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**Speech perception and involuntary orientation to speech stimuli in individuals with  
Autistic Spectrum Disorder**

**Reana Young-Morrison**

**Abstract:**

Individuals with autism spectrum disorder (ASD) are known to have language and social deficits, yet the exact reasons for these deficits are not fully understood. Language develops from exposure. Deficits in perception of speech can have devastating effects on an individual's ability to reproduce language and communicate effectively. The MMN and P300 ERP components can be used to assess sound discrimination and orientation, respectively. In previous work, individuals with ASD have shown little difference in MMN amplitudes to pure and complex tones but diminished P300 amplitudes for speech sounds, suggesting they can hear differences in speech components but cannot attend to them. This study uses EEG to look at auditory perception and involuntary attentional orientation. Using an oddball paradigm, the subjects were presented with four distinct auditory conditions: pure tones, complex tones, synthetic speech, and human speech. The MMN and P300 for each individual with ASD was compared to those of typically developing (TD) individuals. Differences, in MMN for pure tone and in P300 for complex tone, synthetic speech, and human speech, were found between ASD and TD participants. The distinct speech conditions were included to allow a deeper comparison and understanding of speech perception and involuntary attentional orientation in individuals with ASD.

## **Introduction**

The purpose of this experimental study is to obtain a greater understanding of underlying components of language processing in individuals with Autism Spectrum Disorder (ASD). ASD is a neurodevelopmental disorder seen in 1 in every 59 children (Centers of Disease Control and Prevention, 2016) which greatly affects stimulus processing, motor functions, social emotional processing and interaction, and most importantly for this study, language production and acquisition. A variety of disorders of speech production and speech perception are very common in individuals with autism, particularly in more severe individuals. Difficulties can range from inappropriate speech, echolalia, limited vocabularies, markedly unintelligible speech, or even no apparent speech production or no sensory perception. It is estimated that approximately 25% of individuals with ASD have little to no functional speech and are characterized as “non-verbal” (Turner, Stone, Pozdol, & Coonrod, 2006). Those with functional speech often have pervasive production deficits that limit their social and communication skills, ability to function in society, and quality of life. Although deficits in any of the areas of language and communication can significantly impact the quality of life for individuals with autism, one of the most devastating problem areas is language function. Because language is central to communication, deficits in this area can place enormous strain on individuals with autism as well as their parents, caregivers, educators, and clinicians.

Although language skills in ASD have been widely studied, it remains unclear why some individuals never develop functional language and remain “minimally verbal”. The experiment used event related potentials (ERPs) to identify whether attentional orientation to speech and non-speech sounds differ in individuals with ASD compared to TD individuals.

*The link between speech perception and speech production*

There are a number of plausible underlying bases for deficits in speech production in ASD, such as generalized intellectual impairments or developmental dyspraxia of speech. Motivation may also play a role: some individuals can speak if prompted by the appropriate incentive despite remaining minimally verbal the majority of the time. Other factors such as anxiety or attention may also factor into deficits in speech production. One component of the deficits in speech perception may be an inability to discriminate different speech sounds and a failure to automatically orient to speech.

Perception is an important aspect of speech development, and auditory processing of sound stimuli strongly influences one's speech. Previous literature has reported links between auditory discrimination and language impairments (Jones et al., 2009; O'Connor, 2012). Many theories of speech perception acknowledge the importance of sensorimotor input. Although a complete review of such theories is outside the scope of this study, as illustration, the Perception-for-Action-Control Theory (PACT) of speech communication proposes that speech perception is closely linked to motor production (Schwartz, Basirat, Ménard, & Sato, 2012). Similarly, the motor theory of speech perception also proposes that the motor system is recruited for perceiving speech (Galantucci, Fowler, & Turvey, 2006). Perception deficits are especially pronounced in children who were born deaf or who lost their hearing before the age of three, but are less severe in children who acquired deafness at age five or later (Osberger, Todd, Berry, Robbins, & Miyamoto, 1991). Moreover, phonetic perception, which has been shown to begin development in infants before 6 months of age, precedes word acquisition and affects future perception of distinct speech sounds (Kuhl, 1992). Even deficits in speech perception that develop after

normal language has been acquired are expected to create considerable difficulties in the normal process of language production (Bouchard, Ouellet, & Cohen, 2009).

Given this relationship between speech perception and production, it is especially important to study the speech perceptual abilities of those individuals with autism with limited speech production, since deficits at the level of perception may contribute directly to at least some limitations in verbal production. If this relationship were also shown to be true in individuals with severe symptoms of autism, one approach to the treatment of speech production deficits may be to improve speech perception abilities in these individuals. It would also be important to assess the extent to which speech perception deficits are accompanied by deficits in basic auditory perception. For example, understanding the impact of deficits in speech perception in the presence of normal auditory processing abilities could provide information about the nature of perception deficits and cognitive processing in individuals with autism. Those individuals with the largest deficits in speech production – those who often, by the very nature of their limited verbal and non-verbal communication abilities, receive a diagnosis of a higher severity level and may be identified as “low functioning” – may be most informative to the study of speech perception and may also benefit the most from it.

### ***Auditory Processing in Typically Developing Individuals***

In order to understand the deficits that may occur in individuals with ASD or other neurological disorders and diseases we first must understand the underlying patterns present in TD individuals. There are many different ways of measuring and understanding auditory processing, including behavioral testing, electroencephalography (EEG), and

magnetoencephalography (MEG) (Čeponienė et al., 2003; Duncan et al., 2009; Groppe, Urbach, & Kutas, 2011; Lepistö et al., 2006). Structural and functional magnetic resonance imaging (MRI) has also been used to examine brain areas and pathways involved in auditory perception (Linke, Jao Keehn, Pueschel, Fishman, & Müller, 2018). Here we focus on EEG measures of perception and attentional orientation to deviant sensory stimuli.

