Neural Evidence for Speech Processing Deficits During a Cocktail Party Scenario in Minimally and Low Verbal Adolescents and Young Adults with Autism

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As demonstrated by the Cocktail Party Effect, a person's attention is grabbed when they hear their name in a multi-speaker setting. However, individuals with autism (ASD) are commonly challenged in multispeaker settings and often do not respond to salient speech, including one's own name (OON). It is unknown whether neural responses during this Cocktail Party scenario differ in those with ASD and whether such differences are associated with expressive language or auditory filtering abilities. We measured neural responses to hearing OON in quiet and multispeaker settings using electroencephalography in 20 minimally or low verbal ASD (ASD-MLV), 27 verbally fluent ASD (ASD-V), and 27 neurotypical (TD) participants, ages 13–22. First, we determined whether TD's neural responses to OON relative to other names could be quantified with early frontal mismatch responses (MMRs) and late, slow shift parietal and frontal responses (LPPs/FNs). Second, we compared the strength of MMRs and LPPs/FNs across the three groups. Third, we tested whether participants with poorer auditory filtering abilities exhibited particularly weak neural responses to OON heard in a multispeaker setting. Our primary finding was that TDs and ASD-Vs, but not ASD-MLVs, had significant MMRs to OON in a multispeaker setting, and strength of LPPs positively correlated with auditory filtering abilities in those with ASD. These findings reveal electrophysiological correlates of auditory filtering disruption within a clinical population that has severe language and communication impairments and offer a novel neuroimaging approach to studying the Cocktail Party effect in neurotypical and clinical populations. *Autism Res* 2020, 00: 1–15. © 2020 International Society for Autism Research and Wiley Periodicals LLC.

Lay Summary: We found that minimally and low verbal adolescents and young adults with autism exhibit decreased neural responses to one's own name when heard in a multispeaker setting. In addition, decreased strength of neural responses in those with autism correlated with decreased auditory filtering abilities. We propose that these neural deficits may reflect the ineffective processing of salient speech in noisy settings and contribute to language and communication deficits observed in autism.

Keywords: auditory attention; autism; cocktail party effect; minimally verbal; mismatch

Introduction

Using a process colloquially known as the Cocktail Party Effect, a person can monitor a scene and switch their attention to a speaker who has piqued their interest [Cherry, 1953]. In a classic case, you are engaged in a conversation and your attention switches to an uninvolved speaker who has just uttered something salient like your name. Through this process of selective auditory attention, humans can parse multispeaker scenes and use salient speech to guide conversational discourse. Researchers have demonstrated that it is possible to quantify neural processes similar to those that underlie this response to salient speech by measuring evoked responses when listeners attend to rare, speech-like sounds that pop out from a multispeaker scene [Getzmann & Näätänen, 2015]. Here, we modify this approach to investigate the neural indices of selective auditory attention to meaningful speech in a clinical population that has auditory processing and attentional problems—autism.

Many individuals with autism (ASD) exhibit symptoms related to atypical selective auditory attention [American Psychiatric Association, 2013; Marco, Hinkley, Hill, & Nagarajan, 2011; Ocak, Eshraghi, Danesh, Mittal, & Eshraghi, 2018]. For instance, individuals with ASD often feel overwhelmed in loud, multisource settings [Alcántara,

Weisblatt, Moore, & Bolton, 2004; Birch, 2003; Grandin, 1995], and overarousal may be related to overarching problems filtering targets from noise [Haigh, Heeger, Dinstein, Minshew, & Behrmann, 2015; Simmons et al., 2007; Vilidaite, Yu, & Baker, 2017]. Symptoms can vary in severity, but at least 30% of individuals with ASD meet the criteria for a secondary attention-deficit/hyperactivity diagnosis [Joshi et al., 2013; Plesa Skwerer, Joseph, Eggleston, Meyer, & Tager-Flusberg, 2019]. Most research on attentional deficits in ASD has been conducted on verbally fluent participants with autism (ASD-V), but recent studies suggest that attentional deficits are even more common in individuals who are minimally or low verbal in their language abilities [Lerner et al., 2018; Plesa Skwerer et al., 2019].

Selective auditory attention deficits have been identified in individuals with ASD using a range of methods. Parent questionnaires such as the Short Sensory Profile Auditory Filtering Subscale [SSP; Dunn, 1999] reveal that individuals with ASD show more problems filtering out sounds than neurotypical listeners (TDs) [Tomchek & Dunn, 2007] and other developmentally delayed, non-ASD peers [McCormick, Hepburn, Young, & Rogers, 2016; Rogers, Hepburn, & Wehner, 2003]. Psychoacoustic and neuroimaging experiments focused on the ability to filter sounds have been conducted exclusively on ASD-V participants. In these studies, researchers have similarly found that compared to TDs, ASD-V listeners require a larger pitch and loudness separation between target and masking signals in order to effectively detect targets [Lepistö et al., 2009; Plaisted, Saksida, Alcántara, & Weisblatt, 2003]. However, the targets used in such experiments have been limited to sounds like tones or nonword speech tokens that are unfamiliar and do not carry strong meaning to the participant. It is unknown whether deficits extracting a target from background noise persist when the target is a highly salient speech cue designed to grab a person's attention.

From a young age, humans use directed speech to guide attention and one's own name (OON) is a particularly salient guide: neurotypical infants preferentially turn their head to the sound of OON by 4–9 months [Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Mandel, Jusczyk, & Pisoni, 1995]. In contrast, infants who later develop ASD commonly fail to orient consistently toward speakers using directed, social speech, including OON [Miller et al., 2017; Osterling, Dawson, & Munson, 2002; Werner, Dawson, Osterling, & Dinno, 2000]. This failure to respond to OON is so pronounced that it is one of the first major signs of ASD and is included in gold-standard diagnostic measures of the disorder [Constantino & Gruber, 2012; Lord et al., 2012; Lord, Rutter, & Le Couteur, 1994]. However, it is unknown what disruptions in neural processes lead to this poor orienting response.

