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PAPER

Enhanced perceptual processing of speech in autism

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Abstract

Theories of autism have proposed that a bias towards low-level perceptual information, or a featural/surface-biased information-processing style, may compromise higher-level language processing in such individuals. Two experiments, utilizing linguistic stimuli with competing low-level/perceptual and high-level/semantic information, tested processing biases in children with autism and matched controls. Whereas children with autism exhibited superior perceptual processing of speech relative to controls, and showed no evidence of either a perceptual or semantic processing bias, controls showed a tendency to process speech semantically. The data provide partial support to the perceptual theories of autism. It is additionally proposed that the pattern of results may reflect different patterns of attentional focusing towards single or multiple stimulus cues in speech between children with autism and controls.

Introduction

Autism is a pervasive neurodevelopmental disorder that is diagnosed on the basis of difficulties in social interaction, atypical language, stereotyped interests, and repetitive behaviors (American Psychiatric Association, 1994). The level of intellectual functioning is highly variable within this population, and co-occurring intellectual impairment is noted in approximately 50–75% of individuals (Rapin, 1997; Spence, Sharifi & Wiznitzer, 2004). However, global measures of IQ can be uninformative and/or misleading, as uneven cognitive function characterizes many diagnosed individuals. A weakened tendency to preferentially attend to social stimuli is also noted in autism (Rapin, 1997), and it is therefore unsurprising that cognitive strengths are often noted in areas that do not entail social interaction. For example, while studies investigating auditory information-processing in autism have reported deficits in processing speech prosody (Kujala, Lepistö, Nieminen-von Wendt, Näätänen & Näätänen, 2005; see McCann & Peppé, 2003, for a review), relatively intact or enhanced musical pitch processing has also been extensively documented (Appelbaum, Egel, Koegel & Imhoff, 1979; Bonnel, Mottron, Peretz, Trudel, Gallun & Bonnel, 2003; Heaton, 2003, 2005; Heaton, Hermelin & Pring, 1998; Heaton, Pring & Hermelin, 1999; Mottron, Peretz & Ménard, 2000). These contrasting findings are interesting given that speech prosody and music share significant acoustic features, such as similar fundamental frequency and temporal variations of similar period.

Neurological investigations have provided further evidence of discrepant auditory information-processing across speech and non-speech domains in autism. In support of the behavioral findings (e.g. Heaton *et al.*, 1998; see McCann & Peppé, 2003), this work, utilizing event-related brain potentials (ERPs; Čeponienė, Lepistö, Shestakova, Vanhala Alku, Näätänen & Yaguchi, 2003), positron emission tomography (PET; Boddaert, Belin, Chabane, Poline, Barthélémy, Mouren-Simeoni, Brunelle, Samson & Zilbovicius, 2003; Boddaert, Chabane, Belin, Bourgeois, Royer, Barthélémy, Mouren-Simeoni, Philippe, Brunelle, Samson & Zilbovicius, 2004), and functional magnetic resonance imaging (fMRI; Gervais, Belin, Boddaert, Leboyer, Coez, Sfaello, Barthélémy, Brunelle, Samson & Zilbovicius, 2004) has identified a pattern in which the neural processing of speech or vocal sounds, but not musical or environmental sounds, appears abnormal in individuals with autism relative to typical controls. These studies have prompted the suggestion that autism may 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 processing and atypical prosodic processing in autism is that a general bias towards non-vocal information results in enhanced

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processing of musical or non-linguistic pitch and, correspondingly, diminished appreciation of linguistically functional pitch, that is, prosody (Gervais *et al.*, 2004).

Although pragmatics has been identified as the only aspect of language that is universally and specifically impaired in autism (e.g. Lord & Paul, 1997; Wilkinson, 1998), semantic deficits have commonly been reported as well. However, studies examining semantic processing in autism have varied greatly in terms of specific semantic requirements, and have provided mixed results. Findings from a large-scale study examining the phonological, grammatical, semantic, and pragmatic language abilities of 491 pre-school-age children, of whom 229 were diagnosed with an autistic spectrum disorder, and 262 with a developmental language disorder (Allen & Rapin, 1992), showed that, whereas none of the children with autism exhibited typical comprehension of speech, over a third of those without autism did so.

The majority of experiments examining semantic processing in autism have involved reading. Some studies have highlighted a reduced ability to provide appropriate pronunciations of homographs in semantic contexts (Happé, 1997; Jolliffe & Baron-Cohen, 1999; Frith & Snowling, 1983; López & Leekam, 2003), although other studies have also found that such difficulties decrease when participants with autism are specifically instructed to focus upon the semantic level of the presented stimuli (Happé, 1994; Jolliffe & Baron-Cohen, 1999; Snowling & Frith, 1986). Research has also shown comprehension deficits in autism in the absence of ambiguous information. For example, participants tested by Jolliffe and Baron-Cohen (1999, 2000) and Norbury and Bishop (2002) made significantly more errors when answering multiple choice and open-ended format questions about a previously read text. In these studies, participants could only respond correctly if they made inferences about the text and about world knowledge. However, a recent study examining an on-line effect of priming caused by an inference showed that participants with autism did not show difficulty in bridging inferences, even when the content was social (Saldaña & Frith, 2006). This suggests that even if individuals with autism can make implicit inferences on-line, they may still show poor comprehension 'off-line'. A question that remains, however, is whether a focus upon the semantic level of language is the 'default' or primary processing mode of individuals with autism.

Two perceptual theories of autism have addressed the strengths and weaknesses in cognitive performance in individuals with the disorder. The first of these accounts is the weak central coherence (WCC) theory (Frith, 1989; Happé, 1999; Happé & Frith, 2006), which predicts that the typical propensity to process perceptual, visuospatial-constructional, and verbal-semantic stimuli, both globally and in context, is weakened in individuals with autism. Consequently, such individuals show superior performance over those without the disorder in tasks where a featural/surface-biased information-processing style is advantageous (Happé, 1999). By contrast, a strong propensity to process information globally is hypothesized to hamper perceptual functions in those without autism.

