Verification and Validation of Remote-Microphone Technology on Children and College-Age Adults who have Autism Spectrum Disorder

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ABSTRACT

Children and young adults who are diagnosed with autism spectrum disorder (ASD) often perform significantly poorer on speech recognition tasks in noise when compared to neurotypical peers due to abnormal auditory processing. Multiple studies support the use of open-ear remote-microphone (RM) technology to address the deleterious effects of noise. However, given the common sensory issues in this population, special considerations are necessary for an appropriate device fitting. As a result, the goal of this study was to examine data from a three-step, evidence based approach to RM system fitting, verification, and validation in 22 children and college-age adults who are high-functioning and have a diagnosis of ASD. During laboratory-based testing, the 22 participants completed the fitting and verification procedures while using non-occluding open-ear digital RM receiver. Twenty of the participants completed a 12-week trial period with the technology as well as pre-post speech-in-noise testing and questionnaires. Educational need for RM technology was documented with speech recognition and qualitative measures; these same measures validated the fitting following a trial period with RM technology. The real ear measures used to fit the RM technology confirmed that an appropriate fitting within approximately 5 dB of prescriptive targets is possible with the device used in this study. Overall, the three-step approach will provide the evidence necessary to gain access to RM technology in the schools for individuals with ASD, confirm an appropriate fitting, and validate the benefit of the device.

INTRODUCTION

Children and adults who have normal hearing sensitivity, but are diagnosed with autism spectrum disorder (ASD) demonstrate abnormal processing of complex sensory stimuli in multiple domains including auditory, visual, tactile, smell, and taste (Tomcheck & Dunn, 2007; Ashburner, Rodger, & Ziviani, 2008). Auditory-specific processing issues experienced by 70-100% of individuals with ASD include filtering (underresponsiveness and overresponsiveness), attention, distractibility, responding, and poorer speech recognition in noise as compared to neurotypical peers (Alcántara, Weisblatt, Moore, & Bolton, 2004; Ashburner et al., 2008; Rance, Chisari, Saunders, Rault, 2017; Rance, Saunders, Carew, Johansson, & Tan, 2014; Schafer et al,, 2013; Tomcheck & Dunn, 2007). Temple Grandin (1992), an adult who has ASD and is an advocate for ASD communities, summarizes her processing difficulties (1992): “My hearing is like having a hearing aid with the volume control stuck on ‘super loud’. It’s like an open microphone that picks up everything. I have two choices: turn the mike on and get deluged by sound, or shut it off.”

Although few clinical audiologists are currently fitting hearing technology on individuals with ASD, open-ear remote-microphone (RM) technology that is designed for individuals with normal hearing has the potential to greatly improve auditory function in this population. Multiple studies suggest that, in children with ASD, use of RM technology at home, school, and in everyday situations significantly improves speech recognition in noise, auditory comprehension, on-task behaviors in the classroom, parent-rated auditory function, physiologic stress levels, and self-perceived listening abilities (Rance et al., 2014, 2017; Schafer et al., 2013, 2014b, 2014c, 2016, 2019). In addition, individuals with ASD that underwent intense auditory training and used RM technology for 12 weeks showed significant changes in auditory behavioral performance and in auditory electrophysiological responses (Schafer et al., 2018; Gopal et al., 2019).

Rationale

Given the specific auditory needs and tactile sensitivities in many people who have ASD, appropriate methods for fitting and validation are critical to ensure an individualized RM-technology fitting and to document benefit from the device. In particular, we propose a three-step, evidence-based approach that can be used to (1) document educational need for RM technology, which will be required to include this assistive technology in a child’s Individualized Education Program at school (IEP; Individuals With Disabilities Education Act, 2004), (2) refine the RM technology fitting and verification procedures for children with ASD as compared to a previous investigation (Schafer et al., 2014a) and (3) examine multiple strategies that may be used to validate individual benefit from the device.

METHODS

Participants

Study participants included 22 children and college-age adults, ages 7-21 years old (M =14;9 years; SD =5;3), with a formal diagnosis of ASD per parent report. Additional information about the participants is provided in Table 1. Participants had normal air conduction hearing thresholds of at least 15 dB HL in each ear from 250 to 8000 Hz. A hearing screening was conducted rather than obtaining traditional hearing thresholds due to the levels of cooperation of the participants. Participants were recruited by distributing flyers to clinics within the community.

