideal, and auditory memory conditions may be interpreted as medium while the multiple inputs and auditory attention conditions yielded small effect sizes. As a result, the medium effect sizes paired with the significant differences found with the Wilcoxon analysis for the

**Table 8**
Results of informal validation questionnaire for participants ($n = 10$).

| Question | Answers |
|---|---|
| 1. Any trouble putting on FM system, at first? | 9: Yes |
| | 1: No |
| 2. Did it get easier to put on once you used it more? | 8: Yes |
| | 2: No |
| 3. Did the FM system stay in your ear? | 7: Yes |
| | 3: No |
| 4. Was the volume of the system comfortable? | 9: Yes |
| | 1: No |
| 5. Would you have liked the volume louder or softer? | 6: Yes (2 softer; 3 louder) |
| | 4: No |
| 6. Was the system comfortable? | 8: Yes |
| | 2: No |
| 7. Did you like using the system? | 10: Yes |
| | 0: No |
| 8. Do you think the system helped you to listen in class? | 10: Yes |
| | 0: No |
| 9. Would you like to continue using it? | 9: Yes |
| | 1: No |
| 10. What did you like about the system? | Pretty cool ($n = 2$); could hear class in restroom ($n = 2$); like the way it looks ($n = 2$); can hear better ($n = 2$); fun; easy to communicate with teacher; helps you remember what the teacher says; no irritating wires; helped kids learn; nothing I liked |
| 11. What did you not like about the system? | Nothing I disliked ($n = 6$); fell out ($n = 2$); would like to hear other people also; itchy and distracting; want volume control |

noise, quiet, ideal, and auditory memory conditions likely represent true differences between the no-FM and FM system conditions. However, significance in the auditory attention condition paired with the small effect size yields a less powerful finding.

### 3.6.2. Informal participant and teacher questionnaires

To validate the observations in this study, informal questionnaires were given to the 10 remaining participants and two teachers at the end of the study. An investigator administered the questionnaire with the children by reading each question aloud and by recording the child's response. Teachers were asked to complete an open-ended questionnaire about device effectiveness in the classroom and convenience of use.

Results of the child questionnaire are provided in Table 8 and suggest highly positive responses regarding the ease of use and comfort of the FM receiver, volume of the receiver, and benefit from the device for classroom listening. Nine of 10 children wanted to continue device use; however, one child with ASD and one with ADHD reported that the receivers were uncomfortable. Results from the teacher questionnaire were also highly positive. According to responses from the two teachers, the transmitter was easy to use, but they would like to be able to "dial in" to specific individuals. The children's receivers were also easy to use, and over time, most children could insert them independently. Teachers reported that, on average, the children benefited from using the FM system, especially in noisy situations, with more activity, and once the novelty of the device decreased. Overall, it was easier to gain the children's attention when using the FM system; however, the teachers reported that some children had more difficulty than others with the device because of sensory issues. Both teachers stated that the system may be more helpful in a mainstreamed public school classroom with less independent work and where all children are working at the same academic level.

## 4. Discussion

In this initial investigation, which included children who were diagnosed with ASD and ADHD, use of personal, bilateral FM receivers resulted in significantly improved speech recognition in noise, on-task behaviors, and teacher-rated auditory listening behaviors in several listening conditions. However, use of the FM system did not improve teacher ratings related to the children's levels of educational risk. Informal questionnaires given to the participants and teachers suggested that the FM systems were helpful and beneficial for most children; however, as expected, some children had tactile sensitivities to the receivers.

### 4.1. Speech recognition in noise

The BKB-SIN speech recognition test was used to estimate each child's speech-in-noise threshold in dB signal-to-noise ratio at the 50% correct level (i.e., lowest signal-to-noise ratio where the child is able to repeat 50% of key words in sentences) in a no-FM and a FM system condition. Results from this testing suggest that the children with ASD and ADHD achieved significantly better speech recognition in noise when using the FM system as compared to a no-FM condition in two separate test sessions. When comparing their no-FM performance to typically functioning peers, the ASD and ADHD groups had significantly poorer speech recognition in noise. However, use of the FM system by the children with ASD and ADHD improved their speech recognition in noise to the level achieved by the typically functioning peers in a no-FM condition.

