J Autism Dev Disord (2006) 36:665–675
DOI 10.1007/s10803-006-0106-1

ORIGINAL PAPER

Discrimination in Autism Within Different Sensory Modalities

Michelle O'Riordan · Filippo Passetti

Abstract Recent studies have suggested that unusual visual processing in autism might stem from enhanced visual discrimination. Although there are also many anecdotal reports of auditory and tactile processing disturbances in autism these have received comparatively little attention. It is possible that the enhanced discrimination ability in vision in autism might extend to other modalities and further that they may underlie many reports of unusual touch and audition. The present study investigated the performance of children with and without autism on auditory and tactile discrimination tasks and revealed superior auditory but comparable tactile discrimination in autism relative to controls. These results extend previous findings of perceptual discrimination in autism and may be relevant for a neuro-developmental hypothesis of the disorder.

Keywords Autism · Discrimination · Auditory · Tactile

Autism is diagnosed on the basis of impairments in social behaviour, deficits in communication, and the presence of repetitive behaviour (APA, 1994). However, these are not the only characteristics of the disorder and other phenomena, such as disturbed processing of incoming stimuli, have also long been associated with autism (Kanner, 1943). Reports of stimulus processing abnormalities in autism extend across all sensory modalities. Reports of unusual visual processing in autism include the focus on certain stimuli to the exclusion of others (Bryson, Wainwright-Sharpe, & Smith, 1990) and an extraordinary ability to notice minor features and changes in the environment (Hayes, 1987; NASC, 1978). Children with autism are also reported to be hypersensitive[1] to particular noises that are neither intrinsically threatening nor uncomfortably loud to a typical individual (Bettison, 1996; Grandin, 1997; O'Neill & Jones, 1997; Rosenhall, Nordin, Sandstrom, Ahlsen, & Gillberg, 1999) and, in the tactile modality, parents frequently report their autistic child's excessive fascination with certain textures, such as the continual rubbing of a particular material (i.e. proprioceptive seeking behaviour; Baranek, Foster, & Berkson, 1997; Grandin, 1992a, 1997). The extreme avoidance of some textures is also reported and this avoidance of touch extends to refusing human contact or being held (Grandin, 1992b). Although there are numerous reports of unusual perceptual processing in autism, the mechanisms underlying such phenomena and the possible relationship between these and the characteristic social and communicative deficits remain poorly understood.

Previous psychological studies on the perceptual abnormalities of autism have been biased towards investigations of visual disturbances. There have been several empirical demonstrations of unusual visual perception. For example, individuals with autism have been found to be superior to typically developing individuals on the

M. O'Riordan · F. Passetti
University of Cambridge, Cambridge, UK

M. O'Riordan (✉)
Autism Research Centre, Department of Developmental Psychiatry, Douglas House,
18b Trumpington Road, Cambridge CB2 2AH, UK
e-mail: mafo100@cam.ac.uk

---

[1] Hypersensitivity is defined here as apparent excessive or abnormal sensitivity and distress to sensory stimuli which is evident in the behavioural reactions of the individual.

embedded figures task, in which participants are required to detect a target shape, which is embedded within a larger picture (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). Autistic superiority has also been observed on the block design task, in which participants are required to construct a pre-specified pattern from cubes with differently patterned red and white faces (Rumsey & Hamberger, 1988; Shah & Frith, 1993). It has been suggested that this unusual visual processing in autism may potentially stem from an enhanced ability to discriminate between visual stimuli (O'Riordan & Plaisted, 2001; Plaisted, O'Riordan, & Baron-Cohen, 1998a). According to this interpretation, the superior performance on the embedded figures and block design tasks might stem from an enhanced ability to discriminate the target from the distractor shapes in the embedded figures task and the different block faces from one another in the block design task (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001; O'Riordan & Plaisted, 2001). Several phenomena support the notion of enhanced processes of visual discrimination in autism. For example, there are direct demonstrations that both children and adults with autism are better than matched controls at discriminating between novel, highly similar stimuli (Plaisted et al., 1998a; Plaisted & O'Riordan, manuscript in preparation). In addition, it has been shown that children with autism are superior to typically developing children in visual search tasks (O'Riordan et al., 2001; O'Riordan & Plaisted, 2001; Plaisted et al., 1998b), in which the ease of performance is dependent upon the discriminability of the display items (Duncan & Humphreys, 1989; O'Riordan & Plaisted, 2001; Wolfe, Cave & Franzel, 1989). Thus, enhanced discrimination seems at least in part to characterize the visual disturbances associated with autism.

Of the sensory modalities, the most evidently affected by autism seems to be not the visual, but the auditory modality (Dahlgren & Gillberg, 1989; Ornitz, 1974) and some authors have gone so far as to suggest that auditory abnormalities should be included among the diagnostic criteria of the disorder (Gillberg, 1990; Gillberg et al., 1990). In addition, a link has been suggested between the presence of early auditory abnormalities and the development of the language and communication deficits of autism (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Rapin, 1997). While a large number of studies have addressed the issue of the neurophysiological mechanisms underlying auditory abnormalities in autism (e.g. Bruneau, Roux, Adrien, & Barthélémy, 1999; Collet et al., 1993; Courchesne, Kilman, Galambos, & Lincoln, 1984; Dawson, Finley, Phillips, Galpert, & Lewy, 1988; Khalfa et al., 2001; Lincoln, Courchesne, Harms, & Allen, 1995; Minshew, 1996; Muller et al., 1999; Thivierge, Bedard, Cote, & Maziade, 1990), fewer studies have been concerned with systematically examining the specific psychological consequences of such abnormalities.