Table 1. Demographic Information about Participants

Participant	Age	Sex	Other Disabilities
1	9;6	F	ADHD, APD
2	21;8	F	ADHD, anxiety disorder
3	21;9	M	ADHD
4	21;5	F	ADHD
5	7;11	M	ADHD, language disorder, anxiety disorder
6	16;8	M	ADHD, learning disorder
7	10;3	M	None reported
8	12;0	F	SLI, language disorder
9	20;8	M	Suspected syndrome
10	20;6	M	ADHD, APD, learning disorder
11	16;4	F	anxiety disorder
12	10;2	M	None reported
13	23;5	F	ADHD, depression, anxiety disorder
14	9;5	M	None reported
15	15;5	M	None reported
16	8;10	M	ADHD, language disorder, apraxia, APD
17	15;2	M	Language disorder, learning disorder
18	10;11	F	ADHD, anxiety disorder
19	10;11	M	APD
20	9;1	F	language disorder
21	17;2	F	ADHD, language disorder, anxiety disorder
22	15;11	M	ADHD, language disorder, anxiety disorder

Note. ADHD=attention-deficit hyperactivity disorder; APD=auditory processing disorder. For this study, adult performance is defined as $\geq$ 14 years.

Equipment

Each participant was fit with bilateral Phonak Roger Focus receivers, size 0 to 2 slim tube, and small domes. The receivers were synched to a Roger Pen transmitter. Adjustments to the receiver volume were made with a Phonak Roger inspiro transmitter, which was synched to the receivers when adjustments to receiver volume were necessary. To verify that the fitting was appropriate for the participants, real-ear to coupler difference and speech-mapping was conducted on each ear using the Audioscan Verifit 2 as measures of verification.

Procedures

This study was approved by the University of North Texas Institutional Review Board. Before testing ensued, an informed consent form was signed by the parent or participant as well as a child assent form for participants less than 18-years-old. Participants were required to pass the hearing screening as well as a non-verbal intelligence test (i.e., IQ of > 70).

Determining Educational Need

Following the three-step approach proposed in the rationale, the first step was to determine educational need for hearing technology with behavioral and qualitative measures that were feasible to administer in an audiology clinical or educational setting. Behavioral speech-in-noise thresholds were assessed in cooperative participants using the recorded version of the Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN) test (2005) calibrated to 60 dBA. This test estimates a person's speech-in-noise threshold at the 50% correct level. Participants also completed the student version of the Listening Inventory for Education – Revised Student Appraisal (Student L.I.F.E.; Anderson, Smaldino, & Spangler, 2011), where participants rate their classroom listening abilities as compared to peers on a scale of 5 (always easy) to 1 (always difficult). Parents of children less than 14 years of age and participants greater than 14 years of age were asked to complete the auditory subtest of the Child Sensory Profile 2 (Dunn, 2014) and the entire Adolescent/Adult Sensory Profile (Brown & Dunn, 2002), respectively. Parents or older participants who were not accompanied by a parent were asked to complete a case history form, which included a checklist (Table 2) of reported listening difficulties (Schafer et al., 2019). The use of multiple measures offers multiple assessments to examine potential listening difficulties in various situations.

Table 2. Parent- or Participant-Reported Listening Difficulties

Difficult Listening Situation	Participant Number
In most situations	1,2,4,8,10,13,15,19,20,21,22
In small groups	8,10,13
In large groups	2,5,7,9,10,11,13,14,16
In the classroom	2,5,7,8,9,10,13,14
At parties	2,4,5,9,10,11,13,14
In restaurants	2,5,8,9,10,13,14
In other social situations	2,4,10,11,13,14,16
Listening Problems	
Paying attention	1,2,3,4,5,7,8,9,12,13,14,15,18,20,22
Confused in noisy situations	1,2,5,7,8,9,11,14,15,16,17,18,19,21
Sensitive to loud sounds	1,2,3,4,5,6,7,8,9,11,15,16,17,19,20,21,22
Difficulty sitting still	2,4,5,9,10,11,15,20,22
Often daydreams	1,2,3,4,8,10,11,12,13,14,15,18,20,22
Prefers to play/do activities alone	2,4,8,9,11,14,15,16,19,21
Shy and anxious	2,7,8,10,13,15,16,18,20.22
Does not complete assignments	1,2,8,9,14,18,20,22
Easily distracted	1,2,3,4,5,7,8,9,11,12,13,14,15,18,20,22
Difficulty following directions	1,4,7,8,9,10,13,14,15,18,19,20,21,22
Easily upset by new situations	1,2,4,6,8,10,15,16
Impulsive	2,3,5,6,9,10,11,15,20,22
Often asks for repetition	1,2,4,7,8,10,14,15,20,22
Yelling or rowdy behavior	7,10,20,22
Lacks self confidence	2,4,6,8,10,11,12,13,15,16,17
Easily frustrated	1,2,3,4,5,6,7,8,9,10,11,14,15,16,17,18,19

