LISTENING DIFFICULTY IN CHILDREN WITH AUTISM SPECTRUM DISORDER: EVALUATION AND INTERVENTION

By

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DEDICATION

To my mother, Janet Patton, who used our time together, although much too short, to encourage to me to always pursue my dreams. And to her sister, Sudie Smith, who picked up right where she left off.

To my dad, Brian Patton, who has always believed I can accomplish anything I set my mind to.

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OVERVIEW

My program of research has focused on the identification of listening difficulties (LiD) in children with Autism Spectrum Disorders (ASD) and language impairments, and on the possibility of using Remote Microphone (RM) systems as an intervention for LiD in these children. The overall premise of this work is that listening is a critical skill for the development of functional language and that listening deficits, characteristic of some children with ASD, are a risk factor for atypical language development. Research in this area has been limited by the lack of psychometrically sound measures of LiD that are valid for use in children with ASD, and also by a focus on older children with ASD who do not have comorbid language impairments. In this dissertation, I describe my program of research which was designed to begin to address some of these gaps in the literature.

The present work had four aims: (i) to develop a reliable, stable, and valid parent report measure of listening behavior designed for children with ASD, (ii) to examine the relationship between listening and language ability in ASD, (iii) to evaluate the effect of improving signal to noise ratio (SNR) by using RM systems in preschool-aged children with ASD and language disorder, and (iv) to investigate the effect of improving SNR by using RM systems on minimally verbal school-aged children with ASD.

In Chapter 1, I review the literature on the conceptualization, measurement, and treatment of LiD outside of ASD as a way to guide the development of my research on listening in ASD, and then review the literature relevant to listening deficits in ASD with a focus on the specific gaps in this literature that motivates my research. Chapter 2 of this work describes the development of a parent-report measure of listening behavior designed for children with ASD and examines the hypothesis that listening is related to language ability in ASD. In Chapter 3, the effectiveness of a soundfield RM system was studied in 10 preschoolers with ASD in the classroom setting. In Chapter 4, a soundfield RM system was used in the laboratory setting with 14 children with ASD and severe language disorder. Finally, in Chapter 5, a summary of the findings of the studies in these projects is presented, and the implications of these findings for future research and practice are discussed.

CHAPTER 1

Introduction

1.1 Listening Difficulty

Listening difficulty (LiD) is defined as developmental difficulty in listening despite the presence of normal hearing; this difficulty is often exacerbated in noisy environments (Magimairaj et al., 2020; Moore et al., 2020). Symptoms of LiD include asking for verbal repetition, difficulty following spoken instructions, difficulty modulating attention, and an increased level of distractibility in noisy environments (Magimairaj et al., 2020; Sharma et al., 2014). Listening challenges despite normal hearing have been characterized by some as auditory processing disorder (APD), however, this diagnosis has not gained universal acceptance, so we have made the decision to refer to the group of symptoms using the more generic and non-diagnostic term LiD (Moore et al., 2020).

Listening is a critical skill for everyone, but especially for children, as language development relies on the adequate listening to and processing of quality language input (Rost & Candlin, 2014; Zimmerman et al., 2009). Studies have shown that children have poorer speech-in-noise recognition skills than adults and thus require a higher speech-to-noise ratio (SNR) to adequately listen to verbal input (Stuart, 2008). Because adequate listening is required to absorb critical language input, listening could also be crucial for proper language development. Thus, LiD could interfere with the quality language input that is necessary for children to develop language in a typical fashion. Studies have shown that prolonged LiD can have a negative impact on children's academic and reading development (Dodd-Murphy and Ritter, 2012, Sharma et al., 2009; White-Schwoch et al., 2015).

Additionally, LiD can negatively impact social-communication function, as good listening skills are necessary for adequate social communication in acoustically challenging environments such as restaurants and classrooms (Pang et al., 2019; Phatak et al., 2019). If an individual is not able to adequately listen to communicative input, it will be difficult to respond and participate appropriately.

1.1.1 Listening is Multifactorial

Established theoretical models conceptualize listening as multifactorial in nature and impacted by a variety of components including auditory processes, attentional processes, and sensory sensitivities (Magimairaj et al., 2020). Based on these models, LiD can be conceptualized as a deficit in one or more of these components that contribute to listening performance.

Auditory processing factors that can impact listening ability include lateralization and localization of sound, auditory discrimination, and temporal processing (ASHA 2005; Magimairaj et al., 2020; Magimairaj & Nagaraj, 2018). There are established links between these auditory processing deficits and LiD. Children with auditory processing deficits have long been shown to have difficulty listening, especially in environments that are not acoustically favorable (Smoski et al., 1992). In a 2014 study of 10-15 year old children with LiD, Sharma et al. found that the LiD group demonstrated significantly poorer performance, compared to the control group, on tests of auditory processing including the Frequency Pitch Pattern Test (FPT) and a masking level difference (MLD) task. This relationship between LiD in children and reduced auditory processing skills supports the hypothesis that auditory processing is an important factor contributing to listening skills.

Attentional processes are also thought to contribute to listening performance (Zhang et al., 2012). A 2006 study examined the auditory attention in the presence of auditory masking in 23 children and 10 adults with normal hearing (Wightman et al.). Results indicate that children demonstrated significantly reduced ability to use auditory attention to accurately detect a speech signal in the presence of informational masking compared to adults. Informational masking occurs when unwanted sounds compete with the target sound (Kidd et al., 2008). Children's performance was not improved when a video of the speaker's mouth was presented along with the auditory signal. This indicates that children have significantly poorer auditory attention skills compared to adults, and that developmentally immature attention skills can negatively impact their ability to listen in noise.

The influence of sensory perception/processing on listening is one that remains unclear. Although it has been thought that abnormal sensory processing might play a part in auditory processing deficits, the results of recent studies have shown otherwise. A review of sources of pathology that underly listening deficits in children (Moore, 2015) concluded that auditory processing difficulties are more likely caused by cognitive or attention deficits as opposed to sensory processing deficits. Additionally, a study by Moore (2012) cited the lack of listening measures as a barrier to identifying any definitive relationship or lack thereof between listening and sensory processing. Although sensory processing may not be a challenge for the average listener, it could be a point of concern for individuals with co-morbid conditions such as intellectual and developmental disabilities. It is notable that children with diagnoses that exhibit LiD, such as autism spectrum disorder (ASD) and attention deficit hyperactive disorder (ADHD) also demonstrate and increased incidence of sensory processing difficulties (Panagiotidi, et al., 2018; Tomcheck & Dunn, 2007.

1.1.2 Measurement of Listening

Studies of listening have used a variety of measurement approaches to study effects of acoustic environment (e.g. noise level) on listening performance. Objective measures can use physiological or neural markers. Physiological markers include measurement of cortisol levels or heart rate while listening (Rance, 2017). Neural markers, like functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) show how and where the brain activates while listening to auditory stimuli (Moore et al., 2020). These methods of measuring listening are advantageous because they are objective in nature, they are psychometrically sound, and they can be tailored specifically to the factor of interest (e.g., auditory attention). However, these methods also have drawbacks. They are less easily used in clinical settings, and they only measure one factor in the multifactorial process of listening.

There are also existing subjective measures of listening components, which usually rely on caregiver or self-report. These measures include the Listening Inventory for Education – Revised (LIFE-R; Anderson et al., 2011), the Children's Auditory Performance Scale (CHAPS; Smoski et al., 1998), and the Children's Home Inventory for Listening Difficulty (CHILD; Anderson & Smaldino, 2000). While these tests are less objective, they permit measurement of a variety of factors that contribute to listening (e.g., academic performance, on-task behavior, sensory perception) and are more easily administered in clinical settings.

1.1.3 Intervention

Studies have shown that listening-focused interventions, such as remote microphone (RM) systems improve listening performance in noisy settings as measured by both objective measures and multifactorial caregiver or self-report measures (Crandell et al., 2001; Mendel et al., 2003; Stavrinos, 2020; Zanin & Rance, 2016). RM systems work by improving the signal-to-noise ratio (SNR) by amplifying the signal (often a speaker's voice) so that it is more audible compared to the background noise that is present in the environment. RM systems utilize a microphone located on or near the speaker of interest and transmit the signal to a receiver (either a speaker [soundfield RM system] or an ear-level device [personal RM system]).

1.2 Listening in Autism Spectrum Disorder

Listening performance has clinical significance for children with ASD as hallmarks of a diagnosis of ASD include social-communication deficits and atypical language development. Social-communication deficits and atypical language development are two possible consequences of listening difficulties (Krijger et al., 2020; Magimairaj et al. 2020; Zimmerman et al., 2009). Additionally, atypical reactions to auditory stimuli are often noted in children with ASD. By way of example, a gold-standard screener for ASD, the Modified Checklist for Autism in Toddlers – Revised (MCHAT; Robins et al., 2014), asks caregivers to report if they have ever suspected that their child was deaf, because parents often suspect hearing loss in their children with ASD who have normal hearing due to their unusual reactions to sound (e.g., seeking out unusual noises, hyper- or hypo-reactivity to sound; Tharpe et al., 2006).

Because listening is a multifactorial process, which includes auditory processing abilities, attention, and sensory perception, studies have investigated the different components of listening in the ASD population. Auditory processing abilities have been studied at length in children with ASD, as deficits in auditory processing often appear to co-occur with ASD. A 2012 systematic review of the literature on auditory processing and ASD found that children with ASD exhibit substantial auditory processing deficits on both behavioral and neurological measures ranging from atypical sensory perception to speech recognition in noise (O'Connor).

Auditory attention has also been studied in children with ASD. Attention deficits have been noted in children with ASD dating back to the earliest identification of the disorder (Kanner, 1943). More recent works have focused specifically on auditory attention in ASD. A study by Whitehouse and Bishop (2008) found that some children with ASD “switch off” to speech sounds. The study used a sample of 15 children with ASD and 15 typically developing (TD) children. Children were recorded via EEG while responding to sounds in two oddball conditions in which repetitive “standard” sounds (condition 1: vowel; condition 2: complex tone) were replaced with a deviant sound (vowel sounds) and a novel sound (800 Hz complex tone). Event-related potentials (ERP) were calculated. The researchers found that when children with ASD are not attending to sounds, they had attenuated ERPs to speech. They concluded that children with ASD allocate attention to speech sounds differently than TD children.

Sensory perception difficulties have been well documented in individuals with ASD. A study by Jones et al. (2009) investigated the potential link between auditory sensory differences and auditory discrimination abilities in 78 adolescents with ASD and 48 TD adolescents. Participants completed auditory discrimination tasks consisting of frequency discrimination, intensity discrimination, and duration discrimination. Participants also reported sensory symptoms via the Adolescent/Adult Sensory Profile (Brown & Dunn, 2002). Results showed that atypical sensory reactions were related to increased auditory sensory behaviors in the ASD group. The researchers concluded that individual differences in auditory discrimination abilities may influence auditory sensory behaviors in individuals with ASD.

Despite these documented deficits in specific components of listening in children with ASD, and their potential clinical significance, LiD has been significantly under-studied in this population. It is especially important to consider the role of listening in children with ASD because of the potential relationship between listening and language development (Paul et al., 2007, Schwartz et al., 2020). If there is a relationship between LiD and language deficits in ASD, then established interventions (e.g., RM systems) could also improve listening performance in ASD, which could in turn improve language outcomes in the subset of children with ASD who are at risk for severe language impairments.

1.2.1 Listening Intervention in ASD

A number of studies have investigated the use of RM systems with children with ASD. Rance et al. (2014) evaluated the effect of RM system use on a group of 20 verbal children with ASD. Ten children from the sample used RM systems during the day at home and at school for six weeks. Results from participant self-report and teacher questionnaires showed that RM system use resulted in a benefit for the children, including improved ease of communication. Children who used the RM system also had improved speech discrimination in the presence of background noise in a controlled laboratory setting while the RM system was on. The authors concluded that use of RM systems improve speech discrimination and noise, as well as social and educational outcomes, for children with ASD. In another study of RM efficacy in ASD, Rance et al. (2017) examined the effects of an RM system in a classroom of 27 children with ASD without language disorders. Listening stress in these children was significantly reduced as measured by cortisol levels.

Schafer et al. (2013) evaluated the effect of RM systems on 11 children with ASD, ADHD, or both. Children used personal RM systems in their self-contained classroom in two RM trials. An observational measurement method was used to measure changes in on-task behavior as a result of the RM system. The children's teachers rated their auditory and educational performance before and after the intervention. Children in the sample also participated in speech recognition in noise tasks with and without RM after the intervention. Eleven TD children served as a control group for the speech recognition in noise task. Results showed that the use of RM systems improved on-task behavior in the classroom, speech recognition in noise, and teacher ratings of listening behaviors for the children with ASD and children with ADHD.

In a subsequent study of RM systems and listening in ASD, Schafer et al. (2016) evaluated the use RM systems as a form of assistive technology for 12 children ages 6–17 years with ASD who did not have language disorder. RM systems were used at home, at school, and in a laboratory setting. A within-subjects design was used, which allowed for the analysis of individual differences in outcomes; this is essential given the large degree of variability in phenotypic expression and treatment response that can be common in samples of children with ASD (Thurm et al., 2007). Significant improvements in listening ability, as measured via parent report on commonly used rating scales, were reported for a subset of the children in the study.

Taken together, these studies suggest that RM systems are feasible for use with school-age children with ASD and could be effective in improving listening performance, as measured by behavioral observations, parent-report, and teacher ratings. Most of the children in these existing studies did not have a language disorder, and all were school-age (Rance et al., 2014, 2017; Schafer et al., 2013, 2016). While these studies are important steps in this new line of research investigating listening interventions for children with ASD, questions remain about to the effectiveness of this technology across a wider range of ages, language abilities, and settings.

1.3 Gaps in the Literature

While there is clear evidence of deficits in factors that contribute to LiD in ASD, there are no studies that investigate the multifactorial nature of listening in ASD with instruments *designed specifically for individuals with ASD*. The existing studies mainly rely on caregiver and self-report measures that were designed for children with hearing loss which load heavily on social and language skills, which are often impaired as a result of a child's ASD, *not their listening deficit.* Furthermore, these measures often ask caregivers to compare their child to same aged peers which may not be appropriate for children with severe developmental delay. Studies on listening interventions in ASD have been limited to verbally fluent participants. There have been limited studies to date that examine the potential relationship between listening and language ability in children with ASD, which is critical to determining whether LiD is contributing to language disorders in ASD, and if established listening interventions could improve the language impairments that are so often associated with an ASD diagnosis.

There is evidence that listening interventions such as RM systems can improve listening performance in ASD, but these studies have been limited to children with ASD who are verbally fluent and school aged, and thus there is a need for studies to examine the effectiveness of RM systems in young children with ASD and children with ASD who have co-occurring language disorder, including those who are considered minimally verbal. These existing studies have used caregiver and self-report measures designed for children with hearing loss, which are often not appropriate for children with ASD due to the fact that they load heavily on language and social factors. Therefore it is unclear whether RM systems can effectively improve listening in young children with ASD, as well as those who have severe language disorder.

1.4 The Present Work

The present work had four aims: (i) to develop a reliable, stable, and valid parent-report measure of listening behavior designed for children with ASD, (ii) to examine the relationship between listening and language ability in ASD, (iii) to evaluate the effect of improving SNR by using RM systems in preschool-aged children with ASD and language disorder, and (iv) to investigate the effect of improving SNR by using RM systems on minimally verbal school-aged children with ASD.

Chapter 2 of this work describes the development of a parent-report measure of listening behavior designed for children with ASD and examines the hypothesis that listening is related to language ability in ASD. In Chapter 3, the effectiveness of a soundfield RM system was studied in 10 preschoolers with ASD in the classroom setting. In Chapter 4, a soundfield RM system was used in the laboratory setting with 14 children with severe language disorder. Finally, in Chapter 5, a summary of the findings and limitations of the studies in these projects are presented, and future directions for research and practice are discussed.