In this study, the stimuli and the loudspeaker placement at 0° and 180° allowed for testing of FM system benefit in a well-controlled, ideal listening situation in noise. This arrangement is practical for testing in a real classroom, but this arrangement is also idealistic because the intensity of the primary speaker's voice was at a constant level of 60 dBA and background noise was stationary. Certainly, in a typical classroom, the teacher's voice is dynamic, and the noise sources are dynamic and diffuse. As a result, the speech-in-noise thresholds from the children with ASD and ADHD and the typically developing peers are likely better than what would be expected in a real classroom. Nonetheless, a particularly large difference was detected between the ASD and ADHD groups and typically functioning group in the no-FM condition. Specifically, a direct comparison of speech recognition performance of the children diagnosed with ASD and ADHD to typically developing peers revealed significantly poorer performance for the ASD and ADHD groups on the order of an average 5.4 dB. Nilsson, Soli, and Sullivan (1994) suggest that every 1 dB is equivalent to approximately 10% speech recognition when testing near threshold. Therefore, children with ASD and ADHD may be recognizing approximately 50% fewer words spoken by the teacher in a noisy classroom as compared to peers when listening at threshold. However, it is important to note that the groups differences will vary given the dynamic nature of typical classrooms where signal-to noise ratios throughout a school day could range from −18 to +5 (Larsen & Blair, 2008; Sanders, 1965). In the classroom from the present study, the signal-to-noise ratios may have varied even more than the aforementioned research because of occasional outbursts from students.

Results of the group comparison are similar to findings in a previous study (Alcántara et al., 2004) where children with ASD had significantly poorer speech recognition in noise thresholds by up to 3 dB when compared to a control group. The larger group difference in the present study as compared to the Alcántara et al. (2004) study is related to the use of multi-talker babble versus other types of noise (i.e., single-talker and speech-shaped noise) used in the previous work. The present and aforementioned investigation clearly highlights the speech recognition in noise deficits experienced by children with ASD and ADHD. In addition, as outlined in the introduction, these auditory behavioral deficits are also observed and reported

by parents and teachers via questionnaires (Ashburner et al., 2008; Mangeot et al., 2001; Tomchek & Dunn, 2007). These auditory difficulties relate, in part, to external auditory stimuli that may be managed and controlled through the use of hearing assistance technology, such as FM systems.

The results of the present study suggest that use of the FM system by the children with ASD and ADHD significantly improved sentence recognition in noise by an average of 5.9 dB as compared to their no-FM system performance. This improvement is particularly large given that only a 1 dB change can improve performance by 10% when listening at threshold levels (i.e., 50% correct level; Nilsson et al., 1994). Moreover, the children's performance with the FM system is statistically comparable to speech recognition of the typically developing group in a no-FM condition. In other words, use of the FM system addressed the auditory limitations in noise faced by the children with ASD and ADHD when compared to typical peers. It is reasonable to assume that the typically functioning participants would also achieve significantly improved speech-in-noise thresholds when using an FM system; however, these children were not tested in the FM condition. Furthermore, they do not show the same deficits in noise experienced the children with ASD and ADHD. Realistically, use of an FM system will not be able to address the global attention problems and sensory deficits faced by children with ASD and ADHD in typical classrooms; however, these results suggest that the FM has the potential to ease listening difficulties in this one sensory area.