In typical development, preferential neural responses to OON have been detected in children as young as 4 months old [Imafuku, Hakuno, Uchida-ota, Yamamoto, & Minagawa, 2014; Parise, Friederici, & Striano, 2010; Tateuchi, Itoh, & Nakada, 2015]. These neural responses persist throughout the lifespan [Carmody & Lewis, 2006; Key, Jones, & Peters, 2016; Tamura, Mizuba, & Iramina, 2016], albeit with slightly shifting morphologies in neural response that stabilize considerably by adolescence [Eggermont & Moore, 2012; Mahajan & Mcarthur, 2015]. Prior electroencephalography (EEG) research has identified early neural responses to OON between 100 and 300 milliseconds (ms) over frontal scalp regions and late responses between 300 and 800 ms over frontal and posterior scalp regions, particularly when OON occurs only occasionally and unpredictably [Berlad & Pratt, 1995; Holeckova, Fischer, Giard, Delpuech, & Morlet, 2006; Nijhof, Dhar, Goris, Brass, & Wiersema, 2018; Pratt, Berlad, & Lavie, 1999]. These robust neural responses to OON can be elicited in both attentive and inattentive states, including even when participants are asleep or comatose [Fischer, Dailler, & Morlet, 2008; Perrin et al., 2006]. Such responses to OON are consistent with reports that especially salient words or sounds can exogenously "grab" listeners' attention and elicit early, frontal responses (often characterized as mismatch responses or MMRs), late, slow parietal positive shift responses (LPPs), and late, slow frontal negative shift responses (FNs) [Folstein & Van Petten, 2008; Holeckova et al., 2006; Näätänen, 1985; Ponton, Eggermont, Kwong, & Don, 2000]. Reports also find amplified LPPs in TDs when they think about themselves compared with when they think about other people [Fan et al., 2013; Gray, Ambady, Lowenthal, & Deldin, 2004; Su et al., 2010]. Overall, OON MMRs appear to index early, automatic acoustic detection and orientation to OON, while OON LPPs/FNs likely reflect later cognitive stages of auditory attention, self-other discrimination, and familiarity effects [Friedman, Cycowicz, & Gaeta, 2001; Herzmann & Sommer, 2010; Näätänen, Simpson, & Loveless, 1982; Nieuwenhuis, De Geus, & Aston-Jones, 2011]. While MMRs and LPPs/FNs to OON has been measured exclusively in quiet settings, both could serve as sensitive measures of response to salient speech in a multispeaker setting, as well.

Past research has demonstrated that neural measures of OON response in quiet settings are sensitive enough to differentiate individuals with ASD from TD controls. For instance, ASD-V adults produce MMRs to OON that are similar in amplitude to that of TDs but LPPs/FNs to OON that are smaller in amplitude compared with that of TDs [Nijhof et al., 2018]. ASD-V children, adolescents, and young adults show similarly reduced amplitude of LPPs when viewing their face or written name amidst other random names and faces [Cygan, Tacikowski, Ostaszewski, Chojnicka, & Nowicka, 2014; Gunji, Inagaki, Inoue, Takeshima, & Kaga, 2009; Nowicka, Cygan, Tacikowski, & Ostaszewski, 2016]. These reports suggest that ASD-V individuals have an intact system involving early detection of

OON as a salient stimulus but a disordered high-order processing system pertaining to selective attention [Lombardo et al., 2010; Nijhof et al., 2018].

Neural responses to meaningful speech like OON have never been measured in individuals who have not developed fluent expressive language (hereon referred to as minimally or low verbal, or ASD-MLV). However, prior research hints at the possibility of greater impairments in this group. For example, ASD-MLV children demonstrate atypical orienting responses to auditory stimuli, as demonstrated by atypical MMRs to speech-like and non-speech sounds when compared to ASD-V and TD peers [Matsuzaki et al., 2019; Roberts et al., 2019]. Furthermore, ASD-MLV children show atypical patterns of neural activity during higher-level speech processing, as evidenced by decreased FNs to semantic mismatches between images and their accompanying aurally-presented labels [Cantiani et al., 2016; DiStefano, Senturk, & Jeste, 2019]. It is also plausible that atypical neural responses to salient speech are associated with impaired language given the previously established relationship between behavioral responses to social bids for attention (like responding to OON) and language abilities [Bottema-Beutel, 2016; Dawson et al., 2004]. Although this is a compelling idea, there is little evidence demonstrating that individuals with severe language impairments have significant impairments selectively encoding salient speech.

Our first objective was to investigate whether a salient utterance like OON would pop out from two, insignificant speech utterances like strangers' names, while all three names were heard against a multispeaker background. We predicted that TD participants would show early, automatic (MMR) and late, higher-level (LPP/FN) neural responses to OON, similar to what has been identified in quiet settings. Our second objective was to investigate whether neural responses to OON in quiet and multispeaker settings looked atypical in ASD-V or ASD-MLV participants. We predicted that while all ASD participants would show a decreased neural response to OON, deficits would be most pronounced in the ASD-MLV group. Our third objective was to test whether, among those with ASD, the strength of neural response to OON in a multispeaker context correlated with reported problems with filtering auditory inputs. In doing so, we sought to test whether the neural measurement of saliency response in a multispeaker setting was a neural correlate of observed selective auditory attention abilities in those with ASD.

Materials and Methods

This study was approved by Boston University's Institutional Review Board and all testing was conducted at Boston University's Center for Autism Research Excellence.

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Participants

Participants were between 13 and 22 years old and spoke English as their primary language. None had any known history of hearing loss, concussion, or traumatic brain injury.

Twenty-eight TD participants were enrolled as a reference group to define regions of interest in the EEG portion of our study. Controls came to the lab for one visit and were not assessed with any cognitive measures. None had a diagnosis of intellectual, developmental, or psychiatric disability, nor a sibling with an ASD diagnosis. One control was excluded due to experimenter error during EEG collection.

Fifty ASD participants (28 ASD-V, 22 ASD-MLV) were enrolled in this study and their data were collected over one to four lab visits. The clinical diagnosis was confirmed with the Autism Diagnostic Observation Schedule (ADOS), Second Edition Modules 3 and 4 [Lord et al., 2012] for ASD-V participants and Adapted ADOS Modules 1 and 2 [Bal et al., 2020] for ASD-MLV participants, administered and scored by an ADOS research-reliable experimenter. Group assignment was based on expressive language [Bal, Katz, Bishop, & Krasileva, 2016]. ASD-MLV participants primarily communicated with single words, phrases, or limited and brief sentences, while ASD-V participants reliably and consistently used complex sentences. Nonverbal intelligence (NVIQ) was measured with the Leiter International Performance Scale, Third Edition [Roid, Miller, Pomplun, & Koch, 2013]. Parent-reported adaptive functioning and communication skills were measured with the Vineland, Third Edition, Comprehensive Parent/Caregiver Form [Sparrow, Cicchetti, & Saulnier, 2016].