EEG and MEG studies measure auditory perception primarily through the use of an “oddball paradigm.” In this paradigm a participant hears a string of sounds (e.g. pure tones or speech sounds), the majority of which are of one type (e.g. a pure tone of a given frequency or a given speech sound); these stimuli are called the “standards.” A small percentage of these sounds (typically 10-20%) are interspersed with different sounds (e.g. a pure tone of a different frequency or a different speech sound), which are called “deviants.” The difference in amplitude between event related potentials (ERP) responses to standards and deviants can be used to assess various aspects of auditory processing. The oddball paradigm typically elicits two components of interest: the MMN and the P300.

### *MMN*

The MMN (or MMNm, which is the corresponding wave in MEG studies) is an ERP component found approximately 200ms after stimulus presentation (Figure 1). It is an enhanced negativity associated with automatic recognition of a deviant stimulus compared to a standard stimulus. It is measured as a difference wave found by subtracting the waveforms produced when the standard stimulus is presented and when the deviant stimulus is presented. It is thought to function as a measure of short-term auditory memory and thus can be used as a measure of sound discrimination (Kraus, McGee, Carrell, & Sharma, 1995). Sensory auditory information is

processed by features of the stimuli such as frequency, duration and pitch; there is some evidence that suggest that these are processed in different regions of the auditory cortex. These features help to construct a representation of the stimulus in short term auditory memory (Risto Näätänen & Winkler, 1999). Repetitive presentation of a standard stimulus builds a predictive representation of the stimuli. If the subsequent stimulus (the deviant) does not match this model, a different neural population will be activated creating a different ERP (in amplitude or latency), and an enhanced negativity (the MMN) can be measured between the resulting ERPs (R. Näätänen, Paavilainen, Rinne, & Alho, 2007; Risto Näätänen & Winkler, 1999). The MMN can be evoked using a large variety of methods such as deviants in duration, tone, frequency, or as done in this study, pitch of the auditory stimuli. It is also present regardless of conscious attention and can be found in some stages of sleep as well as when individuals are concentrating on other tasks and ignoring the stimulus (Joos, Gilles, Van de Heyning, De Ridder, & Vanneste, 2014). A review by Naatanen et al. (2007) summarizes data from intracranial readings, fMRI studies, and EEG and MEG studies, concluding that the presentation of the MMN component originates in the bilateral auditory cortex, temporal cortex, and frontal cortical areas (Näätänen et al., 2007). In relation to speech perception, this component can reveal if the different features of the sounds that make up speech are being perceived as individual representations.

### *P300*

The P300 ERP component is an enhanced positivity for deviant stimuli compared to standard stimuli occurring approximately at 300ms after stimulus presentation in TD individuals (Figure 1). This component has been associated with the involuntary allocation of attention to an informative stimulus (Picton, 1992; Polich, 2007; Polich & Criado, 2006). The inferior parietal

lobe, temporoparietal junction, cingulate gyrus and various prefrontal areas are large contributors to this component (Knight and Scabini 1998; Wang, Ulbert, Schomer, Marinkovic, & Halgren, 2005). A review by Linden et al. (2005) looked at research from intracranial readings, fMRI studies, lesion studies, and EEG and MEG studies. The authors concluded that due to the bilaterally implicated neurological generators it is reasonable to argue the P300 can signify attentional orientation to novel and deviant stimuli in the oddball paradigm. Additionally, the investigators suggested that the P300 is involved in involuntary orientation, since it does not require attention-oriented tasks and is present even when individuals are ignoring the stimulus (Linden, 2005). Deficits in this component therefore suggest a lack of attentional orientation to sensory stimuli. With respect to speech, if an individual is not attending to auditory stimuli as speech, then comprehension and production of the same stimuli will be impacted.

### ***Auditory processing in individuals with ASD***

The MMN and P300 have been used to explore the possibility that linguistic deficits in individuals with ASD come from disorder in cortical processing of the auditory stimuli, specifically of speech stimuli.

#### ***MMN:***

In relation to auditory sensory processing in TD individuals, findings from the MMN/MMNm component in individuals with ASD are notably variable (see Bomba & Pang, 2004; Haesen et al., 2011; Kujala, Lepistö, & Näätänen, 2013; O'Connor, 2012; Roberts et al., 2008 for reviews). Some studies have shown individuals with ASD present a greater sensitivity to auditory stimuli (i.e. larger MMN responses) than their TD counterparts (Ferri et al., 2003; T.



Lepistö et al., 2006). For instance, Ferri et al. (2003) found larger MMN responses to deviant pure tone stimuli in “lower-functioning” children and adolescents with ASD. Likewise, Lepistö et al., (2005) found larger MMN responses for both speech and non-speech pitch changes in children with ASD. In contrast, other studies have found normal or reduced MMN responses to speech and non-speech sounds in individuals with ASD (Gonzalez-Gadea et al., 2015; Kemner, Verbaten, Cuperus, Camfferman, & van Engeland, 1995). For instance, children and adolescents with ASD have shown similar MMN amplitudes in response to complex tones (Gonzalez-Gadea et al., 2015) and vowel sounds (Kemner et al., 1995) compared to TD individuals, whereas Dunn et al. (2008) reported smaller MMN responses for tones in children with ASD. Still other studies report similar MMN amplitudes between ASD and TD groups of children but differences in latency for both pure tones and speech stimuli (Berman et al., 2016; Kasai et al., 2005; Oram Cardy, Flagg, Roberts, & Roberts, 2005; Roberts et al., 2011; Tecchio et al., 2003). The latency delay has been associated with greater language impairment (Berman et al., 2016; Roberts et al., 2011) and greater autism symptom severity (Kasai et al., 2005). Overall, while there is variability in the results of the MMN in ASD individuals, the evidence suggests that individuals with ASD have enhanced or normal discrimination of both tonal and speech-sound stimuli. This would suggest the issue in speech production, individuals with ASD stems from a higher cortical processing pathway and is not a disruption in sensory speech perception.

#### *P300:*

Additional insight into speech perception in ASD comes from the P300 component. In general, individuals with ASD have an elevated or normal P300 response when exposed to pure or complex tones, yet when exposed to speech tones they demonstrate a reduced P300 response.