Alternatively, the theory of enhanced perceptual functioning (EPF; Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert & Burack, 2006) proposes that neural networks underpinning perceptual processing are 'over-specialized' and predispose locally oriented and enhanced perceptual functioning in autism. However, although perception may play an unusually dominant role in high-level cognitive tasks in autism, higher-order functions are assumed to be unimpaired. Thus, while cognitive processing in individuals without autism is characterized by mandatory higher-order control, regardless of the nature of a task, those with autism are able to regulate the perceptual versus higher-order control more flexibly.

Evidence for intact or enhanced pitch processing (e.g. Heaton *et al.*, 1998; Mottron *et al.*, 2000), and theories conceptualizing high-level language difficulties resulting from a bias towards either featural/surface, or low-level perceptual, information, raise interesting questions about processing biases that may occur when individuals with autism are presented with a stimulus that includes competing perceptual and semantic information, that is, speech. One previous study has reported overly focused selective attention towards a limited number of available cues in complex auditory stimuli in participants with autism (Schreibman, Kohlenberg & Britten, 1986). In this study, either non-verbal or echolalic children with autism and typical controls were trained on both intonation and content components of complex auditory stimuli. The results showed that, while the children with autism responded selectively to either the intonation or content components of the stimuli, the controls either selectively responded to content, or showed no evidence of selectively responding to either stimulus component.

Two experiments were designed to test perceptual and semantic speech processing biases in verbally fluent children with autism and age- and intelligence-matched controls. The studies varied in terms of the perceptual information included in the auditory stimuli: while in Experiment 1, speech and music samples incorporated a simple and clearly defined pitch contour, Experiment 2 was designed to examine rhythm perception over meaningful speech and linguistically meaningless vocal stimuli. The processing of the semantically meaningful speech stimuli at both the perceptual and the comprehension level was assessed in both studies. The rationale for including both pitch contour and rhythmic information is that it allows investigation of the extent to which these two sources of perceptual information may independently influence the pattern of perceptual and sentence comprehension abilities of those with autism.

The following hypotheses can be derived from the theories described above. The WCC theory predicts that individuals with autism will show higher levels of performance than controls only in the perceptual tasks where stimuli are meaningful speech. This is because WCC predicts better inhibition of higher-level semantic information in individuals with autism in comparison to those with the typical drive towards central coherence (CC). According to the EPF theory, perception is universally enhanced in autism so it is predicted that participants with autism will outperform their controls in all perceptual tasks.

Experiment 1

Method

Participants

Twenty children with a formal diagnosis of autistic disorder or Asperger disorder according to DSM-IV criteria (APA, 1994) participated in the experiment. The diagnostic information was gathered from school files of documented medical diagnoses and clinical reports. The children selected all met the following criteria: they had a monolingual English-speaking home environment, and no evidence of a hearing or a neurological impairment. This sample was recruited from a specialist educational establishment for children with high-functioning autism (HFA) and Asperger syndrome (AS). Further, only children who showed fluent use of spoken language were included in the study. This information was gathered from the children's teachers and verified by the experimenter in a pre-test conversation phase. The control children were matched on an individual basis to those with autism for chronological age (CA), as well as verbal (VIQ) and non-verbal intelligence (NVIQ). As 10% of children in the autism group were intellectually impaired, the same proportion of children in the control group had moderate learning difficulties (MLD). The children in this group were recruited from a mainstream primary school, a primary school for children with MLD, and a mainstream secondary school with a specialist unit for children with MLD. Only children with MLD conditions that were of unknown origin were included, so as to rule out the influences of any accompanying disorder. The diagnostic information was gathered from school files of documented medical diagnoses and clinical reports. The children selected all met the same criteria as specified for those with autism. Children were also screened for musical training. Only those who had not undergone periods of extensive musical training, defined as having taken two or more years of individual music lessons, were included in the study.

Table 1 shows the demographic characteristics of the two groups of children. No significant between-group differences in age, the British Picture Vocabulary Scale (BPVS; Dunn, Whetton & Pintilie, 1997), or the Raven's Standard Progressive Matrices (RSPM; Raven, Court & Raven, 1992) standardized scores are revealed (t-tests all $p \geq .526$). Furthermore, the samples did not differ in terms of gender ratio (Chi square test $p = .677$).

Table 1 *Characteristics of the two participant groups in Experiment 1 (SDs in parentheses)*

	Mean CA (years)	Sex	Mean VIQ (BPVS)	Mean NVIQ (RSPM)
Autism group (n = 20)	12.55 (2.57)	17M; 3F	84 (19.83)	87 (14.43)
Control group (n = 20)	12.03 (2.62)	16M; 4F	83 (20.11)	84 (16.12)

Experimental stimuli

Experiment 1 incorporated a simple and clearly defined pitch contour that the participants had to match to one of four representations of the possible contours. The stimuli included 16 speech and 16 perceptually analogous musical samples: whereas the contours were produced by variation in prosody in the speech samples, the analogous contours were created using five-tone sequences in the music stimuli. The order of presentation of the 32 stimuli was randomized with respect to the ordering of the different pitch contours and stimulus type. The stimuli were presented on a laptop computer, and each auditory sample was followed by a visual display representing the four pitch contours, shown in Figure 1.