CHAPTER 2

Development of a Novel Measure of Listening for children with ASD

2.1 Introduction

A common concern of parents who have a child with ASD, after observing their child fail to respond to others, is that their child is deaf (Guinchat et al., 2012; Robins et al., 2014). However, formal hearing testing for children with ASD typically reveals that these children have normal hearing (Beers et al., 2014; Gravel et al., 2006; Tharpe et al., 2006). Additionally, previous studies have reported that atypical reactions to auditory stimuli are common in children with ASD (Guinchat et al., 2012; Tecchio et al., 2003). One hypothesis that follows from these observations and findings is that children with ASD have deficits in listening, as opposed to hearing. LiD is defined as developmental difficulty in listening, despite the presence of normal hearing, which is often exacerbated in noisy environments (Moore et al., 2020). As described in Chapter 1, recent conceptual models of listening have emphasized that listing is multifactorial in nature and impacted by a variety of components including auditory processing, auditory attention, and sensory processing (Magimairaj et al., 2020). In this chapter I will (a) examine evidence from research in ASD related to each of the components of the multifactorial model of listening as a way to guide the study of LiD in ASD, (b) describe the methods and results of my study designed to develop a measure of LiD for children with ASD, and (c) discuss the potential clinical and research implications of the findings of my study.

2.2 Auditory Processing in ASD

Auditory processing difficulties, sometimes referred to as APD, have long been thought to be responsible for LiD in children with ASD. A 2012 systematic review of the literature on auditory processing and ASD (O'Connor, 2012) found that children with ASD exhibit substantial auditory processing deficits on both behavioral and neurological measures ranging from atypical sensory perception to speech recognition in noise. For example, Boddaert et al. (2004) investigated the auditory cortical processing in children with ASD and children with intellectual disability (ID) who did not have ASD. The researchers found that when completing passive listening to speech-like sounds there was a significant difference between the two groups. While the children with ID demonstrated activation patterns of the auditory cortex that mimicked what has been found in typical adults (superior temporal cortex bilateral activation with left-biased asymmetry), the ASD group did not show the normal, left-dominance pattern. The authors concluded that these atypical results in the ASD group could be related to atypical responses to sound and language impairment in children with ASD.

However, other studies on children *without* ASD have concluded that perceived deficits in auditory processing might actually be due to attention or working memory, as opposed to a true deficit in auditory processing. Moore et al. (2010) studied 1,469 children (ages 6-11 years). Children completed assessments in the areas of auditory processing, speech in noise, cognition, and attention; caregivers completed questionnaires about children's listening and communication skills. Analyses revealed a high degree of variability on the auditory processing tests, and that attention and cognition were the best predictors of listening, communication, and speech-in-noise skills. Another study by Ahmmed et al. (2014) completed a factor analysis of the outcomes of 110 children (ages 6-11 years) with suspected APD on a clinical test battery and a research test battery. These batteries included tasks focusing on masking, frequency discrimination, nonverbal intelligence, working memory, reading, alerting attention, motor reactions, and dichotic listening. The factor analysis extracted three factors: general auditory processing, working memory and executive attention, and processing speed and alerting attention. Combined, these findings support the idea that auditory processing difficulties might be related to attention or working memory deficits.

2.2.1 Auditory Attention in ASD

Auditory attention deficits have been documented in children with ASD dating back to the earliest identification of the disorder (Kanner, 1943). More recent research has found that some children with ASD "switch off" to speech sounds, which could impact listening performance by denying a child critical access to verbal input over time (Whitehouse & Bishop, 2008).

A study by Funabiki and colleagues (2012) used spectroscopy to measure oxygenated hemoglobin (OxyHb) in the prefrontal and temporal cortices during listening and ignoring tasks in children with ASD and who are TD children. Results showed that both children with ASD and the TD children exhibited an increase in OxyHb when listening intentionally. In the ASD group, however, children showed an abnormal pattern of hemispheric laterality switching when attempting to regulate auditory attention. Additionally, during a recall listening task, children with ASD recalled more parts of a story that they were instructed to ignore; the authors hypothesized that difficulty with attention control might account for this. Based on the results of this study, the authors concluded that the auditory cortex in children with ASD does respond to sound and voices when they are attended to. Thus, the specific symptom of failure to orient to speech sounds in ASD could be explained by more general deficits in auditory attention regulation in this population. Such a deficit could directly contribute to LiD in children with ASD.

2.2.2 Sensory Processing in ASD

Sensory perception difficulties also frequently occur in children with ASD (Robertson & Baron-Cohen, 2017). Jones et al. (2009) found that that atypical sensory reactions were related to increased auditory sensory behaviors in the children with ASD. They concluded that individual differences in auditory discrimination abilities may be influenced by auditory sensory behaviors in individuals with ASD. If true, it is possible that atypical auditory sensory behaviors may be an indicator of auditory discrimination difficulties that could detrimentally affect listening skills.

2.2.3 Listening and Language Development in ASD

Despite these documented deficits of specific components of listening in children with ASD, and their potential clinical significance, LiD has been significantly under-studied in this population. It is especially important to consider the role of listening in children with ASD because of the potential relationship between listening and language development. A 2007 study by Paul et al. investigated the impact of auditory attention on listening and language in children with ASD. 52 toddlers with ASD, 32 toddlers with developmental delay, 44 age-matched TD toddlers, and 30 TD language-matched children participated in the study. The children were assessed on time spent oriented to auditory stimuli that mimicked child-directed speech. The results showed that toddlers with ASD had a reduced preference for child-directed speech compared to TD children. Further, in the ASD group, time spent listening to child-directed speech was significantly correlated with their receptive language abilities one year later. The researchers concluded that developmental changes in auditory attention may impact language acquisition in children with ASD. These findings support the hypothesis that LiD may contribute to disruptions in the early response to and acquisition of language in pre-verbal children with ASD.

Schwartz et al. (2020) studied 83 children with ASD (ages 5-21 years). They tested whether atypical auditory behaviors (e.g., covering ears, requesting headphones, humming when in the presence of loud or multiple speakers) were related to language deficits in these children. They found that children with ASD who were minimally verbal exhibited atypical auditory behaviors significantly more frequently than the children with ASD who were verbal. Further, reduced receptive language abilities in the minimally verbal group were predicted by increased incidence of atypical auditory behaviors. The findings of this study suggest that among all children with ASD , the relationship between LiD and/or atypical reactions to sound may be most pronounced in the subset of children with ASD who have severe language deficits such as children who are considered minimally verbal.

2.3 Measurement of Listening Difficulties

Existing measures of LiD were designed for children with hearing loss. Examples include the Listening Inventory for Education – Revised (LIFE-R; Anderson et al., 2011), the Children's Auditory Performance Scale (CHAPS; Smoski et al., 1998), and the Children's Home Inventory for Listening Difficulty (CHILD; Anderson & Smaldino, 2000). Recent studies of listening in children with ASD have used these existing LiD measures. However, the validity of these instruments as measures of LiD in ASD is unclear. These measures are often not appropriate for children with ASD as many of them load heavily on social language (e.g., response to name) or academic achievement. These areas may be delayed simply due to the nonspecific effects of ASD core symptoms, as opposed to a specific effect of LiD, causing children with ASD to score low on listening solely because of their ASD diagnosis. Additionally many of these measures require the rater (i.e., parent or teacher) to compare the child to his/her same aged peers. This is not appropriate in ASD because the majority of children with ASD exhibit developmental delays in many domains of development and thus do not perform at the level of their chronological age. For example if an eight year old child with ASD has the language or cognitive level of a four year old child, it would not be appropriate to compare them to other eight year old children to evaluate listening performance. Using these existing peer-referenced approaches to measure LiD could result in over-inflation of estimates of LiD in ASD dues to general developmental delay as opposed to specific deficits in LiD.

2.4 Gap in the Literature

There is a need for a measure of LiD that is appropriate for children with ASD across the spectrum of age, language ability, and academic performance. A listening measure designed specifically for children with ASD would allow for further and more specific investigations of listening difficulty in the ASD population. Despite the widespread acceptance of the multifactorial model of listening outside of ASD, research in ASD continues to be dominated by a relatively narrow focus on auditory processing. With an ASD-specific measure of LiD, research in this area could expand beyond auditory processing and begin to examine the role of other factors such as attention or sensory processing as well as the interaction of these factors with auditory processing. This could, in turn, support research on the relationship between LiD and language deficits in ASD, as well how the various components of listening impact this relationship. Finally, research on listening-related interventions in ASD, such as RM systems, has begun and an ASD-specific listening measure could increase the rigor of these studies through the use of an ASD-valid measure of LiD.

2.5 Aims

This study consisted of four aims: 1) To develop a novel, parent report measure of listening designed for children with ASD, 2) To evaluate the reliability, stability, and validity of the novel measure of LiD in children with ASD across a range of ages and language levels, 3) To examine the relationship between LiD, as measured by this new instrument, and deficits in attention and sensory processing, and 4) To investigate the relationship between LiD and language performance in ASD.

2.6 Method

This research was prospectively reviewed and approved by the Vanderbilt University Institutional Review Board.

2.6.1 Scale Development Procedure

A six step iterative procedure was used to develop the pool of items used to construct the scale: (1) Development of a working definition, (2) Review of existing measures, (3) Refining of the item pool, (4) Expert review, (5) Author review to reduce to final pool, and (6) Online scale validation study.

2.6.2 Development of working definition

We developed a working definition of listening behavior in children with ASD ("*The ability to appropriately attend to speech signals in the presence of everyday background noise*.") to guide the development of this measure. This definition was used to guide the selection of items for the scale.

2.6.3 Review of existing measures

We conducted a review of the items from six existing listening behavior scales designed for children with hearing loss or auditory processing deficits. These scales were: the Screening Identification for Targeting Educational Risk (SIFTER; Anderson, 1989), the Listening Inventory for Education – Revised (LIFE-R; Anderson et al., 2011), Children's Home Inventory for Listening Difficulty (CHILD; Anderson & Smaldino, 2000), Children's Auditory Performance Scale (CHAPS; Smoski et al., 1998), and the Sensory Profile 2 (Dunn, 2014). Additionally, the Auditory Attention and Discomfort Questionnaire (Dunlop et al., 2016) was included as it was designed for individuals with ASD. The review of these six existing measures resulted in an item bank of 200 items from across the scales.

2.6.4 Refining item pool

We used the working definition to reduce the item pool and help ensure construct validity. Each item in the initial pool of 200 was reviewed using the working definition. Using a consensus procedure two raters (MAK, JB) determined if each item was related to the working definition: (a) if both raters agreed that the item fit the definition, then the item was retained, (b) if both raters agreed that the item did not fit the working definition, then the item was dropped, and (c) if the two raters disagreed, then the item was discussed further to reach a consensus of retaining/dropping the item. In a second step, raters identified if an item related to core features of ASD (social deficits, restricted repetitive behavior); if either rater endorsed the item as potentially relating to ASD core features then the item was dropped. This second step was added to help ensure that the scale measured listening difficulties as opposed to other deficits associated with ASD. Using this process, the item pool was reduced from 200 to 88 items.

2.6.5 Expert review

A sample of 13 clinical experts was recruited, consisting of speech-language pathologists, audiologists, and teachers of the deaf with experience in pediatrics. These experts rated each of the items in the 88 item pool based on two questions 1) “Do you think this item is related to functional listening as defined above?” (referring to our working definition of LiD), 2) “If yes, how well is it related?”. Answer options were either yes/no (question 1) or a 4 point likert scale ranging from “not very confident” to “very confident” (question 2). Items that scored, on average across all raters, less than 50% “yes” on question one and less than an average score of three on question two were removed. Based on this expert feedback on item fit and confidence, the pool was reduced further from 88 to 55 items.

2.6.6 Author review to reduce to final pool

Two raters (MAK, JB) reviewed the remaining items to further reduce the item pool by removing items that were judged to be redundant. This reduced the items to a final pool of the 15 items. We have termed this final 15-item scale the “Listening Behavior in Autism Scale” (LBAS).

2.6.7 Online Scale Validation Study

To examine the psychometric features of the LBAS, a sample 84 parents of children with ASD and 49 parents of typically developing (TD) children completed the scale, as well as additional demographic, social communication, auditory attention, sensory processing, and vocabulary measures. As this study was conducted during the time of the COVID-19 restrictions on in-person data collection for research, an online method was used to collect this data from all study participants.

2.6.8 Participants

We recruited a sample of 84 parents of children with ASD and 49 parents of TD children between the ages of 2 years and 19 years with normal hearing. Inclusion for the ASD group were: (a) clinical diagnosis of ASD, (2) between 2 – 19 years of age, and (3) no reported hearing deficits. Inclusion criteria for the typical development (TD) group were: (1) no diagnosis of ASD, (2) between 2 – 19 years of age, and (3) no reported hearing deficits. Summary demographic data on both samples is displayed in Table 1.

Table 1. Demographics of ASD group and TD group.

	ASD group	TD group
Age in years [mean (SD)]	9.6 years (3.7)	9.09 years (4.68)
Sex (%)		
Males	76%	47%
Females	24%	53%
Caregiver race (%)*		
Black	14%	4%
Asian	3%	0%
Hispanic	0%	8%
White	83%	88%
Minimally verbal (%)	18.6%	0%

*Race data only available for 65 of 84 ASD participants

To assess test-retest stability of the LBAS, a subset of participants (n=25) in the ASD group completed the LBAS for a second instance approximately 14 days following their initial completion of the measure.

2.6.9 Measures

Demographic and developmental questionnaire: We asked each caregiver a series of demographic and developmental questions. The demographic questions collected information about the child's age and race. The developmental questions included queries about their history of an ASD diagnosis (e.g., When was the child first diagnosed with ASD?), their hearing status (e.g., Has your child had their hearing tested? When was your child's last hearing tested?, Does your child have normal hearing? Do you think your child has had an ear infection in the last week?), and language development (e.g., How does your child most often communicate with others?).

Social Communication Questionnaire (SCQ; Rutter et al., 2003): The SCQ is a parent report ASD-screening measure made up of 40 items that measure the presence or absence of the core features of ASD arranged in three subscales: social interaction, communication, and stereotyped behaviors.

Listening Behavior in Autism Scale (LBAS): Each parent to complete the 15 item listening LBAS described above (see Appendix A).

Attention checklist: Parents completed 11 questions about their child's attentional skills in everyday life derived from the SNAP-IV (Swanson, 1992). Items from the SNAP-IV that measured attention or distractibility problems and overactivity were chosen. Example items were: "My child has difficulty keeping attention on tasks or play activities.", "My child runs around or climbs too much in situations when it is not appropriate." (See Appendix B).

Sensory checklist: Parents completed 10 questions about their child's sensory skills which were derived from the Sensory Profile (SP) 2 (Dunn, 2014). The SP is a measure designed to assess their sensory performance across their daily lives. We selected items that were relevant to auditory or visual attentional processes (e.g., "My child is distracted when there is a lot of noise around.", "My child likes to watch people as they move around the room."). (See Appendix C).

Measure of language: The ASD group also completed a 179 question vocabulary questionnaire. The vocabulary questionnaire was developed by cross referencing a 500 item vocabulary questionnaire designed by Plesa Skwerer and colleagues (2016) for minimally verbal children with ASD and the Macarthur-Bates Communication Development Index Words and Gestures (MBCDI; Fenson, 2007). This was used as a measure of vocabulary to identify the subset of ASD participants who met criteria for minimally verbal status. (See Appendix D).