This is part of what is called the allophonic perception theory, which says children with ASD develop a deficit in auditory perception solely for phonetic sounds (You, Serniclaes, Rider, & Chabane, 2017). For example, Čeponienė et al. (2003) observed similar MMN responses between children with ASD and TD children in response to pure tones, complex tones, and vowels. In contrast, a P300 was present in both the TD and groups with ASD for pure and complex tones, but was absent in the group with ASD only for vowel sounds. Similarly, Lepistö et al. (2005) found larger MMN responses in children with ASD for pitch changes in both speech and non-speech stimuli, suggesting superior pitch processing abilities. However, the P300 was diminished in children with ASD for speech stimuli, but not non-speech stimuli, suggesting that involuntary orienting was impaired for speech in ASD. Finally, Huang et al. (2018) looked at both the MMN and the P300 responses in Chinese children with ASD. The study came to similar conclusions, noting a diminished and delayed MMN responses in ASD for pure tones, and no significant group difference in the vowel condition. In the P300 condition the ASD group showed no difference in P300 amplitude between standard and deviant tonal stimuli and a significantly diminished amplitude for the vowel condition. Overall, these results suggest that discrimination of both tones and speech sounds is not impaired in individuals with ASD. The difference in P300 responses to speech stimuli suggests a difference exists in the involuntary orientation to deviant sounds only for speech stimuli (Kujala et al., 2013; O'Connor, 2012).

### *Current Study*

Prior literature in auditory processing in individuals with ASD points to potentially intact auditory processing of speech sounds in individuals with ASD. These studies, however, used atypical attentional orienting to speech sounds specifically. This suggests that speech deficits

may lie not in the ability to discriminate speech sounds but in involuntary attentional orientation to speech. Because attention to speech is linked to successful language and social development, deficits in attentional orienting to speech might have important consequences for wider language development.

The relationship between auditory discrimination of and attentional orienting to speech is especially important to investigate in individuals with autism who have more severe deficits in speech production. As previous literature has reported links between auditory discrimination and language impairments (Jones et al., 2009; O'Connor, 2012), it seems highly possible that we might observe differences in speech perception between those individuals with autism who develop more functional speech repertoires and those who do not. For example, although some previous studies have reported intact MMN responses for more verbal individuals with ASD compared to typically developing individuals, this may not hold true for individuals with more limited expressive language, especially for speech contrasts (Duncan et al., 2009; Dunn et al., 2008; Lepistö et al., 2006; You et al., 2017). Similarly, the previous finding of relatively intact speech discrimination abilities but impaired attentional orienting to speech may hold true only for those individuals with better language production abilities. It is thus possible that both auditory discrimination of speech (i.e. MMN amplitude) and attentional orienting to speech (i.e. P300 amplitude) are more severely affected in individuals with more limited verbal abilities. However, research with these individuals is scarce, so the nature of the relationship between auditory discrimination of and attentional orienting to speech in this population remains unclear.

The intention of this study is to expand on previous work by looking at these patterns in a range of symptom severities including, and perhaps most importantly, in minimally-or non-verbal individuals with ASD, thereby providing a more comprehensive characterization of the

relationship between speech perception and speech production in individuals with autism. The data presented here is preliminary: the participants present with a range of symptoms yet are primarily verbally fluent. The continuation of this study will allow for larger sample sizes and the testing of more minimally verbal participants.

An additional manipulation we included is the distinction between synthesized and human-produced speech sounds. Ceponiene et al. (2003) suggested that the difference in P300 seen in ASD individuals when presented with the vowel stimulus was due to the “speechness” quality of the sounds rather than sound stimulus itself. Synthesized speech, such as when your computer reads to you, is easily recognizable as “non-human”. Comparing synthesized and non-synthesized speech provided insight into whether challenges in speech perception in individuals with ASD arise from language itself (in which case we would expect both synthesized and human speech to show reduced P300 amplitudes) or from the “humanness” or social aspect of it (in which case we would expect reduced P300 amplitudes only for the human speech). This study sought to test this theory by including computer generated speech stimuli that matched the vowel stimuli generated by humans.

Working with severe cases of autism is not all that common, especially in studies using neuroimaging technologies, yet research with these individuals is key for the complete and thorough understanding of any theory in ASD. By looking at the above criteria in subjects with autism who are minimally-or non-verbal, we better understand if involuntary attentional orientation to language worsens with symptom severity or language abilities which can then lead to possible interventions to support development of communication skills. In addition, looking at two distinct vowel conditions, one of synthetic origin and one of human origin, we were able to make a distinction, whether it is the complexities of language or it is the human factor (i.e.

social interaction) that causes language to be such a difficult skill to develop in autism. This distinction can impact the way in which the community approaches therapies for these individuals.

### **Methods:**

We tested 11 individuals with ASD (9 males, one trans male, and 1 female), with a mean age of 31 years (5-54 years). One participant did not take the EEG well and the data yielded no reliable ERP activity. This data was omitted from the statistical analysis. Individuals with an ADOS module score of two or less were characterized as minimally verbal. Included in the data were two minimally verbal individuals with ADOS module scores of 1 and 2. All other ASD participants had scores of 4. Diagnosis for the ASD group was confirmed with medical or educational records, as well as the Autism Diagnostic Observation Schedule (ADOS-2) (Hus & Lord, 2014). We also tested 10 TD individuals (8 females and 2 males) with a mean age of 23 years (18-32 years). All participants underwent an initial screening consisting of the Kaufman Brief Intelligence Test (KBIT), assessing verbal and non-verbal intelligence; the Peabody Picture Vocabulary Test (PPVT), assessing receptive vocabulary (Dunn & Dunn, 2007; Kaufman & Kaufman, 2004); the Wide Range Achievement Test (WRAT) (Wilkinson & Robertson, 2006) assessing word reading and sentence comprehension; the Expressive Vocabulary Test (EVT) (Williams et al. 2007), assessing expressive vocabulary; a digit span task, assessing working memory; and the Autism Quotient (AQ) (Baron-Cohen et al. 2001), assessing self-reported autistic traits. Participants, or a parent or caregiver, also completed a History Form, which included brief information regarding participants' medical history, current medications,

demographics, and language background, and the Edinburgh Handedness Inventory, which assesses handedness (Oldfield et al, 1971). Two participants were found to be left-handed.

