Auditory processing and sensory behaviours in children with Autism Spectrum Disorders as revealed by mismatch negativity

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Abstract

Sensory dysfunctions may underlie key characteristics in children with Autism Spectrum Disorders (ASD). The current study aimed to investigate auditory change detection in children with ASD in order to determine event-related potentials to meaningless and meaningful speech stimuli. 11 high functioning boys with a diagnosis of autism spectrum disorders (mean age = 13.0; *SD* = 1.08) and 11 typically developing boys (mean age = 13.7; *SD* = 1.5) participated in a mismatch negativity (MMN) paradigm. Results revealed that compared to TD controls, the children with ASD showed significantly reduced MMN responses to both words and pseudowords in the frontal regions of the brain and also a significant reduction in their activation for words in the Central Parietal regions. In order to test the relationship between sensory processing and auditory processing, children completed the Adult and Adolescent Sensory Profile. As predicted, the children with ASD showed more extreme sensory behaviours and were significantly higher than their typically developing controls across three of the sensory quadrants (sensory sensitivity, low registration and sensory avoidance). Importantly, only auditory sensory sensitivity was able to account for the differences displayed for words in the frontal and central parietal regions when controlling for the effect of group, revealing an inverse relationship of the higher sensory sensitivity scores the less activation in response for words. We discuss how the expression of sensory behaviours in ASD may result in deficient neurophysiological mechanisms underlying automatic language processing.

Keywords: EEG, Sensory behaviours, auditory processing, language

Abnormalities in auditory processing are one of the most commonly reported sensory processing impairments in children across the autism spectrum (Kellerman, Fan & Gorman, 2005; Nieto Del Rincón, 2008; Samson, Mottron, Jemel, Belin & Ciacca, 2006). Many of these children are reported to show a lack of response to sounds, an inability to interpret auditory stimuli, and an absence of orientation reflex to such stimuli. These diminished responses to sound are often interpreted in the literature as hyposensitivity (e.g. lack of response to their name). In contrast, other children are reported as hypersensitive and show a heightened reactivity to seemingly meaningless stimuli (e.g. intense tantrum responses to the hum of a blender; Allen & Courchesne, 2001). Importantly, sensitivity to auditory stimuli in infancy has been shown to be a powerful predictor that a child would have a diagnosis of autism (Dahlgren & Gillberg, 1989), with both auditory hypersensitivity (Bettison, 1994; Gillberg & Coleman, 1996; Rimland & Edleson, 1995) and auditory unresponsiveness being reported in those who received an autism diagnosis (Baranek 1999; Ostering & Dawson, 1994; Wing, 1966).

Atypicalities in the processing of auditory stimuli by individuals with ASD has also been shown in the way they react to non-speech stimuli compared to speech-like stimuli (Allen & Courchesne, 2001). Research has consistently found that individuals with autism not only perceive music well but also outperform their peers in pitch discrimination (Heaton, 2003, 2005; Heaton et al., 1998; Mottron et al., 2000; O'Riordan and Passetti, 2006) and in the perception of the detailed structure of segments of melodies (Bonnel et al., 2003). Therefore findings suggest that individuals with autism are able to successfully process certain types of complex nonverbal auditory input. This is in marked contrast to the deficits observed in their speech-like perception. For example, they have been shown to have particular difficulties processing speech in background noise, as demonstrated by high speech perception thresholds and poor temporal resolution and frequency selectivity (Alcantara, Weisblatt, Moore, & Bolton, 2004). Deficits in processing speech prosody have also been observed (Kujala, Lepistö, Nieminen-von Wendt, Näätänen, Näätänen, 2005; McCann & Peppe, 2003).

Autism may then be characterized by a speech-specific attentional deficit in orienting towards the 'speechness' quality of sounds, and correspondingly, an attentional bias towards non-speech information. Thus, one possible explanation for the pattern of behavioral findings that indicates co-occurring unimpaired musical and pitch perception, is that a general bias towards non-vocal information results in enhanced non-linguistic stimuli (Järvinen-Pasley, Pasley, & Heaton, 2008). Yet, it is unclear why

differences in auditory perception of speech and non-speech like stimuli occur given that speech prosody and music share significant acoustic features (Jarvinen-Päsley, Wallace, Ramus, Happé & Heaton, 2008).

Deficient feature encoding in autism has often been cited alongside explanations of atypical sensory processing. Functionally, an individual must be able to select certain sensory inputs for enhanced processing while either filtering or suppressing others. Our attention system is not infinite and therefore to process sensory input effectively and efficiently, we need to select what we attend whilst ignoring other features. Children with ASD appear to have particular difficulties when requiring automatic attention, showing an inability to automatically shift their attention to changes in sounds failing outside of their attention spotlight unless they are specifically requested to redirect their attention (Dunn, Gomes & Gravel, 2008). It is therefore suggested, that the multi-flow of information is impaired in individuals with ASD and that this disruption in cortical communication underlies the inability to attend to their environment in a flexible and meaningful way (Marco, Hinkley, Hill, & Nagarajan, 2011).