2.6.10 Analytic Plan

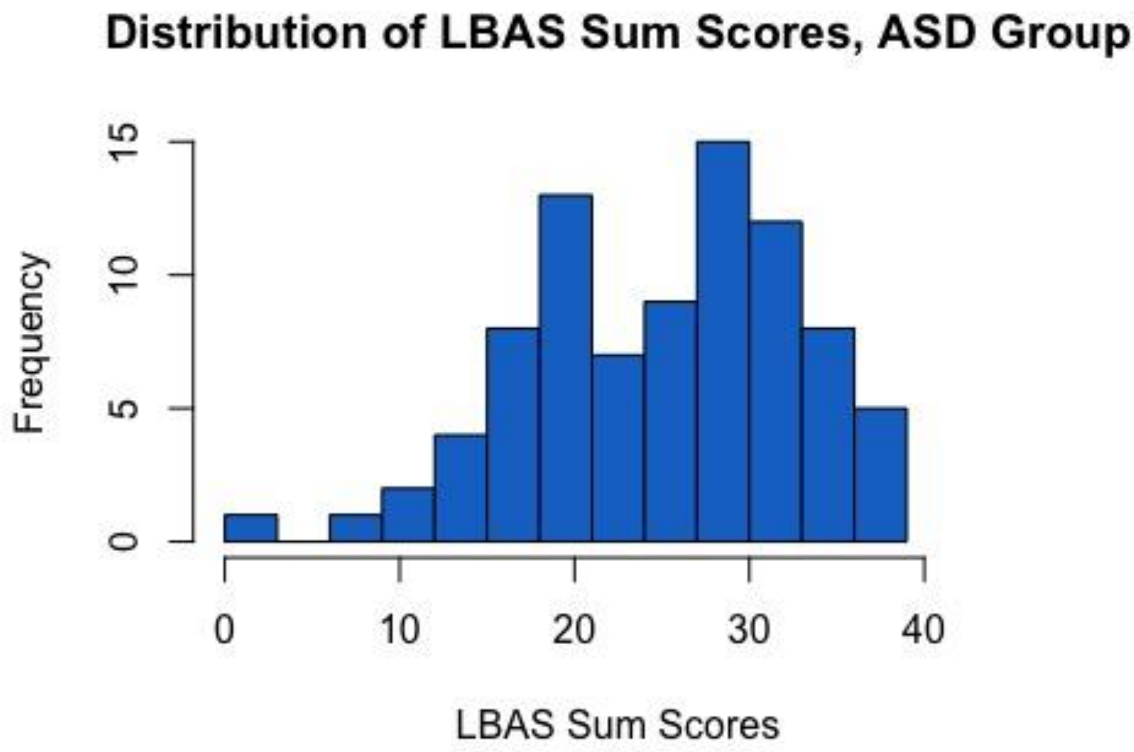
In order to assess the psychometric properties of the listening scale, several analyses were completed. Distributional characteristics of the LBAS for the ASD sample were examined (fit to normal distribution, skewness, kurtosis), and differences in score distribution as a function of child sex and age were examined. Cronbach's alpha was calculated to determine internal consistency of the LBAS items. Stability was determined by calculating a test-retest coefficient of test-retest reliability. Convergent validity was analyzed by examining the correlation of the LBAS total score with the SCQ social communication subscale scale in the ASD group. To evaluate whether language performance was related to LiD in this study, the ASD sample was divided into two subgroups: "minimally verbal" and "verbally fluent". The minimally verbal group consisted of any children for whom the parents indicated "uses no words" or "uses a few words" and was considered inappropriate for age (n=15). The verbally fluent group consisted of children whose parents marked "uses phrases" or "uses back and forth conversation" (n=70). The correlation between the number of expressive words used as endorsed by parents on the vocabulary checklist and the LBAS total score was computed to provide an additional examination of the relation between language ability and LiD in the ASD sample. To examine if LiD, as measured by the LBAS, in the ASD sample was related to either attention deficits or sensory processing deficits, two further analyses were conducted: (a) the ASD sample was sub-grouped into high-attention deficits (n = 23) and low-attention deficits (n = 24) based on the upper and lower quartile of the total score on the attention checklist respectively, and the mean LBAS total scores for these subgroups were compared using a t test, and (b) the ASD sample was sub-grouped into high-sensory deficits (n = 25) and low-sensory deficits (n = 23) based on the upper and lower quartile of the total score on the sensory checklist respectively, and the mean LBAS total scores for these subgroups were compared using a t test. All analyses were completed in R.

2.7 Results

2.7.1 Distribution of LBAS scores

The LBAS scores in the ASD sample were near normally distributed (see Figure 1). The LBAS total score ranged from 1-39 (highest possible score = 60), with a median score of 26, a mean score of 25.4, and a standard deviation was 7.91. Skewness was -0.49. Kurtosis was -0.21. The differences in LBAS total score between ASD males (mean = 28.80, SD = 7.61) and females (mean = 24, SD = 8.92) was not significant (p = 0.43). The relation of child age to LBAS scores was not significant (r = -0.14, p = 0.18).

Figure 1. Distribution of LBAS sum scores in the ASD group.



2.7.2 Internal consistency and stability of LBAS

Cronbach's alpha is a measure of the degree of homogeneity of responses and provides an estimate of the measure's internal consistency for a specific population. Cronbach's alpha for the LBAS was 0.91, indicating very high internal consistency and suggesting that the individual LBAS items are all measuring a single construct. Test–retest reliability (second test offered at 14 days), as calculated by interclass correlation, for a randomly selected subset of 25 cases was 0.89, suggesting high temporal stability.

2.7.3. Validity of LBAS

A comparison of the ASD and the TD samples on LBAS total score indicated that the LBAS was able to discriminate these two groups (ASD mean = 25.4, SD = 7.9, TD mean = 5.7, SD = 5.9; $t_{(1)}$ =16.263, p = .0001) indicating good discriminant validity for the scale with respect to ASD. The correlation of the LBAS total score and the SCQ social-communication subscale score in the ASD sample was significant (z = 3.9268 and p = .002), indicating good convergent validity for the LBAS with respect to ASD severity.

2.7.4 Relation to Language Ability

The mean LBAS total scores of the verbally fluent (n = 70) and the minimally verbal (n = 14) ASD subgroups was not significantly different (t(1) = -0.543, p=0.594). In addition, no significant correlation was found between the number of words used from the vocabulary checklist and LBAS total score (r = .038, p=0.727).

2.7.5 Association of Listening, Attention, & Sensory

For the ASD sample, the correlation of LBAS total score and total score on the attention checklist was significant (r = 0.528, p = .001). The mean LBAS total scores for the upper quartile (n = 23) and lower quartile (n = 24) attention checklist subgroups of ASD participants are shown in Figure 2. The difference in mean LBAS scores for these attention checklist subgroups was significant (t(1) = -7.70, p = 0.001). The correlation of LBAS total score and total score on the sensory checklist was significant (r = 0.432, p = .001). The mean LBAS total scores for the upper quartile (n = 25) and lower quartile (n = 23) sensory checklist subgroups of ASD participants are shown in Figure 3. The difference in the mean LBAS scores for these sensory checklist subgroups was significant (t(1) = -6.36, p =.001).

Figure 2. LBAS scores by high and low quartile of attention scores.

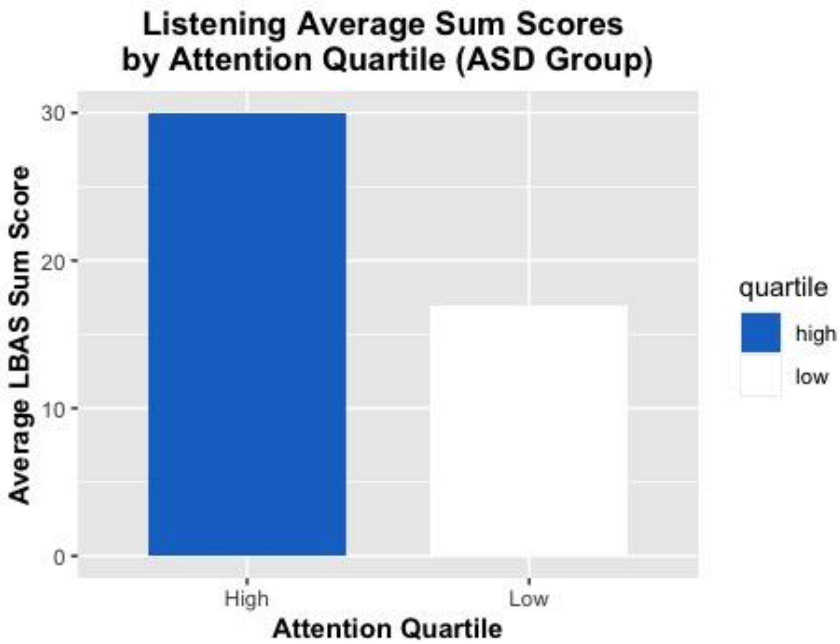
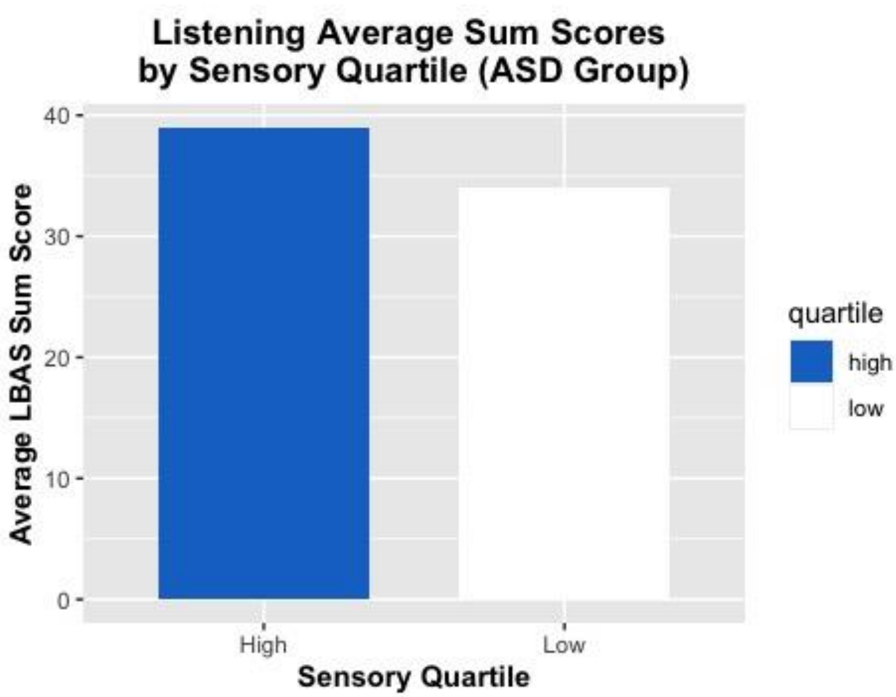


Figure 3. LBAS scores by high and low quartile of sensory scores



2.8 Discussion

The present study sought to fill a significant gap in the literature by creating and validating a measure of LiD specifically designed for children with ASD with normal hearing. We created a novel measure – the LBAS – designed for children with ASD and found that this measure has a low time burden (15 questions), and has acceptable levels of internal consistency, stability, and validity for a clinical rating scale.

The LBAS successfully distinguished between the two groups in this study (ASD and TD). Additionally, the ASD group demonstrated significantly higher levels of LiD, which would be expected, and suggests that LiD should be considered in the context of ASD.

Listening, however, is not comprised of a single factor and it must be considered within the multifactorial model of LiD that has been established in TD and other clinical groups. This model includes attention and sensory challenges. Such challenges have also been well documented in the ASD population. We found that LiD, as measured by the LBAS, was significantly and positively associated with both attention deficits and sensory challenges in the ASD group. Importantly, we endeavored to include only specific items related to LiD in the LBAS, and therefore the associations between LiD, attention deficits, and sensory challenges, which we found, are unlikely to be due to item-overlap in the measures of these constructs that we used. If this finding is replicated, then this would support the use of the LBAS in ASD to begin to unpack the potential differential or additive effects of attentional and sensory processes on listening deficits in children with ASD.

We hypothesized that there would be an association between LiD and language performance in children with ASD. However, multiple tests of this hypothesis failed to reveal such a relationship in our ASD sample. This could mean that LiD exists across the spectrum of

ASD and is not specifically linked to language impairment in this population. However, given the online nature of the study, and the fact that we used an unvalidated and proxy measure of language performance to examine this relationship, more rigorous and standardized measures of language performance, including approaches that can examine receptive language performance specifically, may be required to identify a relationship between LiD and language performance in ASD.

2.8.1 Limitations

The results of this study should be considered in the context of its limitations. One limitation is a small sample size that did not allow for factor analysis to determine if the 15-item LBAS yields a unidimensional measure of LiD. The results of the analysis of internal consistency of the LBAS items for the ASD sample suggest that the 15 LBAS items are highly internally consistent and therefore likely to be measuring a single construct. However, examination of this in a larger sample would permit factor analysis to address this question more definitively. Additionally, because the study was conducted online, in-person hearing evaluations were not possible. Thus, the authors relied on parent report to indicate normal hearing, which was an inclusion criterion. The same limitation exists for language assessment, which was collected only based on parent report; future studies should include a full language evaluation as part of their procedure. Another limitation of this online format was that it did not address potential concerns with shared method variance as parent report was used on all measures. This increases the possibility of "halo" effects – e.g. parents scoring of listening items may have influenced their scoring of attentional, sensory, and language items resulting in a greater correlation between these domains than might be found using a mixed methods approach (e.g.

parent rating scale and standardized or objective tests). The fact that significant correlations were found between some domains measured in this study (LBAS, attention checklist, sensory checklist), but not other domains measured also using parent report (language performance) provides some evidence that the results were not entirely driven by shared method variance; however future research in ASD should examine the LBAS in relation to these domains using a mixed-methods approach.

CHAPTER 3[1]

RM System Use in the Preschool Classroom for Children with ASD

3.1 Introduction

Children with ASD often exhibit co-occurring communication deficits, as language disorder occurs in at least 65% of children with autism spectrum disorder (Anderson et al., 2007; Tager-Flusberg, 1981; Turner et al., 2006). Language disorder refers to deficits in both expressive language and receptive language and has a substantial impact on an individual's ability to communicate effectively. Critical to effective communication is the processing of language input, which relies on the adequate processing of auditory stimuli. Children with ASD have been found to demonstrate atypical auditory responses and atypical attention to speech sounds (Kuhl et al., 2005; Whitehouse & Bishop, 2008; Tharpe et al., 2006). Studies have found evidence that children with ASD who have normal hearing require a higher signal-to-noise ratio (SNR) than their normal hearing peers when listening in the presence of high levels and different types of background noise (Alcantara et al., 2004; Peters et al., 1998, Rance et al., 2014; Russo et al., 2009; Schafer, et al. 2013). This specific difficulty, difficulty hearing in the presence of background noise in the absence of hearing loss, will be referred to in the present article as LiD. Listening to verbal input is critical to language development, as natural language input as well as evidenced based ASD therapies rely on adequate listening performance to interpret verbal speech (Hart & Risley, 1995). In this chapter I will (a) examine evidence from research related to

[1] Portions of this chapter have been adapted with permission from Keller, M. A., Tharpe, A. M., & Bodfish, J. (2021). Remote Microphone System Use in Preschool Children With Autism Spectrum Disorder and Language Disorder in the Classroom: A Pilot Efficacy Study (Vol. 30, No. 1, pp. 266-278). American Speech-Language-Hearing Association.

intervention for LiD in children with ASD, (b) describe the methods and results of my study designed to assess the feasibility and efficacy of using RM systems for children with ASD in the preschool classroom setting, and (c) discuss the potential clinical and research implications of the findings of my study.

3.1.1 Remote Microphone Systems

The listening performance of individuals with ASD has been shown to benefit from increased SNR (Rance et al., 2017; Schafer et al., 2016; van der Kruk et al., 2017). A 2017 systematic review of five studies concluded that improving SNR for children with ASD can lead to improved classroom performance (van der Kruk et al., 2017). Technology designed to impact SNR in typical listening environments might support children with ASD in gaining improved access to and understanding of spoken language. A technology that improves the SNR is RM technology. RM systems provide low-delay and reliable broadband audio broadcast to listeners, allowing better access to speech in noise by improving the SNR (Ching et al., 2005; Holt et al., 2005; Schafer & Thibodeau, 2006). Although this technology was originally designed for individuals with hearing loss, previous studies have shown that children with a variety of developmental conditions, such as ADHD and Dyslexia, can benefit from RM system use in both controlled settings and in classrooms (Anderson & Goldstein, 2004; Flynn et al., 2005; Hornickel et al., 2012). RM systems have been shown to improve children's abilities to listen to and understand speech as indicated through structured assessments of listening and comprehension, as well as parent, teacher, and participant ratings. These improvements have important implications for classroom applications, as classrooms often do not meet noise standards set by the American National Standards Institute (ANSI, 2010; Knecht et al., 2002).

3.1.2 Remote Microphone Systems in Autism Spectrum Disorder

Given the link between SNR and auditory access to speech in children with ASD, a few studies have examined the use of RM systems with children with ASD. Rance and colleagues (2014, 2017) found that RM systems improved ease of communication and speech discrimination in background noise, and listening stress in children with ASD without language disorder. Schafer and colleagues (2013, 2016) found that the use of RM systems improved on-task behavior in the classroom, speech recognition in noise, and teacher ratings of listening behaviors for the children with ASD and children with ADHD. Additionally, significant improvements in listening performance as determined by parent report on standardized rating scales were reported for a subset of the children in a school-age ASD sample. Together these studies suggest that RM systems are feasible for use with school-aged children with ASD and might be effective in improving speech-in-noise perception, as indicated by behavioral observations and parent and teacher ratings. However, the majority of the children in these existing studies on RM in children with ASD were verbally fluent, and all were school-aged. Questions remain as to the effectiveness of this approach across a wider range of child ages, language levels, and settings.

