DOI: 10.1093/brain/awg274 Advanced Access publication August 22, 2003 *Brain* (2003), **126,** 2703–2709

Absence of auditory 'global interference' in autism

Jessica M. Foxton,[1] Mary E. Stewart,[3] Louise Barnard,[1] Jacqui Rodgers,[1] Allan H. Young,[1] Gregory O'Brien[2] and Timothy D. Griffiths[1]

[1]*University of Newcastle upon Tyne,* [2]*Northumbria University, Newcastle upon Tyne, UK and* [3]*Department of Psychiatry, Royal Edinburgh Hospital, Edinburgh*

Correspondence to: Jessica Foxton, Auditory Group, School of Neurology, Neurobiology and Psychiatry, University of Newcastle, Framlington Place, Newcastle NE2 4HH, UK
E-mail: j.m.foxton@ncl.ac.uk

Summary

There has been considerable recent interest in the cognitive style of individuals with Autism Spectrum Disorder (ASD). One theory, that of weak central coherence, concerns an inability to combine stimulus details into a coherent whole. Here we test this theory in the case of sound patterns, using a new definition of the details (local structure) and the coherent whole (global structure). Thirteen individuals with a diagnosis of autism or Asperger's syndrome and 15 control participants were administered auditory tests, where they were required to match local pitch direction changes between two auditory sequences. When the other local features of the sequence pairs were altered (the actual pitches and relative time points of pitch direction change), the control participants obtained lower scores compared with when these details were left unchanged. This can be attributed to interference from the global structure, defined as the combination of the local auditory details. In contrast, the participants with ASD did not obtain lower scores in the presence of such mismatches. This was attributed to the absence of interference from an auditory coherent whole. The results are consistent with the presence of abnormal interactions between local and global auditory perception in ASD.

Keywords: audition; autism; contour; pitch; weak central coherence

Abbreviations: ASD = Autism Spectrum Disorder; WAIS-III = Wechsler Adult Intelligence Scale—third edition; WCC = weak central coherence

Introduction

Autism Spectrum Disorder (ASD) is characterized by a distinctive pattern of impairments in social interaction, communication and imagination, and is accompanied by restricted, repetitive interests and behavioural patterns. Much interest has recently been devoted to cognitive models that attempt to explain the wide array of symptoms present in the disorder. These have included accounts that attribute the primary cause to social impairments (Hobson, 1993; Baron-Cohen, 1995) and deficits in executive functioning (Harris, 1993; Ozonoff, 1995).

An appealing recent approach has been to focus not on the impairments present in ASD, but rather on the islets of ability that remain. These abilities typically include detailed, focused perceptual processing. It has been proposed that these intact abilities relate to a style of cognitive processing termed 'weak central coherence' (WCC) (Frith and Happe, 1994). This cognitive style is proposed to result in a weakening of the tendency to perceptually integrate sensory stimuli into a 'gestalt' or 'perceptual whole', while the ability to focus on stimulus details is preserved or even enhanced. This theory is able to account for superior performance by ASD subjects on a number of tests. For instance, participants with ASD perform superiorly on the Embedded Figures Test, which requires the identification of a component shape that is 'camouflaged' by integration into a wider pattern or picture. As the presence of WCC in these subjects would be expected to weaken the integration of these component shapes into the wider pattern, this theory correctly predicts superior performance in these subjects (Shah and Frith, 1983; Jolliffe and Baron-Cohen, 1997).

The WCC theory of autism predicts that these perceptual abnormalities should be apparent in all modalities. However, while the presence of WCC is well established in the visual domain, this is not the case for auditory perception. Happe (1999) has cited the high incidence of perfect pitch (the ability to label isolated musical notes) in ASD (Heaton *et al*., 1998) as evidence for WCC in auditory perception. Similarly, Heaton *et al*. (1999) have argued that exceptional musical abilities that are present in rare ASD individuals relate to WCC. However, this inference is not clear-cut, as case studies