Consequences of abnormal automatic processing can be linked to many of the key characteristics observed in ASD, such as under-reactivity to sound and failing to notice important auditory information in the environment, in other words hyposensitivity. Automatic processing has also been linked specifically to language development, mainly semantic organization. If children with ASD are unable to automatically process information outside of their attention spotlight, likely results would be memorization of isolated facts of schemas but poor organization of semantic material, resulting in a weak understanding of the relationships among concepts. This idea is given further support by the many studies cited in the literature showing that abnormalities exist in semantic processing in ASD (e.g. Dunn & Bates, 2005; Toichi & Kamio, 2001).

Within the auditory modality, attentional switch has typically been tested using a mismatch negativity (MMN) component of the auditory event-related potential (ERP). The MMN is elicited by any perceptible change in the auditory input even when the subject is not attending to sounds. Its amplitude and latency also closely correlate with the individual's behavioural discrimination skills (Amenedo & Escera, 2000; Kujala et al., 2001; Novitski et al., 2004), making the MMN a feasible tool for evaluating sound-discrimination abilities. Neural processing of speech and vocal sound, but not tonal and environmental sounds, has consistently been shown to be abnormal in individuals with autism relative to typically developing controls using the MMN paradigm (Čeponienė et al., 2003; Gervais et al., 2004). Children with ASD have been shown to have frontocentrally diminished N4 response to standard speech but not to non-speech stimuli, indicating deficient speech-sound encoding (Lepistö et al., 2006). It is concluded that this might be due to the fact that enhanced low-level perceptual processing in ASD children negatively affects the perception of speech sounds at a higher processing level. This is further supported in a later study by Lepistö et al. (2008) showing the children with ASD to have enhanced MMNs for pitch changes irrespective of feature variations but not when the ASD children were processing phoneme-category changes. These authors interpret this on the basis of impairments of phoneme discrimination in a speech-like context which requires abstracting invariant speech features from varying input. Thus enhanced pitch discrimination often associated with ASD may eradicate in the context of speech stimuli (Lepisto et al., 2006; 2008).

Whilst there are conflicting findings reported for MMN amplitude in ASD, it is widely viewed that reduced MMN is observed in ASD when requiring passive responses. For example, Dunn, Gomes and Gravel (2008) carried out a study looking at automatic and active processing of simple stimuli using the MMN paradigm and found that amplitudes of MMN in children with autism was significantly smaller than in children with typical development (Seri et al., 1999; Kuhl et al., 2005). Only when children attended to the auditory stimuli did they show similar amplitudes to the typically developing children. Lepisto et al., (2005, 2006) also found smaller amplitudes in the autistic group compared to controls using a paradigm requiring passive responses.

The present study aimed to test whether high functioning children with a diagnosis of ASD were impaired in auditory discrimination of speech sounds using an MMN paradigm with two types of deviants, words and pseudowords, compared to a matched group of typically developing children. This paradigm allows the recording of cortical responses to words and pseduowords in a constantly varying auditory environment, and is thus more similar to the discrimination challenges posed by natural speech. More specifically, this study aimed to assess whether a relationship existed between sensory behaviours and underlying brain activity for processing speech properties of acoustically matched stimuli. Auditory discrimination of speech sounds has previously been shown to be abnormal in children with a diagnosis of ASD. However whilst several studies have considered differences between speech and non-speech stimuli, fewer studies have addressed the influence of semantic content of the stimuli using a MMN task. When considering that many children (and adults) with ASD have difficulties processing language, one could assume that this would be reflected in a reduction of MMN using real (meaningful) words and meaningless pseudowords. It was also predicted that if children with ASD demonstrate differences in their MMN, there would also be expected to show larger differences in their auditory sensory processing compared to typically developing controls. Importantly, it was anticipated that scores across these sensory measures may predict their responses to the deviants across the MMN auditory paradigm.

Method

Participants

Children with Autism Spectrum Disorders (ASD) and typically developing control participants (TD) were recruited through local mainstream schools. Twelve children with a diagnosis of Autism Spectrum Disorders were recruited and took part in the study and were paid for their participation. However one child was female and was not included in the final analysis in order to match for gender. Eleven boys aged 11-16 years with a diagnosis of Autism Spectrum Disorder—9 subjects with diagnosis "High Functioning Autism" and 2 with Asperger's Syndrome—and 11 typically developing boys were included in the final

analysis. Their ages ranged from 11 years 1 month- 16 years (mean age = 13 years; *SD* = 1.08) in the ASD group and ages ranged from 11 years 11 months- 15years 8 months (mean age = 13.7 year; *SD* =1.5) in the control group. All children were native monolingual speakers of English. Their parents confirmed that partaking children did not suffer from any hearing problems or any other psychopathological or neurological disorders, and had not suffered from such a disease in the past. Children were matched for verbal and nonverbal IQ as well as for handedness (Oldfield, 1971). Details of participant characteristics are displayed in Table 1.