Auditory filtering ability was measured via parent report using the Short Sensory Profile (SSP) Auditory Filtering Subscale [McIntosh, Miller, Shyu, & Dunn, 1999]. This subscale includes six, five-point Likert-scale questions probing whether the participant in question has difficulties with selective auditory attention or gets distracted in noisy environments. One question specifically asks how often the child responds when their name is called. Separately, we asked participants' parents, "On a daily basis, when you call your child's name or nickname, regardless of surrounding noise level, how often do they respond the first time?" Scores were rated on a Likert-scale with the same five options as the SSP Auditory Filtering Subscale (from 1, always, to 5, never).

The final study sample is described in Table 1. Twenty-seven TD participants had usable data from the EEG study. In the ASD groups, two participants did not complete EEG testing and a third did not provide enough usable EEG

data to be included, leaving us with 27 ASD-V and 20 ASD-MLV participants. There were no significant group differences in terms of age, gender ratio, race, or ethnicity. As expected, ASD-MLV participants had significantly lower NVIQ, receptive and expressive communication skills, and adaptive functioning skills (Table 2). There were also no significant differences in auditory filtering ability scores between the two ASD groups. Furthermore, there were no significant differences between ASD groups in response to how often participants responded immediately to their name, regardless of noise level, according to parent report ($U = 249$, $p = 0.88$), with a median score of three for both groups (i.e., participants, on average, occasionally respond immediately to their name when called).

EEG

About one-third of ASD participants (most of whom belonged to the ASD-MLV group) went through EEG desensitization procedures as described by Tager-Flusberg et al. [2017]. Desensitization required between 10 minutes in one session to 3 hours over the course of three sessions to complete.

For the EEG experiment, participants sat in an electrically shielded, sound-attenuated room and watched a self-selected silent, subtitled video that was unrelated to the experiment. They were told not to worry about any sounds they heard. Brain signals were recorded with a 128-channel EEG system (EGI Geodesics, sampling rate 1000 Hz). Auditory stimuli were presented binaurally from two loudspeakers, placed +/−45 degrees in front of participants. At the beginning and middle of the experiment, we confirmed that all channels had scalp impedance levels less than 50 Ohms. Not including setup, desensitization, or breaks, the experiment took 35 minutes to complete.

Stimuli. Batches of participant names were pre-recorded by the lead experimenter (a female, American English

speaker). Names ranged in length from 440 to 740 ms, with an average of 577 ms ($SD = 69$ ms). A background multispeaker mixture was composed from the overlay of six male English speakers reciting sentences from the American English Matrix Test [Zokoll et al., 2013]. The choice to contrast a female speaker with male speakers was to help listeners distinguish the sounds based on pitch. Given the purpose of this study, all names were removed from these background sentences.

Pre-EEG recording protocol. Directly following initial study consent, participants and legal guardians were asked to indicate from a list of names whether any was the name of a "close other" to the participant such as a sibling or friend. Only names from that list that were indicated as not special to the participant were considered as options when selecting stimuli to be presented alongside their own name.

Paradigm. Each participant heard their own name (OON) and two other participants' names (referred to as SN, or strangers' names) in quiet and multispeaker settings. Names were presented at equal probability, randomly presented in groups of three. The paradigm was designed to elicit a mismatch response in which, presumably, the two other names would be grouped as similar and OON would elicit a unique response. No two names across the three shared the same first phonemic sound. Gender allocation for names was random, but given that ASD is more common in males, more of the names were male too. Names were presented with an interstimulus interval of 1800 ms with 0–200 ms jitter and were presented at 60 dB SPL. When heard in multispeaker settings, names were louder than competing sounds at 8 dB signal-to-noise ratio—a sound level ratio that is perceptually similar to hearing your name in a crowded restaurant. We presented 972 trials of the three names across three quiet and three multispeaker setting trial blocks.

Table 1. Comparative Demographics of TD and ASD Participants Included in EEG Analyses

		TD	ASD-V	ASD-MLV	Sig.	η^2
Participants	*N*	27	27	20		
Age (years)	*Mean (SD)*	17.81 (3.00)	17.21 (2.08)	16.81 (2.64)	*NS*	0.03
	Range	13.13–22.21	13.42–20.86	13.15–21.76		
M:F	*Ratio*	16:11	22:5	13:7	*NS*	
Race					*NS*	
	Asian	7	1	4		
	Black/African American	3	0	1		
	White	15	18	13		
	Multiple Races	1	5	1		
	Prefer not to respond	1	3	1		
Ethnicity					*NS*	
	Hispanic	2	1	1		
	Non-Hispanic	25	22	18		
	Prefer not to respond	0	4	1		

Table 2. Cognitive-behavioral Characteristics of ASD Participants Included in EEG Analyses

			ASD-V	ASD-MLV	Sig.	η^2
Autism Severity	ADOS Calibrated Severity Score	*Mean (SD)*	7.37 (2.32)	8.05 (1.40)	*NS*	0.03
		Range	3–10	5–10		
Nonverbal IQ	Leiter-3 Standard Score	*Mean (SD)*	109.63 (20.83)	54.75 (20.24)	*p< <0.001*	0.64
		Range	74–141	30–111		
Adaptive Functioning Level	Vineland-3 Adaptive Behavior Composite Score	*Mean (SD)*	75.41 (10.80)	48.20 (16.08)	*p < <0.001*	0.52
		Range	57–102	23–71		
Communication Skills	Vineland-3 Receptive Domain Age Equivalent (Months)	*Mean (SD)*	74.41 (55.90)	25.85 (11.15)	*p < <0.001*	0.25
		Range	26–264	11–44		
	Vineland-3 Expressive Domain Age Equivalent (Months)	*Mean (SD)*	89.41 (60.21)	18.90 (12.12)	*p < <0.001*	0.37
		Range	27–204	1–40		
Auditory Filtering Skills	Short Sensory Profile Auditory Filtering Subscale Raw Score	*Mean (SD)*	16.62 (5.42)	16.95 (4.45)	*NS*	0.001
		Range	10–29	9–28		

Note. ADOS Calibrated Severity Scores were computed based on the tables set forth by Hus and colleagues (Hus, Gotham, & Lord, 2014; Hus & Lord, 2014).

Quiet and multispeaker setting trial blocks were presented semi-randomly in pairs.