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

	Age (years)	Sex	Mean hearing level (dB HL)	Music training (years)	FSIQ	VIQ	PIQ
ASD group (n = 13)	18.1 (2.0)	11 M; 2 F	15.8 (9.5)	2.6 (3.1)	87.9 (10.9)	92.5 (14.5)	83.9 (8.1)
Comparison group (n = 15)	17.7 (2.2)	13 M; 2 F	11.3 (6.1)	2.4 (2.6)	89.1 (10.0)	91.2 (10.9)	88.0 (10.7)

FSIQ = full-scale IQ; VIQ = verbal IQ; PIQ = performance IQ; M = male; F = female.

of musically gifted individuals with ASD have failed to reveal deficits in central coherence on standard tasks (Mottron *et al*., 1999; Heaton *et al*., 1999). Furthermore, these enhanced musical abilities are the exception rather than the rule in ASD, and so the results cannot be generalized to auditory processing in the majority of individuals with ASD.

A number of previous studies have attempted to identify the presence of WCC in the auditory domain in ASD, employing subjects who were not selected for musical talent (Heaton *et al*., 1999; Mottron *et al*., 2000). These studies used short melodies and described the actual pitches present in the tunes as the 'local' feature, and the pattern of rises and falls in pitch (the pitch contour) as the 'global' feature, or auditory 'gestalt'. These studies argued that WCC would result in a tendency to focus on the 'local' pitch details at the expense of extracting the 'global' pitch contour pattern. However, this was not found. None of the studies reported inferior perception of the 'global' pitch contour in subjects with ASD (Heaton *et al*., 1999; Mottron *et al*., 2000), although Mottron *et al*. did observe superior 'local' representations.

However, it is questionable whether pitch contour perception represents a 'global' level of auditory perception. Previous studies that endorsed this model considered pitch contour to be a 'global' feature, as it represents a large-scale structure that embeds smaller scale auditory features, such as absolute pitches and interval sizes (Dowling, 1978; Peretz, 1990). However, by definition, pitch contour consists of a succession of simple ascending and descending pitch directions. These representations of pitch direction can be regarded as 'local' features and must simply be added together to obtain the large-scale contour representations. This process does not therefore require the involvement of a higher level of perceptual organization where the whole is greater than the sum of the parts, a characteristic that defines true 'global' perception.

In this study we define pitch contour features, such as changes in pitch direction, as 'local' auditory features, rather than 'global' features. This is in line with work by Dyson and Watkins (1984), who presented evidence that pitch contour reversals are perceived in an analogous manner to simple 'local' features in the visual domain, specifically the angles or points of intersection of a figure. We propose a new definition of the 'global' feature in the context of melodies, where the 'local' auditory features are integrated to form a 'gestalt' percept or 'coherent whole'. Specifically, we propose that 'local' pitch contour features, such as pitch direction changes, are perceived in association with other 'local' auditory features, such as the absolute pitch values and the exact time points of these changes, to form an auditory 'gestalt'. We are therefore defining 'global' in an entirely different manner from the previous reports, and we would argue that our definition is closer to that used in studies of WCC in the visual domain. In the rest of this report, the term 'global' is consistently used to refer to the combination of contour and absolute pitch values.

In this study we assess the presence of WCC in the auditory domain within the framework of this model. We employ a novel auditory task, which assesses whether the perception of a 'local' auditory feature (pitch direction change) is susceptible to interference from the auditory 'coherent whole'. The tasks require pitch direction change matching between two pitch sequences, which are either matched in terms of the relative time points of change and the actual pitches (no interference condition), matched in terms of the time points of change but not the actual pitches (local pitch interference), or mismatched in terms of both the relative time points of change and the actual pitches (local pitch and timing interference). Any deterioration in task performance in the latter two conditions reflects interference from the auditory stimulus 'coherent whole'. Normal control subjects are therefore expected to exhibit worse performance in these interference conditions as a result of central coherence; a preference for processing the auditory coherent whole. In contrast, it is proposed that WCC in those with ASD will weaken the perception of the auditory 'coherent whole', and that this will lead to superior performance in these subjects in comparison to control subjects.