Table 1. Psychometric data for ASD and TD children with differences between groups

	Group		Difference	*p* value
	ASD (*N*=11)	TD (*N*=11)	*t* (20)	
Age in years	13.0 (1.08)	13.7 (1.5)	1.37	.65
Verbal IQ	100.9 (10.4)	99.7 (18.2)	.75	.87
Non verbal IQ	97.4 (12.7)	93.4 (12.8)	.19	.21
Laterality quotient	73.25 (13.6)	90.0 (6.32)	3.69	< .001

Note: Standard Deviations are in parenthesis

The Autism Diagnostic Observation Schedule Generic (ADOS-G; Lord et al., 2000) was carried out on the clinical group to confirm their diagnosis of autism and to gain additional information about their social and language patterns of behaviour. The ADOS-G was carried out by researchers trained to use it for research purposes. The protocol consists of a series of structured and semi-structured tasks that involve social interaction between the examiner and the participant. All ASD participants had an unambiguous clinical diagnosis of autistic disorder or Asperger's syndrome according to DSM-IV criteria, and scored above threshold for ASD on the ADOS-G diagnostic algorithm. None had identifiable medical conditions underlying their ASD.

Materials

Clinical and behavioural data were collected from all children (ASD and TD groups) including the following measures: The Adolescent/Adult Sensory Profile Questionnaire (Brown & Dunn, 2002), the Edinburgh Handedness Questionnaire (Oldfield, 1971), Nonverbal IQ based on the Ravens Matrices (Raven et al., 1992), and verbal IQ using the British Picture Vocabulary Scale (Dunn et al., 1997).

The Adolescent/ Adult Sensory Profile (Brown & Dunn, 2002) is a 60 item self-reporting questionnaire which measures responses to sensory events in everyday life. Individuals complete the questionnaire by reporting how frequently they respond in the way described by each item using a 5 point Likert scale. A high score on that scale indicates a high level of sensory behaviours. The Sensory Profile Questionnaire includes four subscales: Low Registration (passive behavioural responses such as missing stimuli or responding slowly), Sensation Seeking (active behavioural responses such as seeking items to identify responses and characteristics such as enjoyment, creativity, and the pursuit of sensory stimuli); both subscales reflecting a high neurological threshold for noticing and responding to stimuli. The other two subscales include Sensory Sensitivity (passive behavioural responses such as noticing behaviours, distractibility and discomfort with sensory stimuli) and Sensation Avoiding (passive behavioural responses such as noticing behaviours, distractibility and discomfort with sensory stimuli); both reflecting a low neurological threshold for noticing and responding to stimuli. Sensory sensitivity denotes a passive behavioural response to this neural over-responsiveness, whereas sensation avoiding denotes an active behavioural response of reducing and preventing exposure to sounds.

The Edinburgh Handedness Questionnaire (Oldfield, 1971) was used to assess handedness and a laterality quotient was calculated for each participant. Whilst all participants were right handed, the mean handedness quotient was significantly reduced in the ASD group consistent with previous reports (Hauck & Dewey, 2001; McManus, Murray, Doyle & Baron-Cohen, 1992). Participants' psychometric data are shown in Table 1.

MMN Stimuli. The stimuli in the present study were identical to those previously used by Garagnani, Shtyrov, & Pulvermüller (2009). Digital recordings (sampling rate 44.1kHz) of a large sample of the items [baj], [paj], [bajt], [baip], [paip] and [pajt] spoken in random order by a female native English speaker were acquired in a soundproof room. From this set of stimuli we chose a pair of Consonant vowel (CV) syllables [baj] and [paj] and extracted the syllable-final phonemes [p] and [t]. The two chosen CV syllables had the same F0 frequency (272 Hz), and were carefully adjusted to have equal duration (330 ms) and average sound energy, or root-mean-square (RMS) power (−9.4 dB relative to the maximal amplitude allowed by the stimulus file format). The chosen samples of the critical phonemes [p], [t] had the same length (75 ms) and similar envelopes; their amplitudes were also normalized to match for Averaged RMS power (−36.6dB).

The word deviants [bajt] (bite) and [pajp] (pipe) and pseudoword deviants [bajp] and [pajt] were obtained by cross-splicing the same recordings of the coda consonants [p], [t] onto both CV syllables [baj] and [paj]. This avoided differential coarticulation cues and minimized acoustic differences between the stimuli. The silent closure time between CV end and onset of the plosion of the final stop consonant was adjusted to a value typical for English unvoiced (80 ms) stops. The duration of the word and pseudoword deviants was 485 ms.

For the analysis and generation of the acoustic stimuli, we used the CoolEdit 2000 program (Syntrillium Software Corp., AZ, USA). The stimuli were delivered at a comfortable hearing level through headphones and were controlled by a personal computer running E-prime software (Psychology Software Tools, Inc., Pittsburgh, PA, USA).