Post-recording name selection. We compared responses with OON with responses to one of the two presented SNs. Names selected for analyses occurred once across both OON and SN conditions in 92% of the cases. Participant cancelations prevented us from counterbalancing all participant names across conditions in the remaining cases. Balance across conditions allowed us to better control for any differences in brain responses generated by names with different phonetic structures or lengths and ensured that the primary difference between stimuli was name ownership and familiarity.

Signal processing. All electrodes on the outer rim of the cap were discarded to avoid potential contamination of muscle artifacts, leaving a remainder of 99 electrodes. Data were filtered between 0.2 and 35 Hz. Trials were segmented into 1200 ms epochs with 100 ms prestimulus baselines. Trials were rejected if they exceeded a 200 microvolt peak to peak threshold. Trials were baseline-corrected relative to their 100 ms prestimulus baselines. Channels were average scalp referenced and subsequently excluded if more than 37% of trials were unusable (equivalent to less than 20 trials per name and condition). Each participant had between 20 and 54 accepted trials for each name in each block, with a total of 69–162 accepted trials for each name in both quiet and multispeaker conditions (Table S1). There were no significant differences between the number of trials for OON and SN in any group for any block ($p > 0.05$). However, the number of overall trials did differ between groups and, therefore, was accounted for in subsequent analyses.

Spatial–temporal ROI identification in a typical sample. Spatial and temporal regions of interest (ROIs) were determined based on our reference TD group. Experimental data were z-score normalized relative to 2 minutes of raw, baseline state data collected for each participant. Spatial ROIs were selected from frontocentral (FCz: EGI 5, 6, and 12) and parietal-occipital (Oz: EGI 71, 75, and 76) channels based on visual inspection of full scalp topography. To determine temporal ROIs, we relied on nonparametric cluster permutation t-tests as defined by Maris and Oostenveld (2007). Using this method, we compared responses between conditions (OON vs. SN) in each spatial ROI across time, from 150 to 750 ms post-stimulus, and determined temporal clusters in which the signals generated from the two conditions significantly differed above a t-test threshold of $p < 0.01$. We then created a distribution of t-value clusters by calculating t-values and resulting in significant time clusters in 1000 mock samples of data. These mock samples were created by randomly switching OON and SN trials across participants. Finally, we compared the original t-value cluster data with the distribution of mock data and selected clusters that met a threshold of $\alpha < 0.15$. As described by Maris and Oostenveld (2007), the chosen threshold is somewhat arbitrary; however, a lower threshold can be useful when anticipating a more widespread effect, as can be the case for a longer time span. This allowed us to determine temporal windows of interest along with both spatial ROIs.
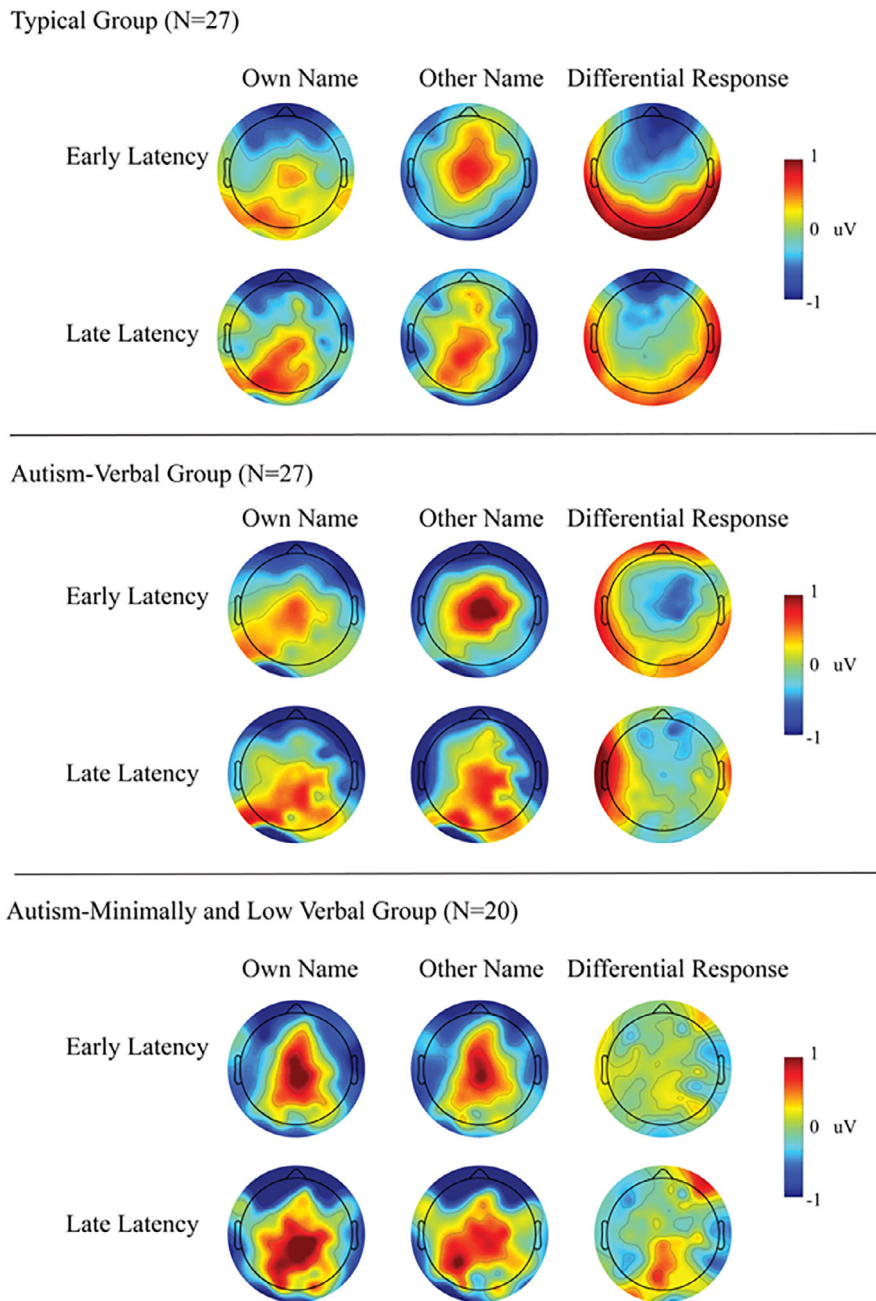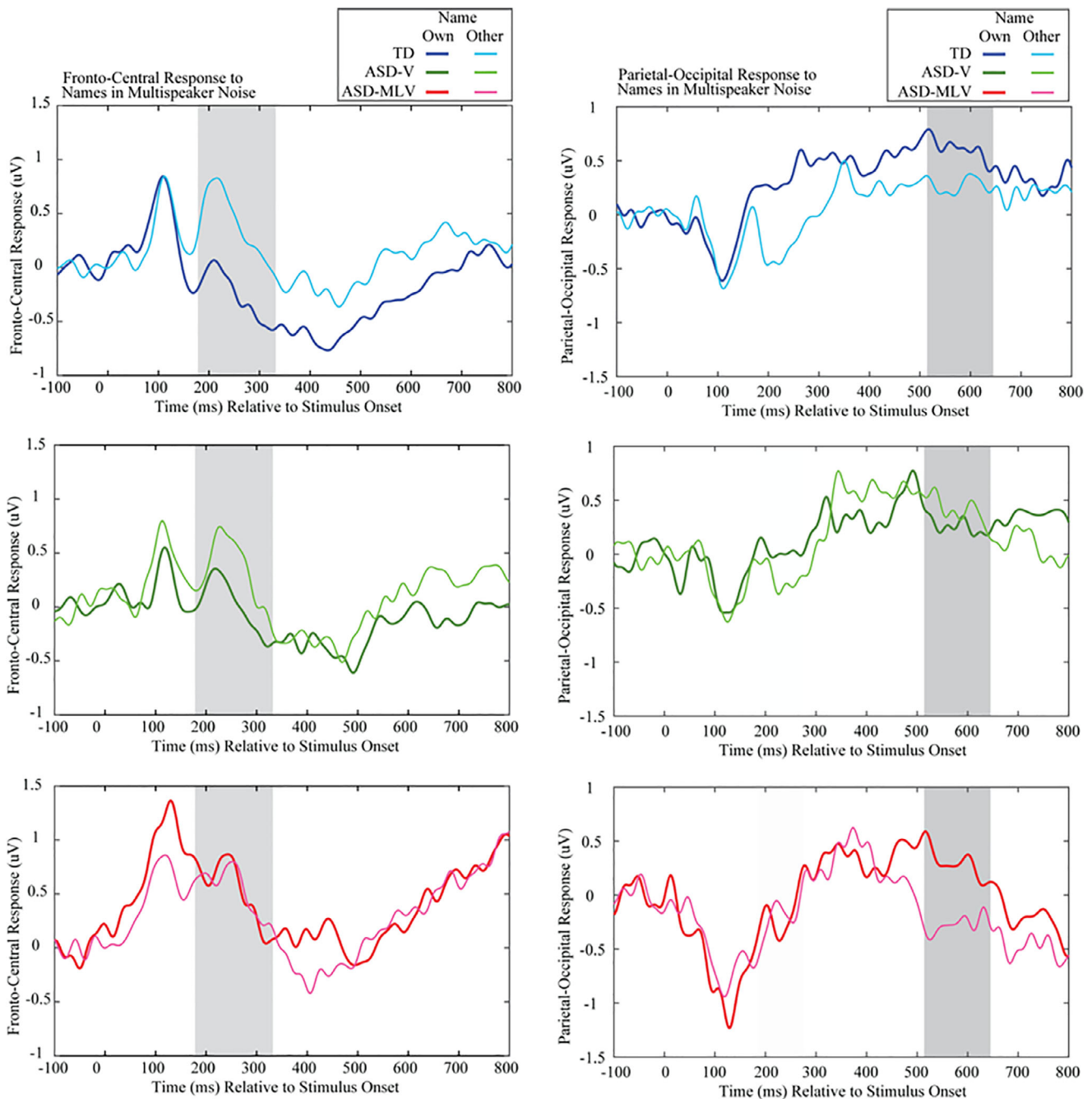
Figure 1. Topography of neural response to names presented in the multispeaker condition. Results are based on group averages of all trials across all three blocks of name presentations. Responses are plotted for early latency mismatch responses (MMR; 178–332) and late latency parietal positive shift responses (LPP; 514–645 ms). Responses are plotted for response to own name, other name, and differential response of own name relative to other name in microvolts (uV)