Patients and methods

Subjects

Twenty-eight subjects were recruited in total. Thirteen students were recruited from a specialized college for those with ASD. All of these subjects underwent a semi-structured psychiatric interview and 11 were thus ascertained to satisfy DSM-IV (Diagnostic and Statistical Manual of Mental Disorders—Edition IV) criteria for Asperger's syndrome and two for autistic disorders (American Psychiatric Association, 1994). The two students who met DSM-IV criteria for autistic disorder differed from the Asperger's

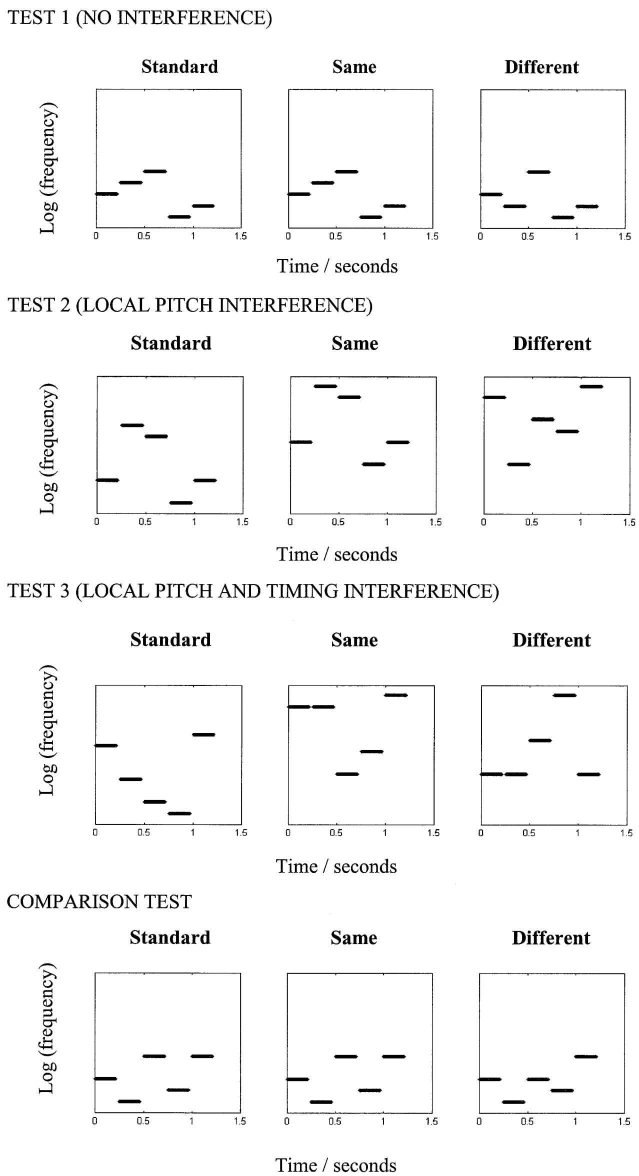

Fig. 1 Examples of the auditory tests. The standard sequence represents the first pitch sequence presented to participants. The 'same' sequence is the second sequence presented when the correct response is 'same'; the 'different' sequence is the second sequence presented when the correct response is 'different'.

syndrome group in one respect only: both had a lifelong history of delay in the use of language for social communication. All 13 members of the group can be described under the umbrella term ASD (Gillberg, 2002). Fifteen control subjects were recruited from a local college for further education. None of the control subjects had been diagnosed with autistic disorder or Asperger's syndrome, and none reported a family history of either disorder. For both groups, none of the subjects had a history of epilepsy or any other neurological disorder, and none reported having 'perfect pitch' (the ability to verbally label isolated pitches taken from the musical scale).

All our methods conformed to the Declaration of Helsinki, with respect to the treatment of human subjects. All subjects gave informed consent and ethical approval was obtained from the Ethics Committee of the University of Newcastle upon Tyne, and from the Ethics Committee of the college from which the experimental subjects were recruited.

Table 1 describes the characteristics of the two groups. The groups did not differ significantly in terms of age, amount of music training, hearing level (mean of pure tone thresholds obtained at octave intervals between 250 and 8000 Hz) or the Full Scale, Verbal and Performance IQ indices from the Wechsler Adult Intelligence Scale—third edition (WAIS-III) (t tests were not significant at the $P < 0.05$ level).