Linguistic perceptual condition: Sixteen sentences were uttered in such a way as to produce one of four pitch contours: ascending, descending, low-high-low (or inverted 'U'-shaped), and high-low-high (or 'U'-shaped). Fundamental frequency was then extracted every 10 milliseconds using the Praat speech editor (Boersma, 2001). Visual inspection of the fundamental frequency (F_0) curves was used to ensure that the contours were produced as intended; when needed, sentences were re-recorded until the desired contours were obtained. Each sentence was five syllables in length, and was constructed using verbs,

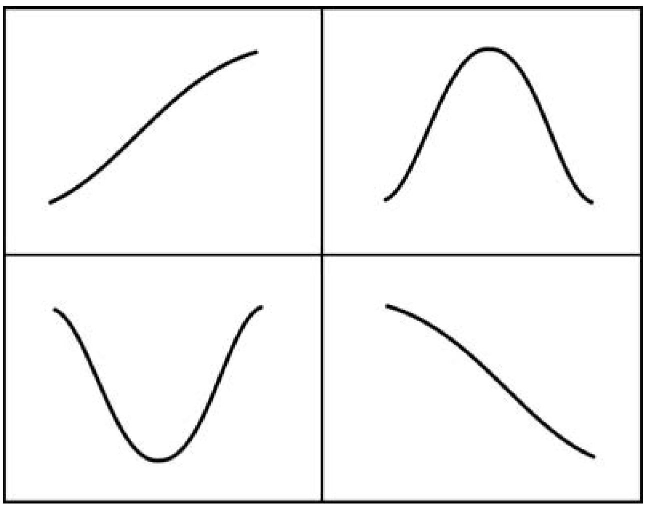

Figure 1 *Graphic representation of the four different pitch contours.*

nouns, and adjectives that occur frequently in spoken language in British English. Examples of sentences included 'Reading books is fun' and 'Tom loves eating chips'. Full details of stimuli are included in the Appendix. The sentences were uttered by a native English-speaking female. Each sentence conformed to one of the four pitch contours shown in Figure 1, so that four sentences corresponded to each contour shape.

Linguistic comprehension condition: Sixteen test questions, relating to varying degrees to the semantic information given in each of the sentences in the linguistic perceptual condition, were generated. Therefore, the degree of explicitness with which the target event described in the sentence was primed in the wording of the test question was manipulated over stimulus items. In order to provide a correct answer, participants were required to construct meaning by inference, or to utilize the linguistic context provided. This type of task specifically taps into comprehension/semantic knowledge (Beal, 1990). However, the sentences were generally clear and easy to understand, even when a more implicit type of inference was required. The participants were also told explicitly that the questions were based upon the information given in the sentence. The rationale for this design was to prevent ceiling-level performance in the control group, although the ability to make inferences to aid text comprehension develops early in typical development (Beal, 1990). For the same reason, the test questions did not directly name any of the words (with the exception of characters' names) incorporated into the speech stimuli. An example of a sentence requiring a relatively explicit inference is, 'All my pens are blue'. For this, the test question was, 'What color ink does the lady like to use?' The answer 'blue', or a color describing a shade of blue scored one point. Any response referring to another color or irrelevant information scored zero points. An example of a sentence requiring a more implicit inference is, 'Tom loves eating chips'. For this, the test question was, 'What is Tom's favorite food?' Here, the children were required to infer that the answer must be 'chips' as it was the only food term present in the sentence. Full details of the stimuli and scoring criteria are given in the Appendix. The experimenter recorded the children's responses. Each correct answer thus scored one point, making the maximum score for this condition 16. All of the children's responses in this measure were double-rated by a psychologist blind to the participants' diagnostic status (between-rater agreement of 100%). No modifications to the children's scores were necessary, and all of the children's answers were either exactly correct or completely inaccurate.

Non-linguistic perceptual condition: Sixteen five-tone contours, analogous perceptually to the speech samples, were generated using a Casiotone 202 electronic keyboard (acoustic piano setting). Pitch trajectories of the intact sentences in the speech pitch condition were traced using the Melodyne software package (Neubäcker & Gehle, 2003), and musical forms were produced accordingly. For example, the pitch trajectory of the high-low-high contour in the sentence 'Racing-bikes go fast' included G#, A, D#, B, and G#. Thus, each musical contour corresponded to one of the four pitch contours shown in Figure 1. These stimuli were recorded directly onto a laptop computer using the GoldWave® software package. The musical contours were matched for duration to the stimuli in the speech condition.

Procedure

The children were tested individually in a quiet room in their own school, and all stimuli were presented via loudspeakers. A training phase preceded the experimental testing. The child was told that s/he was going to hear some short, spoken sentences and short melodies. Three training blocks of four sentences were given, one corresponding to the linguistic perceptual condition, one to the linguistic comprehension condition, and one to the non-linguistic perceptual condition, and the order of these blocks was counterbalanced across participants. However, the linguistic perceptual condition training always preceded the linguistic comprehension condition training. In the linguistic perceptual condition training, the child was told that sentences could be said in different ways so as to form differently sounding shapes, depending on how 'high' the voice sounded. The child was then shown the visual display on the laptop computer, and told that his or her task would be to point to the shape that s/he thought best matched each sound. A training block of four sentences, similar to those used in the actual experiment, was then played on the computer. If the child's response was inaccurate, the experimenter corrected the child. In order to move to the second block of training, the child was required to have made at least two correct judgments out of four stimuli in response to the contour information. If not, then a different block of sentences was played, until this criterion had been reached. Participants took as many practice trials as needed until reaching this criterion. Seventy-five percent of the children achieved this during the first trial, and the remaining children reached this on a second trial.

The child was further told that each of the sentences told a little story, and now the experimenter was going to play the sentences again, but this time she would ask a simple question relating to the information that was given in the sentence. The exact instructions were: 'I will now play the same sentence again but this time, I would like you to pay attention to the meaning of what the lady says'. The experimenter replayed the four sentences and recorded the participants' responses. As semantic processing deficits are commonly observed in autism (e.g. Allen & Rapin, 1992), no such criterion as in the perceptual conditions was applied to the linguistic comprehension condition training.