The average scores on each assessment and group differences can be seen in Table 1. The ASD group produced significantly lower scores than the TD group for digit span forward and backward, AQ, KBIT verbal and nonverbal, and WRAT sentence comprehension tests (all  $p$ 's  $< 0.1$ ). All other comparisons were not significant.

The oddball experiment consisted of a train of “standard” stimuli (85% of stimuli) and “deviant” stimuli (15% of stimuli). There were four types of stimuli classes: human-produced speech sounds, synthetic speech sounds, complex tones, and pure tones. The “standard” speech sound stimuli represented the vowel sound [æ], a frontal “a” vowel sound; the “deviant” speech sound represented the vowel sound [ɒ], an open “O” vowel sound. This was consistent in both speech conditions, speech and synthetic. The standard complex tone consisted of three sinusoidal waves, the frequencies of which matched the strongest harmonics in the standard vowel sound (Čeponienė et al., 2003; Tuulia Lepistö et al., 2005). The standard pure tone consisted of one sinusoidal wave with a frequency matching the strongest formant in the standard vowel sound. The deviant complex tone stimuli were created from the three sinusoidal waves from the [ɒ] vowel sound. The deviant pure tone stimuli were created by increasing the standard pitch by 10%. To create the sound stimuli, PRAAT software was used to manipulate the tones and match frequencies. Each stimulus was presented for 250 ms, with an SOA of 700 ms. Stimulus type was blocked. Auditory stimuli were presented using E-Prime version 2.0.8.74. During the EEG recording, participants watched a series of silent videos while the auditory stimuli were played over a computer speaker.

For EEG recording, electrodes were soaked in a solution of potassium chloride and water and fitted to the scalp by means of an elastic net. Following initial net application and set-up, the researchers performed frequent (i.e. every 15 minutes) checks to ensure that the electrodes were still wet and are making good contact with the scalp. Impedances remained under 50 k $\Omega$  wherever possible. EEG preprocessing was performed with EEGLab version 14.1.1 (Delorme & Makeig, 2004) and Matlab 2019b (“MATLAB,” 2019) and included standard steps such as filtering, re-referencing, segmentation, and artifact correction.

The primary outcome measures were the amplitude of the MMN and P300 ERP components for pure tones, complex tones, synthesized speech sounds, and human speech sounds. The MMN and P300 components were calculated by subtracting the amplitude of standard stimuli from that of deviant stimuli. ERP amplitude was evaluated at 9 electrodes across the scalp, taken from the 10-20 distribution (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4).

### *Statistics*

Visual inspection of waveform graphs were used to classify the time windows used for the MMN and P300 components. The difference waves between the standard and deviant stimuli (deviant minus standard) were calculated for each condition in each participant and entered into two repeated-measures ANOVAs for each component individually, with factors of condition, group, and hemisphere. The ANOVA tests were limited to the frontal electrode clusters after visual inspection. Because this is an exploratory study with a small sample size, all trends ( $p \leq 0.1$ ) were considered significant and followed up using additional ANOVAs and between-groups t-tests tests.

Latency was also investigated due to the previous literature that uses this form of measurement (Berman et al., 2016; Kasai et al., 2005; Oram Cardy, Flagg, Roberts, & Roberts, 2005; Roberts et al., 2011; Tecchio et al., 2003). Latency for each peak was averaged over participants within groups. Repeated-measures ANOVAs were run on the latency data for each component separately, with factors of condition, group, and hemisphere. All statistical tests were identical to those for amplitude.

Correlational statistics were run to compare MMN/P300 amplitude with PPVT, EVT, and ADOS module measures, to test for verbal ability in relation to auditory perception and attentional orientation ability. ADOS modules were correlated to identify any trends in ASD severity and auditory perception ability and attentional orientation ability.

## Results

Visual inspection of the deviant minus standard waveforms showed negative peaks at approximately 250-350ms and positive peaks at approximately 350-450ms; these time windows correspond to the MMN and P300, respectively, and were used for statistical analyses to look for group differences in each component, Figure 2. Large peaks were seen in the frontal clusters in both ASD participants as well as TD participants. Parietal and central electrode clusters both showed smaller differences between standards and deviants. In response to these observations, statistical analyses were restricted to the frontal electrode clusters, Figure 3, This is corroborated by previous literature that has shown larger peaks in frontal and central hemispheres (Čeponienė et al., 2003; Lepistö et al., 2006). Visual inspection suggested approximately similar MMN amplitudes and latencies between ASD and TD groups, smaller P300 amplitudes for the ASD group as compared to the TD group, and no apparent differences in latency between groups,



Figure 3. These effects were followed up statistically using repeated-measures ANOVAs in MMN/P300 amplitude and latency.

*MMN component: 250-350 ms*

The ANOVA for amplitude differences in the 250-350ms time window showed a three-way interaction between hemisphere, condition, and group ( $F(6,108)=2.11, p=0.07$ ; Table 2).

Follow-up ANOVAs showed an interaction between condition and group only in the right hemisphere ( $F(3,57)=2.42, p=0.08$ ; Table 3). The left and midline hemispheres failed to show any significance or trends. Additional *t*-tests were performed to identify differences between groups in each condition in the right hemisphere. There were significant differences in amplitudes between ASD and TD groups only for the pure tone stimuli ( $t(18.88)= -1.73, p=0.10$ ; Table 4), with larger negative amplitudes (i.e. larger MMN components) in the TD group (mean = -0.77) than in the ASD group (mean = -0.43). The complex tone, speech tone, and synthetic tone conditions failed to produce any significant differences in the MMN amplitude between ASD and TD participants.

There was no evidence of any significant correlations between MMN difference wave amplitude and the EVT, PPVT, or ADOS module (all  $p$ 's > 0.18). Additionally, the ANOVA conducted on the latency of the MMN peak failed to reveal any significant main effects or interactions (all  $p$ 's > 0.99).