Statistical Analyses

Between-group comparisons between conditions. In order to test our hypotheses, we sought to investigate the interaction between-group and response to name. Effect of

the group (TD, ASD-V, and ASD-MLV) on strength of OON and SN responses were evaluated based on the mean amplitude (in microvolts) for each spatial–temporal ROI in every trial. Analyses were conducted with full factorial linear

Figure 2. Amplitude of neural response to names presented in the multispeaker condition. Results are based on all trials across all three blocks of name presentations. Responses are plotted on the left panel for early fronto-central mismatch responses (MMR; 178–332 ms) and on the right panel for late parietal positive shift responses (LPP; 514–645 ms). Responses to own and other names are plotted in microvolts for TD (*N* = 27, top row), ASD-V (*N* = 27, middle row), and ASD-MV (*N* = 20, bottom row) participants. Note: The visually distinct peaks in the ASD-MLV group were confirmed to be non-significant ROIs based on post hoc permutation t-tests (Maris & Oostenveld, 2007), in which no cluster of time was found to be significantly different in response to OON and SN

mixed-effects models of all trials with the participant as a random effect. This allowed us to avoid biasing that might be the result of significant differences in the number of trials between groups. Statistical significance for linear mixed-effects models was calculated using Likelihood Ratio Tests [Winter, 2013]. Significant tests were followed up with post-hoc analyses for main effects and interactions using analyses of variance. All significance thresholds were based on a threshold of α < 0.05 after correcting for multiple comparisons with Bonferroni adjustments.