3.1.3 Gap in the Existing Literature

Previous research on RM system efficacy in ASD has focused on school-aged children with ASD who do not have language disorder and thus there is a need to extend this work to examine the feasibility and efficacy of RM systems in preschool-aged children with ASD, as well as those with co-occurring language disorder. In addition, previous studies in this area have assessed RM effects in controlled lab or testing settings; thus, research is needed that measures RM system effects in naturalistic settings such as the classroom. Also, previous studies have used un-blinded parent or teacher report measures of outcomes that do not account for potential nonspecific or "placebo" effects that could have contributed to the reported effect of the RM system. Extending the results found in these open trials of RM system effects in children with ASD to examination under blinded treatment conditions is now warranted. Finally, existing studies of RM system effects have largely focused on children with ASD who do not have language disorders; thus, examination of the efficacy of RM systems across the full range of language ability seen in ASD is warranted.

3.1.4 Present Study

The present study addressed gaps in the existing RM system literature by examining the feasibility and efficacy of RM systems in a small (n =8) sample of preschool children with ASD and language disorder in a classroom setting. We hypothesized that the use of RM systems would improve the LiD in preschool aged children with ASD and language disorder. In this pilot feasibility study we sought to answer the following research questions:

1. Do RM systems improve the listening performance of some preschool-aged children with ASD and language disorder?
2. Do individual preschool-aged children with ASD and language disorder respond to RM systems, as measured by level of prompting needed for successful responses, response latency, or both?

3.2 Methods

The protocol for this study was approved by the Vanderbilt University Medical Center Institutional Review Board. Consent was gathered for all participants by caregivers prior to beginning the study.

3.2.1 Participants

A total of 10 children with ASD were recruited for this study. One participant was excluded due to inadequate hearing status records, and one participant was excluded due to frequent absences during the course of the study that resulted in an inadequate number of baseline sessions, leaving eight participants enrolled in this study (see Table 1). The study sample ranged in age from 46 to 57 months. Criteria for inclusion were (a) preschool age, (b) diagnosis of ASD, and (c) clinical diagnosis of language disorder. Criteria for exclusion were (a) abnormal hearing or inadequate hearing records and (b) less than five baseline sessions collected.

Table 2. Participant demographics

Participant	Age (months)	Sex	Diagnoses	Hearing Status	Mullen months delayed (CA – age equivalent score)	ADOS Comparison Score
1	46	F	ASD; LD	Within normal limits (WNL)	15	10
2	57	M	ASD; LD	WNL	32	7
3	53	M	ASD; LD	WNL	26	10
4	45	M	ASD;LD	WNL	11	9
5	50	M	ASD;LD	WNL	41	10
6	47	M	ASD;LD	WNL	33	10
7	48	M	ASD;LD	WNL	6	9
8	48	M	ASD;LD	WNL	6	6

3.2.2 Inclusionary Criteria

Autism Diagnostic Observation Scale, Second Edition (ADOS-2, Toddler Module and Module 1). The ADOS-2 (Lord et al., 2012) is a gold-standard, standardized observational measure used to diagnose ASD. It was used to confirm prior diagnoses of ASD. All administrations of the ADOS were completed within two years of study participation. The ADOS was administered by ADOS trained clinicians and collected to report for this study.

Mullen Scales of Early Learning. The Mullen Scales of Early Learning (Mullen, 1995) is a standardized measure of cognitive, language, and motor development. The Mullen was used to determine presence of a language disorder. Participants were considered to have a language disorder if they tested six months delayed or more. The Mullen was administered within two years of study participation by Mullen trained clinicians and collected to report for this study. Because the Mullen was administered at different time points for different participants, and then collected for this study, results are reported in terms of how many months they were delayed at time of testing. All participants continue to carry the diagnosis of language disorder based on continued re-evaluation by a licensed speech-language pathologist.

3.2.3 Exclusionary Criteria

Hearing status was considered an exclusion criterion. Participants for whom the authors were unable to confirm normal hearing were excluded. Number of baseline condition sessions was also considered an exclusion criterion. If a participant participated in less than five sessions in the baseline condition they were excluded.

3.2.4 Hearing Status

Medical record review revealed that nine participants received developmentally appropriate audiologic evaluations by certified audiologists confirming normal hearing sensitivity in at least one ear. Note that because of aversion by some participants to wearing earphones, sound field screening was required in those circumstances, thus only one ear could be screened. Individual participant hearing records are available by request from the authors.

3.2.5 Experimental Design

This study used a single case, alternating conditions design, with one condition being the RM-on condition and other condition being the RM-off condition that served as a no-intervention baseline (Barlow & Hayes,1979; Kazdin, 1982). In this design, no-intervention baseline condition sessions are repeatedly alternated with intervention condition sessions to permit a comparison of intervention relative to baseline during the same time period and in the same observation setting. The order of conditions (RM-on and RM-off) was randomized within participants across sessions. This design helps to control for practice or learning effects during repeated administration of similar conditions that can be operative in other single-subject designs (e.g., reversal or multiple baseline designs). We reasoned that a single-subject design was sensible at this stage of this work given the presumed high degree of inter-subject variability inherent in preschool children with ASD (Yoder et al., 2015). Furthermore, this design relies on observational measurement of target performance that is useful given that standard measures of listening performance are likely to be less valid or feasible in children with ASD and language disorder (Kasari et al., 2013; Tager-Flusberg & Kasari, 2013).

3.2.6 Setting

The setting for this study was the Preschool for Children with Autism (PCA) at the Vanderbilt Bill Wilkerson Center. Students enrolled in this program range in age from 18 months to 5 years and have a diagnosis of ASD and language disorder. Each of three classrooms contains five children and at least two adult instructors. An American Speech-Language-Hearing Association certified speech-language pathologist leads each class and focuses on individual functional communication goals in the group setting.

All experimental sessions took place within the preschool classrooms during group free play. During each session, the participant and examiner sat across from one another at a table and completed an observational measure of listening performance. Sessions took place on separate days across a time span of two and a half months. All sessions were conducted in the morning. Generally, sessions within participants were separated by one to seven days. For three participants, there was one instance in which two sessions were administered on the same day, separated by approximately 30 minutes. For two participants, there were two instances in which two sessions were administered on the same day, separated by approximately 30 minutes. For one participant, there were three instances in which two sessions were administered on the same day, separated by approximately 30 minutes. During both intervention (RM-on) and baseline (RM-off) sessions, regular classroom activities continued for the children in the classroom who were not participating in an experimental session. The level of background noise was measured using a sound level meter in the three classrooms in which the study was conducted. These three measurements were then averaged, resulting in an average of 65 decibels (dB). This noise level is typical in a classroom setting (Crandell & Smaldino, 2000). This setting was considered to be appropriate for investigating the RM system's impact on the listening performance of preschool children with ASD as it was an ecologically valid environment.

3.2.7 Equipment

Although personal RM systems that are worn at ear level are a common style for students with hearing loss, given the young age and sensory aversion of the participants in our sample, the present study used soundfield RM systems that transmitted the examiner's voice to a wall-mounted speaker and did not require a child to tolerate an in-ear device. This method is also desirable as an entire classroom can receive benefit of an improved SNR from one piece of equipment.

One soundfield Phonak Roger^{TM} DigiMaster 5000 wall-mounted speaker was installed in each of the three classrooms to be used in the RM-on condition sessions. All systems were mounted on a wall out of reach of children and were located within a range of 4 feet to 10 feet of participant session locations, which was within the distance recommended by the manufacturer based on the size of the classroom (Phonak, 2013). This range in distance was necessary due to the varied physical layouts of the three classrooms. The systems used in this study were dynamic RM systems, which maintain a steady SNR despite changing background noise levels in the classroom. For example, when the background noise reaches 54 dB SPL (sound pressure level) as measured by the transmitter, the RM system increases the volume of the signal being broadcast to the classroom. This dynamic system maintains 66 to 76 dB SPL to ensure a minimum SNR of 14 dB in the classroom (Phonak, 2013). The examiner wore a wireless Phonak Inspiro lapel microphone/transmitter in all sessions. When the RM system was activated (RM-on condition) the speech signal was then transmitted to the wall speaker.

Finally, because the examiner wore the microphone during both conditions (RM-off, and RM-on) and the outcome measure presses (described below) were videotaped for later behavioral coding, this arrangement allowed us to keep the coder blind to the experimental condition during coding of the videotapes.

3.2.8 Outcome Measurement

Listening Performance – Observational Procedure

Listening performance was assessed using an observational measurement approach based on three instructional presses administered by the examiner during each assessment session: 1) response to name, 2) object identification, and 3) completion of a one-step direction. These presses were chosen because they span different developmental levels and are building blocks of more advanced language skills. Each session involved the presentation of these presses using a least-to-most prompt hierarchy, with a 10 second wait time provided after any given prompt (DiCarlo et al., 2017; See Table 3). The 10 second wait time was chosen to allow adequate response time for children with delayed processing, while attempting to avoid measuring non-intentional behaviors. In each session, three common objects were used to complete the presses. The objects used in each session were randomly chosen from a list of 16 common nouns taken from the MBCDI to ensure that all items would be familiar to the children and developmentally appropriate. Additionally, the participants' caregivers and speech-language pathologists reported that these children were familiar with the items used. These objects were randomized across sessions in an attempt to avoid habituation by the participants to the objects. When generating the list of the three objects used for each session, the focus was placed on including at least one item that would be feasible for other objects to be placed "on" (i.e., plate, book, block, cup) in the one-step direction press. The other 12 objects were chosen randomly to pair with the four items listed above. The order of presses and objects used was randomized across all sessions.

Table 3. Least-to-most prompt hierarchy

Step	Response to Name	Identification	One Step Direction
1.	**1st call:** Call name one time, wait up to 10 seconds for response.	**Verbal prompt**: Give verbal command, wait up to 10 seconds for response. Example:"Touch the car."	**Verbal prompt**: Give verbal command, wait up to 10 seconds for response. Example: "Put the cow on the book."
2.	**2nd call:** Call name one time, wait up to 10 seconds for response.	**Gestural prompt**: If no successful response to verbal prompt, give verbal command with gestural prompt, wait up to 10 seconds for response. Example: "Touch the car." + examiner points to the car	**Gestural prompt**: If no successful response to verbal prompt, give verbal command with gestural prompt, wait up to10 seconds for response. Example: "Put the cow on the book." + examiner points to cow and book
3.	**3rd call:** Call name one time, wait up to 10 seconds for response.	**Physical**: If no successful response to gestural prompt, give verbal command with partial physical prompt, wait up to 10 seconds for response. Example: "Touch the car." + elbow prompt	**Physical**: If no successful response to gestural prompt, give verbal command with partial physical prompt, wait up to 10 seconds for response. Example: "Put the cow on the book." + elbow prompt
4.	If no successful response, indicate completion.	If no successful response, indicate completion.	If no successful response, indicate completion.

In order to approximate near stable levels of the dependent measure, at least five sessions were scheduled for each participant in both conditions (Kratochwill et al.,2010). However, due to repeated absences from the preschool classroom, one participant completed only four sessions in the baseline condition; as we were not able to collect at least five sessions with this participant, this participant was dropped from the analyses. All other participants completed between five and seven assessment sessions in each condition. This observational approach permitted blinded measurement of both level of independence (minimum prompt level required) and speed of response (response latency).

Operational Definitions

Successful responses were defined specifically for each of the three presses administered in every session. Success for the *response to name press* was defined as the child making eye-contact with, or clearly and intentionally shifting gaze toward the examiner within 10 seconds of his or her name being called. Successful response to the *identification press* was defined as touching the object named by the examiner prior to touching other objects within 10 seconds of the instruction. Lastly, successful response to the *one-step direction press* was defined as following the one-step direction as instructed by the examiner prior to initiating other actions with the objects within 10 seconds of the direction.

3.2.9 Observational Measurement

Every session in the study was audio and video recorded using a stationary, tripod video camera. The video files were uploaded and manually coded in ProcoderDV (Tapp & Walden, 1993). Once coded, Multi-Option Observation System for Experimental Studies (MOOSES) software (Tapp et al., 1995) was used to quantify specific response prompt levels and response latencies manually for each trial. An operational definition of a successful response for each of the three presses was used to code the videotaped sessions. Each press was coded for: 1) level of prompt independence, and 2) latency of correct response. A numeric score was given based on the level (e.g., amount) of prompting the child needed to respond successfully (Table 4); *higher scores* denote responding that relied on less prompting and index better performance on this measure. Latency was calculated, using ProcoderDV software, as the number of seconds from the time the examiner finished administering the command to the moment the child responded appropriately. Each press was terminated after 10 seconds of wait time as indicated by a silent digital timer, thus the longest latency score that a child could receive was 10; *lower values* denote faster responding and index better performance on this measure.

Table 4. Scores for child responses

Score	Level of prompting required for successful response
3	**Response to name (RN)**: Child responded on first call of name **Identification (ID) and One step direction (OSD):** Child responded to verbal command only
2	**RN:** Child responded on second call of name **ID and OSD:** Child responded to gestural prompt with verbal command
1	**RN:** Child responded on third call of name **ID and OSD:** Child responded to partial physical prompt with verbal command
0	Did not successfully complete press

As a control check, this observational measure of listening performance was tested in a preliminary study of 10 preschool-aged children with ASD and language disorder prior to use in the present study. The purpose of this was to ensure that the measure was feasible, reliable, stable, and was not subject to excessive floor or ceiling effects in preschool children with ASD. All 10 children in the preliminary study were able to complete the assessment on all sessions attempted (between 3 to 7 sessions per child) suggesting that the measure was feasible for use with preschool children with ASD. The majority of participants (90%) showed neither floor nor ceiling effects. Test-retest results for the sample indicated significant stability over time ($r = 0.86$, $p < .01$).

3.2.10 Blinding

The sessions were videotaped for later coding to ensure that the coder was blinded to the treatment condition (RM-off, RM-on). As a control check on this blinding procedure, we examined whether the session condition could be kept blind from the data coder (i.e., could the coder detect that the RM system was "on" while watching the videotapes?). For the preliminary study, eight different 30 second videos of preschool children with ASD were recorded (four RM-on and four RM-off conditions). The order of the videos was randomized, and the videos were watched by a set of 14 unique data coders. While the RM status (on vs. off) was perceivable in the room during sessions, when played back via video, thirteen of fourteen coders were not able to identify the listening condition correctly across the videotapes, indicating that the status of the RM system (on or off) was not able to be consistently detected from videotaped sessions and thus blind coding of videotaped sessions was possible.

3.2.11 Fidelity

The examiner kept a detailed log of the assessment sessions for all participants and noted any deviations in procedure in this log (e.g., repeating a prompt level twice due to participant's challenging behavior such as throwing the press objects). The video coder scored fidelity of the examiner's application of the listening performance assessment procedure for a randomly selected 20% of all trials across participants. This was done to ensure that the procedures established for this study were implemented correctly, with a goal of 80% procedural fidelity (Reichow, 2011; Wilczynski & Christian, 2008; Wolery, 1994). Fidelity of the prompt sequence of the presses (overall percentage of sessions wherein the examiner correctly applied the prompt sequence) was 88%. Fidelity of the wait time for the presses (overall percentage of sessions that the examiner correctly applied the 10 second wait criteria) was 96%.

3.2.12 Reliability

To assess the reliability of data collection, 20% of session videotapes were scored by a trained coder. The observer was first trained to use the MOOSES and ProcoderDV software. The observer then completed trial coding sessions using test videos in order to become familiar with the coding and analysis procedures. After completing trial coding on three test videos, which were taken from the existing pool of participant videos from this study, the coder coded the randomly selected 20% of session videos. The test videos were not included in the 20% of videos coded for reliability. Intraobserver agreement was calculated, with a goal of 80% (Reichow, 2011; Wilczynski & Christian, 2008). The resulting overall intra-rater reliability of the observational measurement procedure was 99% for prompt level and 99% for latency (using an error window of one second).

3.2.13 Data Analysis

Prior to analyzing the results of each participant, stability of baseline data was examined. Stable baseline data was defined as one unit or less deviation from the condition mean in the prompt level data, and three seconds or less deviation from the condition mean in the latency data for each participant. Only participants who met this criterion for stability were included in further analyses.