For the non-linguistic perceptual condition training, the experimenter told the child that musical melodies could form the same shapes as could the sentences.

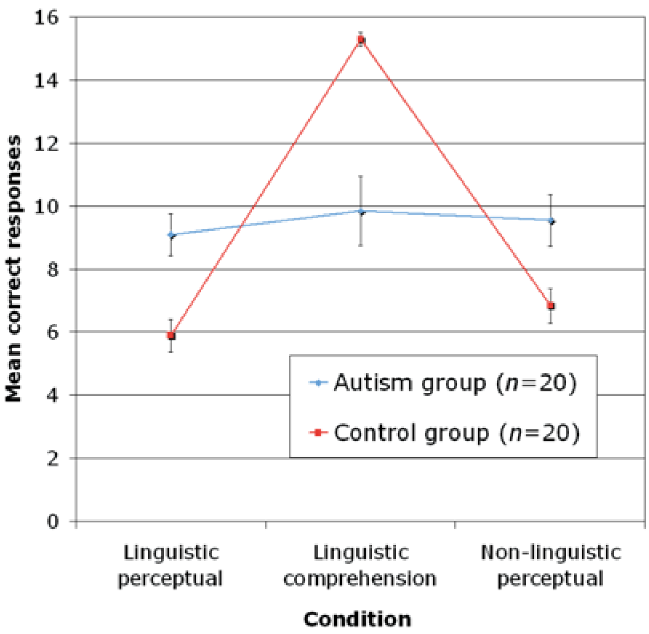

Figure 2 *Means and standard error means (±1 SEM) for the raw scores of the children with autism and their matched controls across the three experimental conditions in Experiment 1 (maximum score per condition = 16).*

The training block, consisting of four different musical contours, was then played on the computer, and the child was instructed to match each of the melodies to the visual display of the pitch contours. The experimenter again corrected the child until s/he had made two accurate responses. Following the successful completion of the perceptual training blocks, the experimenter told the child that she had more similar sentences and melodies recorded onto the computer. No feedback was given during the testing phase. Following each perceptual judgment in response to the linguistic stimuli, the experimenter told the child to focus upon the meaning of the sentence. The sentence was re-played and the test question was administered.

Results

The means and standard error means for the raw scores of the two groups of children across the linguistic perceptual, linguistic comprehension, and non-linguistic perceptual conditions in Experiment 1 are displayed in Figure 2.

The children's scores in the linguistic perceptual and non-linguistic perceptual conditions were compared against chance level performance (4) by applying one-sample t-tests setting the population value to 0.25. This analysis showed that performance in both groups of children was significantly above chance in both conditions (Autism: linguistic perceptual $t = 7.63$, $p < .001$; and non-linguistic perceptual $t = 6.75$, $p < .001$; Control: linguistic perceptual $t = 3.75$, $p = .001$; and non-linguistic perceptual $t = 5.19$, $p < .001$).

The scores in the non-linguistic perceptual, linguistic comprehension, and linguistic perceptual conditions were not normally distributed (Levene's Test for Equality of Variance F-statistic for the variables: linguistic perceptual: $p = .18$; linguistic comprehension: $p < .001$; and non-linguistic perceptual: $p = .05$). Consequently, logarithmic transformations were performed on all variables included in the parametric analyses. This transformation resulted in all the variables being normally distributed (Levene's F-statistic for the transformed variables: $p = .62$; $p = .11$; and $p = .17$, respectively). A three-by-two repeated-measures analysis of variance (ANOVA) was then carried out on the data, with condition (linguistic perceptual/linguistic comprehension/non-linguistic perceptual) entered as the within-participants factor, and diagnosis (autistic/control) as the between-participants factor. This analysis revealed a significant effect of condition ($F(2, 37) = 26.87$, $p < .001$); diagnosis ($F(1, 38) = 62.82$, $p < .001$); and a condition by diagnosis interaction ($F(2, 37) = 7.57$, $p = .002$).

Follow-up t-test analyses showed that, whereas children with autism performed at a significantly higher level compared to their matched controls in the linguistic perceptual condition ($t(38) = 3.61$, $p = .001$) and in the non-linguistic perceptual condition ($t(38) = 2.34$, $p = .025$), the control children showed superior sentence comprehension compared to those with autism ($t(38) = 6.44$, $p < .001$). Pair-wise comparisons of perceptual condition type with Bonferroni α adjustments were then carried out for each group. Within both groups of children, there was no significant difference in perceptual performance between the linguistic perceptual and non-linguistic perceptual stimuli (Autism: ($t(19) = .25$, $p = ns$); Controls: ($t(19) = 1.64$, $p = ns$)).

Finally, Bonferroni α corrected correlations were carried out between experimental, psychometric, and age data. For the children with autism, performance in the linguistic perceptual condition correlated positively with performance in the non-linguistic perceptual condition ($r = .81$, $p = .05$), and performance in the linguistic comprehension condition was positively associated with age ($r = .62$, $p = .05$). No other significant correlations were found for the children with autism (all $r < .33$). All correlations for the children in the control group failed to reach significance (all $r < .39$).

Discussion

The first experiment reported here sought to address processing biases towards perceptual (pitch contour) and semantic information present in auditory stimuli in individuals with autism and controls matched for age, gender, and intelligence. The main finding showed that neither group of children showed evidence of semantic interference upon perceptual processing ability, as similar levels of performance across the linguistic perceptual and non-linguistic perceptual conditions were seen. However, important group differences were noted in the study, namely superior perceptual processing of both speech and music stimuli in participants with autism, and superior sentence comprehension in the control group. The first of these findings is consistent with literature reporting enhanced pitch processing in autism (Bonnel *et al.*, 2003; Heaton *et al.*, 1998, 1999; Heaton, 2003, 2005; Mottron *et al.*, 2000). Although no evidence of semantic interference upon perceptual ability was found in the controls, they were noticeably more proficient at linguistic than at perceptual processing. However, as the perceptual and linguistic conditions were not equated for difficulty, a direct comparison between absolute levels of performance across the conditions cannot be made. It should also be noted that the controls performed at ceiling level in the comprehension task, and that between-conditions differences should be interpreted with caution for reasons specified above.