Auditory tests

The auditory tests were all same–different decision tests. The stimuli were pairs of five-note pitch sequences separated by 1-s gaps. For all of the tests, the pitches were taken from an octave split into seven equally spaced 'notes' on a logarithmic scale. The notes were all pure tones of 250 ms duration (smoothed with 20 ms gating windows) and the lowest pitch in each sequence was randomized to one of five values: 250, 268, 287, 308 or 330 Hz. Each test was administered in two runs out of 20, with 40 different sequence pairs presented for each condition. Before each test section, the task was described and six practice examples were administered with immediate feedback and repetitions when necessary. See Fig. 1 for examples of each of the auditory tests.

Test 1 (no interference)

For this test, the 'same' sequences were exactly the same. For the 'different' sequences, one of the notes was changed by a magnitude of two 'notes', and this violated the pattern of rises and falls in pitch. The position of this note was randomized, but always avoided the first and last notes. Subjects were instructed to decide whether the tunes were the same or different. They were told that they would be able to detect differences between the tunes by listening to the pattern of rises and falls.

Test 2 (local pitch interference)

For this test, the second sequence of each pair was always transposed up in pitch by half an octave. For the 'same' sequences, this was an exact transposition of the sequence. Therefore the pattern of rises and falls in pitch was maintained. For 'different' sequences the pattern of rises and falls from note to note was different. Participants were instructed to listen to the pattern of rises and falls in the tunes and to decide whether these were the same or different.

Table 2 *Percentage correct scores on the auditory tests (SEs in parentheses)*

	ASD group	Comparison group
Test 1 (no interference)	73.1 (4.5)	79.7 (3.3)
Test 2 (local pitch interference)	69.6 (5.1)	69.0 (3.6)
Test 3 (local pitch and timing interference)	63.3 (4.0)	55.3 (2.6)
Comparison test	67.9 (3.1)	68.0 (3.8)

Test 3 (local pitch and timing interference)

For this test each sequence had one of two possible contour patterns: a rise followed by a fall in pitch, or a fall followed by a rise in pitch. In other words, each sequence contained just one change in pitch direction, but this could go either way. For the 'same' sequence pairs, the contour patterns were the same, but the exact points of the rises and falls in pitch differed between the two sequences. For example, the pitch directions in the first sequence might follow the series 'up-down-down-down', while for the second sequence the pitch directions might follow the series 'up-up-up-down'. So both sequences rise and then fall in pitch, although the relative time points of these changes do not match. For the 'different' sequences the contour patterns were different. In other words, one sequence rose and then fell in pitch and the other sequence fell and then rose in pitch. For all test items, the second sequence was transposed up in pitch by half an octave. Subjects were instructed to listen to the pattern of rises and falls in the tunes and to decide whether these were the same or different. They were informed that there would be just two types of pattern: one where the pattern would go up and then down, and another where the pattern would go down and then up.

These three tests were administered in the order: Test 3, Test 2 then Test 1. Test 3 was administered first in order to prevent subjects developing a task strategy based on the absolute pitch values or time points of change.

Comparison test

This test was identical to Test 1, but the note changes did not violate the pattern of rises and falls in pitch. As for Test 1, the note changes were two notes in magnitude, and could occur at any position apart from the first and the last notes. For this test, participants were instructed to decide whether the tunes were the same or different. They were told that the pattern of rises and falls would not change. The inclusion of this test allowed comparison with previous studies that assessed WCC in the auditory domain in autism, through assessing the perception of pitch sequence differences that either violated the pitch contour, or left this unaltered (e.g. Mottron *et al.*, 2000).