MMN Design

The design was nearly identical to the one described by Garagnani et al. (2009) and used a multi-feature design. In this paradigm, the standard stimulus was presented in every second trial alternating with one out of 2 different deviant stimuli (pseudo-random sequence). The MMN was recorded for two standard types ([bai], [pai]) and for two deviant types for each standard. CVC syllables ending in [p] or [t] were used as word and pseudoword stimuli. The overall percentage of standard and deviant stimuli for each condition was as follows: 60% standard stimuli (30% [baj] and 30%[pai]), 20% deviant CVC pseudowords (10% [baip] and 10% [pait], 20% CVC words (10% [bait], and 10% [paip].

The stimulus was presented in two blocks. In each block one standard stimulus was presented 500 times and deviants were presented 125 times each. This provided a sequence of 625 stimuli per block which lasted approximately 15 min. Block order was counterbalanced between participants providing an overall duration of approximately 30 min of auditory stimulation. The stimulus onset asynchrony (SOA, delay between onsets of two consecutive stimuli) was 1000 ms. All stimuli were presented to both ears simultaneously.

Procedure

After psychometric testing, children engaged in a mismatch negativity (MMN) task. During the MMN task, children were seated comfortably in a video-controlled, electrically shielded and sound-proof chamber. The stimuli were presented via headphones placed on the children's head. The children heard the stimuli as coming from the back midline space at an intensity of 60dB while they were watching a silent movie of their choice. There were at least two breaks where children were offered refreshments. The overall duration of the experiment was 30 min. During the experiment, children were instructed to attend to a silent movie of their choice and to ignore the incoming acoustic stimuli.

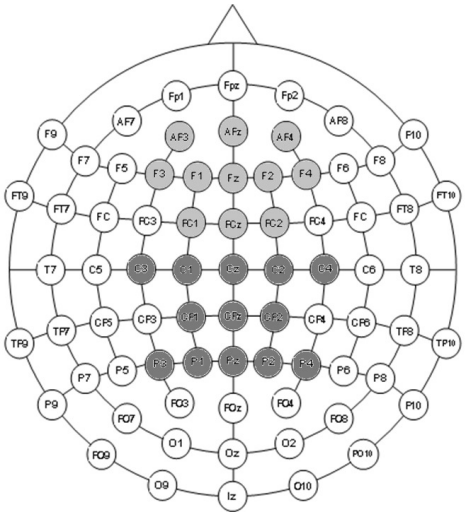
EEG recording

Throughout the experiment, electrical brain activity was continuously recorded from 32head positions, using a 10-20 system electrode cap (EASYCAP GmbH, Hersching, Germany, Figure 1). A 32-channel EEG amplifier system (Brainproducts, Munich, Germany) was used and electrodes were referenced to CPz during EEG data acquisition. Data were recorded with a sampling rate of 200 Hz and a bandpass from DC to 30 Hz. Impedances were kept below 5 kOhm. Data were recorded continuously and stored for off-line analysis. Horizontal and vertical electrooculogram (EOG) was recorded as two separate bipolar traces with respect to the EEG reference.

Data Analysis

Data Analysis was conducted using Brainproducts Brain Vision Analyzer 1 Software (Brainproducts Inc., Munich). Data analysis of each participant was digitally rereferenced to linked mastoids. EOG artefact correction was carried out using the Gratton, Coles & Donchin (1983) method. After correction of eye artefacts, trials were averaged separately for each participant and condition across trials. Trials containing artefacts with voltage variation above 100 microVolts were omitted. The average number of accepted trials for each deviant type was 159.51 (range 100 - 197, *SD* = 31.18) for the participants with ASD and 162.00 (range 103 - 168, *SD* = 27.92) for the typically developing children. The average number of accepted trials for the standard stimuli was 796.64 (range 537– 978, *SD* = 162.97) for the ASD participants and 807.45 (range 541 –975, *SD* = 146.63) for the TD children. Stimulus-triggered event-related potentials (ERPs) starting at 100 ms before stimulus onset and ending 900 ms after onset were computed from the filtered data for each stimulus. ERPs were digitally filtered with a passband of 1.5-20 Hz and baseline corrected with respect to the 100 ms pre-stimulus period.

Figure 1. Electrode Arrangement for Recording Showing Frontal region (Light Grey) and Centro-Parietal region (Dark Grey).



The epochs of the stimulus blocks with standard stimulus /pai/ and those with /bai/ were combined. Grand averages waveforms were formed for each stimulus type for both groups (Figures 2 and 3). Standard stimulus elicited P1, N1, and N4

deflections, which are typical for children at this age (Cepoiene et al., 2005; 2008; Kujala et al., 2010). These responses were identified from the group grand average waveform with the following time window: P1 as the maximum positive peak between 100-150ms and N2 and N4 as the maximum negative peaks between 200-250ms and 300-400ms, respectively. Difference waveforms for each participant and for both groups were obtained for each deviant stimulus by subtracting the ERP elicited by the standard stimulus from that elicited by the deviant stimulus. The MMN was identified as the negative peak in the grand average difference waveform within the time window. All peaks were identified using the software's maximum peak search function.