One question that arises from the results, however, is whether different types of perceptual information may influence the pattern of perceptual processing of individuals with autism. Acoustically, speech prosody is manifested by, but not limited to, variations in fundamental frequency, amplitude, and duration (Lehiste, 1970), with the most significant prosodic effects being produced by the linguistic use of pitch or intonation (Lieberman, 1960). Experiment 2 was designed to address this question by examining the processing of regular temporal variation of amplitude in naturalistic speech samples, and perceptually analogous non-speech vocal samples, which contained no semantic information.

Experiment 2

Method

Participants

Twenty children with a formal diagnosis of autistic disorder or Asperger disorder according to DSM-IV criteria (APA, 1994) participated in this experiment. Sixty percent of these children had also participated in Experiment 1. Seventeen children were recruited from a specialist educational establishment for children with HFA and AS, and a further three children were recruited from a school for children with MLD with a specialist provision for children diagnosed with autism. Again, only children with fluent expressive language were included in the study, and they were selected as described in Experiment 1. The control children were matched on an individual basis to those with autism for CA, VIQ, and NVIQ. As 25% of children in the autism group were intellectually impaired, an equal proportion of children in the control group had MLD. The children in this group were recruited from a mainstream primary school, a primary school for children with MLD, and a mainstream secondary school with a specialist unit for children with MLD. Again, only children with MLD conditions that were of unknown origin were included. Sixty percent of these children also participated in Experiment 1.

Table 2 *Characteristics of the two participant groups in Experiment 2 (SDs in parentheses)*

	Mean CA (years)	Sex	Mean VIQ (BPVS)	Mean NVIQ (RSPM)
Autism group (n = 20)	12.86 (2.31)	20M; 0F	78 (19.89)	85 (18.98)
Control group (n = 20)	12.86 (2.44)	16M; 4F	77 (18.71)	79 (15.21)

Table 2 shows the demographic characteristics of the two groups of children. No significant between-group differences in age, the BPVS, or the RSPM standardized scores are revealed (t-tests all $p \geq .289$).

Experimental stimuli

Experiment 2 was designed to examine rhythm perception over meaningful speech and linguistically meaningless vocal stimuli. The stimuli included 16 intact speech and 16 perceptually analogous non-speech vocal samples. We employed clearly defined syllabic rhythm patterns as a simple approach to collecting data on performance with stimuli that varied according to their temporal patterning. Here, the sequence was produced by temporal variation of amplitude of voice uttering a sentence in the speech condition, and by the repetition of vocal sounds in the non-speech stimuli. The order of presentation of the 32 stimuli was randomized with respect to the ordering of the different sound patterns and also the stimulus class. The stimuli were presented on a laptop computer via loudspeakers, and each auditory sample was followed by a schematic illustration of the four sound patterns, shown in Figure 3. Each stimulus conformed to one of four distinct sound patterns, shown in Figure 3. In this illustration, each sound pattern was presented on a separate horizontal line, and vertical lines represent word boundaries in some cases. Each black chunk corresponded to a syllable, and thus, the schematic

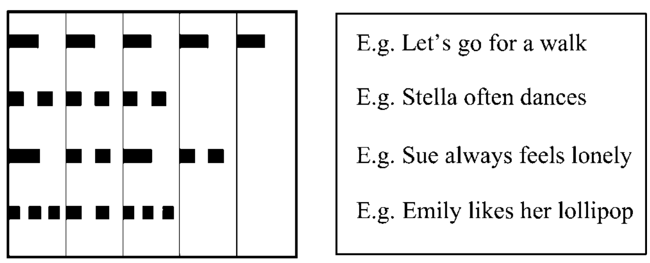

Figure 3 *Schematic illustration of the four sound patterns used in the auditory stimuli (left) and examples of corresponding speech stimuli (right).*

illustration essentially represents number of words and number of syllables in each word.

Linguistic perceptual condition: Sixteen sentences corresponding to one of the four sound patterns shown in Figure 2 were generated. Pattern one comprised five monosyllabic words (e.g. 'Let's go for a walk'); pattern two comprised three bi-syllabic words (e.g. 'Katie gathers conkers'); pattern three was constructed of a repeated pattern of a monosyllabic word followed by a bi-syllabic word (e.g. 'Your trainers are dirty'); and pattern four consisted of a tri-syllabic word followed by two monosyllabic words followed by a tri-syllabic word (e.g. 'Annabel is from Italy'). Full details of the stimuli are included in the Appendix. These sentences were read by the same native English-speaking female as in Experiment 1, in a declarative tone of voice, exaggerating the pronunciation of the syllables. Each sentence was recorded directly onto a laptop computer using the GoldWave® software package. The sentences were constructed using nouns, verbs, and adjectives that are neutral and that occur frequently in spoken language in British English. As the experiment was designed to assess perceptual processing of naturalistic speech, these stimuli contained natural fundamental frequency variations.

Linguistic comprehension condition: Sixteen test questions, based to varying degrees upon the semantic information given in each of the sentences in the linguistic perceptual condition, were generated as in Experiment 1 (see Appendix). As for Experiment 1, answers were again double-rated by a psychologist blind to the participants' diagnostic status, and between-rater agreement was again 100%.