Of the most recent publications on FM systems, the Johnston et al. (2009) study most closely aligns with the methods and population tested in the present investigation. When comparing the results of the current study and the Johnston et al. (2009) study, results in the present study are slightly different. The children with auditory processing disorders in the Johnston et al. study obtained worse average thresholds in the no-FM condition (+6.5 dB) and FM system conditions (−4.7 dB) compared to children with ASD and ADHD in the current study in the no-FM (−4.8 dB) and FM system conditions (−10.6 dB). These differing thresholds are likely related to the methods and stimuli used in the Johnston et al. study. Unlike the present study where speech recognition was conducted in a classroom with two loudspeakers, testing in the Johnston et al. study was done in a soundbooth with an array of one signal speaker and four noise speakers beside and behind the participant. Also, speech-shaped noise accompanied the sentences instead of the multi-talker babble used in the present study. Therefore, as suggested above, results of the present study may underestimate the improved speech recognition that could occur with an FM system. However, the testing arrangement used in the present study represents a feasible equipment set-up that may be used in a child's actual classroom during a real assessment.

## 4.2. Classroom observations

Classroom observations were conducted by two independent observers to determine if use of the FM system would improve classroom behavior. A group analysis of the on-task behaviors and behavior codes suggested a significant increase in on-task behaviors as well as a significant decrease off-task behavior categorized under Code 1 and Code 3 (Table 2). These findings reveal that use of the FM system has the potential to improve classroom behavior in children with ASD and ADHD, which may be partially related to the improved signal-to-noise ratio provided to the listener through the FM system. The analysis of the specific behavior codes revealed that use of the FM system resulted in a decrease in the following off-task behaviors: does not follow teacher directions, engages in distractible behaviors, and does not sit quietly. Because the FM receiver did not occlude the ear canal, participants were still able to hear others in the room; however, the intensity of the teacher's voice took precedence relative to other signals. Therefore, the investigators hypothesize that the FM system helped most children to focus on the primary auditory signal from the teacher while deemphasizing less important auditory signals generated from classmates. These findings also support the effectiveness of the device in the classroom and that some of the benefit measured in the speech recognition in noise task (i.e., efficacy measure) may transfer to improved classroom behavior.

## 4.3. Teacher questionnaires

In this initial investigation, the questionnaires were aimed at determining whether the primary teacher observed any changes in levels of education risk or listening behaviors when the FM system was in use. Teacher ratings on the two questionnaires yielded inconsistent findings, with the S.I.F.T.E.R. showing no average change with the FM system and the C.H.A.P.S. showing significant average improvements with the FM system in most listening conditions. These differences may be related to the content within each questionnaire, the short duration of the FM use per day, and the fairly limited FM trial periods. The S.I.F.T.E.R. assesses the teacher's rating of educational risk relative to peers in the areas of academics, attention, communication, class participation, and social behavior. The questions on the S.I.F.T.E.R. focus on performance on academic achievement (e.g., reading level, vocabulary level), general behavioral characteristics (i.e., distractibility, emotional/social regulation), and specific tasks (i.e., completing homework, volunteering information). However, the C.H.A.P.S. assesses the child's level of difficulty and auditory behaviors in specific listening conditions, such as noise, quiet, ideal, multiple inputs, as well as the child's auditory memory sequencing and auditory attention span. In short, the S.I.F.T.E.R. is a more academic/behavioral questionnaire while the C.H.A.P.S. directly evaluates listening difficulties.

Although the FM system did not significantly improve teacher ratings on the S.I.F.T.E.R., a closer examination of the ratings reveals some notable findings. First, over half of the children were at risk or marginal risk in all five areas of the

questionnaire, suggesting that these children have educational problems relative to peers. This finding may not be surprising, given the children's diagnoses; however, this data further supports the needs for additional intervention strategies for children with ASD and/or ADHD. Second, one child did show improved ratings with the FM system on the S.I.F.T.E.R. (details in Section 4.4). This finding might suggest that the FM system has the potential to improve the level of educational risk for some children, especially under different trial conditions. It is possible that several more children would show improved S.I.F.T.E.R. ratings if the FM system was used for longer periods of time during the school day (i.e., >45 min) and/or for a longer trial period (i.e., >5 weeks).