Figure 2. MMN wave form for words

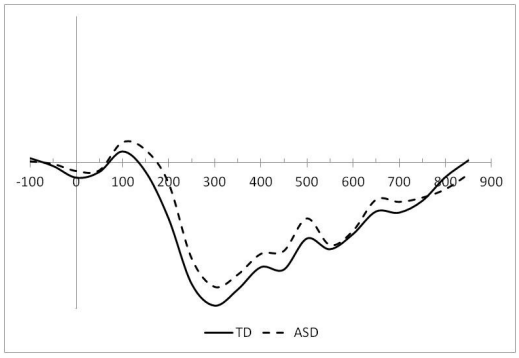
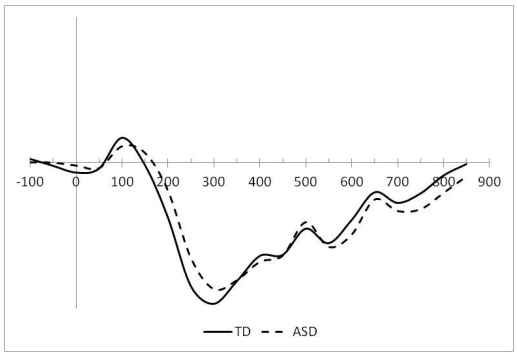


Figure 3. MMN wave form for pseudowords

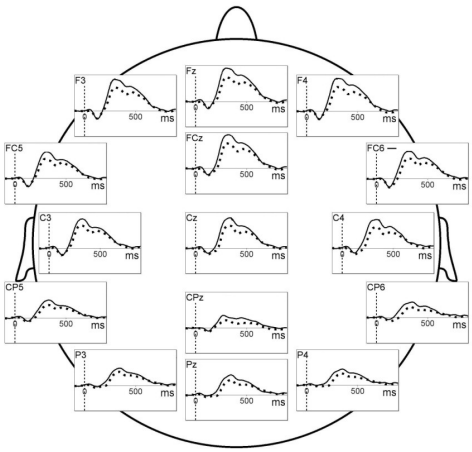


Results

Standard Stimuli Responses

The standard responses [baj] and [paj] were averaged to create one single score for each of the two regions and the P1, N2 and N4 waveform combinations. The waveforms analysed were selected based on visual inspection and the maximum peak reported by the software (Brainproducts Inc., Munich). The P1 peak was identified between 75 and 175 ms from onset. The N2 region was identified as the wave ranging from 260 to 385 ms from onset. Finally, the N4 wave ranged from 435 to 515 ms from the onset of the stimuli (Figure 4).

Figure 4. ERPs at 15 scalp sites for TD and ASD groups in response to standard stimulus presentation showing the frontal, central and parietal electrode positions. The Obligatory ERP waveform of P1-N2-N4 is clearly visible in both groups.



A two-tailed *t*-test revealed that all the responses in the ASD group were significantly different from zero in both regions (Table 2). For the TD group, the P1 responses in both regions were not significantly different from zero, whereas the N2 and N4 amplitudes were significantly different from zero in both regions (Table 2). In order to compare differences between groups a repeated measures ANOVA with a 2 (Region: Frontal vs. CP, within participants) x 3 (Wave: P1 vs. N2 vs. N4, within participants) x 2 (Group: ASD vs. TD, between participants) was used. Results revealed a significant main effect of Region, F (1, 20) = 41.30, MSE = .80, $p < .001$, $\eta^2 = .67$, showing overall larger amplitudes in the frontal region than in the CP region. A main effect of Wave was also present, F (2, 40) = 98.57, MSE = 5.64, $p < .001$, $\eta^2 = .83$, showing that the peak amplitudes in the three waves were significantly different from each other. The main effect of group was marginally significant, F (1, 20) = 3.16, MSE = 12.46, $p = .09$, $\eta^2 = .14$, showing overall higher activation in the TD group than on the ASD group. The Wave x Region interaction was significant, F (2, 40) = 87.89, MSE = .20, $p < .001$, $\eta^2 = .81$, showing significantly larger amplitudes in the frontal region compared to the CP region for the tree waves but this effect was stronger in the N2 and N4 waves than on the P1 wave. The Wave x Group and the 3-way interactions resulted non-significant, F (2, 40) = 1.10, MSE = 5.64, $p = .34$, $\eta^2 = .05$ and F (2, 40) = 2.18, MSE = .20, $p = .13$, $\eta^2 = .10$, respectively.

Table 2. Mean and standard deviations of amplitudes in P1, N2 and N4 peak latencies by region (Frontal=FR and Centro-Parietal=CP) and group.