Non-linguistic perceptual condition: Sixteen 'sound strings', perceptually analogous to the sentences used in the linguistic perceptual condition, were generated so that, instead of words, one of the vowels /a/, /e/, /o/, and /u/ were used. Each of the sound strings conformed to one of the four sound patterns shown in Figure 3. They were uttered by the same female voice as in the linguistic perceptual condition. Each sound pattern was read once using the four different vowels. Thus, the sound patterns for the vowel /a/ were as follows: 'A-A-A-A-A', 'AA-AA-AA', 'A-AA-A-AA', and 'AAA-A-A-AAA'.

Procedure

The procedure was carried out as described under Experiment 1, with the exception that the child was told that s/he was going to hear some short sentences and voices/sound strings. The child was further told that the sentences and voices were said in such a way that they produced four differently sounding patterns, resulting from the length of individual sounds and the position of pauses within them. Here, 77.5% of the children reached the training criterion on the first trial, and the remaining children achieved this on a second trial. Comprehension training was carried out as described under Experiment 1.

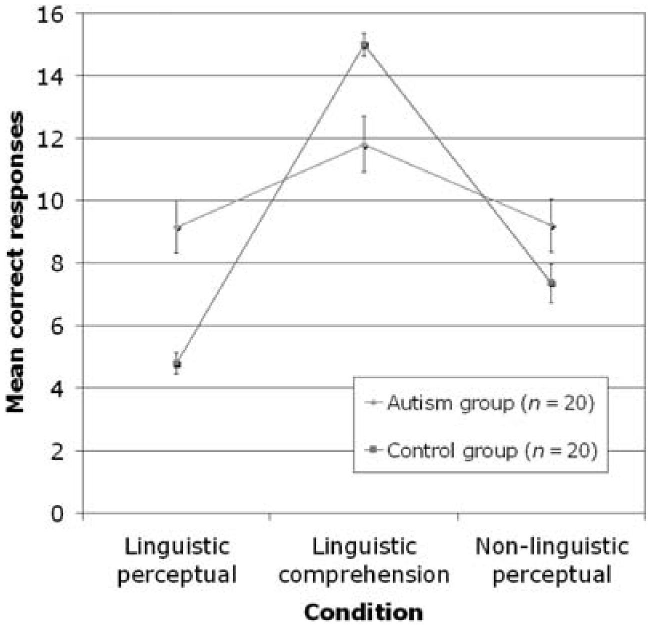

Figure 4 *Means and standard error means (±1 SEM) for the raw scores of the children with autism and their matched controls across the three experimental conditions in Experiment 2 (maximum score per condition = 16).*

Results

The means and standard error means for the raw scores of the two groups of children across the linguistic perceptual, linguistic comprehension, and non-linguistic perceptual conditions in Experiment 2 are shown in Figure 4.

The children's scores in the linguistic perceptual and non-linguistic perceptual conditions were compared against chance level performance (4) by applying one-sample t-tests setting the population value at 0.25. This analysis showed that performance in both groups of children was significantly above chance in all conditions (Autism: linguistic perceptual $t = 6.13$, $p < .001$; and non-linguistic perceptual $t = 6.13$, $p < .001$; Control: linguistic perceptual $t = 2.32$, $p = .032$; and non-linguistic perceptual $t = 5.43$, $p < .001$).

The scores in the linguistic perceptual, linguistic comprehension, and non-linguistic perceptual conditions were not normally distributed (Levene's Test for Equality of Variance F-statistic for the variables: linguistic perceptual: $p = .002$; linguistic comprehension: $p = .001$; and non-linguistic perceptual: $p = .18$). Consequently, logarithmic transformations were performed on all variables included in the parametric analyses. This transformation resulted in all the variables being normally distributed (Levene's F-statistic for the transformed variables: $p = .15$; $p = .35$; and $p = .48$, respectively). Again, as for Experiment 1, a three-by-two repeated-measures ANOVA was carried out on the data, with condition (linguistic perceptual/linguistic comprehension/non-linguistic perceptual) as the within-participants factor, and diagnosis (autistic/control) as the between-participants factor. This analysis revealed a significant effect of condition ($F(2, 37) = 25.61$, $p < .001$);

diagnosis ($F(1, 38) = 35.76$, $p < .001$); and a condition by diagnosis interaction ($F(2, 37) = 5.39$, $p = .009$).

Follow-up *t*-test analyses showed that children with autism performed at a significantly higher level compared to their matched controls in the linguistic perceptual condition ($t(38) = 5.42$, $p < .001$), and that control children showed superior sentence comprehension compared to those with autism ($t(38) = 3.83$, $p < .001$). There was no significant between-group difference in performance in the non-linguistic perceptual condition ($t(38) = 1.32$, *ns*). Pair-wise comparisons of perceptual condition type with Bonferroni α adjustments showed that, for children with autism, there was no significant difference in perceptual performance between the linguistic perceptual and non-linguistic perceptual stimuli ($t(19) = .23$, p = *ns*). For controls, performance in the non-linguistic perceptual condition was significantly higher than in the linguistic perceptual condition ($t(19) = -4.33$, $p < .001$).

Finally, Bonferroni α corrected correlations were carried out between age, psychometric, and experimental data. For the children with autism, the only significant correlation emerged between performance levels in the linguistic and non-linguistic perceptual conditions ($r = .78$, $p = .05$). For the children in the control group, a significant positive correlation emerged between the RSPM standardized score and performance in the linguistic perceptual condition ($r = .76$, $p = .05$), and performance in the linguistic comprehension condition was positively associated with age ($r = .59$, $p = .05$). No other significant correlation was found either for the children with autism (all $r < .40$) or for the children in the control group (all $r < .50$).