Procedure

The tests were conducted in quiet rooms at the colleges. The stimuli were created digitally at a sample rate of 44.1 kHz and

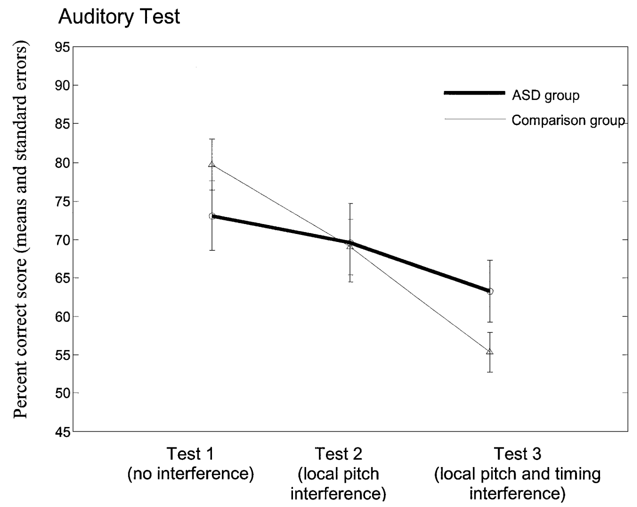

Fig. 2 Performance on the three pitch direction change tests. Mean data for the two groups. Error bars correspond to SEs.

were presented to subjects through Sennheiser HD 265 headphones (Sennheiser, Wedemark, Germany) at 80 dB sound pressure level (SPL). Subjects were given a button box, and were required to press buttons labelled 'same' and 'different' for their responses. After each response, four lights would come on to provide feedback. Flashing lights signalled a correct response, and static lights signalled an incorrect response. This feedback lasted 1 s and was followed by a further 1-s gap before presentation of the next pair of sequences. This feedback was provided for both the practice and the test runs.

Pure tone audiograms were obtained at the end of the session. The WAIS-III was administered in a separate session, always on a different day.

Results

Table 2 shows the scores for the auditory tests plotted in Fig. 2. Kolmogorov–Smirnov Z tests revealed that the distribution of scores did not depart from normality ($P < 0.05$ level).

There were no significant differences between the first and second runs of each test for either group (t tests, $P > 0.05$ in all cases). Therefore the performance feedback was not seen to improve performance on any of the tests in these subjects.

A repeated measures analysis of variance (ANOVA) was run to assess the presence of WCC in the perception of pitch direction change patterns. WCC theory predicts differences in the effect of global interference on the task, which would be manifest as a group by task interaction. The auditory task (Test 1, 2 or 3) was the within-subjects variable, and the subject group was the between-subjects variable. There was no main effect of Group [$F(1,26) = 0.02$, $P > 0.05$], but there was a main effect of Task [$F(2,52) = 24.9$, $P < 0.001$]. A significant Group by Task interaction was demonstrated

[$F(2,52) = 4.5$, $P < 0.05$] (see Fig. 2). *Post hoc t* tests revealed that for the two groups combined, Test 3 scores were significantly lower than Test 2 scores, and that Test 2 scores were significantly lower than Test 1 scores ($P < 0.01$ for both comparisons with Bonferroni correction). Further *post hoc* analyses revealed that the main effect of Task was present for the control group [$F(2,28) = 31.3$, $P < 0.01$], but not for the ASD group (although there was a trend in this direction); [$F(2,24) = 3.38$, $P < 0.1$]. This demonstrates that the differences in task performance only apply to the control group subjects. Additional *post hoc* analyses showed that there were no significant group differences for scores on any of the auditory tests (Bonferroni *t* tests; $P > 0.05$). However, the experimental hypothesis predicts that the ASD group should perform superiorly on Test 3 as a result of reduced 'global' interference. Therefore, a one-tailed *t* test was carried out to assess group differences in performance on this test. This showed that the difference between the groups marginally failed to reach significance at the 0.05 level [$t(26) = 1.69$, $P = 0.052$].

In order to enable comparison with previous studies that assessed WCC in the auditory domain in ASD, scores on the comparison test (previously labelled 'local') and Test 1 (previously labelled 'global') were analysed. A repeated measures ANOVA was run with the task (Test 1 or comparison test) as the within-subjects variable, and the subject group as the between-subjects variable. There was a main effect of Task [$F(1,26) = 20.07$, $P < 0.01$], but no main effect of Group [$F(1,26) < 1$], and no significant interaction [$F(1,26) = 2.96$, $P > 0.05$]. Superior performance on Test 1, called a 'global advantage' in other studies, was therefore demonstrated, and was not found to differ significantly between the groups. These results replicate the previous studies that failed to support the presence of WCC in the auditory domain.