Fitting and Verifying the RM Technology

The second step was to obtain two real-ear measurements that we propose when fitting the Roger Focus receiver to individuals diagnosed with ASD. All 22 participants (43 ears) completed the fitting and real-ear verification portions of the investigation during the initial testing session. One participant would only tolerate the real-ear measures on one ear. The primary goals of the fitting with the Audioscan Verifit 2 were to (1) individualize the fitting by adjusting for the real-ear-to-coupler difference (RECD) and (2) ensure that the output from the receiver, as measured in the ear, met the Desired Sensation Level (DSL) v5 prescriptive targets (2005). To begin real-ear measurements, “Speech-map” was chosen from the given list provided on the Audioscan Verifit 2. Measurements were obtained using DSL v5 - Child targets and inserts + foam for the HL transducer. “On-ear” was selected as the mode, and “FM” was selected as the instrument. The participant’s chronological age was selected, and flat 15 dB HL hearing thresholds from the hearing screening were entered for both ears. After insertion of the probe-tube into the ear canal and coupling of the RECD transducer to the foam eartip, the real-ear response curve and RECD were obtained for both ears, as tolerated.

Following the RECD measurement, “on-ear” was selected for the mode, and “FM” was selected for the instrument. The first measurement was obtained by inserting the probe microphone into the participant’s ear. The FM receiver was, then, placed on the ear, and the Roger Pen was placed inside the sound chamber with the receiver microphones facing the reference microphone. A real-speech input, which is appropriate for a chest-level transmitter microphone (i.e., 84-dB sound pressure level [SPL]), was used to measure the output of both receivers at 1000, 2000, 3000, and 4000 Hz. If the average DSL targets at 1000, 2000, 3000, and 4000 Hz were not met within 2 dB, the volume of the receivers was adjusted using the inspiro transmitter, and the receivers was, then, re-synched to the Roger Pen. This procedure was replicated until the average output was as close as possible to the targets at 1000, 2000, 3000, and 4000 Hz. It is important to note that frequency-specific adjustments are not possible on the Roger Focus, so the final volume level that was used for the study was the level that resulted in the smallest difference between the targets and measured output.

In contrast to a previous study on children with ASD (Schafer et al., 2014a), RECD was measured in the present study. Also, in the present study, maximum power output (MPO) was not measured because results of the previous study showed (1) that the MPO with a similar receiver never exceeded and was often substantially lower than the children’s estimated uncomfortable loudness level, and (2) that the children reported the settings determined via real ear measures to be comfortable when listening to speech in the presence of background noise according to loudness ratings. In addition, the maximum output value of the Roger Focus receiver coupled to the SlimTubes is a conservative 80 dBA free field equivalent.

Validation Measures

All participants were asked to use the system at home and at school during a 12-week trial period. After the trial, the L.I.F.E questionnaire was repeated, and cooperative participants were asked to complete percent correct speech recognition in noise with and without the RM technology using fixed-intensity stimuli from the BKB-SIN. The examiner presented the monitored live-voice speech stimuli at 65 dBA from a head-level loudspeaker located 0 degrees azimuth in the soundbooth, and the associated noise from the compact disc was presented at 70 dBA from a head-level loudspeaker located at 180 degrees azimuth (-5 dB signal-to-noise ratio [SNR]). A challenging SNR was used to simulate listening in a noisy classroom (Knecht et al, 2002; Cruckley et al, 2011). In the RM technology condition, the examiner wore the talk-over microphone and the transmitter microphone (6 in from mouth). In addition, after the trial period, the L.I.F.E. and Sensory Profile questionnaires were repeated.

RESULTS

Documented Educational Need

A summary of the performance on the behavioral and qualitative test measures is provided in Table 2. All participants showed listening difficulties on at least one measure, and all but two showed difficulty on two measures. Eleven of the participants showed poorer-than-expected performance on three or four of the measures.