When compared to the S.I.F.T.E.R. ratings, an even higher percentage of the children were rated as "at risk" in every condition on the C.H.A.P.S. As discussed previously, there is ample evidence to suggest that children with ASD and ADHD have listening difficulties, and according to the teacher ratings on this small sample of 11 children, this particular questionnaire is sensitive for identifying these problems. When using the FM system, several children shifted from the "at risk" to the "pass" category; however, the majority of the children remained "at risk" for listening difficulties when using an FM system. Nonetheless, the average improvements in the teacher ratings revealed significantly lessened listening difficulties for the children when using the FM systems in the noise, quiet, ideal, and auditory memory conditions as compared to no-FM system. Therefore, it is possible that the significantly improved speech recognition in noise was transferred to listening behaviors for certain situations in the classroom. The only listening condition that did not result in significant improvements was the multiple inputs category. This finding is not surprising given that the FM system only provided improved signal-to-noise ratio for the teacher's voice and is not used to amplify multiple sound sources. In addition, it is possible that the significance detected in the auditory attention category was due to chance given the smaller effect size. Overall, the significant average improvements on the C.H.A.P.S. combined with the significantly improved speech recognition in noise supports the need for additional research on the benefits of personal FM systems for children with ASD and ADHD in public school settings, with different age groups, and with longer trial periods.

## 4.4. Case example

One child, diagnosed with ASD, had a different pattern of results as compared to the other children in the study. His speech recognition in noise was similar to the other children with an average improvement of 6.5 dB from the no-FM to the FM system condition. In addition, he had substantially poorer no-FM performance (1.75 dB) as compared to the average of the typically functioning peers (−10.25 dB). According the classroom observations, this participant did not show much improvement in on-task behaviors from the no-FM (66.7%) to the FM system (68.4%) condition for the first trial, but showed a large difference between the no-FM (45.7%) and FM system (65.8%) conditions in the second trial period. Similar to the findings of the group analyses of behavior codes, this child had a reduction in the occurrence of Code 1 (5.3% decrease) and slight reduction in Code 3 (2.7% decrease). The teacher questionnaires revealed substantially different teacher ratings when compared to the other participants. First, on the S.I.F.T.E.R., this child improved from fail to marginal for attention and from marginal to pass for communication and class participation with the use of the FM system. The rating shifts represent improvements of two scale scores, on a 5-point scale. Ratings for academics and social behavior did not change. However, the C.H.A.P.S. did not show positive improvements with the FM system. Ratings for this child shifted from the category of pass to fail in the noise, ideal, auditory attention, and total conditions. Ratings for quiet, multiple inputs, and auditory memory conditions did not change. During a brief interview with the teacher, she stated that the student could not adjust to the system on his ear and that it was overly distracting to him. Anecdotally, the examiners noted that this child, in particular, seemed to have greater tactile sensitivities as compared to his peers; however, he stated that he liked to use the system. Following the study, the examiners recommended discontinued use of the FM system for this child under the trial conditions used for the study. Given the potential for the FM system to improve this child's speech recognition and school performance in some areas, a second attempt at FM system use is warranted under different trial conditions. This child may benefit from FM system use during all academic instruction over a period of 4–6 weeks. Extended FM system use throughout the school day might decrease his tactile sensitivities related to the system as well as make the system a part of his daily routine. The examiners hypothesize that, following a longer FM system trial period with this child, the teacher's ratings on the C.H.A.P.S. questionnaire would show improved listening with the FM system because the device would be a regular part of his daily routine (i.e., less disruptive from a routine and sensory aspect).

## 4.5. Study limitations

This study represents a first attempt to implement FM systems into a private school classroom for children with ASD and ADHD. There are several limitations to the present study, which will be addressed in future research. First, the findings in this private school may not extend to children served in the public schools, especially if they are included in classrooms of typically functioning peers. In an inclusive education classroom, use of the FM system could have social consequences, as the child with ASD or ADHD may be the only child using special equipment. However, it is highly unlikely that the child will be the only one using assistive technology given the number of children receiving special education and using various types of equipment in the classroom.