Individual participant data was analyzed using both visual inspection and quantification of effect size using summary statistics developed for single subject research designs. Visual inspection was used to identify consistent separation of data points between conditions. Given recommendations that single case design effect size statistics can complement interpretation of single case design results (Boyd et al., 2011), we also included an analysis of effect size. Effect size was calculated for each participant as a measure of condition differences using percentage of non-overlapping data points (PND) and percentage of data points exceeding the mean (PEM). PND was used because it is considered a meaningful index of treatment effects, and is easily interpretable (Olive & Franco, 2008). PEM was used, as it is considered a reliable measure in the presence of potential in the presence of ceiling or floor effects (Chen & Ma, 2007). To calculate PND, the number of non-overlapping data points was divided by the total number of data points in the intervention phase. To calculate PEM, the median of the baseline phase calculated. This was used to determine the percentage of data points above the line in the treatment phase (Ma, 2006; Vannest & Ninci, 2015). PND and PEM above 50% was considered a positive response to the RM-on condition, as this is above chance levels of difference between conditions (Olive & Franco, 2008; Vannest & Ninci, 2015). Composite scores were calculated for each condition for each participant by averaging all their press scores across sessions by condition.

3.4 Results

Using the criteria of one unit or less variability for prompt level data and three seconds or less variability for response latency, data from participants 2 and 5 were determined to not be stable and thus were excluded from further analysis. Participants 1, 3, 4, 7, and 8 were stable for at least one data type (prompt level or latency) and were analyzed further using the stable data type only.

The composite scores for each participant for each condition are reported by condition in Table 6. Based on PND analysis, one participant met criteria for positive response to the RM-on condition for prompt level (Participant 4). One participant met criteria for positive response to the RM-on condition for latency (Participant 7). Based on PEM analysis, two participants met criteria for positive response to the RM-on condition for prompt level (participants 3 and 4). Three participants met criteria for positive response to the RM-on condition for latency (participants 1, 3, and 8).

Table 5. Composite score results by condition.

Composite Score Results: Prompt Level and Latency Scores by Condition*			
Participant	**Data Type**	**RM-off Mean Score**	**RM-on Mean Score**
1	Prompt Level	2.83	2.90

	Latency	1.75	1.24
3	Prompt Level	2.87	2.94
	Latency	2.28	1.97
4	Prompt Level	1.94	2.2
	Latency	4.19	4.29
7	Prompt Level	3	3
	Latency	1.67	1.28
8	Prompt Level	3	2.87
	Latency	2.05	1.74

*Note: For prompt level data, a higher score indicates increased independence. For latency data, a lower score indicates

Table 6. Effect size results.

Effect Size Results: Prompt Level and Latency Score			
Participant	**Data Type**	**PND**	**PEM**
1	Prompt Level	0%	0%
	Latency	---[1]	---[1]
3	Prompt Level	0%	83%*
	Latency	50%	67%*
4	Prompt Level	80%*	60%*
	Latency	---[1]	---[1]
7	Prompt Level	0%	0%
	Latency	60%*	60%*
8	Prompt Level	0%	20%
	Latency	0%	60%*

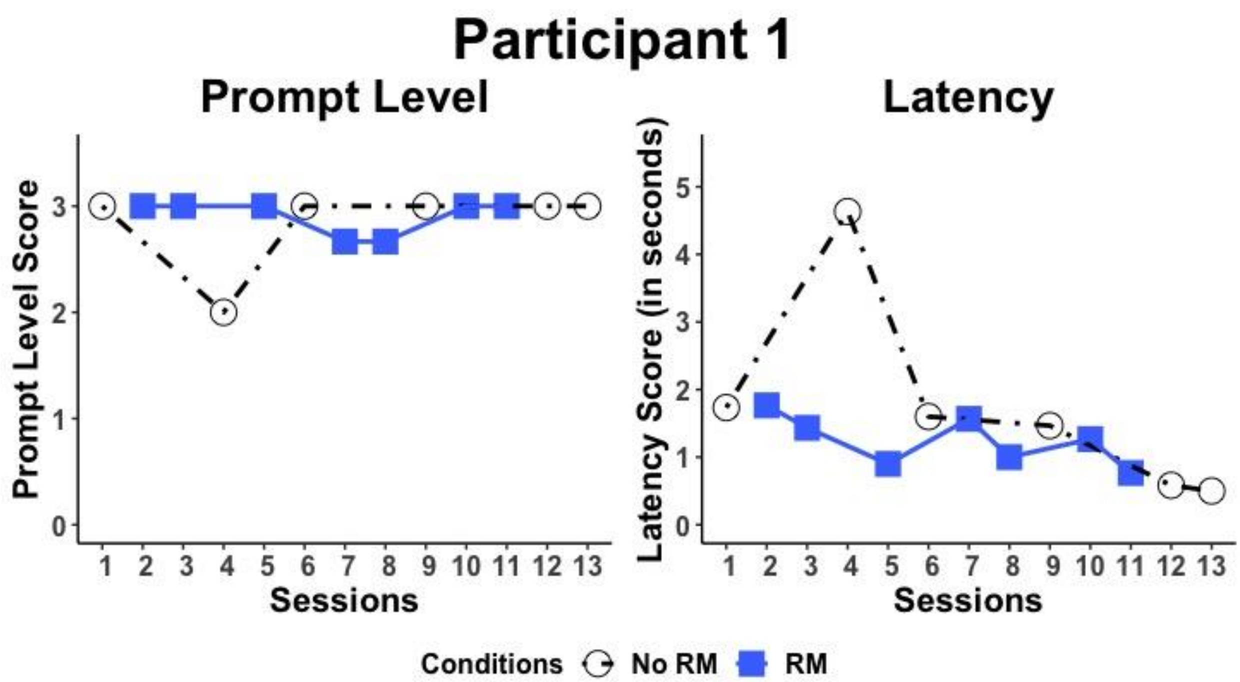
* indicates significant, positive result.

[1] score omitted

Participant 1

Participant 1 met criteria for stability in prompt level only. Participant 1 did not demonstrate a positive response to the RM-on condition for prompt level (PND = 0%; PEM = 0%).

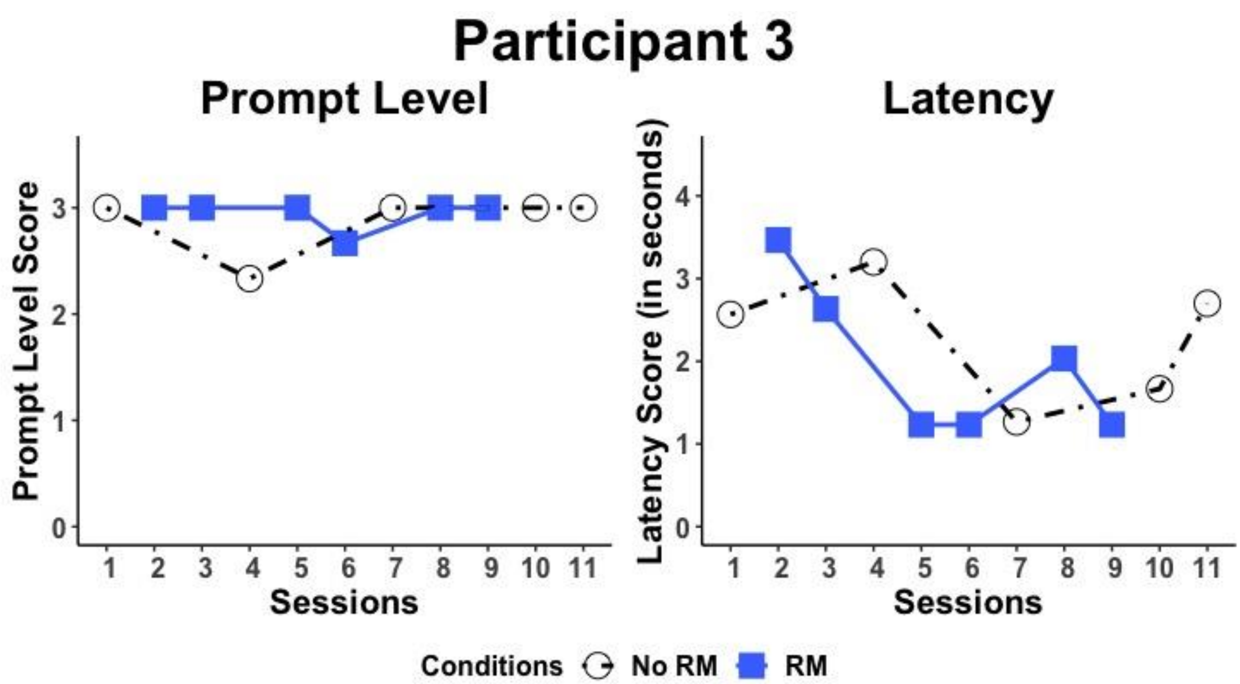
Figure 4. Participant 1 prompt level and latency results.



Participant 3

Participant 3 met criteria for stability in both prompt level and latency data. Participant 3 demonstrated a positive response in the RM-on condition for prompt level based on PEM only (PND = 0%; PEM = 83%) and a positive response in the RM-on condition for latency based on PEM only (PND = 50%; PEM = 67%).

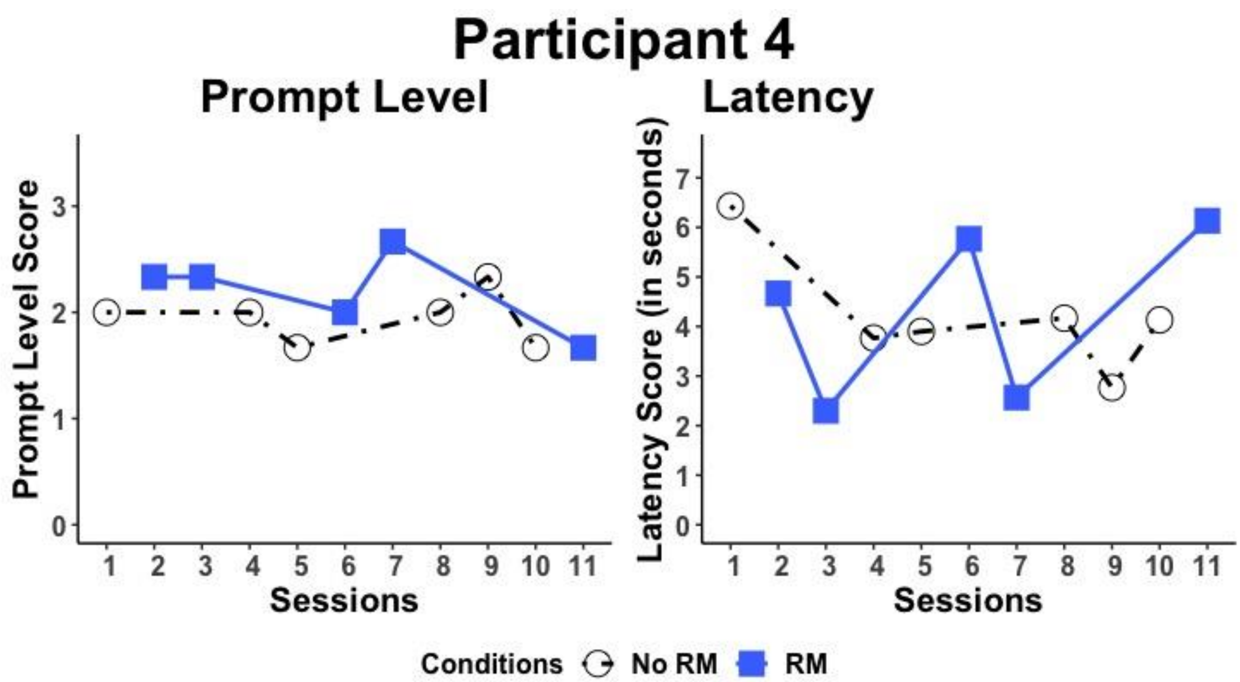
Figure 5. Participant 3 prompt level and latency results.



Participant 4

Participant 4 met criteria for stability in prompt level only. Participant 4 showed a positive response in the RM-on condition for prompt level based on both PND and PEM (PDN = 80%; PEM = 60%).

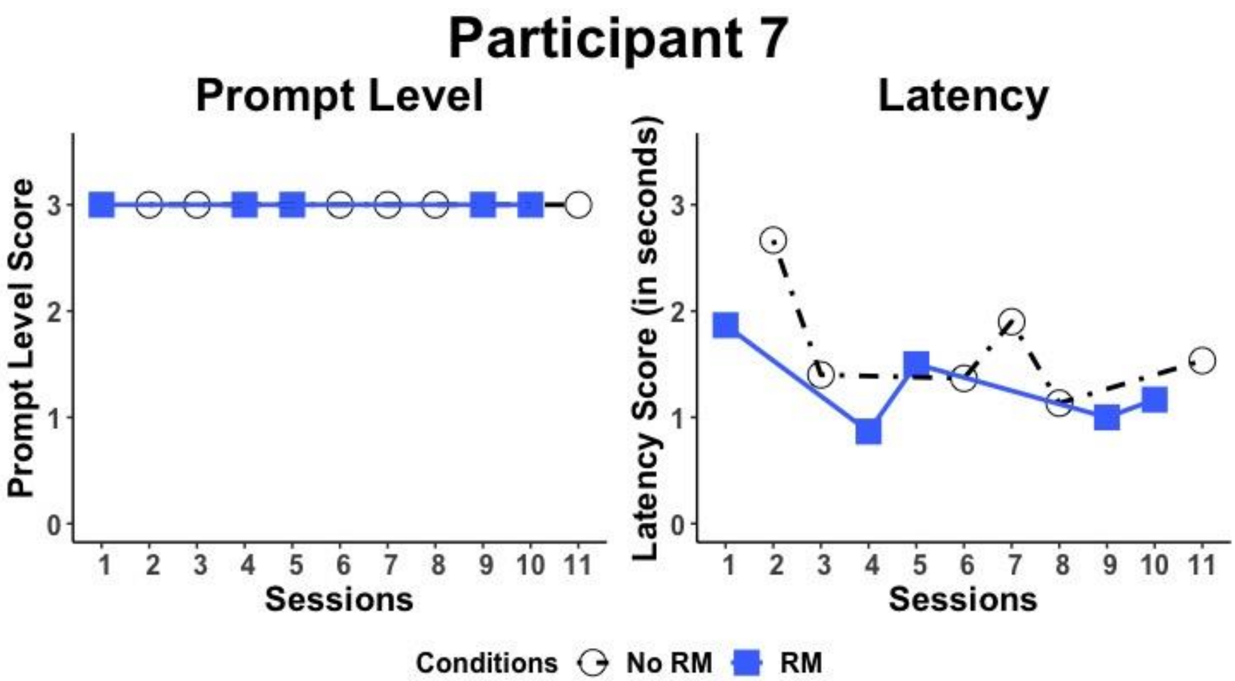
Figure 6. Participant 4 prompt level and latency results.



Participant 7

Participant 7 met criteria for stability in both prompt level and latency data. Participant 7 did not show a positive response in the RM-on condition for prompt level (PND = 0%; PEM = 0%) but did show a positive response in the RM-on condition for latency based on both PND and PEM (PND = 60%; PEM = 60%).

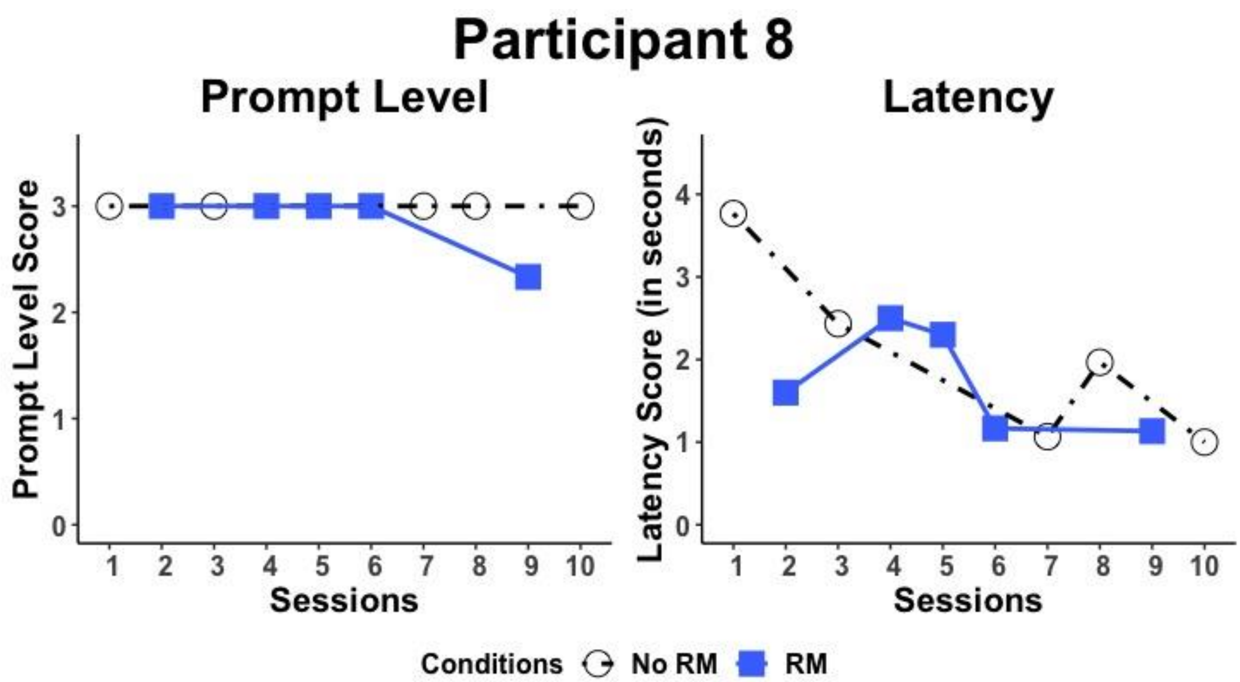
Figure 7. Participant 7 prompt level and latency results.