Discussion

The second experiment reported here sought to identify perceptual and semantic information processing biases acting upon temporally patterned rather than pitch information. Unlike Experiment 1, the results from Experiment 2 provided evidence of 'semantic capture' for controls. Here, performance levels were significantly higher when stimuli included no semantic information than when stimuli were semantically meaningful. By contrast, and consistent with results from Experiment 1, participants with autism exhibited similar levels of perceptual performance across linguistically meaningful and meaningless stimuli, suggesting that semantic interference did not inhibit perceptual processing. These results provide evidence for superior processing of the perceptual components of speech in autism. However, the results from the linguistic comprehension condition in Experiment 2 were consistent with those from Experiment 1 in showing inferior sentence comprehension in autism relative to controls.

General discussion

The present experiments were designed to test perceptual and semantic speech processing biases in children with autism and matched controls by utilizing stimuli that incorporated competing perceptual and semantic information. The principal aim of the studies was to identify atypical patterns of auditory processing, which may be implicated in higher-level language abnormalities in individuals with autism. The main findings from the studies showed that when the perceptual task was to process pitch contour information, neither controls nor children with autism succumbed to semantic interference. By contrast, when the perceptual task was to detect differences in temporal patterning, control participants exhibited clear semantic capture, achieving significantly higher levels of perceptual discrimination of semantically meaningless as compared to semantically meaningful stimuli. The most striking finding from the experiments was that the participants with autism showed enhanced processing of the perceptual level of speech. While the participants with autism were matched to controls on measures of age, NVIQ, and receptive vocabulary, the results from the linguistic comprehension conditions of the experiments showed that their sentence comprehension ability was inferior to that of controls. Indeed, ceiling levels of performance, seen in controls, may well have camouflaged even greater between-group differences.

While theories of autism cannot be adequately tested without examining information processing across perceptual and higher (e.g. linguistic) levels, equating tasks for difficulty poses considerable challenges. The tasks used in the current experiments vary along several dimensions. For example, in the perceptual conditions there were significant meta-cognitive demands in that participants were required to map pitch contour and temporal patterns onto their visual representations. In contrast, participants made verbal rather than visually based responses in the comprehension task. While this might suggest that task demands in the linguistic comprehension conditions were higher, this was not reflected in the results showing ceiling-level performance in the controls. Similarly, the meta-cognitive demands in the perceptual tasks did not inhibit performance levels in the autism group. Clearly, variations in task demands impact differently upon children with and without autism.

Although stringent matching procedures were adopted in the current studies, the within-group differences in age range and intellectual ability necessitated some variation in task difficulty within the linguistic comprehension conditions. Therefore, the degree of explicitness with which the target event described in the sentence was primed in the wording of the test questions was manipulated over stimulus items. Inspection of the distribution of correct responses for the autism group showed that they were not advantaged in explicit priming trials, resulting in similar levels of performance across explicit and implicit stimulus items. It is unlikely, given that overall correct performance levels were 63–75%, that these findings reflect a failure to understand the task. Instead, the results confirm sentence comprehension difficulties widely described in autism (e.g. Jolliffe &

Baron-Cohen, 1999, 2000; Norbury & Bishop, 2002). Such difficulties have even been observed in tasks assessing local coherence, here defined as information that is in short-term or working memory at the same time (one to three sentences) (e.g. Jolliffe & Baron-Cohen, 1999). Indeed, the comprehension task in the current study assessed the ability to process linguistic context so as to achieve local coherence. As previous studies have shown that task instructions can significantly influence the manner in which participants with autism respond to presented stimuli (Happé, 1994; Snowling & Frith, 1986; Plaisted, Swettenham & Rees, 1999), children were explicitly instructed to focus upon either the perceptual or the semantic level in the various conditions in Experiments 1 and 2. While training criteria were included in the perceptual conditions, this was not the case for the linguistic comprehension conditions, and this may have disadvantaged the children with autism. However, given that the results from the linguistic comprehension conditions are consistent with a large body of research (e.g. Happé, 1997; Jolliffe & Baron-Cohen, 1999; Norbury & Bishop, 2002), it seems likely that any such effects would be minimal.

Two hypotheses, derived from the WCC and EPF theories, respectively, were outlined in the introduction. The current pattern of results is consistent with the WCC theory (e.g. Happé & Frith, 2006) insofar as in Experiment 2, the controls, unlike those with autism, exhibited deterioration in perceptual performance with semantically meaningful stimuli, while no between-group differences were evident in the non-linguistic perceptual condition. Thus, the WCC account does not predict enhanced perceptual processing in autism *per se*, but rather, it predicts better performance in contexts where those without autism process stimuli at higher levels. This then suggests that WCC in autism contributes to such individuals' higher-level language processing difficulties.

The current pattern of results is also consistent with the EPF theory (Mottron & Burack, 2001; Mottron *et al.*, 2006) insofar as in Experiment 1, participants with autism exhibited superior perceptual performance over their controls with both the speech and music stimuli. However, the finding showing poorer sentence comprehension in the autism group fails to support this theory, as higher-level functions are assumed to be unimpaired. Indeed, according to this theory, higher-order control over perception is proposed to be flexible and non-mandatory in autism. In contrast, cognition in typical development is characterized by mandatory higher-order control, even when it is detrimental for performance.

Taken together, the findings showed superior perceptual processing of speech in individuals with autism relative to age- and intelligence-matched controls. The results also suggest that for them, semantic-level processing is not the primary, or 'default', speech-processing mode. These findings are largely consistent with the WCC and EPF theories. However, one unexpected and interesting finding that cannot be explained by these theories was that controls responded differentially to the type of perceptual information (pitch variations/temporal patterning) in the conditions comprising meaningful speech. Linguistic pitch or intonation is an extremely significant prosodic cue (Lieberman, 1960), and the perceptual stimuli included in Experiment 1 corresponded to speech intonation. It may then be the case that for controls, pitch contour information in speech has increased salience, and is more 'independent' of the semantic context than temporal information, which is less significant prosodically (Experiment 2). Such different effects across perceptual conditions were not seen in the responses of the autism group, for whom both types of perceptual information appeared to be similarly salient.