*P300 component: 350-450 ms*

The ANOVA for the 350-450ms time window showed a three-way interaction between hemisphere, group, and condition ( $F(6,108)=3.82, p<.01$ ; Table 2). This interaction arose from a

group by condition interaction in the right hemisphere ( $F(3,54)=2.30, p=0.09$ ; Table 3). The midline and left hemispheres failed to reveal any significance or trends. Between-group  $t$ -tests conducted in each condition in the right hemisphere revealed significant differences between TD and ASD for complex tones ( $t(14.03)=2.62, p<0.05$ ), speech sounds ( $t(17.98)=2.59, p<0.05$ ), and synthetic speech sounds ( $t(17.28)=1.82, p=0.09$ ; Table 4). In contrast to the MMN results, the P300 amplitudes in the TD group were significantly larger than those of the ASD group in all of these conditions.

There was no evidence of any significant correlations between P300 difference wave amplitude and the EVT, PPVT, or ADOS module (all  $p$ 's  $> 0.18$ ). Additionally, the ANOVA conducted on the latency of the P300 peak failed to reveal any significant main effects or interactions (all  $p$ 's  $> 0.56$ ).

### Discussion

The purpose of this study was to provide insight into a possible reason for language deficits in individuals with ASD. Studies by Huang et al. (2018), Ceponiene et al. (2003), and Lepisto et al. (2006), have shown that there are differences in the processing of speech stimuli and pure and complex auditory stimuli within individuals with ASD. Differences in the MMN amplitude and latency allude to differences in sensitivity and functionality of the primary auditory pathways. The results of this study showed individuals with ASD presented with a smaller amplitude for the MMN for pure tone stimuli and similar amplitudes for the MMN in all other conditions as compared to TD individuals. Individuals with ASD presented with minimal auditory perception deficits, with the only significant deficits presenting in the pure tone condition. This is in line with some previous work done by Huang et al. (2018) where they found significantly lower MMN amplitudes and delayed latency for the pure tone condition only (Huang et al., 2018). A

study by Lepistö et al. (2006) found that individuals with ASD presented with lower MMN amplitudes for non-speech stimuli over the left hemisphere but, larger amplitudes over the right hemisphere. Lepistö et al.'s results only show auditory deficits in the non-speech condition (Lepistö et al., 2006). Our results showed lower MMN over the right hemisphere, and no difference was found over the left hemisphere. These results suggest that there may be a slight deficit in the basic auditory pathways, and that part of this deficit may be hemispheric reorganization in individuals with ASD as compared to TD individuals (Linke et al., 2018). It is interesting that the deficit only presents in the pure tone condition. A possible explanation for this could be the stimulus itself. The pure tone stimulus was the only stimulus produced with a percent increase in pitch as opposed to a vowel change. This was done to increase the pitch difference because the two human speech tones used had almost identical base line pitches, due to being produced by the same person. It may be that a 10% increase was enough for TD participants to hear but not enough for ASD participants. Alternatively, it may be due to the small sample size in this preliminary data. The lack of difference in MMN amplitude between groups in the speech condition suggests that individuals with ASD can perceive the differences in speech stimuli, meaning deficits in speech production are likely not a result of an inability to discriminate between speech stimuli.

The P300 waves found in the time window of 350-450ms of the frontal electrode clusters are associated with higher cortical processing contributing to involuntary attentional orientation to sensory stimuli. Allophonic perception theory states that individuals with ASD may acquire deficits in language development due to issues with attending to speech stimuli (You et al., 2017). Our results showed significantly lower P300s for ASD participants than for TD participants in complex tone, synthetic speech, and human speech conditions. In some ways this

corroborates the allophonic perception theory, as it does show individuals with ASD having lower capacity to orient to complex sensory stimuli. Yet, it contradicts this theory on the basis that both speech and non-speech stimuli posed difficulties for these participants. These conclusions imply that deficits in speech production and language development in individuals with ASD may arise from the inability to orient to complex sound stimuli.

### *Laterality effects*

Language has been shown to display a primarily left hemisphere dominance. Uniquely, individuals with ASD do not always follow this trend; a review by Bomba and Pang (2004) concluded that individuals with ASD have a greater usage of the right hemisphere during language production and learning. This is interesting when considering that the only significance was found in the right hemisphere during our study. If the right hemisphere was more dominant in language for individuals with ASD, we would expect to see higher activity in both MMN and P300 responses, alluding to greater activity overall in the right hemisphere. We did in fact find higher amplitudes for MMNs in the right hemisphere in comparison to the TD participants. However, we also found lower P300 amplitudes. In the study by Lepisto et al. (2006) similar hemispherical results were seen. Lepisto et al. reported larger MMN amplitudes in the right hemisphere of ASD children as compared to TD children. The left hemisphere presented the opposite trend: ASD children had smaller MMN amplitudes as compared to their TD counterparts. In accordance with this, in our data the P300 component showed increased effects over the right hemisphere in individuals with ASD. That is to say the already lower P300 amplitudes found in individuals with ASD were even less present particularly in the right hemisphere. These results would be in line with the idea that language deficits in ASD develop

from abnormalities in hemispherical organization and categoration of activity (Bomba & Pang, 2004). Hemispherical reorganization, hypersensitivity to sensory stimuli, and inability to orient to complex stimuli could all be explanations for abnormal behavior and social development in ASD.

### *Synthetic Speech*

In an effort to identify the reasons and specific characteristics of language that pose issues for individuals with ASD, this study looked at synthetically produced vowel sounds as well as human produced and recorded vowel sounds. The hypothesis was that these two conditions would be processed differently and perhaps give insight as to the reason behind the deficits in involuntary orientation in individuals with ASD to speech stimuli as opposed to tone stimuli. The results showed significantly lower P300 amplitudes in complex tone, human speech, and synthetic speech conditions. These results suggest that it may be the complexity of the tone as opposed to the “humanness” or speechlike quality of the tone that affects an ASD participant’s ability to orient to the sound. There have been conflicting results published on the MMN and P300; our results support the evidence that individuals with ASD have attentional orientation deficits, since participants had difficulties attending (i.e. lower P300 amplitudes) to complex, synthetic speech, and human speech (Čeponienė et al., 2003; Huang et al., 2018; Lepistö et al., 2006). Our results do not support the idea that it is speech alone that poses difficulties; rather, it is the complexity of speech. Furthermore, there was no significant difference between the P300 amplitude seen between synthetic and human speech stimuli, implying that deficits in attention may not come from the social “humanness” quality of spoken language. This is not to say that deficits in attentional orientation to complex stimuli are not a

possible reason for impaired language development. On the contrary, the speech stimuli played during this and much of the previous literature have been simple vowel sounds while fluent speech is exceedingly more complex. If, as our results suggest, the speech production deficits in ASD individuals is in part due to an inability to orient to complex sounds, then fluent speech would pose even lower P300 values.