Participant 8

Participant 8 met criteria for stability in both prompt level and latency data. Participant 8 did not show a positive response in the RM-on condition for prompt level (PND = 0%; PEM = 20% but did show a positive response in the RM-on condition for latency based on PEM only (PND = 0%; PEM = 60).

Figure 8. Participant 8 prompt level and latency results.



3.5 Results Summary

Two of the five participants who met criteria for stable responding in their prompt level data demonstrated evidence for a functional relation between RM-on condition and prompt level (Participants 3 and 4). All three of the participants who met criteria for stable responding based on their response latency data demonstrated evidence for a functional relation between RM-on condition and response latency (Participants 3, 7, and 8).

3.6 Discussion

The present study sought to extend the existing literature on RM system use in children with ASD through a pilot study of the feasibility and efficacy of RM systems in preschool children with ASD and language disorder in the classroom setting. In the present study, significant improvements in LiD were seen for a subset of the sample. Two of five (40%) participants who achieved data stability in their prompt level data showed evidence of short-term efficacy of the RM system. Three of three (100%) participants who achieved data stability in their response latency data showed evidence of short-term efficacy of the RM system. The results suggest that listening performance can be improved using an RM system in a subset of preschool children with ASD and language disorder. Although the effects were modest in magnitude and were not sufficient to indicate that RM systems are an effective tool for all preschool-aged children with ASD, they provide preliminary evidence that RM systems might be a feasible and efficacious approach for improving indices of LiD for some preschoolers with ASD and language disorder. These results, when taken in context with the observational and single case design research methods used in the current study, suggest an approach by which RM systems can be evaluated at the individual level in the classroom or clinical setting.

We found that the application of an RM system during a standard instructional procedure can the decrease prompt level required and diminish response latency for some children with preschool-aged ASD and language disorder. Even though these effects are small in magnitude (e.g.,51% improvement in prompt level or latency relative to RM-off), even small improvements in these dimensions of LiD may be clinically significant. For example, decreased latency of responding to instructions and decreased level of prompting required can increase the amount of active instruction delivered in a given time period.

Previous studies of RM systems in children with ASD have found that use of RM systems results in improvements in speech recognition in noise, on-task behavior in the classroom, and parent and teacher rated listening behavior. The results of the present study are in line with these findings, as all participants who established initial stability showed an improvement in listening performance. This is important to note, as it indicates that the improvements previously noted in studies of RM system effects in children with ASD without language disorder might extend to a subset of children with ASD and co-occurring language disorder.

The results of this study should be considered in the context of the study limitations. This study used a small sample size that limited the study's external validity. Thus, the present results should be considered preliminary and proof-of-concept in nature and could be used to support the design of larger studies (e.g., a group randomized controlled trial). Future studies with larger sample sizes would allow for more adequately powered group level analyses. Additionally, although efforts were made to ensure that children were familiar with the items used in the listening presses, due to the age and the language level of these participants, it was difficult to confirm this with certainty due to the dearth of effective receptive language measures available for this population. Mullen scores were collected to determine presence of a language disorder in the participants. Because these scores were collected from administrations completed previously, months delayed at administration (age equivalency subtracted from chronological age) was used to determine language status. Future studies should administer the Mullen at the start of the study to allow for more conventional comparison of standard scores. Furthermore, a formal generalizability (G) study was not completed using the outcome measure prior to the present study. G studies provide information on how much repetition of a measure is needed to measure a trait most accurately. Use of a G study should be considered for future studies that use the listening press procedure developed for this study to improve measurement stability.

Because the individual effects of the RM system were modest in magnitude and seen only in some children, the results of this study suggest that the use of RM systems should not be considered a stand-alone treatment, but rather a tool that might work well in conjunction with other existing evidence-based practices. It is possible that RM systems could augment the effects of other intervention approaches for children with ASD. For example, RM systems could be combined with evidenced-based developmental behavioral interventions (Dawson et al., 2010; Kaiser et al., 2000; Kasari et al., 2008) or other assistive technologies like augmentative and alternative communication (AAC) devices (Checkley et al., 2012; Ganz, 2015; Light et al., 1998). This is clinically significant given that many forms of evidenced-based intervention in ASD involve spoken instruction and interaction and depend on child having intact listening skills. RM systems may help augment the effects of instruction-based interventions by increasing the salience of spoken instructions to the child, thereby potentially improving the child's active engagement with the intervention.

To assess these effects of RM systems, researchers and clinicians must be able to accurately measure the listening performance of all children who receive these interventions. This includes young children and children who have severe language disorder. Historically, children with ASD, especially preschool-aged children who have severe receptive and expressive disorder, have been considered "untestable" (Kasari et al., 2013; Plesa Skwerer et al., 2015). The measure of listening performance used in this study appears to be sensitive to both individual differences in language ability within our sample of children with ASD, and to RM-related changes in listening performance in these children. The measure was feasible in all children tested in the context of this study. Even those with the most severe language disorders were able to complete repeated administrations of the measure successfully. This is important, as many existing measures of listening performance are not feasible for young children with ASD, especially those who have severe language disorder (Kasari et al., 2013; Tager-Flusberg and Kasari, 2013).

In summary, we found evidence for modest short-term effects of RM system use on listening performance for a subset of the preschool-aged children with ASD examined. The present study also provides a demonstration of a method for feasibly measuring the effect of an RM system on the listening performance at the level of individual children with ASD. The results of this study indicate that future research on the effects of RM systems in preschool-aged children with ASD and language disorder is warranted.

CHAPTER 4

RM System Use in Minimally Verbal Children with ASD

4.1 Introduction

Children with ASD often exhibit co-occurring communication deficits, with language disorder occurring in at least 65% of children with autism spectrum disorder (Anderson et al., 2007; Tager-Flusberg, 1981; Turner et al., 2006). Furthermore, severe language disorders are present in approximately 30% of children with ASD. This subgroup, who often uses few to no words, is referred to as minimally verbal (Tager-Flusberg & Kasari, 2013). Children with minimally verbal autism (MVA) have traditionally been excluded from studies due in large part to their difficulty participating in testing. However, this is a sizeable subgroup for whom it is critical to determine the effectiveness of interventions. In this chapter I will (a) review the current literature as it relates to interventions for LiD in children with MVA, (b) assess the feasibility and effectiveness of RM systems as an intervention for children with MVA, and (c) discuss the implications of my findings on this subgroup.

4.1.1 Listening and Language Development in ASD

One of the most common and clinically significant features of ASD is language disorder (Anderson et al., 2007; Tager-Flusberg, 1981; Turner et al., 2006). Language disorder refers to deficits in both expressive language and receptive language and has a substantial impact on an individual’s ability to communicate effectively. Language disorders are often exacerbated for the subgroup of children with ASD who are nonverbal or use limited spoken language (Bal et al., 2016), commonly referred to as MVA.

Critical to effective communication is the processing of language input, which relies on the adequate processing of auditory stimuli. Children with ASD have been found to demonstrate atypical auditory responses and atypical attention to speech sounds (Kuhl et al., 2005; Whitehouse & Bishop, 2008; Tharpe et al., 2006). Furthermore, children with ASD who have normal hearing require a higher SNR than their typically developing peers when listening to speech in the presence of high levels and different types of background noise (Alcantara et al., 2004; Schafer, et al. 2013; Peters et al., 1998, Rance, et al., 2014; Russo et al., 2009). In the present article, we refer to this specific difficulty of listening in the presence of everyday background noise in the absence of hearing loss as Listening Difficulty (LiD). We will refer to the performance of listening in background noise as listening performance. It stands to reason that increased listening performance would improve LiD.

A recent study in our laboratory compared groups of children with ASD who had specific language profiles (minimally verbal, phrase speech, verbally fluent) on event related potentials (ERP) of auditory processing of speech sounds using electroencephalogram (EEG). This study found that deficits in the early neural processing of speech sounds were present in the MVA subgroup only (Whitten et al., 2020). This finding is consistent with other studies that have documented a relationship between auditory processing deficits, such as listening to speech in noise, and language performance in children with ASD (Siegal & Blades, 2003). Together, these findings suggest that targeting listening-in-noise deficits in children with MVA could be a reasonable strategy for enhancing language performance.

4.1.2 Remote Microphone Systems

The listening performance of individuals with ASD has been shown to benefit from increased SNR (Rance et al., 2017; Schafer et al., 2016; van der Kruk et al., 2017). A 2017 systematic review of five studies concluded that improving SNR for children with ASD can lead to improved classroom performance (van der Kruk et al., 2017). RM systems improve SNR by providing low-delay and reliable broadband audio broadcast to listeners, allowing better access to speech in noise by improving the SNR (Ching et al., 2005; Holt et al., 2005; Schafer & Thibodeau, 2006). As outlined in previous chapters, RM systems have been shown to improve children's abilities to listen to and understand speech as indicated through structured assessments of listening and comprehension, as well as parent, teacher, and participant ratings.

4.1.3 RM System Use in Children with ASD

Recent studies have begun to investigate the efficacy of using RM systems in children with ASD. Results from these studies indicate that RM systems are feasible for use with some children with ASD and can be effective in improving speech-in-noise perception in controlled settings in these children (Rance et al., 2014; Rance et al., 2017; Schafer et al., 2013; Schafer et al., 2016). However, these studies have been restricted to older children with ASD who do not have language disorder. Although these are important steps in this new line of research investigating improved listening-in-noise performance in children with ASD, several questions remain as to the effectiveness of this approach across a wider range of child ages, language ability, and settings.

4.1.4 Present Study

The present study sought to examine the effects of RM system use on LiD in a narrowly-defined sample of children with ASD and severe language disorder (MVA), typically defined as children with ASD who use no more than single words or rote phrases to communicate (Kasari et al., 2013). This study was guided by two research aims:

1. to evaluate whether an RM system improves listening performance in school-age children with MVA;
2. to determine if the effects of an RM system in school-age children with MVA are greater in nonsocial listening presses relative to social listening presses.

4.2 Methods

The protocol for this study was approved by the Vanderbilt University Medical Center Institutional Review Board. Consent was gathered from all caregivers prior to beginning the study.

4.2.1 Participants

A total of 16 school aged (4 years, 10 months – 16 years old) children with MVA were recruited. Inclusion criteria were: (a) clinical diagnosis of ASD, (b) normal hearing status as reported by parent and/or medical records, and (c) minimally verbal expressive communication ability. ASD was confirmed by administration of the Autism Diagnostic Observation Schedule

(ADOS-2). MVA was defined as using only single words and rote phrases during administration of Module 1 of the ADOS and an expressive language age-equivalency of less than 18 months. This MVA criteria was derived from previous studies (Bal et al., 2016; Paul et al., 2013). Two participants were excluded following recruitment; one participant was unable to complete the study activities, and one participant did not meet MVA inclusion criteria. This resulted in a final sample of 14 participants with MVA. The final study sample ranged in age from 4 years, 10 months to 16 years, 8 months. See Table 7 for demographic information on the final sample.

Table 7. Participant characteristics.

Participant ID	Age (years; months)	Sex	PPVT-5 Standard Score	MBCDI Words Understood	Vineland Communication Standard Score
1	7;4	M	57	273	---[2]
2	16;8	M	49	363	---[2]
3	10;4	M	40	363	34
4	5;10	F	53	381	36
5	12;4	M	40	399	34
6	6;4	M	40	219	29
7	10;5	F	67	358	47
8	8;6	M	40	192	42
9	5;9	M	---[1]	34	---[2]
10	11;9	M	40	394	31
11	16;8	F	---[1]	248	30
12	4;10	M	---[1]	344	34
13	8;0	M	40	395	36
14	4;10	F	80	368	49

[1] Participant was not able to complete testing.
[2] Parent did not complete form.

4.2.2 Hearing Status

To screen children for hearing status, parents were asked to respond to the question "What is your child's hearing history?" with the following responses: a) "My child has passed a hearing test and I have no concerns about their hearing.", b) "My child passed a hearing test but I am still concerned about their hearing.", c) "My child has failed a hearing test.", d) "My child has only had a newborn hearing screening.", e) "My child has not had any recent hearing test, including a newborn hearing test." Thirteen of 14 answered "My child has passed a hearing test and I have no concerns about their hearing." One parent indicated "My child has only had a newborn hearing screening" and indicated no concern regarding the child's hearing when asked.

4.2.3 Experimental Design

This study used a within-groups experimental design. All participants were evaluated in two conditions: RM-off and RM-on. The order of conditions was randomized within participants. Each participant completed three trials in each condition. Three trials of each condition was chosen in an effort to balance the need for repeated measurement with the likelihood that children at this age and with MVA are at increased risk for a variety of forms of inattentive and off-task behaviors (e.g., noncompliance, leaving the area, behavior problems) that can be exacerbated by longer experimental protocols. We chose a protocol with three trials per condition to help ensure completion by avoiding fatigue or noncompliance in this subgroup of children with ASD.

4.2.4 Setting

All sessions were conducted in a laboratory setting in the presence of background noise. The background noise was four talker babble at 55 dB sound pressure level (SPL), as measured by a sound level meter placed at the approximate location of the child's ear. This babble was produced by two speakers in the room, one to the left and one to the right of the child, each approximately three feet away. Fifty-five dB SPL was used, as this replicates common noise levels in classrooms (Crandell & Smaldino, 2000). Four-talker babble was used to replicate a classroom setting wherein multiple talkers are common, which has been used in prior studies of RM systems in children with ASD (Rance et al., 2014; Schafer et al., 2016). During each session, the participant sat one-on-one at a table with the examiner.

4.2.5 Equipment

All sessions were video and audio recorded using Noldus Observer cameras and software. A soundfield RM system was used in the RM-on condition sessions. A Phonak Roger DigiMaster 5000 speaker was installed in the testing room and the examiner used a Phonak Inspiro FM microphone/transmitter. The examiner verified that the RM system was working prior to each test session using a sound level meter. The wireless lanyard microphone/transmitter was worn by the examiner in all test sessions. The speaker was mounted on a stand and placed out of reach of and located approximately seven feet from the participant. When the RM was activated (RM-on condition) the speech signal was transmitted to the speaker. One common area of confusion is over the method by which sound is amplified. Although personal RM systems that are worn at ear level are a common method of amplification for students with hearing loss, this type of RM is often not tolerated by some children with ASD who have sensory aversions. Because of this challenge, the present study used soundfield RM systems that amplified sound via a speaker to the entire room and did not require a child to tolerate an in-ear device. This method is also highly feasible for clinical and academic use (Dockrell and Shield, 2012; Rosenberg et al., 1999) , as an entire classroom can receive amplification from one piece of equipment.

This system allowed the researchers to examine each child's response to instructions during RM-on conditions in comparison to trials when the examiner was still wearing the microphone, but the RM system was off (i.e., RM-off condition). Because the examiner wore the microphone during both conditions (RM-off and RM-on) and the outcome measure presses (described below) were videotaped for later behavioral coding, the coder remained blind to the experimental condition while they completed the coding of the videotapes.

4.2.6 Measures

Diagnostic Measures:

Autism Diagnostic Observation Schedule, Second Edition (ADOS-2, Toddler Module and Module 1). The ADOS-2 (Lord et al., 2012) is a gold-standard, standardized observational measure used to diagnose ASD and was used to confirm diagnoses of ASD, which was an inclusion criterion.