In the previous study by Schreibman *et al.* (1986), children with autism exhibited atypically narrow attentional focus when processing speech. For example, children with echolalia tended to respond selectively to the intonation component of complex speech stimuli, while non-verbal children tended to selectively respond to the content component. The typically developing controls showed either selective responding to the content, or no selective responding to either intonation or content components. Given that children were tested on both perceptual and content components in Experiments 1 and 2, the pattern of findings from the autism group may reflect overly selective attention towards a limited number of available cues in speech. By contrast, the response pattern of the controls may reflect increased attention to content information, resulting in poorer perceptual than comprehension performance. Attention to multiple cues might limit the processing capacity/resources available under some conditions, for example, the type of temporal analysis required in Experiment 2.

In conclusion, findings showing atypical perceptual processing of speech in autism are particularly important when considered within the context of well-documented impairments in prosodic processing and sentence comprehension (e.g. Jolliffe & Baron-Cohen, 1999; McCann & Peppé, 2003). While overly focused selective attention towards auditory-perceptual cues may have a limited influence upon the processing of musical and other auditory information, the effects of such a tendency upon linguistic information processing may well be far-reaching (see Schreibman *et al.*, 1986). Indeed, the current pattern of results suggests that overly focused auditory processing of speech in autism may contribute to the undercutting of higher-level language skills. However, the current findings highlight the need for the development and testing of experimental paradigms, in which the perceptual/semantic dimensions are manipulated independently. In addition, future studies should elucidate interpretations of the current data by, for example, varying the level of semantic complexity in the stimuli more widely, and measuring the effects upon perceptual response scores. An experimental paradigm in which the response mode, training, and instructions were carefully equated across the perceptual and linguistic tasks would illuminate the relationship between these abilities without conflicting meta-cognitive demands.

Appendix

Experiment 1

Intact speech stimuli	Linguistic test questions
Rising contour	
(1) I like eggs and ham.	What does the lady like to eat?
(2) What a nice red hat.	What color does the lady like?
(3) Reading books is fun.	How can we learn about exciting stories?
(4) Let's go for a swim.	What does the lady like to do for exercise?
Falling contour	
(5) Cellars can be dark.	What is it like in a window-less basement?
(6) Let's go down the stairs.	Why might the lift be broken in the lady's house?
(7) All my pens are blue.	What color ink does the lady like to use?
(8) Winter is so cold.	At what time of the year is it freezing outside?
Low-high-low contour	
(9) Sue will hate that cat.	Which animals can't Sue stand?
(10) What a noisy dog.	What kind of pet did the lady see?
(11) It's so hot in here.	Why might the lady like to freshen up?
(12) Out we go for lunch.	What is the lady going to do?
High-low-high contour	
(13) Racing-bikes go fast.	What can you ride to travel quickly?
(14) Flowers on your hat.	Tell me what the lady's friend wears.
(15) Eating sweets is bad.	What kind of food damages your teeth?
(16) Tom loves eating chips.	What is Tom's favorite food?

Acceptable correct answers (for 1 point)

1) eggs and ham/egg(s)/ham/egg/ham-based variants
2) red/any color describing a shade of red
3) by reading/reading/from books/books
4) swim/go swimming
5) dark/black
6) because she takes the stairs/she uses the stairs/stairs
7) blue/color describing a shade of blue
8) in winter/winter/name of any winter month/Christmas
9) cat(s)/feline(s)
10) noisy dog/dog/doggy/canine
11) she's hot/it's hot/it's summer
12) go out for lunch/go out/go for lunch/have lunch
13) a racing bike/bike
14) a hat/a hat with a flower on it
15) sweets/sweet/sweet food/any brand name for candy
16) chips/potato chips/potatoes/any potato-based food

Experiment 2

Intact speech stimuli	Linguistic test questions
Temporal sound pattern 1	
(1) We eat chips for lunch.	What food does the lady have for her midday meal?
(2) I will go to Wales.	Where is the lady traveling for her holiday?
(3) All Tim's pens are blue.	What is Tim's favorite color?
(4) Let's go for a walk.	What does the lady like to do for exercise?

Temporal sound pattern 2	
(5) Stella often dances.	Name one of Stella's hobbies.
(6) Poppy's learning English.	Which language is Poppy hoping to speak well, soon?
(7) Katie gathers conkers.	What game does Katie like playing?
(8) Jamie's eating peanuts.	What food did Jamie find in the kitchen?
Temporal sound pattern 3	
(9) My auntie likes yellow.	What is the lady's relative's favorite color?
(10) Jo sometimes writes letters.	How does Jo keep in touch with her friends?
(11) Sue always feels lonely.	How do you know that Sue doesn't have many friends?
(12) Your lessons are over.	What are finished at the end of the school day?
Temporal sound pattern 4	
(13) Emily likes her lollipop.	What kind of sweets does Emily love?
(14) Jonathan has a caravan.	Where does Jonathan like to sleep when he's traveling?
(15) Annabel is from Italy.	Which country does Annabel's family come from?
(16) Saturday's lunch was excellent.	Which meal did the lady really enjoy on the weekend?

Acceptable correct answers (for 1 point)

1) chips/potato chips/potatoes/any answer incorporating the word 'potato'
2) Wales/any city, town or place name in Wales
3) blue/any shade of blue
4) walk/go for a walk/walking
5) dance/dancing/variants (salsa, tango, etc.)
6) English
7) conkers
8) peanuts/nuts
9) yellow/any shade of yellow
10) she writes letters/letters/writing
11) she feels/is lonely
12) lessons
13) lollipop(s)/any brand name for a lollipop
14) (in his/a) caravan
15) Italy/Italian/She's/they're Italian
16) lunch

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