### *Limitations*

The small number of participants in this study is the reason for including and following up all trends as well as significance in the results. This was the first year of the study and the rapid timeline to recruit participants made this an exploratory study. There is need to replicate this study using a larger sample size, including more minimally verbal participants. Another goal of this study was to identify if language deficits, and more specifically MMN and P300 deficits, were correlated with ASD severity and language ability. This study found no significant correlations between EVT, PPVT, or ADOS module and MMN or P300 amplitudes. We expected to see a correlation between verbal ability and MMN/P300 amplitudes as deficits in these components would suggest perceptual deficits, leading to production deficits. However, our result failed to show significant correlations. This may mean that there is in fact no connection between perceptual and attenuating abilities of speech and speech production in individuals with ASD. This may also be due to the low number of participants and/or it may be due to the vast variability that accompanies ASD. There was much variability between participants in this preliminary work, yet language scores and ADOS module scores did not vary much. This variability also points to the need to have a larger sample size of subjects within the

study in order to be able to distinguish between deficits correlated with and/or caused by ASD and those comorbid with other environmental and developmental factors.

One of the challenges of having minimally verbal individuals and individuals with more severe ASD is their ability to sit with the EEG. One participant in this preliminary sample had difficulties sitting with the EEG and the data produced no reliable ERP components. There is a need to develop a methodology and procedure for making the experience more manageable for the participants. For example, perhaps for these individuals the stimuli will need to be broken into smaller time blocks with more opportunities to move. Video recording should be performed so that bad trials, such as those with excess movement or excess environmental auditory stimuli, can be filtered out. Finally, if a standard is set for a minimum number of usable trials, participants may come in for more sessions in order to meet this standard allowing for more usable and reliable data. Development of new methodologies will help to incorporate a greater number of minimally verbal individuals. Greater variety and variability is necessary for understanding any of the correlations with ASD, language development, and auditory and speech processing.

### *Conclusions*

Language is an interesting topic as it is integral to human communication and everyday social participation. Identity is greatly influenced by the reciprocal response within social participation. Deficits in language have drastic effects on the quality of life. Language is a difficult subject to study as the development is not uniform across all people. Language production is influenced by relational interactions, opportunity in one's environment, and one's neurological structures. Understanding of language production deficits in ASD is one of

the foundations for this study; there is a link between perception and production. If one cannot hear the difference between sounds, one is unlikely to be able to reproduce the sound. The larger amplitudes of the MMN in the ASD participants point to evidence that perception alone does not account for the language deficits in individuals with ASD. Significantly smaller P300 amplitudes in ASD participants point to deficits in involuntary orientation to complex sound stimuli as a source of deficits. These preliminary results are in line with much of the previous literature. They propose insight into making important distinctions between auditory perception and attention to complex, synthetic speech and human produced speech. These are distinctions that have not been clarified in previous literature. Further data collection will broaden the scope of this study by including more minimally and non-verbal participants, providing more variability in the sample to determine which specific trends are related to ASD deficits.