Response to Names in Multispeaker Noise
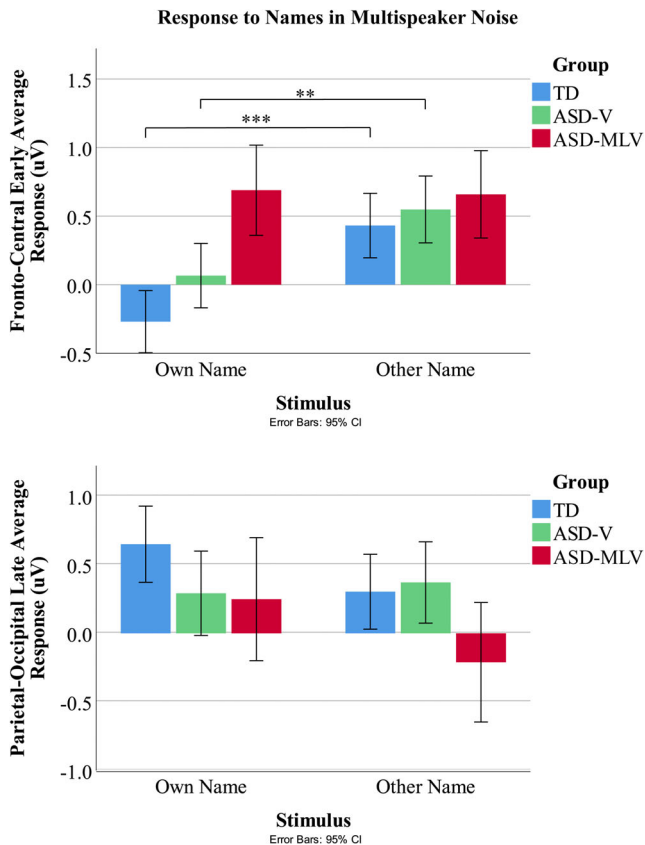
Figure 3. Between-group comparison of the amplitude of neural response to names presented in the multispeaker condition. Results are based on all trials across all three blocks of name presentations. Responses are plotted for the fronto-central early average response (MMR, 178–332 ms) and parietal-occipital late average response (LPP; 514–645 ms). Responses to own and other names are plotted in microvolts for TD ($N = 27$), ASD-V ($N = 27$), and ASD-MV ($N = 20$) participants

Correlates of neural measures. Spearman's rank-order correlation was used to test the hypothesized relationship between the strength of response to OON (the difference in amplitude between response to OON and SN) when heard in a multispeaker background and auditory filtering abilities among all individuals with ASD. In addition, we examined the correlation between brain response and other possible covariates (age, NVIQ, and the number of usable EEG trials). Significant correlations were further considered within the ASD-V and ASD-MLV groups. Bonferroni corrections were applied to account for multiple comparisons ($p < 0.005$).

Results

Spatial–temporal ROI Identification in a Typical Sample

In the multispeaker condition, we identified clustered patterns of neural activity between 178–332 ms along

Table 3. Neural and Behavioral Correlates Among those with ASD ($N = 47$)

	Auditory filtering skills	Nonverbal IQ	Age	Number of EEG trials
MMR	−0.21	−0.15	−0.14	−0.02
LPP	0.44***	−0.16	0.03	−0.09

Note. Results are based on MMR and LPP response when names were heard in the multispeaker condition.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

fronto-central channels (MMRs) and 514–645 ms along parietal-occipital channels (LPPs) in the TD group (Figures 1, 2, Figure S1). OON response was more negative than SN response along fronto-central channels and more positive than SN response along parietal-occipital channels in the multispeaker context.

Temporal window ROIs could not be identified in the quiet condition unless analyses were limited to the first block of trial presentations, between 536–646 ms along parietal-occipital channels (LPPs) and 590–668 ms along fronto-central channels (FNs) (Figure S2). Therefore, subsequent analyses were conducted solely on data collected during this first block. From this ROI clustering analysis, we were unable to detect an early fronto-central response indicative of an MMR.

Quiet Condition: Between-group Analyses

FN (590–668 ms). Group significantly affected neural response ($\chi^2[1] = 6.44$, $p < 0.01$), such that the ASD-MLV group had significantly more negative responses than the ASD-V group ($MD = -0.93$ [−1.56 to −0.29, $p < 0.001$). There was no significant effect of name ($\chi^2[1] = 2.45$, $p = 0.12$). The interaction between-group and name significantly affected neural response ($\chi^2[1] = 4.23$, $p < 0.05$). TD participants had a more negative late fronto-central response to their own name compared to another name ($MD = -0.89$ [−1.52 to −0.26] uV, $p < 0.01$) while ASD-V and ASD-MLV participants did not show a difference in neural response between the two names (Figure S3; ASD-V: $MD = 0.04$ [−0.60–0.69] uV, $p = 0.90$; ASD-MLV: $MD = 0.11$ [−0.71–0.93] uV, $p = 0.79$). Response difference for TDs did not meet statistical thresholds for being significantly different from ASD-V ($MD = 0.92$ [−0.08–1.92], $p = 0.07$) or ASD-MLV ($MD = 0.95$ [−0.18–2.09], $p = 0.10$) participants.

LPP (536–646 ms). We found no significant effect of name ($\chi^2[1] = 1.50$, $p = 0.22$) nor group ($\chi^2[1] = 1.27$, $p = 0.26$) on neural response. The interaction between the two terms also did not significantly affect response ($\chi^2[1] = 0.96$, $p = 0.33$).

Multispeaker condition: Between-group analyses

MMR (178–332 ms). Group was a significant factor influencing neural response (χ^2[1] = 4.24, $p < 0.05$) such that the fronto-central responses to both names were more negative in the TD than in the ASD-MLV group ($MD = -0.59$ [-0.87 to -0.32] uV, $p < 0.0001$) and were more negative in the ASD-V than in the ASD-MLV group ($MD = -0.37$ [-0.64 to -0.09] uV, $p < 0.01$) (Table S2). Name significantly influenced neural response (χ^2[1] = 17.35, $p << 0.0001$), such that the early fronto-central response to OON was more negative compared to SN ($MD = -0.39$ [-0.63 to -0.14]). The interaction between-group and name was also significant (χ^2[1] = 6.58, $p < 0.05$; Figure 3). TD and ASD-V participants had more negative fronto-central MMRs to OON compared to SN (TD: $MD = -0.70$ [-1.04 to -0.36] uV, $p < 0.001$; ASD-V: $MD = -0.48$ [-0.83 to -0.14] uV, $p < 0.01$), while ASD-MLV participants did not respond differently to OON and SN ($MD = 0.03$ [-0.40 to -0.46], $p = 0.89$). This difference between stimulus conditions in the TD group was greater than the difference between stimulus conditions in the ASD-MLV group ($MD = 0.71$ [0.10–1.34], $p < 0.05$) and not greater than the difference between conditions in the ASD-V group ($MD = 0.21$ [-0.34–0.77], $p = 0.44$). The difference between conditions for the ASD-V group also did not differ from the ASD-MLV group ($MD = 0.50$ [-0.12–1.12], $p = 0.11$).

LPP (514–645 ms). There was no significant effect of name (χ^2[1] = 2.58, $p = 0.11$) or group (χ^2[1] = 1.25, $p = 0.26$) on neural responses. The interaction between name and group was also not significant (χ^2[1] = 0.02, $p = 0.89$; Figure 3).