One previous study demonstrated 'local' superiority in subjects with ASD (Mottron *et al*., 2000). An additional one-tailed *t* test was therefore carried out to investigate whether differences could be identified between the two groups on this test (the comparison test). This additional analysis did not reveal a significant group difference [$t(26) = –0.02$, $P = 0.49$].

Discussion

This study investigated whether WCC could be identified in the auditory domain in ASD. Tests were administered that required the comparison of pitch direction changes ('local' level) when the sequence pairs were either matched or mismatched in terms of other 'local' features: the absolute pitches and the relative time points of change. It was hypothesized that a 'gestalt' percept of the pitch direction changes in association with the absolute pitches and relative time points would result in performance deterioration in the presence of the mismatches ('global' interference). The results demonstrate the presence of such performance deterioration in the control participants, in line with the presence of interference from the auditory sequence 'coherent whole'. The pattern of results suggests that there is an additive effect of each local feature mismatch on the magnitude of the interference produced. Specifically, with one interfering feature of local pitch, the scores were significantly lower than those obtained in the absence of an interfering feature, while with two interfering features (local pitch and timing), the scores were in turn significantly lower than with one interfering feature. In contrast to this pattern, the participants with ASD did not exhibit performance deterioration in the presence of such mismatches. This suggests that they were not susceptible to interference from an auditory 'coherent whole'. This is in accordance with the presence of WCC in the auditory domain in these subjects. These results parallel findings in the visual domain, where it is found that subjects with ASD are not affected by interfering visual gestalts to the same extent as control subjects (Shah and Frith, 1983; Jolliffe and Baron-Cohen, 1997).

Previous studies examining WCC in the auditory domain assessed the ability to detect differences between pitch sequences that violate the absolute pitch values or the pitch-direction change patterns (Heaton *et al*., 1999; Mottron *et al*., 2000). It was proposed that WCC would result in superiority in the perception of the absolute pitch values, and a deficit in the perception of the pitch direction change patterns. These studies failed to demonstrate this result in groups of subjects with autism, a finding that was replicated in the present study.

We suggest a model where pitch-direction changes are perceived in association with absolute pitch and time values as a 'coherent whole' in normal subjects. This represents the 'global' level of perception that will be impaired as a result of WCC. The results of the study support this model, as the lack of interference in ASD participants is consistent with there being no 'coherent whole' representation.

However, it should be noted that the results of the study could also be interpreted within the framework of another, similar theory of autism, namely the hierarchization deficit hypothesis (Mottron and Belleville, 1993). This hypothesis states that the perception of both 'global' and 'local' forms is normal in ASD, but that the perceptual interactions between them are abnormal. This theory can account for the results of this study, as it could be argued that the perception of the auditory 'coherent whole' is normal in the subjects with ASD, but that this 'global' form does not interfere with perception of the isolated pitch direction changes. In other words, the participants with ASD would be able to perceive the pitch direction changes in association with the absolute pitches and time values, but this 'gestalt' representation would not interfere with the perception of isolated 'local' features.

An additional theory, proposed by Plaisted *et al*. (2003), could also account for the results of the study. This theory states that there is superior sensory processing in ASD, which results in enhanced detection of simple perceptual features, with no effect on the processing of 'global' configurations of features. This hypothesis is in line with the Enhanced Perceptual Processing Model (Mottron and Burack, 2001), which states that low-level information processing systems for sensory stimuli are overdeveloped in autism. In the current study it could be argued that the group by test interaction results from enhanced perception of the pitch direction change 'feature' in the ASD group. In support of this, the ASD group performed superiorly on Test 3 (pitch and timing interference), which can only be performed through detection of the pitch direction change 'feature' (although this superiority just failed to reach statistical significance). The lack of superiority on Test 1 (no interference) could be attributed to the fact that a 'global' conjunction of auditory features (absolute pitch, timing and pitch direction change features) could be used in task performance. The ASD group can therefore be seen to show superior performance on a single feature task, but not on a 'global' conjunction task, in line with the theory of Plaisted *et al*. (2003).