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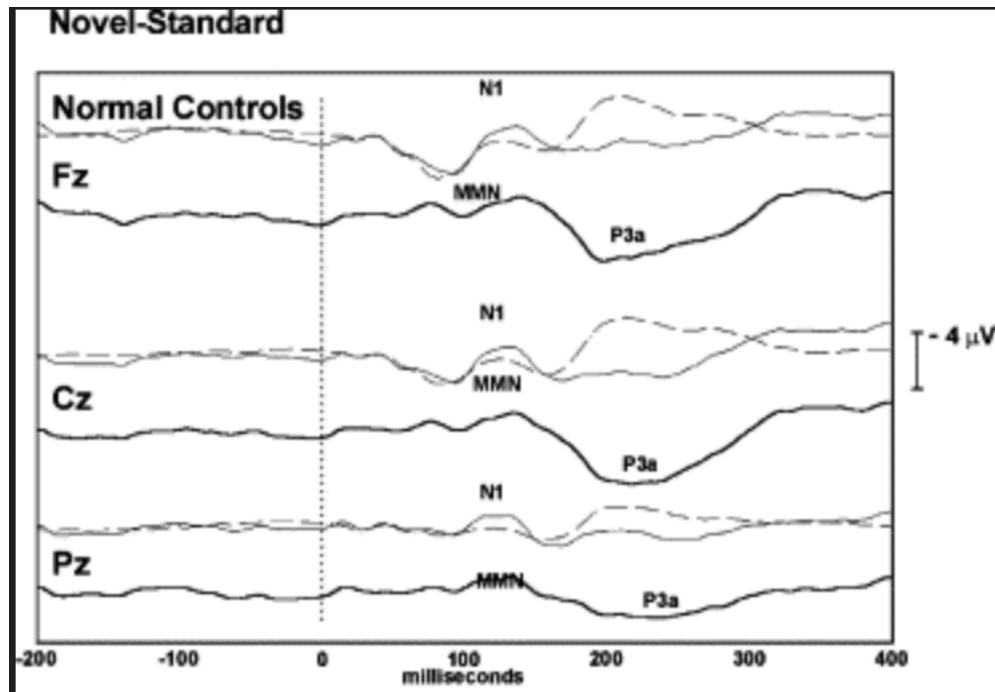
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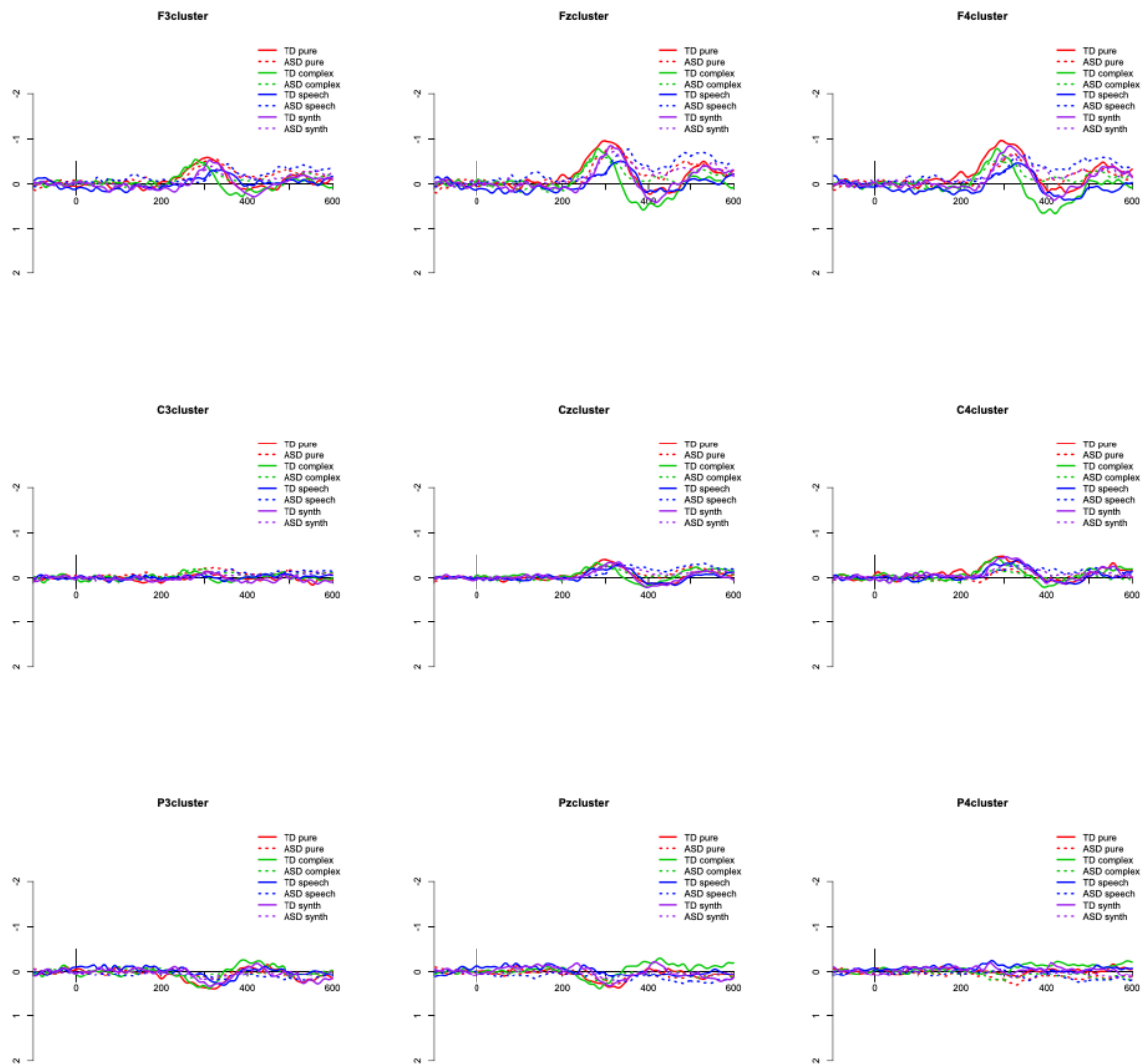
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## Figures