Table 3. Performance Across Measures to Assess Educational Need

Participant	BKB-SIN	Student L.I.F.E.	Sensory Profile	Difficulty Checklist
1	–	–	–	–
2	–		–	+
3	+	+	+	–
4	–	+	–	–
5	–	–	+	–
6	–	–		+
7	–	–	–	–
8	–	–	–	–
9	+	–	–	–
10	+	–	–	–
11	–	–	–	–
12	+		–	+
13	+		–	–
14	+	–	–	–
15	–		+	–
16	–	–	+	–
17	–		–	+
18	+		–	–
19	+	–	–	+
20	+	–	+	–
21	–	–	–	+
22		–	+	–
Average	0.73	45.8	25.6	10.4 problems
SD	2.6	13.7	5.7	3.8

Note. + = normal or better-than-expected performance using test manual; – and shaded = worse-than-expected performance. Lower performance on the L.I.F.E. was defined as at least some listening challenges. Lower performance on the Child Sensory Profile 2 questionnaire was defined as at least one SD below the mean raw score; on the Adult/ Adolescent Sensory Profile, at least two of four abnormal quadrants (i.e., rating of more or much more than most people). On the parent/participant checklist poor performance was defined as reported listening problems in at least one-third (8/23) checklist items (Table 2). Empty cells indicate missing data.

Verification of RM Technology

All 22 participants (43 ears) completed RECD and real ear measures to attempt to meet DSL targets. As shown in Figure 1, the examiners were able to meet the target within a few dB with the greatest difference at 2000 Hz.

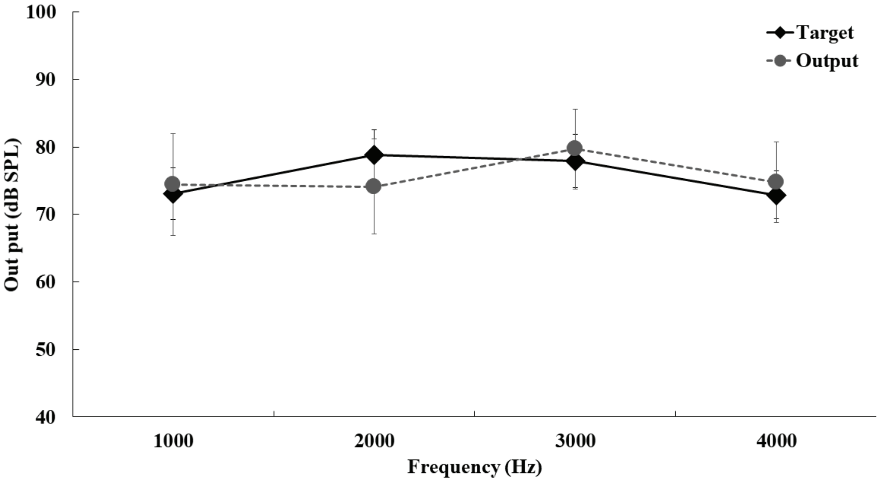

Figure 1. Average Desired Sensation Level prescriptive target and measured output from the RM technology.

To determine if there was a significant average difference between the targets and the output (condition), a two-factor repeated measures analysis of variance (RM ANOVA) was conducted. The analysis revealed no main effect of condition (*F* [1, 344] = .01, *p* = .94), but a significant main effect of frequency (*F* [3, 344] = 75.1, *p* < .0001) as well as an interaction effect between condition and frequency (*F* [3, 344] = 32.0, *p* < .0001). Post-hoc analyses of the main effect of frequency with the Tukey Kramer Multiple Comparisons Test suggested that all frequencies resulted in different output with the exception of 1000 and 4000 Hz. The post-hoc analysis on the interaction effect yielded no significant average difference between target and output for 1000 Hz (*p* > .05) but significant average differences for 2000 Hz (4.8 dB), 3000 Hz (1.9 dB), and 4000 Hz (1.8 dB) (*p* < .05). Despite the average differences, the Speech Intelligibility Index for average speech is at or above 94% for every ear.

Validation

Twenty of the 22 participants completed the trial period, and with the exception of one participant, completed at least two post-trial measures: percent correct speech recognition in noise, the student L.I.F.E., and the Sensory Profile (Table 4).