Second, no control group of children with ASD and ADHD from the same private school was included in this study. The private school only had one classroom per grade level, which did not allow for use of a control group of students who were the same age. In addition, another classroom would represent a different population of children also with various learning differences. However, the use of within-subjects design in the present study resulted in each student serving as his or her own control through two different FM system trials as well as periods of time before and after each trial to evaluate no-FM system performance. In addition, the typically functioning peers served as a control/comparison group to the children in this study for the speech recognition measures. Third, the children only used the FM system for a short period of time each day (i.e., 45 min) and only for 2 and 3-week trials. The FM system may provide even larger effects on the questionnaires when it is used for a several hours per day over a longer trial period. In addition, longer trial periods may decrease adverse sensory difficulties found in some children with ASD. Fourth, the participants did not receive full audiological evaluations just prior to the study; therefore, it is possible that the typically functioning group had better hearing thresholds than the children with ASD and ADHD. The examiners do not believe this is the case, however, because all children passed recent school hearing screenings, and parents of the children with ASD and ADHD reported normal hearing according to previous audiological evaluations. Fifth, differences in speech recognition between the two groups may have been partially related to the children's levels of expressive and receptive language and cognitive functioning. While this is certainly a possibility, it is not likely given the fact that, when using FM systems, the children with ASD and ADHD performed similar typically functioning group. In other words, if these developmental and linguistic factors were playing a large role in the speech recognition deficits of the children with ASD and ADHD, simply improving the signal-to-noise ratio (via FM system use) would not increase their performance to the level of typical peers. Finally, only one teacher provided ratings of educational risk level on the S.I.F.T.E.R. questionnaire and ratings of listening difficulty on the C.H.A.P.S. questionnaire, and it is possible that this teacher had bias for or against personal FM use. Additionally, it is possible that this one teacher exaggerated the modest improvements realized by most of the students. However, these improvements were also supported by the results of the speech recognition measures and classroom observations. Replication studies will lend further support to the validity of the results from the questionnaire.

## 5. Conclusion and clinical implications

The FM system significantly improved speech recognition in noise of children diagnosed with ASD and/or ADHD when compared to a no-FM system condition. Typically functioning children had significantly better no-FM performance than the children with ASD and ADHD; however, use of the FM system provided improvements in speech recognition to the level of performance of the typically functioning peers. Two independent observers recorded a significant increase in on-task behaviors when the FM system was used by the children with ASD and ADHD in two separate trial periods, and off-task behaviors relating to inattention and distractibility significantly decreased when the FM system was used. Teacher questionnaires revealed that, on average, use of the FM system improved teacher ratings related to auditory listening behaviors on the C.H.A.P.S. questionnaire but did not change ratings related to educational risk on the S.I.F.T.E.R. questionnaire. Informal questionnaires given to the teachers and the participants yielded positive reports about the FM system and validated the FM benefit found in the speech recognition measures, observations, and formal teacher questionnaires. Overall, the two FM system trials yielded positive results for most of the children with ASD and ADHD, and as a result, future research is warranted to examine potential benefits of FM system use for children with ASD and ADHD in other school environments.

Although much of this initial investigation focused on average improvements in speech recognition, classroom behavior, and teacher ratings, determining the need for an FM system for a child with ASD and ADHD should be done on an individualized basis. As shown in this study, some children will show more FM system benefit than others, especially according to the teacher questionnaires, and some children will have tactile sensitivities that may interfere with potential benefit from an FM system. An evaluation to determine FM system candidacy should include audiological components, such as a full hearing evaluation and speech recognition in noise testing, as well as a functional evaluation in the child's customary environment. In our functional evaluations, we include a trial with the FM system, teacher questionnaires, a classroom observation to determine on- and off-task behaviors with and without the FM system, teacher and student interviews, and a review of the child's special education file or previous test results. The combination of the audiological evaluation, speech recognition testing, and functional evaluation will provide a well-rounded view of the potential FM system benefit that may be achieved by an individual student who is diagnosed with ASD and/or ADHD.