It is of much interest to consider whether this possible form of auditory 'enhanced perceptual processing' might parallel findings in the visual domain. One recent study, carried out by Plaisted *et al*. (2003), assessed performance on tasks that required the processing of individual visual features or conjunctions of visual features. In comparison with age- and IQ-matched controls, it was found that children with autism were superior in learning to associate responses with individual visual features, but not in learning to associate responses with particular conjunctions of visual features. This result suggests that children with autism are superior in processing individual visual features, but not in processing 'global' conjunctions of visual features. This result can be seen to parallel the current study, and therefore suggests that equivalent deficits might be present in both the auditory and visual domains in ASD. However, it is important to note that the tasks employed in the study by Plaisted *et al*. (2003) are very different to the simple 'same or different' decision tasks employed in the current study, and so direct comparisons cannot be made. In the future, it will be of considerable interest to investigate performance on equivalent tasks in the two domains in order to be able to draw more accurate conclusions about processing parallels between different modalities.

The current study did not demonstrate superiority in the perception of 'local' pitch changes (comparison test) in the ASD group. This could be taken as evidence against the Enhanced Perceptual Processing Model of ASD, which predicts superior pitch perception. However, it is possible that superiority in the perception of such pitch changes is only evident when investigating the perception of fine-grained pitch differences. In support of this, studies have observed superior fine-grained pitch discrimination in participants with autism (Heaton *et al*., 1999; Bonnel *et al*., 2003), and one study demonstrated that this is no longer apparent when the pitch differences are increased (Heaton *et al*., 1999). The present study employed relatively large pitch differences between the notes that exceed the smallest semitone pitch changes that occur in western music. It is therefore possible that superior performance on the comparison test would have been observed in the ASD group if smaller pitch differences had been employed. This remains to be tested in future studies.

Whatever the basis for the effects observed, the results demonstrate that auditory processing systems operate differently in individuals with ASD. In accordance with this, abnormalities at different levels in the auditory pathway have been suggested to occur in ASD, from the cochlea (Plaisted *et al*., 2003) to the cortex (Gomot *et al*., 2002). For instance, a psychophysical study by Plaisted *et al*. (2003) suggested that the frequency selectivity of neurons at the level of the cochlea is poorer in individuals with ASD than in control participants. At the cortical level, it has been found that cells in the auditory association areas in the temporal lobe are more densely packed and are abnormally organized in ASD (Casanova *et al*., 2002). In addition, SPECT (single photon emission computed tomography) studies have demonstrated that there is reduced cerebral blood flow to the temporal lobes in individuals with ASD (George *et al*., 1992; Gillberg *et al*., 1993), and ERP (event-related potential) studies have identified abnormalities in electrical potentials evoked in response to auditory stimuli (Gomot *et al*., 2002). The present study has demonstrated changes in auditory processing at the level of patterns of discrete pitches. Although further work is required to define the neural substrate for the abnormality, pitch-pattern analysis in normal subjects involves networks of superior temporal lobe areas distinct from the primary auditory cortices (Patterson *et al*., 2002). This therefore represents a possible locus for the effects observed in this study.

In conclusion, the results are consistent with the presence of abnormal interactions between 'local' and 'global' auditory perception in ASD. To our knowledge, this is the first demonstration of such a processing abnormality in the auditory domain in this disorder.

Acknowledgements

We wish to thank the lecturers at the colleges involved for allowing us to conduct this research, and to the students for their involvement in the study. We also thank Reem Hasan and Remy Marckus for their help in conducting this research. This work was supported by the Wellcome Trust and a grant from Northgate and Prudhoe NHS Trust.

References

American Psychiatric Association. Diagnostic and statistical manual of mental disorders: DSM-IV. 4th ed. Washington (DC): American Psychiatric Association; 1994.

Baron-Cohen S. Mindblindness: an essay on autism and theory of mind. Cambridge (MA): MIT Press; 1995.

Bonnel A, Mottron L, Peretz I, Trudel M, Gallun E, Bonnel AM. Enhanced pitch sensitivity in individuals with autism: a signal detection analysis. J Cogn Neurosci 2003; 15: 226–35.