Behavioral Correlates of Neural Measures

Across both ASD groups, nonparametric correlations revealed that LPP strength correlated with auditory filtering ability (r_s[45] = 0.44, $p < 0.001$; Table 3, Figure 4). Moderate correlations were also present between LPP strength and auditory filtering ability within the ASD-V (r_s[25] = 0.39, $p < 0.05$) and ASD-MLV (r_s[18] = 0.48, $p < 0.05$) groups, but were not statistically significant after controlling for multiple comparisons. We found no significant correlations between LPP strength and NVIQ, age, or number of usable EEG trials. MMRs were not correlated with any of the tested variables.

Discussion
Summary of Objectives and Results

We found that, in a multispeaker setting, ASD-MLV participants did not demonstrate the same degree of early mismatch responses to OON that verbal, age-matched ASD and TD peers did to OON. TDs and ASD-Vs had significantly larger MMRs to OON than SNs, while ASD-MLV participants did not show a significant difference between their neural responses to own and other names. In addition, both ASD-V and ASD-MLV adolescents and young adults demonstrated atypical late processing of OON compared to TD controls when names were heard in quiet. Across ASD participants, the amplitude of late response to OON heard in a multispeaker background was decreased in those with poorer auditory filtering abilities. The results from this study provide insights into a sample of ASD adolescents and young adults whose automatic detection of OON in a setting that requires the extraction of a salient, attention-grabbing stimulus, particularly within background noise, is atypical. Furthermore, the methods and results presented here have considerable implications for assessing the integrity of auditory response to salient speech in clinical populations that are challenged by spoken language and communication.

Early Salience Detection in Response to OON

As a group, ASD-MLV participants did not show early, automatic discrimination of OON from SN as names were heard in a multispeaker scene. With our TD reference sample, we used a data-driven approach to identify a well-known marker of early salience detection (the MMR), generated when participants heard their own

r_s(45) = 0.44, $p < 0.001$ ● ASD-MLV   ● ASD-V
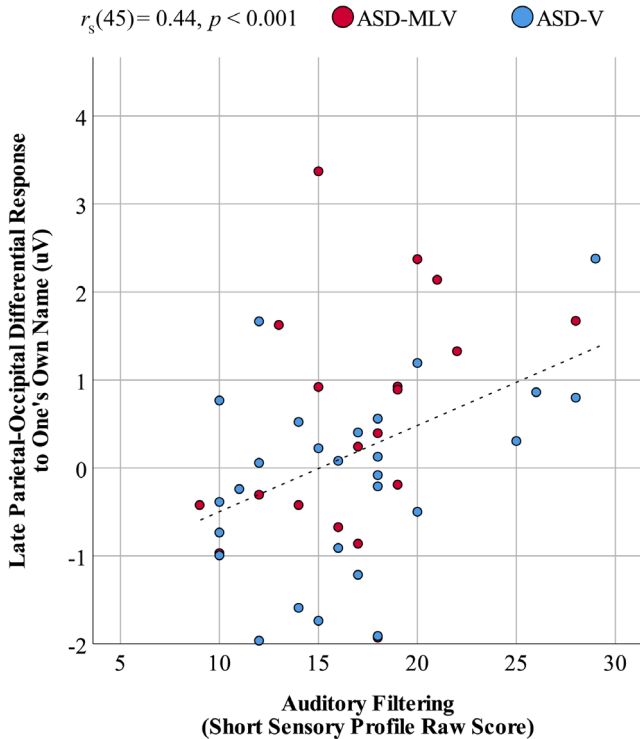
Figure 4. Correlates between the amplitude of LPPs to OON when heard in a multispeaker scene and parent-reported auditory filtering abilities among ASD participants ($N = 47$)

name among other names as those names were heard against a multispeaker background. The identified spatial and temporal ROI was in accordance with prior reports of MMRs to OON in neurotypical samples [Berlad & Pratt, 1995; Holeckova et al., 2006]. Both TD and ASD-V groups produced MMRs to OON, suggesting OON was salient compared to the other names heard, whereas the ASD-MLV group did not. These results support prior findings, which reported no significant differences in MMRs between TD and ASD-V young adults in response to hearing their own versus other, unknown names [Nijhof et al., 2018]. MMR deficits specific to the ASD-MLV group support the hypothesis that those with severe language disorders show atypical neural markers believed to index the discrimination of linguistic information, while those with fluent language do not [Kujala, Lepistö, & Näätänen, 2013; Matsuzaki et al., 2019; Nijhof et al., 2018; Schwartz, Shinn-Cunningham, & Tager-Flusberg, 2018]. These deficits might also point to broader difficulties in organizing and prioritizing language inputs [Kujala, 2007].

Late Attentional Orienting Responses to OON and their Associations with Auditory Filtering Abilities in Adolescents and Young Adults with ASD

In those with ASD, late neural indices of attentional orienting and self-other discrimination were less pronounced than those identified in TD participants. Prominent negative frontal and positive parietal neural signatures detected around 500–650 ms in TDs were consistent with prior reports of OON EEG response in TD samples [Holeckova et al., 2008; Key et al., 2016]. Findings also complemented neuroimaging research that has employed techniques with a better spatial resolution (e.g., fMRI and PET), in which researchers have consistently identified activation of middle and superior temporal cortex, middle frontal cortex (including the medial prefrontal cortex), and regions within the posterior parietal and anterior occipital cortex (including the posterior cingulate, precuneus, and cuneus) when individuals hear their own name [Carmody & Lewis, 2006; Grossmann, Parise, & Friederici, 2010; Kampe, Frith, & Frith, 2003].

Within the quiet condition, there were diagnosis-level group differences in the FN response, a slow late shift response thought to reflect cognitive processing of OON as a familiar input [Herzmann & Sommer, 2010; Holeckova et al., 2008]. We can speculate from these findings that a substantial group of both ASD-V and ASD-MLV participants showed signs of atypical neural processing when engaging in higher-order differentiation between OON and SN—a process that is mediated by selective auditory attention and self-other discrimination. In particular, we found that in comparison to TDs, both ASD-V and ASD-MLV participants had smaller late, prolonged

shifts in their response to OON compared to SN. These results are similar to prior reports that ASD-V young adults show a decreased amplitude in their late neural response to OON, heard in quiet settings [Nijhof et al., 2018; Nowicka, Cygan, Tacikowski, Ostaszewski, & Kuś, 2016; Tacikowski, Cygan, & Nowicka, 2014]. Evidence of decreased FNs to salient speech also resembles prior work showing similarly decreased late-latency FN response in ASD-MLV children when processing speech, albeit during a semantic congruence task [Cantiani et al., 2016; DiStefano et al., 2019]. However, our findings differ from prior reports in that we only identify significant differences with the FN component and not the LPP component [Nijhof et al., 2018; Nowicka, Cygan, Tacikowski, Ostaszewski, & Kuś, 2016; Tacikowski et al., 2014]. Future research is needed to better understand how the processes underlying these slow late positive and negative shifts evoked by OON interact and how differences in their neural morphology reflect underlying differences in higher-level auditory attention or self-referential processing in ASD and TD samples.