	TD				ASD			
	FR	*t* (10)	CP	*t* (10)	FR	*t* (10)	CP	*t* (10)
P1	0.85 (2.34)	1.21	0.38 (1.77)	0.71	1.18 (1.43)	2.75*	0.77 (1.09)	2.34*
N2	-7.96 (2.68)	-9.84***	-5.7 (1.74)	-10.87***	-5.73 (2.85)	-6.66***	-4.21 (2.22)	-6.28***
N4	-6.03 (1.95)	-10.24***	-4.26 (1.76)	-8.02***	-4.77 (2.19)	-7.23***	-3.41 (1.74)	-6.50***

Note: Standard deviations are in parenthesis. *** = $p < .001$, * = $p < .05$. *t* (10) values refer to the difference from 0 of latencies on each region.

Differences in Sensory Processing

All of the children in the study completed the Adolescence Sensory Profile (AASP, Brown & Dunn, 2002). The auditory sensory scores from the AASP were broken down into the four sensory quadrants of the profile: low registration (LR), sensory seeking (SSK), sensory sensitivity (SSN) and sensory avoidance (SA). In order to explore differences between the two groups a 2 (Group: TD vs. ASD, between participants) x 4 (Profile: LR vs. SSK vs. SSN vs. SA, within participants) mixed model analysis of variance revealed a significant main effect of group, F (1, 20) = 35.25, MSE = 6.77, $p < .001$, $\eta^2 = .64$; and a non-significant main effect of Profile, F (3, 60) = 1.74, MSE = 4.04, $p = .17$, $\eta^2 = .08$. A significant interaction was also present, F (3, 60) = 3.83, MSE = 4.04, $p < .05$, $\eta^2 = .16$. Analysis comparing the groups on each quadrant revealed that the ASD group scored significantly higher than the TD group on Low Registration (t (20) = 5.11, $p < .001$), Sensory Sensitivity (t (20) = 2.30, $p < .05$) and Sensory Avoidance (t (20) = 5.81, $p < .001$). The difference between the groups on Sensory Seeking was not significant (t (20) = 1.59, $p = .13$). Means and standard deviations are in Table 3.

Table 3. Mean and standard deviations of sensory profile and MMN amplitude responses in Frontal and Centro-parietal regions by group.

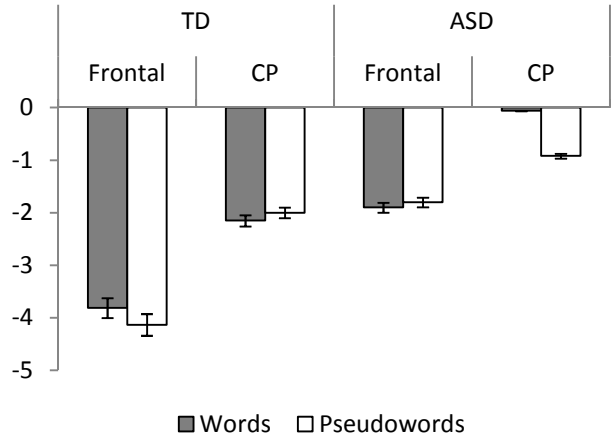
	Sensory Profile				Lexicality / Region			
	LR	SSK	SSN	SA	Words Frontal	Pseudowords Frontal	Words CP	Pseudowords CP
TD	5.36 (2.11)	6.27 (1.95)	6.45 (2.38)	4.55 (1.63)	-3.81 (2.15)	-4.13 (2.49)	-2.15 (1.64)	-2.01 (1.99)
ASD	10.18 (2.32)	7.45 (1.51)	9.18 (3.12)	9.00 (1.95)	-1.90 (1.61)	-1.80 (1.75)	-0.06 (1.16)	-0.92 (1.03)

Note: Standard deviations are in parenthesis. Low Registration = LR, Sensory seeking = SSK, Sensory Sensitivity=SSN, Sensory Avoidance = SA

MMN Amplitude Responses

Analysis of variance with a 2 (Region: Frontal vs. Centro parietal, within participants), x 2 (Lexicality: Words vs. Pseudowords, within participants) x 2 (Group: TD vs. ASD, between participants) revealed a significant main effect of Region, F (1, 20) = 60.13, MSE = .96, $p < .001$, $\eta^2 = .75$, revealing overall more activity in the frontal region than in the CP region. A main effect of group was also present F (1, 20) = 7.61, MSE = 9.93, $p < .01$, $\eta^2 = .28$, showing larger overall amplitudes in the TD group than the ASD group. The main effect of Lexicality, as well as the Lexicality x Region and Lexicality x Group were not significant (all $F < 1.59$, all $p > .22$). These interactions were qualified by a significant Region x Lexicality x Group interaction, F (1, 20) = 6.41, MSE = .44, $p < .05$, $\eta^2 = .24$. Analysis of this interaction (Figure 5) revealed that the TD group showed significantly higher amplitudes than the ASD group for words (t (20) = 2.35, $p < .05$) and Pseudowords (t (20) = 2.54, $p < .05$), in the frontal region. However, the TD group showed significantly higher amplitudes than the ASD group in CP region only when processing words (t (20) = 3.45, $p < .05$), but not when processing Pseudowords (t (20) = 1.61, $p = .12$.