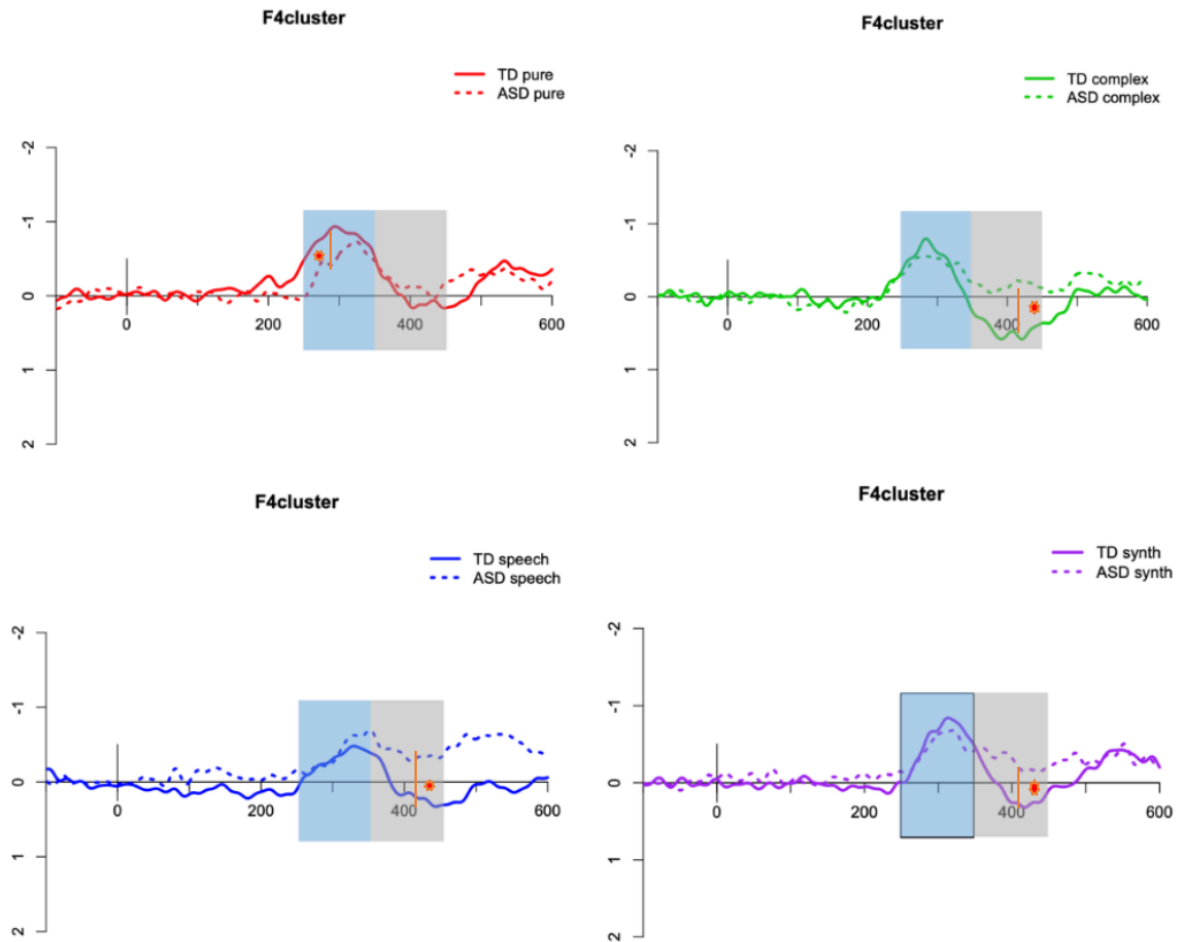


**Figure 1.** This graph was adapted from Ferrie et al. (2003). This is to demonstrate the time signature and pose as example for the MMN and P300 components. These waves were produced from TD children.



**Figure 2** The above graphs are the deviant minus standard waveforms for the left, midline, and right hemispheres for the frontal, central, and parietal lobes. Each graph compares all four conditions for each group. The amplitudes are measured in  $\mu\text{V}$  (y axis) over the time in ms (x axis) after the stimulus was presented. The main activity is seen over frontal sites.





**Figure 3.** The above graphs show the significance between TD and ASD group interactions by condition. The F4 clusters are right hemisphere frontal electrode clusters. The amplitudes are measured in  $\mu\text{V}$  (y axis) over the time in ms (x axis) after the stimulus was presented. The pure condition shows a significantly smaller amplitude for the MMN, 250-350ms, in the TD group compared to the ASD group. The complex tones, speech, and synthetic conditions show significantly larger amplitudes for the P300, 350-450ms, in the TD group compared to the ASD group.

Test Type	Mean score ASD group	Mean score TD group	t-tests between groups (TD-ASD)
Age	30.6	23	$t(12.56)=-1.72$
Digit Span Forward	8.4	12	$t(17.65)=3.38$ ***
Digit Span Backwards	6.56	8.8	$t(16.98)=2.71$ **
AQ	30.1	14.6	$t(16.16)=-5.46$ ****
KBIT verbal	89.36	108.8	$t(15.403)=2.12$ **
KBIT non-verbal	92.64	104.8	$t(18.04)=1.82$ *
KBIT combination	90	108.8	$t(16.55)=2.37$ **
PPVT	92.18	107.4	$t(13.12)=1.64$
EVT	94.8	119	$t(5.54)=1.80$
ADOS communication + social score	9.88	NA	NA
ADOS social affect + restrictive and repetitive behavior (SA+RBB) score	15.45	NA	NA
ADOS calibrated severity score (CSS)	7.18	NA	NA
ADOS module	3.36	NA	NA
WRAT Sentence Comprehension	91	118	$t(11.96)=3.14$ ***
WRAT Word Reading	98.67	106.33	$t(10.12)=0.95$

**Table 1.** The above table shows the mean screening scores and important demographics for the participants by group. The ASD group produced significantly lower scores for digit span forward and backward, AQ, KBIT verbal and nonverbal, and WRAT sentence comprehension tests.

Main Effect or Interaction	MMN (250ms-350ms) F values	P300 (350ms-450ms) F values
Group	0.226	5.563 **
Hemisphere	3.732 **	0.626
Condition	6.929 ****	5.151 ***
Group X Condition	0.947	0.668
Group X Hemisphere	0.092	4.28 **
Condition X Hemisphere	1.266	2.911 **
<i>Group X Condition X Hemisphere</i>	<b>2.017 *</b>	<b>3.819 ***</b>

**Table 2.** This table shows all F-values for the ANOVA run with three variables (hemisphere, condition, and group). A significant three-way interaction was found in both time windows, 250-350ms (MMN), and 350-450ms (P300). Significance scales:  $p \leq 0.1 = *$ ,  $p \leq 0.05 = **$ ,  $p \leq 0.01 = ***$ ,  $p \leq 0.001 = ****$

Right hemisphere main effect or interaction	MMN (250ms-350ms) F values	P300 (350ms-450ms) F values
Group	0.523	6.481 **
Condition	4.634 ***	5.026 ***
<i>Group X Condition</i>	<b>2.423 *</b>	<b>2.299 *</b>

**Table 3.** This table shows all F-values for the ANOVA run with two variables (condition and group), in the right hemisphere. A significant interaction was found in both time windows, 250-350ms (MMN), and 350-450ms (P300). No significant interaction was found in either the midline or left hemispheres. Significance scales:  $p \leq 0.1 = *$ ,  $p \leq 0.05 = **$ ,  $p \leq 0.01 = ***$ ,  $p \leq 0.001 = ****$

Right hemisphere t-test by condition	MMN (250ms-350ms) t values	P300 (350ms-450ms) t values
Pure	<b>-1.7335 *</b>	1.0718
Complex	-0.26391	<b>2.6247 **</b>
Speech	0.352	<b>2.5899 **</b>
Synthetic	-0.6609	<b>1.8182 *</b>

**Table 4.** This table shows all  $t$ -values for the  $t$ -tests run in the right hemisphere for between-group significance. The MMN showed significant between-group differences for the pure tone condition. The P300 showed significant between-group differences for complex, speech, and synthetic conditions. Significance scales:  $p \leq 0.1 = *$ ,  $p \leq 0.05 = **$ ,  $p \leq 0.01 = ***$ ,  $p \leq 0.001 = ****$