Casanova MF, Buxhoeveden DP, Switala AE, Roy E. Minicolumnar pathology in autism. Neurology 2002; 58: 428–32.

Dowling WJ. Scale and contour: two components of a theory of memory for melodies. Psychol Rev 1978; 85: 341–54.

Dyson MC, Watkins AJ. A figural approach to the role of melodic contour in melody recognition. Percept Psychophys 1984; 35: 477–88.

Frith U, Happe F. Autism: beyond 'theory of mind'. Cognition 1994; 50: 115–32.

George MS, Costa DC, Kouris K, Ring HA, Ell PJ. Cerebral blood-flow abnormalities in adults with infantile autism. J Nerv Ment Dis 1992; 180: 413–7.

Gillberg C. A guide to Asperger syndrome. Cambridge: Cambridge University Press; 2002.

Gillberg IC, Bjure J, Uvebrant P, Vestergren E, Gillberg C. SPECT in thirty-one children and adolescents with autism and autistic-like conditions. Eur Child Adolesc Psychiatry 1993; 2: 50–9.

Gomot M, Giard MH, Adrien JL, Barthelemy C, Bruneau N. Hypersensitivity to acoustic change in children with autism: electrophysiological evidence of left frontal cortex dysfunctioning. Psychophysiology 2002; 39: 577–84.

Happe F. Autism: cognitive deficit or cognitive style? Trends Cogn Sci 1999; 3: 216–22.

Harris P. Pretending and planning. In: Baron-Cohen S, Tager-Flusberg H, Cohen DJ, editors. Understanding other minds: perspectives from autism. Oxford: Oxford University Press; 1993. pp. 228–46.

Heaton P, Hermelin B, Pring L. Autism and pitch processing: a precursor for savant musical ability? Music Perception 1998; 15: 291–305.

Heaton P, Pring L, Hermelin B. A pseudo-savant: a case of exceptional musical splinter skills. Neurocase 1999; 5: 503–9.

Hobson RPR. Autism and the development of mind. Hove (UK): Lawrence Erlbaum; 1993.

Jolliffe T, Baron-Cohen S. Are people with autism and Asperger syndrome faster than normal on the Embedded Figures Test? J Child Psychol Psychiatry 1997; 38: 527–34.

Mottron L, Belleville S. A study of perceptual analysis in a high-level autistic subject with exceptional graphic abilities. Brain Cogn 1993; 23: 279–309.

Mottron L, Peretz I, Belleville S, Rouleau N. Absolute pitch in autism: a case study. Neurocase 1999; 5: 485–501.

Mottron L, Peretz I, Menard E. Local and global processing of music in high-functioning persons with autism: beyond central coherence? J Child Psychol Psychiatry 2000; 41: 1057–65.

Mottron L, Burack J. Enhanced perceptual functioning in the development of persons with with autism. In: Burack JA, Charman T, Yirmiya N, Zelazo PR, editors. The development of autism: perspectives from theory and research. Mahwah (NJ): Erlbaum; 2001. p. 131–48.

Ozonoff S. Executive functions in autism. In: Schopler E, Mesibov GB, editors. Learning and cognition in autism. New York: Plenum Press; 1995. pp. 199–219.

Patterson RD, Uppenkamp S, Johnsrude IS, Griffiths TD. The processing of temporal pitch and melody information in auditory cortex. Neuron 2002; 36: 767–76.

Peretz I. Processing of local and global musical information by unilateral brain-damaged patients. Brain 1990; 113: 1185–205.

Plaisted K, Saksida L, Alcantara J, Weisblatt E. Towards an understanding of the mechanisms of weak central coherence effects: experiments in visual configural learning and auditory perception. Philos Trans R Soc Lond B Biol Sci 2003; 358: 375–86.

Shah A, Frith U. An islet of ability in autistic children: a research note. J Child Psychol Psychiatry 1983; 24: 613–20.

Wechsler D. Wechsler Adult Intelligence Scale. 3rd ed. San Antonio (TX): Psychological Corporation; 1997.

Received April 4, 2003. Revised May 29, 2003.
Second revision June 23, 2003. Accepted June 26, 2003