Figure 5. Mean Amplitude Responses by Lexicality, Region and Group



Sensory processing and MMN amplitudes

In order to identify whether auditory sensory processing moderated the differences in the way words and pseudowords were processed a regression analysis was performed using the four quadrants of the sensory profile as predictors of words and pseudowords in two separate analyses. The effect of group (coded 0 = TD, 1 = ASD) was also included as a predictor in order to control for the differences between groups. Results revealed that sensory sensitivity was the only quadrant of the sensory profile that influenced the processing of words, and none of the quadrants significantly predicted the processing of pseudowords (Table 4).

Table 4. Standardised regression coefficients of sensory profile and group predicting words and pseudowords by Region

	Frontal		Centro-Parietal	
	Words	Pseudowords	Words	Pseudowords
LR	-.25	-.17	-.34	-.19
SSK	.01	.14	-.14	.04
SSN	.53*	.15	.43†	.36
SA	-.43	-.29	-.23	-.30
Group	.75†	.73	.89*	.54

Note: * = $p < .05$. † = $p < .08$.

In addition, the effect of sensory sensitivity was significant on the frontal region and marginally significant on the CP region. In order to confirm this finding, a bootstrapping analysis with 5000 replacements and 95 % confidence intervals revealed that sensory sensitivity was the only significant predictor of words in the frontal region and a marginally significant predictor for words in the CP region.

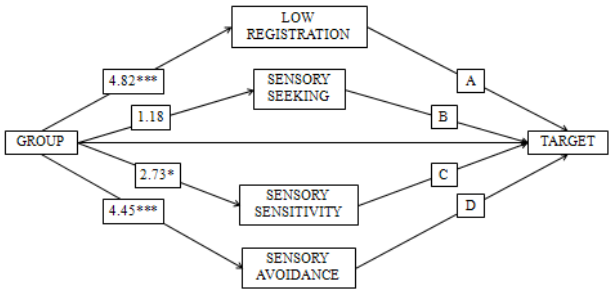
In order to identify whether auditory sensory processing moderated the differences in the way words and pseudowords were processed, a bootstrapping, single-step with multiple mediators technique was carried out using the procedure and macros provided by Preacher and Hayes (2008). The effect of the group (coded 0 = TD, 1 = ASD) was used as an independent predictor of words and pseudowords in separate analysis for each region, including the four quadrants of the sensory as mediators of this relationship.

Results confirmed the significant effect of group on the LR, SSN and SA quadrants of the sensory profiles but not on the SSK quadrant (Figure 6). The analysis also revealed that 'sensory sensitivity' was the only quadrant that consistently predicted response amplitudes, and that this relationship was present only for words and not for pseudowords. The results also showed that the effect of sensory sensitivity was stronger in the frontal region. These results suggest that the inverse relationship between sensory sensitivity and amplitude responses is significant and stronger for words only in the frontal region. Although SSN was the only relevant predictor of words in both regions, results revealed that these effects were marginally different from 0 for words (both $p < .10$), and not significantly different from 0 for pseudowords (both $p > .22$).

Discussion

The current study investigated auditory processing in children with ASD in order to determine electrophysiological correlates of brain activity during automatic language processing. Results revealed children with ASD to show significantly reduced MMN amplitudes for speech like stimuli (both words and pseudowords) compared to the typically developing children. This effect was more marked between groups across the meaningful stimuli whereby children with ASD showed significantly reduced activation in both the frontal and central parietal regions for words but only differences in the frontal regions for pseduowords.

Figure 6. Multiple Mediation Model of Sensory Profile as mediator of the Group and Region/Lexicality combinations.



Target	GROUP	A	B	C	D
WORDS/FRONTAL	1.90*	-.16	-.01	.37*	-.31
PSEUDOWORDS/FRONTAL	2.33*	-.12	.19	.12	-.24
WORDS/CP	2.09**	-.18	-.13	.25+	-.14
PSEUDOWORDS/CP	1.09	-.10	.04	.20	-.17

Note: * = $p < .05$, + = $p = .06$, ** = $p < .01$, *** = $p < .001$

These results support previous behavioural and neuroimaging findings showing auditory processing of speech sounds, revealed by the MMN component, to be abnormal in children with a diagnosis of ASD (e.g. Jansson-Verkasalo et al., 2003). Importantly, auditory sensory sensitivity was found to predict their responses to the deviants across the MMN auditory paradigm. The results therefore suggest lack of automatic attention to sounds in the environment may be a consequence of abnormal auditory processing in individuals with ASD.

Abnormal auditory processing has constantly been reported as being a key characteristic of ASD. The most common pattern presented in the literature suggests a vast difference between how speech and non-speech stimuli are perceived, with enhanced processing of tonal and environmental sound, and impaired processing of speech like stimuli in ASD compared to typical controls (Čeponienė et al., 2003; Gervais et al., 2004). However whilst several studies have considered differences between speech and non-speech stimuli, few studies have addressed the influence of semantic content of the stimuli using a MMN task. The results of the current study support our initial hypotheses in showing a reduction of MMN using real (meaningful) words and meaningless pseudoword in the ASD group, reflecting the fact that children with ASD have difficulties processing speech-like stimuli. The present findings also add to a growing body of research highlighting differences in semantic processing in ASD (Mottron, Morasse, & Belleville, 2001; Toichi & Kamio, 2001; 2002).