## Acknowledgments

## Conflict of Interest Statement

The authors reported no conflicts of interest with the research described in this article.

## Appendix

Overview of week-long education period conducted prior to study.

| Day | Activity |
|---|---|
| Day 1: Introduction | Provided folder with handouts: introduction to personnel with pictures and simple overview of FM receiver insertion and function |
| Day 2: Social Story 1 | Handout with photo of FM receiver: social story read aloud by examiner while using FM system. Children asked to hold one FM receiver up to ear during story. Wearing My FM System – "Starting this semester, I am going to wear an FM system during Math. One part of my FM goes over my ear and the other part goes in my ear. If it does not feel right, I will ask my teacher for help. I will put it on before Math class and take it off after Math class" |
| Day 3: Social Story 2 | Handout with photo of FM receiver: Social story read aloud by examiner while using FM system. Children asked insert one or both FM receivers, if comfortable. How My FM is Helping Me – "When I am in Math, I will wear my FM system. FM systems help students to hear the teacher more clearly. My teachers think the FM system will help me to concentrate and understand, but no one has ever done this before. To see if it works, sometimes my FM system will be turned on and sometimes it will be turned off. My teachers want to see how well I can listen and do my work when it is on or off. My FM system is not too loud and it is comfortable to wear" |
| Day 4: Video Model | Video model: Children watched video created by investigative team of 12-year-old child talking about using her FM system. Children asked insert one or both FM receivers, if comfortable, and FM transmitter plugged into audio for DVD player. In the video, Caitlin, a 12-year-old girl talked about how to put on her FM receiver each day, how the FM receiver worked with the teacher transmitter, how the FM helped her to hear the teacher during class, and how to put the FM receiver away at the end of each day. The video also shows scene of teacher wearing the FM transmitter during instruction and Caitlin sitting at her desk listening with the FM receiver |
| Day 5: Listening Game | Informal Simon Says game led by examiner who sabotaged speech signal by turning back, whispering, and going out of room. Transmitter worn by examiner; children asked to insert both receivers, if comfortable |

*Note.* FM = frequency modulation.

## Continuing education

CEU questions

1. Why was a personal FM system selected for this study?
   a. Personal FM systems provide a more consistent signal to each of the child's ears
   b. Personal FM systems portable and can be used in different classes or therapy rooms
   c. The volume or gain of each FM receiver may be programmed
   d. When multiple transmitters are available, personal receivers allow for different teacher-transmitted channels, within the same classroom, for small groups
   e. All of the above
2. What components were included in the week-long education period about the FM systems?
   a. Overview of FM receiver insertion and function, social stories, video modeling, and sabotaged Simon Says game
   b. Social stories and direct therapy
   c. Video modeling and live peer demonstration
   d. Sabotaged Simon Says game, direct therapy, and live peer demonstration
   e. Direct therapy and applied behavioral analysis
3. When no-FM system was in use, how much worse on average in dB did the children with ASD and/or ADHD perform on speech recognition in noise tasks relative to typically functioning peers?
   a. 2.3 dB
   b. 3.2 dB
   c. 4.5 dB
   d. 5.4 dB
   e. 10 dB

4. On average, the children with ASD and/or ADHD experienced improved average speech recognition in noise by how much in dB when using the FM system?
   a. 3.7 dB
   b. 5.9 dB
   c. 8.4 dB
   d. 10.2 dB
   e. 12.7 dB
5. What is the acronym for the teacher questionnaire used in this study that measured significant improvements in auditory behaviors when using the FM system?
   a. S.I.F.T.E.R.
   b. L.I.F.E.
   c. C.H.A.P.S.
   d. ELF
   e. C.H.I.L.D.

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