Macarthur Bates Communication Development Inventories – Words and Gestures (MBCDI – Words and Gestures). The MBCDI (Fenson et al., 2007) is a questionnaire that asks an adult to indicate words that the child "understands" and words the child "understands and says”. The assessment provided an estimate of a child’s receptive and expressive vocabularies.

Vineland Adaptive Behavior Scales – Second Edition (VABS-2; Sparrow et al., 2005*)* is a caregiver rating form that measures adaptive behavior in five domains: communication, daily living, socialization, motor skills, and maladaptive behavior. The Vineland-3 Communication subtest was used to determine MVA status, which was an inclusion criterion. Participants were considered to have MVA if they produced a standard score below 50.

Peabody Picture Vocabulary Test (PPVT-5). The PPVT-4 (Dunn, 2007) is a receptive vocabulary test designed to assess the breadth and depth of a child’s receptive language vocabulary.

Measurement of listening performance

Each trial within both conditions (RM-on, RM-off) involved the presentation of a series of presses to the child that represented three different categories of listening performance: 1) social press, 2) object identification press, and 3) direction following press. These categories of presses were chosen because they span different domains of listening performance and are building blocks of more advanced communication skills. Each of the three categories of listening performance included presses at three different levels of difficulty designed to correspond to different levels of developmental ability. For example, for the presses designed to tap different developmental levels of object identification, “Level 1” was choosing an object from a field of three, “Level 2” was choosing an object from a field of five, and “Level 3” was choosing an object from a field of seven. The use of developmental levels was guided by the common use of developmental levels or start points across standardized tests designed to assess a range of children’s language abilities (Sparrow et al., 2005; Voress & Maddox, 1998; Zimmerman et al., 2011). Thus, the entire listening-in-noise measurement protocol that was applied on each trial for each condition (RM-on, RM-off) included nine total presses (3 categories of performance X 3 difficulty levels). This took approximately 10 minutes to administer per trial. Each trial was administered 3 times per condition. See Table 8 for a description of each of the press types that was included in the listening measurement protocol.

Table 8. Description of the presses used for the listening performance measurement procedure.

Domain	Example press
	Level 1
Social	Response to name: Call child's name.
Identification	Object identification from a field of three: "Touch the ______."
Direction Following	Simple one-step direction: Example: "Put the ______ on the ______."
	Level 2
Social	Joint attention: Say "Look at that!" and point to a distant object of interest.
Identification	Object identification from a field of five: "Touch the ______."
Direction Following	Related two-step direction: Example: "Put the horse in the barn, then put the man on the tractor."
	Level 3
Social	Social Turn Taking Task
Identification	Object identification from a field of ten. Example: "Touch the ______."
Direction Following	Unrelated two-step direction. Example: "Give me the crayon and then put the teddy bear in the bed."

Common objects were used as referents during the listening performance presses. The objects used in each press were randomly chosen from a list of 65 common nouns taken from the MBCDI and a vocabulary checklist created for children with MVA (Plesa Skwerer, 2016) to ensure that all items would be familiar to the children and developmentally appropriate. These objects were randomized across trials to help ensure that participants did not habituate to the objects.

All presses were administered using a least-to-most prompt hierarchy, a type of dynamic assessment, with a five second wait time provided after any given prompt (DiCarlo et al., 2017; See Table 9). The five second wait time was chosen to allow adequate response time for children with delayed processing, while attempting to avoid measuring non-intentional behaviors (Lee et al., 1987; Rowe, 1986; Tincani & De Mers, 2016).

Table 9. Prompting hierarchy used for the nonsocial presses in the listening performance measurement procedure.

Step	**Identification Examples**	**One Step Direction Examples**
4. Verbal: Give verbal command, wait 5 seconds	"Touch the car."	"Put the cow on the book."
5. Gestural: If no successful response to verbal , give verbal command with gestural prompt, wait 5 seconds	"Touch the car." + examiner points to the car	"Put the cow on the book." + examiner points to cow and book
6. Physical: If no successful response to gestural, give verbal command with partial physical prompt, wait 5 seconds	"Touch the car." + elbow prompt	"Put the cow on the book." + elbow prompt
7. Indicate completion If no successful response to physical, terminate trial.	"All done."	"All done."

4.2.7 Observational coding of listening presses

Each session of the listening performance measurement procedure was audio and video recorded using a video camera. Once the sessions were recorded, the video files were uploaded and coded in ProcoderDV (Tapp & Walden, 1993). The Multi-Option Observation System for Experimental Studies (MOOSES) software (Tapp et al., 1995) was used to quantify (a) the prompt level required to complete each listening press successfully and (b) the response latency for each listening press (i.e., the time in seconds that elapsed between the first prompt delivered by the experimenter to the participant and the successful completion of the press by the participant). An operational definition of a successful response was used to code the videotaped trials**.** A successful response was defined uniquely for each of the three categories of presses administered (See Table 10). For prompt level, a numeric score was given based on the level of prompting the child needed to complete the press successfully (See Table 11); *higher scores* denote responding that relied on less prompting and index better performance on this measure. Each press was terminated after five seconds of wait time, thus the longest latency score that a child could receive was five seconds; *lower values* denote faster responding and index better performance on this measure.

Table 10. Prompting hierarchy used for the social presses in the listening performance measurement procedure

Step	Response to Name Examples	Joint Attention Examples	Turn Taking Examples
1. 1st social bid: Initiate social bid, wait 5 seconds.	Call child's name	Point and call out object (e.g. "Look at that!")	Initiate turn taking game
2. 2nd social bid: If no successful response to 1st bid, give 2nd bid, wait 5 seconds	Call child's name.	Point and call out object (e.g. "Look at that!")	Initiate turn taking game
3. 3rd social bid: If no successful response to 2nd bid, give 3rd bid, wait 5 seconds	Call child's name.	Point and call out object (e.g. "Look at that!")	Initiate turn taking game
4. Indicate completion	"All done."	"All done."	"All done."

Table 11. Numeric score given based on the level of prompting the child needed to complete each press successfully

Score	Level of prompting required for successful response
3	**Social presses**: Child responded to first social bid **Non-social presses:** Child responded to verbal command only
2	**Social presses:** Child responded to second social bid **Non-social presses:** Child responded to gestural prompt with verbal command
1	**Social presses:** Child responded to third social bid **Non-social presses:** Child responded to partial physical prompt with verbal command
0	Did not successfully respond to press

As a control check on the feasibility, reliability, and stability of this listening-in-noise measurement procedure, we applied this procedure to a separate sample of 10 children with ASD, four of whom met criteria for MVA. All 10 children were able to complete the assessment on all trials attempted successfully (between three – seven sessions per child) suggesting that the measure was feasible for use with children with ASD including MVA children. Intra-observer reliability was 99% for prompt level, and 99% for response latency (using an error window of one second). Test-retest results for this control check sample indicated significant stability over time ($r = .86$, $p < .01$).

4.2.8 Blinding

We videotaped all trials of the listening performance measurement procedure for later coding by an independent coder in an effort to ensure that the coder was blinded to the treatment condition (RM-off, RM-on). As a control check designed to assess the degree to which the study could be blinded, we examined whether the trial condition could be kept blind from the data coder (i.e., could coders detect that the RM system was "on" while watching the videotapes?). For this control check, eight different one minute videos of study participants from the present study were recorded (four RM-on and four RM-off). The order of the videos was randomized, and the videos were watched by a set of nine different data coders. Eight of the nine coders were not able to identify the listening condition correctly across the videotapes at greater than chance levels (50%); the average percent of correct identification of condition across the nine raters was 41%. This indicated that the status of the RM system (on or off) was not able to be consistently detected from videotaped sessions and thus blind coding of videotaped sessions was possible.

4.2.9 Reliability

To assess the reliability of data collection, a randomly selected 28% of session videotapes were scored by a trained coder. The coder was first trained to use the MOOSES and ProcoderDV software. The coder then completed trial coding sessions using test videos in order to become familiar with the coding and analysis procedures. After completing trial coding on three test videos, which were taken from the existing pool of participant videos from this study, the coder coded the randomly selected 28% of session videos. The test videos were not included in the 28% of videos coded for reliability. Interobserver agreement was calculated, with a goal of 80% (Reichow, 2011; Wilczynski & Christian, 2008). The resulting mean overall inter-rater reliability, as measured by inter-observer agreement of the prompting procedure, was 89% (range: 81% - 96%). The resulting mean overall inter-rater reliability of the latency procedure was 86% (range: 80% - 96%).

4.2.10 Fidelity

The reliability coder also scored fidelity of the examiner's application of the listening performance measurement procedure for a randomly selected 28% of all trials across participants. This ensured that the procedures established for this study were implemented correctly, with a goal of 80% procedural fidelity (Reichow, 2011; Wilczynski & Christian, 2008; Wolery, 1994). Mean fidelity of the prompt sequence of the presses (overall percentage of sessions wherein the examiner correctly applied the prompt sequence) was 93% (range: 90% - 98%).

4.2.11 Data Analysis

Prompt level and response latency during the listening performance presses were the two outcome measures used in the present study. Data analysis proceeded through three stages. First, the data were examined via group histograms for each measure. The data for both measures were determined to not be normally distributed; therefore, a non-parametric statistical analysis approach was used to evaluate the effect of condition (RM-off, RM-on). Second, the Wilcoxon signed-rank test was used to determine if there were statistically significant ($p < .05$) differences for each outcome measure as a function of condition. Third, condition effects for both outcome measures were examined separately for the social presses and non-social presses using the Wilcoxon signed-rank test. Fourth, effect sizes were calculated for significant results.

4.3 Results

Results indicated a significant effect of RM system use on participants' performance as measured by prompt level ($z = -2.25$, $p = 0.02$; Figure 9). Prompt level performance was significantly improved during the RM-on condition, but the effect size was small ($r = .12$). There was also a significant effect of RM system use on participants' performance as measured by response latency ($z = -2.67$, $p = .007$; Figure 9) with response latency being significantly improved during the RM-on condition but having a small effect size ($r = .14$).

Figure 9. Mean (and standard error) prompt level and latency scores for the listening presses for the MVA sample (n = 14) in the RM off and the RM on experimental conditions (RM = remote microphone). Note: increased prompt level score indicates relatively greater level of independent response.

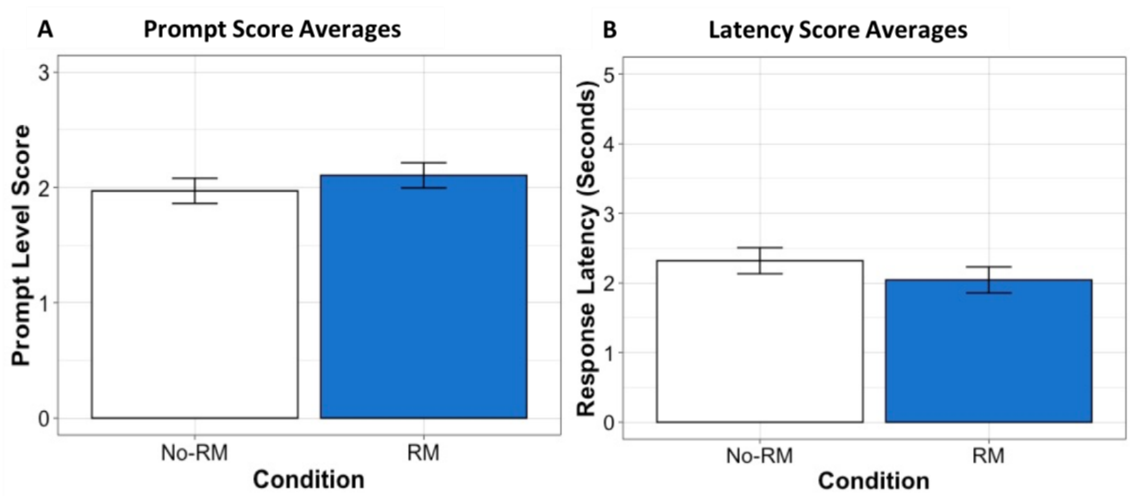


Figure 10. Mean (and standard error) prompt level scores for the listening presses for the MVA sample (n = 14) in the RM off and the RM on experimental conditions (RM = remote microphone), divided by non-social presses. Note: increased prompt level score indicates relatively greater level of independent response.

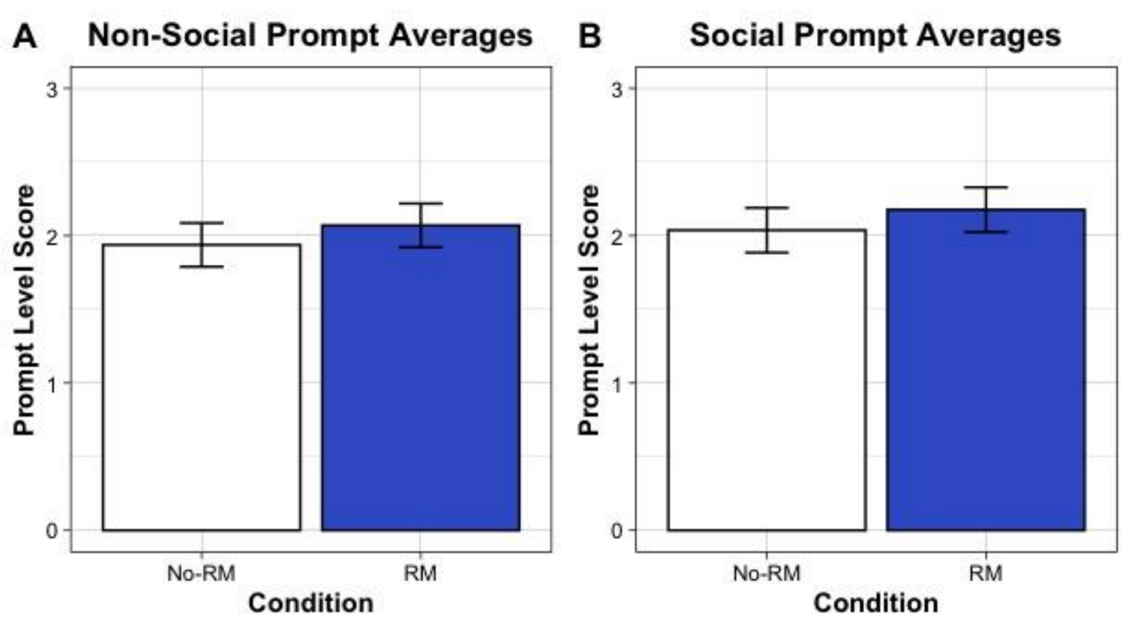
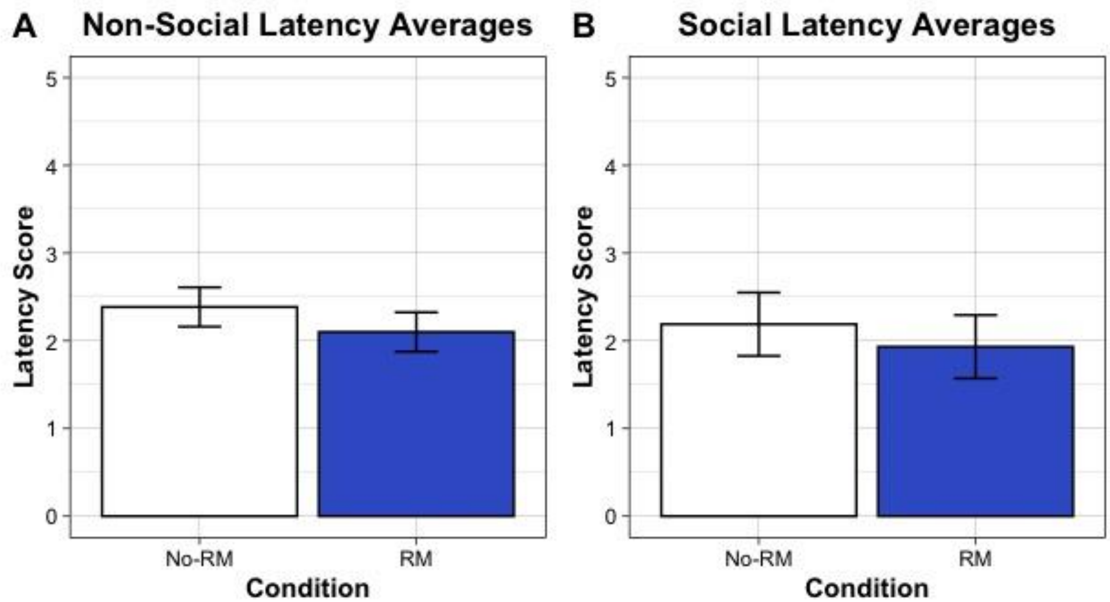


Figure 11. Mean (and standard error) response latency (seconds) to the listening presses for the MVA sample (n = 14) in the RM off and the RM on experimental conditions (RM = remote microphone), divided by non-social and social presses.