Differences in encoding auditory stimuli in ASD have regularly been cited alongside explanations of atypical sensory processing (e.g. Jansson-Verkasalo et al., 2003). However, this has often been addressed in the literature indirectly by showing atypical auditory processing is evident in those individuals with ASD showing higher levels of sensory behaviours (e.g. Jones et al., 2009). In the current study, the relationship between sensory behavior and auditory processing was also first addressed using behavioural data, as measured by the AASP. As expected auditory responsiveness was found to be the most common and pervasive form of sensory behaviour within the ASD group compared to the controls, however, the effect of these auditory sensory behaviours was then further explored. In order to identify whether auditory sensory processing was a moderator of the differences in the way words and pseudowords were processed, a bootstrapping, single-step with multiple mediators technique was used. The results revealed that auditory sensory sensitivity uniquely predicted the differences in processing words when controlling for the effect of group. The higher the autistic children's sensory sensitivity scores the lower the amplitude for words, and sensory sensitivity appeared to be the strongest sensory moderator of this effect.

This is one of the first studies to directly try to show that sensory characteristic underlie abnormal auditory processing for speech like stimuli. For children with ASD, auditory discrimination of infrequent changes in sounds appears to be accomplished through a different mechanism than in typical children (Dunn et al., 2008). Specifically it has been suggested that children with ASD do not automatically attend to changes in auditory stimuli presented in their environment supporting the idea of abnormal automatic auditory processing in children with autism. For children with ASD, research findings have consistently shown an inability to automatically shift their attention to changes in sounds falling outside of their attention spotlight, unless they are specifically requested to redirect their attention (Dunn, Gomes & Gravel, 2008). This has often been interpreted in the literature as resulting from a detail-focused cognitive style in ASD, named weak central coherence (WCC), characterised by a heightened ability to focus on details rather than the whole (Happé, & Frith, 2006).

In the context of sensory processing, WCC may lead to problems with auditory stimuli such that overly focusing on parts of sounds (sensory sensitivity) may contribute to hypersensitivity for particular noises in the environment. This may also lead to hyposensitivity from fixating on specific sounds and blocking out others. For example, if children with autism focus too readily on perceptual cues during speech such as pitch, this may impact negatively upon linguistic processing (Jarvinen-Pälsy, Pälsy & Heaton, 2008; Jarvinen-Pälsy, Wallace, Ramus, Happé & Heaton, 2008). Thus enhanced pitch discrimination often associated with ASD may eradicate in the context of speech stimuli due to problems in feature extraction (Lepisto et al., 2006; 2008)

There are several theories postulating how sensory symptoms may lead to difficulties processing speech like stimuli in ASD which the current results are not able to address. For example, impaired feature extraction could result in poor quality of speech sound properties. Alternatively, they could have abnormal intensity modulation, the process by which sensory responses to

incoming sounds of different intensity are regulated. Jones et al., (2009) discuss how an inability to modulate incoming intensity levels could lead to poorer discrimination ability (the results of a less finely tuned system), but could also mean that behaviour reactions to sounds are augmented due to a threshold mechanism that does not adequately filter or make sense of incoming stimuli (Bruneau, Bonnet-Brilhaulf, Gomet, Adrien & Barthèlèmy 2003; Brueau, Rout, Adrien & Barthèlèmy 1999). Alternatively children with ASD may have fewer resources allocated to attending incoming stimuli. A finding already demonstrated in children with sensory disorders (Davies, Chan & Gavin, 2010)

Whilst the results of the current study are suggestive that auditory sensory sensitivity is particularly important in the auditory perception of speech-like stimuli, it is not clear whether the same affect would be observed in non-speech-like stimuli using a similar paradigm. Sensory behaviours are also highly correlated and consequently impact upon other sensory characteristics (Bettison, 1994; Gillberg & Coleman, 1996; Rimland & Edleson, 1995; Baranek 1999. Therefore given that the children with ASD reported significantly higher auditory sensory behaviours than the typically developing children across three of the sensory quadrants, future studies need to address the interaction between the different auditory sensory measures as well as considering the sensory behaviours across other sensory modalities.

In sum, despite some of the limitations noted, the current study addresses an important question showing sensory behaviours may underlie differences in auditory perception of speech like stimuli in ASD. Specifically, lack of automatic attention to sounds in the environment may be a consequence of abnormal auditory processing in individuals with ASD. Therefore abnormal sensory behaviours could be considered a core deficit to the autistic disorder eventually leading to difficulties in processing language. Further studies are needed to uncover the neural mechanisms responding to sensory stimuli in ASD and their relationship to behavioural deficits. This will help to assist in a better understanding of the nature of the disorder and guide appropriate treatment for children with sensory abnormalities.

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