Table 4. Post-Trial Performance Changes Across Measures

Participant	BKB-SIN	Student L.I.F.E.	Sensory Profile
1	+	+	+
2	+		+
3	+	–	
4	–	–	
5	+	+	–
7	+	+	+
8	+	+	–
9	+	–	
11		–	+
12	–		+
13	+		
14	–	+	+
15	–		–
16	+	–	–
17	+		
18	+		+
19	–	–	+
20	+	+	–
21	+	+	+
22	+	–	

Note. + and shaded = improvement relative to initial measurement; – = no improvement. Notable changes include at least 10% improvement on the BKB-SIN, at least 8 scale scores on the L.I.F.E., and a change of at least one rating category on the Sensory Profile. Empty cells indicate missing data due to lack of cooperation.

Nineteen of the 22 participants were able to complete the speech recognition in noise testing with and without the RM technology. As shown in Figure 2, the average performance improved by 29%, and according to a one-factor RM ANOVA, this improvement was significant (*F* [1, 38] = 22.4, *p* < .001). When examining the individual data, 14 of the 19 participants experienced improvements ranging from 10% to 80% with the remaining participants showing limited or no improvement.

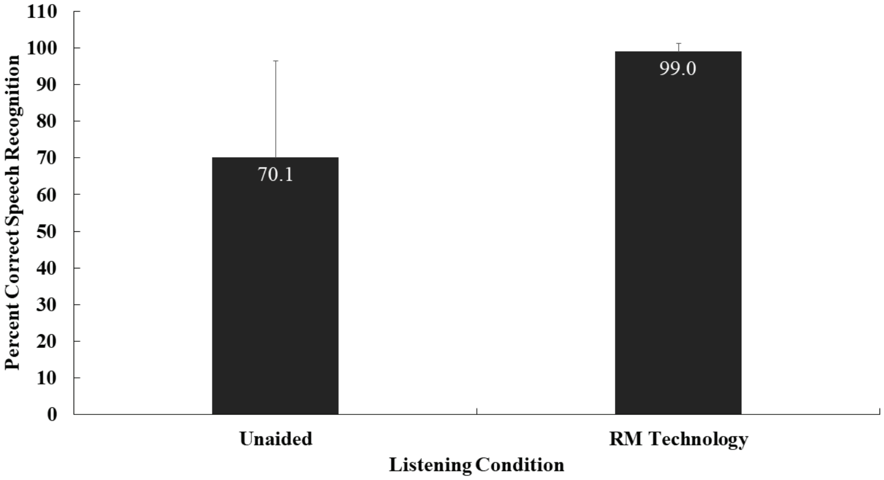

Figure 2. Average speech recognition performance in noise with and without RM technology.

Fourteen participants completed the post-trial L.I.F.E. with reported improvements by seven. On average, the rating changes were significant (*F* [1, 28] = 5.0, *p* = .04). Fourteen participants completed the Sensory Profile with improved ratings reported by nine individuals. Raw scores on the auditory processing section may be calculated on the Child Sensory Profile 2 (Pre-trial Mean=25.6, SD=5.7; Post-trial Mean=20.9, SD=5.8); on average, the rating changes for the 11 children were significantly better (*F* [1, 22] = 13.4, *p* = .004). When examining improvements across the measures, all but one participant improved on one measure and nine participants improved on one or more measures.

DISCUSSION & CONCLUSIONS

This study provided evidence to support the use of a three-step approach to (1) document educational need, (2) fit and verify RM technology in children and college-age adults with ASD, and (3) validate that the device provides benefit. The speech recognition and qualitative measures were able to document expected listening difficulties and educational need for RM technology in the classroom (Table 4). This evidence could easily be collected from a clinical or educational audiologist. Prior to the trial period, RM technology was fit using an objective approach that adjusts for ear canal volume and ensures appropriate output for conversational speech. Although the output of specific frequencies could not be adjusted, overall, the fittings met target within 5 dB SPL, on average. After the RM technology trial, the benefit from the device was validated by noteworthy improvements for most participants on at least two of the measures (Table 4). Previous investigations have utilized additional test measures and questionnaires (e.g., Rance et al., 2014; Schafer et al., 2013, 2014b, 2016) that would likely be sensitive for evaluating pre-post benefit from RM technology. Overall, given the common auditory sensitivities and poor auditory processing in individuals with ASD, RM technology is an important consideration. The proposed three-step approach will ensure a well-controlled and evidence-focused fitting, verification, and validation of RM technology on individuals with ASD.

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