The Wilcoxon signed rank test was used to compare the conditions separately for social and nonsocial presses for both outcome measures. There was a significant improvement in the RM-on condition for prompt level for the non-social presses (*z* = -2.12, *p* =.03) with a small effect size (*r* = .13) (Figure 10). However, there was no significant difference between the conditions for prompt level during social presses (*z* =-1.34, *p* = .18). For response latency, there was a significant improvement in the RM-on condition during non-social presses (*z* = -2.50, *p* = .01) with a small effect size (*r* = .16) (Figure 11). There was no significant difference between conditions in response latency during social presses (*z* = -1.74, *p* = .08).

4.4 Discussion

This study sought to extend the existing literature on RM system use in children with ASD through a study of the efficacy of RM systems in school-age children with MVA.

Specifically, the purpose of the present study was (a) to evaluate whether an RM system improves the listening performance of school-age children with MVA and (b) to determine if the effects of an RM system in school-age children with MVA are greater in nonsocial listening presses relative to listening language presses. Results indicate that RM system use yielded significant but small improvements in listening performance in both level of prompting needed for successful responses, and response latency in this sample of children with MVA. Although the effect sizes were small, these results provide preliminary evidence that RM systems might be an efficacious approach for improving listening performance in some children with MVA. These findings on improvements in listening performance in children with ASD during RM system use are in line with previous studies of RM system use in verbally fluent children with ASD (Rance et al., 2014; Rance et al., 2017; Schafer et al., 2013; Schafer et al., 2016).

When the effect of condition was analyzed separately for social and nonsocial presses, we found a significant effect of RM system on listening performance during non-social presses but not social presses. This was true for both prompt level and latency outcome measures. This pattern of non-social effects is consistent with the broader ASD literature that has consistently reported that children with ASD more readily orient to objects and non-social stimuli relative social stimuli (Dawson et al., 1998; Sasson & Touchstone, 2014; Unruh et al., 2016). This pattern of findings suggests that the ability of an RM system to improve listening-in-noise for children with ASD might be limited to nonsocial contexts. However, improving listening-in-noise in social contexts is a desirable and clinically significant goal for children with MVA. It could be that social attention for children with MVA is impacted by factors such as social motivation (Chevallier et al., 2012; Unruh et al., 2016) in addition to the improved auditory signal produced by an RM system. If so, then additional elements such as explicit visual cueing during social interactions (Leekam et al., 2000; Whalen & Schreibman, 2003) could be added to RM system approaches to determine if social listening can be improved. Given the importance of improving social attention in children with ASD, future research is warranted that examines the effects of a combination RM systems with other approaches specifically designed to impact the perceived salience of social signals.

Although MVA is by definition the most severe form of language disorder seen in the context of ASD, there has been little research focus on this subgroup (Kasari et al., 2013; Tager-Flusberg & Kasari, 2013). One reason for this lack of research focus on MVA is that available outcome measures that are sensitive and appropriate for use with children with ASD in general are not applicable for children who have MVA. Previous studies of MVA have found that language-related performance cannot be validly assessed for most children in this subgroup using conventional standardized tests (Kasari et al., 2013; Plesa Skwerer et al., 2016). Consistent with this finding, four of the 14 participants in the present study received the lowest possible score on the PPVT, which indicates that their receptive ability could not be accurately measured. The remaining 10 participants received very low PPVT scores, again indicating that standardized receptive language measures like the PPVT are not adequately sensitive to detecting intervention-related change in this subgroup of children with ASD. In contrast to the PPVT, the listening performance assessment procedure that we developed for use in the present study was feasible and sensitive to the measurement of changes in performance in this subset of participants. Our findings suggest that an observational approach to measuring listening performance can be standardized and used to measure individual differences in performance for children with MVA and might be a valid approach to examining intervention effects for this difficult-to-assess subgroup of children with ASD.

The results of this study should be considered in the context of its limitations. This study used a small sample size that limited the study's external validity. Smaller sample sizes are common in studies of MVA due to the dearth of outcome measures for this population and their difficulty with behavioral compliance, and our sample is comparable in size to other studies in this area (Rance et al., 2014; Rance et al., 2017; Schafer et al., 2013; Schafer et al., 2016). However, given the positive effects of the RM system that we observed in our sample, approaches that can amass larger sample sizes of this MVA subgroup (e.g., multisite studies) are now needed to advance research and practice. Furthermore, we developed a novel outcome measurement procedure given the problems inherent in measuring language-related performance in children with MVA. Although we found that this approach was feasible, reliable, and sensitive to detecting improvements in performance, the number of repeated trials necessary to estimate stable performance using this approach is unknown. Future studies using this observational approach could include a generalizability (G) study (Cronbach et al., 1963; Cronbach et al., 1972) to determine the optimal number of trials needed.

The potential clinical implications of RM system use are important to consider given the emerging research findings that support the use of RM systems for children with ASD. Based on the results from the present study, RM systems might be a useful clinical tool for targeting listening performance in children with MVA. Furthermore, used in combination with other evidence-based clinical interventions, it is reasonable to assume that RM system use might augment language development in children with MVA. For example, if RM systems improve the listening performance of children with MVA, this could allow better access to interventions that rely on auditory input, such as most forms of behavioral/developmental interventions and services related to these approaches including speech and language therapy.

In summary, the present study found a significant effect of RM system use on listening performance in our cohort of children with MVA. The effects on listening performance found in this study were small in magnitude and acute in nature, and more research is needed to determine how these effects could evolve over time in the context of longer term use of an RM system in children with children with MVA. Finally, the observational measurement system used in this study should be examined further to determine if it can provide researchers with a practical and psychometrically sound approach for measuring listening performance in children with MVA – an approach that might be useful clinically following additional investigation.

CHAPTER 5

General Discussion

5.1 Introduction

In the previous chapters I reviewed the literature as it relates to LiD in ASD and described the methods and findings of a study that developed a parent report measure of LiD, a study that examined the feasibility and effectiveness of RM systems in the preschool classroom for children with ASD, and a study that evaluated the feasibility and effectiveness of RM systems for children with MVA. In the present chapter I will review the findings of these studies and discuss the clinical and research implications of this program of research.

5.2 Gaps in the literature

To date, there are no published studies that have investigated the multifactorial nature of listening in ASD with instruments *designed specifically for individuals with ASD*. The existing studies mainly rely on caregiver and self-report measures that were designed for children with hearing loss. These measures load heavily on social and language skills which are often impaired as a result of a child's ASD, *not their listening deficit.* These existing measures often ask caregivers to compare their child to same aged peers which may not be appropriate for children with severe developmental delay. Thus there is a need to develop an ASD-specific measure of LiD.

There is evidence that listening interventions such as RM systems can improve listening performance in ASD, but these studies have been limited by their use of non-ASD specific measures of listening and limited to children with ASD who are verbally fluent and school aged, and thus there is a need for studies to examine the effectiveness of RM systems in children with ASD and language disorder, including preschool-aged children with ASD with language disorder, and also school-aged children with ASD who have failed to develop spoken language and are designated as minimally verbal.

5.3 Summary of Findings

We developed a measurement of listening behavior designed specifically for children with ASD – the LBAS – using a six step iterative procedure and a series of psychometric analyses. We found that the LBAS was psychometrically strong, based on internal consistency, stability, and validity analyses. Additionally, we found that listening, as measured by the LBAS, was associated with other factors including sensory and attention performance, which is consistent with the established multifactorial model of listening.

In addition to developing a parent report measure of listening behavior, we also developed an observational measurement approach to measure listening performance in children with ASD and language impairments. This subset of ASD comprises up to 30% of all cases of ASD and is often excluded from studies due to floor effects on standardized measures. Further, an observational measure of listening performance has the advantage that it can be blinded in intervention studies, and thus can be used to assess outcomes of listening interventions such as RM systems. We found that this observational measure of listening performance was feasible for use in very young children with ASD with language disorder and in school-aged, minimally verbal children, and also that this approach yielded measures of listening performance in these children with ASD and language impairments that were reliable, stable, and valid.

Finally, we extended our work on LiD in ASD to include initial proof-of-principle studies of the effects of RM systems on listening behavior in children with ASD and language impairments. We focused specifically on preschool-age children with ASD with language disorder and minimally verbal school-aged children with ASD guided by the assumption that

LiD may be contributing to delays or deficits in language development in these subgroups of ASD. In our first RM study we found that the use of an RM system is feasible for preschool children with ASD in the regular classroom settings, and also found evidence that the RM system could improve listening performance in a subset of the participants with ASD. Our second RM study was conducted using a similar observational measurement of listening behavior but focused on school-aged children with MVA. We found that the RM system was feasible for use in this MVA subgroup, and also found evidence that the RM system could improve listening performance in a subset of the participants with MVA.

5.4 Implications

5.4.1 Clinical

Listening in ASD is important due to the nature of the deficits in this diagnosis. Adequate measurement of listening using measures like the LBAS in ASD will not only allow SLPs and Audiologists to measure listening during evaluations, but also allow for the identification of the subset of ASD with a significant degrees of LiD. This, in turn, would support the consideration of interventions that are designed to improve listening performance. RM systems have been assessed as an intervention for school-age children with ASD without language impairment, but in the present work we found RM systems were also feasible and efficacious for preschool-age and school-aged minimally verbal children with ASD. The LBAS could be a useful tool for identifying who might benefit from RM systems. Additionally, the observational measurement tool outlined in Chapters 2 and 3 could be adapted for clinical use to observe whether a child is responding appropriately to the RM system. And finally, RM systems could be used in an augmentative manner in conjunction with existing evidence-based treatments for ASD (e.g., speech therapy, Applied Behavior Analysis (ABA) therapy) to increase access to these orally administered therapies.

5.4.2 Research

Given that we found that RM system use was feasible and led to observable improvements in listening performance in a significant subset of preschool-aged and minimally verbal school-aged children with ASD, RM systems are a promising direction for future language intervention research in ASD. The two measurement approaches that we developed, the LBAS and the observational measurement of listening performance, appear to be both feasible and psychometrically strong, and thus they could be used to increase the measurement rigor of studies of listening difficulty in children with ASD. This is significant because children with ASD and severe language impairments have remained under-researched due to a lack of measurement tools that are both feasible and valid for use in this subset of the ASD population.

5.5 Conclusions

The present studies contribute to the existing evidence on listening in ASD through development of a parent-report measure of listening designed specifically for this population, as well as through study of the feasibility and efficacy of RM systems for young children with ASD and children with ASD who are minimally verbal. The development of the parent-report measure, the LBAS, will allow clinicians like SLPs and Audiologists to better measure listening as part of their assessment process, and for researchers to study listening with more specificity. The two studies of RM systems show that both young children and children with MVA, two populations previously missing from the literature in this area, can benefit from RM systems. This is important for both clinical and research purposes, as these groups can both be affected by

LiD. These results support further study of the measurement and intervention for LiD in ASD, as well as individualized LiD assessment and intervention as part of an interdisciplinary team in the clinical setting.

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Appendices

Appendix A

Listening Behavior in Autism Scale
Mary Alice Keller, M.A., CCC-SLP
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The items below refer to your child's listening behaviors. For each statement, **think about your child's behavior over the past week**. Then mark how true each statement is based on their behavior using one of the four answer options (Not True at all, A little true, Somewhat true, or Very true).

	Not at all true	**A little true**	**Somewhat true**	**Very true**
1. When listening in a noisy room, it is hard for my child to focus on what is said.				
2. It is hard for my child to focus on large group verbal instructions.				
3. When listening in a quiet room, it is hard for my child to focus on what is said.				
4. My child tunes me out or seems to ignore me.				

5. My child finds parties too loud to be able to focus and communicate.				
6. When I am sitting so my child is not looking at my face as I talk, it seems hard for him/her to focus on what I say.				
7. It is hard for my child to focus on what children are saying when they play as a group.				
8. My child has trouble focusing on others when an air conditioner or fan is on.				
9. When I tell or ask my child something without trying to get his/her attention first, it seems hard for her/him to focus on to what I say.				
10. My child has trouble focusing on verbal instruction when the speaker is moving around the room.				
11. It is hard for my child to focus on what I say when I speak from across a large room.				

12. When I am standing behind my child and she/he is looking at something, it seems hard for she/he to focus on what I say.				
13. It is hard for my child to focus on me when there is noise from the TV or music.				
14. My child seems like they don’t hear me when I call their name (even though they have normal hearing).				
15. It is hard for my child to focus on other children when they talk.				

Appendix B

Attention Checklist

The items below refer to your child's attention behaviors. For each statement, **think about your child's behavior over the past week**. Then mark how true each statement is based on their behavior using one of the four answer options (Not True at all, A little true, Somewhat true, or Very true).

	Not at all true	**A little true**	**Somewhat true**	**Very true**
1. My child has a hard time staying on task (e.g., needs reminders from adult to stay on task).				
2. My child seems unaware in a busy environment.				
3. My child has difficulty keeping attention on tasks or play activities.				
4. My child is distracted by noises or activity happening around them.				
5. My child often fidgets with his/her hands or feet or squirms in his/her seat.				
6. My child runs around or climbs too much in situations when it is not appropriate.				

7. My child frequently gets distracted from tasks to notice all the actions in the room.				
8. My child is so active that they are often “on the go” or act as if “driven by a motor”.				
9. My child has a hard time waiting for his/her turn.				
10. My child leaves his/her seat in the classroom or other places when he/she should stay seated.				
11. My child often interrupts or butts into conversations/ games.				

Appendix C

Sensory Checklist

The items below refer to your child's sensory behaviors. For each statement, **think about your child's behavior over the past week**. Then mark how true each statement is based on their behavior using one of the four answer options (Not True at all, A little true, Somewhat true, or Very true).

	Not at all true	**A little true**	**Somewhat true**	**Very true**
1. My child holds his/her hands over ears to protect them from sound.				
2. My child likes strange noises or making noises for fun.				
3. My child reacts strongly to loud or unexpected noises (for example, sirens, dog barking, hair dryer).				
4. My child is distracted when there is a lot of noise around.				
5. It is hard for my child to complete tasks with background noise (for example, fan, refrigerator).				
6. My child needs help finding objects that are obviously visible to others.				

7. My child like to play or do work in low lighting.				
8. My child likes looking at the visual details of objects.				
9. My child likes to watch people as they move around the room.				
10. My child is bothered by bright lights.				

Appendix D

Measure of Vocabulary

For each word below, mark how your child uses the word (Does not understand or say, Understands but does not say, Understands and says).

	Does not understand or say	**Understands but does not say**	**Understands and says**
airplane			
all			
animal			
another			
apple			
asleep			
away			
baby			
back			
bad			
banana			
bath			
bathroom			
bed			
bedroom			
bee			
big			

bird			
bite			
blocks			
blue			
book			
boots			
box			
boy			
break			
bring			
brother			
bubbles			
bug			
bump			
bunny			
cake			
car			
cat			
chair			
child			
clean			
close			
coat			

cold			
cookie			
couch			
cry			
dance			
dark			
dog			
doll			
door			
down			
drink			
drive			
dry			
eat			
eye			
face			
fall			
fast			
father/dad			
finish			
fish			
flower			
food			

garden			
girl			
giraffe			
give			
go			
good			
grandfather/grandpa			
grandmother/grandma			
hair			
hand			
happy			
hard			
head			
help			
her			
his			
home			
horse			
hot			
house			
how			
hurt			
I			

inside			
juice			
jump			
kiss			
lady			
lamp			
light			
lion			
little			
look			
love			
lunch			
man			
me			
milk			
money			
more			
morning			
mother/mom			
my			
nice			
night			
no			

now			
old			
open			
other			
out			
outside			
paper			
park			
people			
picture			
pizza			
plant			
play			
potty			
pretty			
pull			
put			
rain			
red			
read			
ride			
rock			
run			

same			
say			
school			
see			
sheep			
sick			
sister			
sky			
sleep			
snow			
some			
star			
stop			
store			
stroller			
sun			
swim			
table			
take			
teacher			
thank you			
that			
there			

tired			
train			
tree			
truck			
turtle			
tv			
under			
up			
wait			
walk			
want			
watch			
water			
what			
when			
where			
who			
why			
window			
work			
yes/yeah			
you			
your			