Within the multispeaker setting, smaller LPPs to OON compared to SN were associated with poorer auditory filtering abilities in both verbal and minimally verbal adolescents and young adults with ASD. The significant association between LPPs to OON and auditory filtering abilities could arise from challenges in selecting relevant from irrelevant information, particularly in the auditory domain [Lepistö et al., 2009; Minshew, Goldstein, & Siegel, 1997]. This hypothesis is consistent with frequent anecdotal reports that people with ASD feel overwhelmed in noisy settings (particularly with multiple speakers). It is also supported by psychoacoustic and neuroimaging studies in which individuals with ASD require higher levels of signal-to-noise to adequately identify and encode signal features [Alcántara et al., 2004; Lepistö et al., 2009; Russo, Zecker, Trommer, Chen, & Kraus, 2009]. However, more research is needed to determine the extent to which attentiveness to socially relevant stimuli is particularly vulnerable in complex auditory scenes in people with ASD.

Experimental Limitations

We sought to obtain an even more robust neural signal by presenting triple the number of name trials that have classically been presented in OON response experiments. This approach paradoxically led to weak average signals in the quiet condition, which we suspect to be the result of participants adapting to hearing OON. However, the adaptation lessened when we presented names within masking signals. Thus, while differences in adaptation prevented us from directly comparing results between quiet and multispeaker background settings, our approach confirmed that neural adaptation to an

increased number of trials can be mitigated by introducing a masking signal like a multispeaker background [Polich, 2007; Tateuchi, Itoh, & Nakada, 2012].

By design, we chose to conduct an oddball paradigm that introduced OON as a deviant, occurring 33% of the time among two unfamiliar names. However, the MMR is more strongly evoked when the deviant is introduced less frequently, around 20% [Sabri & Campbell, 2001; Sato et al., 2000]. Rather than introduce more than two unfamiliar names or decrease the number of OON trials, we chose to prioritize the presentation of more trials per name to better ensure that we would have enough usable trials from each ASD-MLV participant. We were also limited in how long the experiment could be for ASD-MLV participants. If OON had been presented less frequently, it is plausible that a stronger MMR would have been detected in the quiet condition across groups. In addition, because OON was compared with a stranger's name, but not another familiar name, we cannot discount that familiarity, and not just ownership of the name, played a role in our findings [Key et al., 2016].

In addition, our hypotheses focused on how the strength of response differs between groups and stimuli, as measured by the amplitude of the response. The points in time that we measured amplitude were derived from the TD group alone. From visual inspection, we determined that the latency windows were similar across all three groups. However, it could be that latency differences in the ASD groups, or overall differences in event-related potential morphology, might be significant contributors to the differences in amplitude response that we report.

A final limitation was the nine-year age range of participants, from 13 to 22. This choice was made in order to increase the number of eligible participants, particularly in the minimally and low verbal sample. While neural responses like the MMR and LPP/FN have stabilized considerably by adolescence, there is evidence to suggest that morphologies of these neural responses do continue to change during adolescence [Eggermont & Moore, 2012; Mahajan & Mcarthur, 2015]. We attempt to account for any possible age-related differences between groups by confirming no significant differences in age between participant groups, as well as by focusing our analyses on the within-participant differences between OON and SN. In addition, among those with ASD, we confirmed there were weak and non-significant correlations between neural measures of response to OON in the multispeaker condition and participant age.

Future Directions

By design, the current study was limited to adolescents and young adults. However, given that unique response to OON is detectable with neuroimaging techniques in children as young as 4 months old [Grossmann et al., 2010; Imafuku et al., 2014; Parise et al., 2010], and children of a similar age behaviorally respond to their name in multispeaker settings [Newman, 2005], neural responses to OON in a multispeaker setting could theoretically be measured in younger children as well. Several studies to date have successfully measured neural response to OON in quiet settings in preschoolers with ASD [Carmody et al., 2007; Kellerman, Fan, & Gorman, 2005; Thomas et al., 2019] and infants at risk for ASD [Arslan et al., 2020]. However, more research is needed to elucidate how disordered neural responses in quiet and multispeaker noise relate to current or future clinical impairments. For instance, our findings of pronounced deficits in the ASD group with severe language deficits point to an under-explored hypothesis that an inability to disentangle salient speech from background noise could lead to impoverished language inputs and poor language outcomes.

Furthermore, because TD participants were enrolled exclusively as a normative reference for the neuroimaging experiment, we did not collect behavioral information comparable to that collected on ASD participants. As such, we cannot dismiss the possibility that associations between LPPs and auditory filtering abilities may not be unique to ASD samples. In addition to variation within the TD population, associations might also be present within other clinical groups known to have problems with selective auditory attention and speech processing, such as those with Dyslexia [Calcus, Hoonhorst, Colin, Deltenre, & Kolinsky, 2018; Dole, Hoen, & Meunier, 2012], Attention-Deficit/Hyperactivity Disorder [Riccio, Hynd, Cohen, Hall, & Molt, 1994], and Schizophrenia [Wu et al., 2012]. Future studies are warranted to investigate the extent to which auditory filtering abilities in neurotypical and clinical samples vary with neural measures of selective auditory attention.

Conclusions

This research presents a novel approach to capturing neural processes that support the Cocktail Party effect in a prevalent and understudied clinical population. The results describe neurophysiological evidence suggesting that minimally and low verbal adolescents and young adults with ASD have selective auditory attention processing deficits. This observation demonstrates the intersection between a selective auditory attention process that is critical for effective communication using spoken language and a disordered process present in those with a severe communication disorder. Such findings provide incentives for future research on the broader impact of selective auditory attention deficits in clinical groups with communication impairments.

Acknowledgments

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Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Appendix S1: Supporting information