Early psychological studies of auditory abnormalities in autism suggested deafness (Lockyer & Rutter, 1969) but this was later concluded not to be a specific feature of the disorder (Chess, 1977; Rosenhall et al., 1999). Other work identified that, unlike typically developing children, children with autism show a marked preference for musical stimuli relative to speech (Blackstock, 1978). It has also been found that individuals with autism show superior processing of pitch relative to controls (Heaton, Hermelin, & Pring, 1998). More specifically, after paired associate training with tones and pictures individuals with autism were found to be better than controls at correctly identifying and remembering the associated pairs. In contrast, the two groups were equivalent in their ability to associate linguistic material with the pictures. Another recent study investigated the notion that individuals with autism process the local elements of auditory stimuli at the expense of global processing by presenting participants with a series of pairs of melodies and asking them to make same-different judgments (Mottron, Peretz, & Menard, 2000). Melodies could differ from one another either on a local (i.e. in terms of the pitch of individual notes) or a global level (i.e. a change the direction of the sequence of the notes). No global processing difference was found between the two groups but the autistic group did show greater detection of local differences than controls suggesting enhanced processing of elementary properties of auditory stimuli in autism.

The wealth of reports of disturbed processing in various modalities in autism raise the possibility that enhanced discrimination is not specific to vision but is instead a more general cognitive style. Thus, it is conceivable that, as has been suggested in the visual modality, reports of unusual local auditory processing in autism relate to an enhanced ability to discriminate between auditory stimuli. For example, it is possible that hypersensitivity to sound in autism results from a heightened differentiation of sounds. More specifically, just as enhanced visual discrimination in autism could make minor features and changes in the environment stand out, enhanced auditory discrimination could produce an exaggerated perception of slight changes in a sound or of differences between sounds. This might produce feelings of stimulus overload and thus distress reactions to some sounds, as while unpleasant visual stimuli can be avoided by averting or closing the eyes the same is not true in audition. Enhanced pitch processing in autism may also result from an enhanced auditory discrimination ability. For example, if sound frequencies appear more distinct from one another in autism than in typical, development there will be less interference between notes and thus notes may be stored and retrieved more accurately. Enhanced discrimination could certainly offer a potential account for Mottron et al's (2000) finding that individuals with autism noticed minor changes in auditory sequences better than controls. Thus, the enhanced discrimination hypothesis may potentially account for at least some of the auditory processing abnormalities in autism. An important first step in investigating this notion is to determine whether enhanced discrimination is evident in autism in the auditory modality. If enhanced auditory discrimination is found in autism, further studies will be required to explicitly assess whether there is any link between this and the potentially related behavioural phenomena of autism outlined here.

Although unusual tactile processing in autism has also been reported, considerably less attention has been paid to this modality. The paucity of experimental data regarding tactile perception in autism reflects the general lack of interest in the psychology of touch relative to the other modalities (Heller, 1991). Yet, tactile perception is as complex and sophisticated as visual perception, to which it is often compared. For example, texture and tactile pattern perception is achieved by the integration of information conveyed through four distinct psychophysical channels associated with distinct receptor types embedded under the skin surface (Weisenberger, 1991) and these receptors work in concert with active movements (Weisenberger, 1991) in a similar manner to the way eye movements enable scanning of the environment by the visual system. In autism a preference for use of proximal rather than distal sensory stimulation has been repeatedly suggested on the basis of behavioural observations (Schopler, 1965 but also see Kootz, Marinelli, & Cohen, 1980). Children with autism are also often reported to display excessive fascination with certain textures and the extreme avoidance of others (Baranek et al., 1997; Grandin, 1992a, 1997). In the light of the results in vision and audition discussed above, it seems plausible that at least some of these features of unusual tactile processing in autism might also be understood in the context of the enhanced discrimination hypothesis. For example, a heightened sensitivity to the differences between the ridges and troughs of a texture could give rise to fascination in some circumstances (i.e. proprioceptive seeking behaviour) and avoidance in others (i.e. tactile hypersensitivity). Once again even if enhanced tactile discrimination is found in autism further studies will be required to determine whether this relates behavioural features of autism outlined here.

In summary, the mechanisms underlying the stimulus processing abnormalities observed in autism are not yet fully understood. However, empirical evidence suggests that abnormal visual processing in autism might in part be characterized by an enhanced discrimination ability and it is possible that at least some aspects of abnormal audition and touch in autism might also relate to an enhanced discrimination ability. The present study assessed auditory and tactile discrimination ability in autism and normal development. Experiment 1 compared the performance of children with and without autism on a task in which participants were required to perform a series of successive auditory discriminations. In Experiment 2, a novel tactile discrimination test was used to study texture perception in autism and normal development and, in Experiment 3, tactile discrimination was studied using the Von Frey hairs method (Geldard, 1972). If enhanced discrimination is a general feature of autism, regardless of modality, then children with autism should perform better than controls on all three tasks.[2]

Experiment 1

Method

Participants

Two groups of children participated: a group of 12 high-functioning children with autism, and a group of 12 developmentally normal children. All children in the group with autism had been diagnosed with autism using the Autism Diagnostic Instrument-Revised (Lord, Rutter, & Le Couteur, 1994). The participants with autism were recruited from two different schools for children with autism and the control children were randomly selected from normal primary schools in the same towns. The mean age of the group of children with autism was 8 years, 7 months (standard deviation: 1 year, 7 months) and that of the typically developing children was also 8 years, 7 months (standard deviation: 10 months). The cognitive ability of the children was assessed using Raven's Standard Progressive Matrices (Raven, Court, & Raven, 1992). The mean raw scores were 26.3 and 26.5 for the autistic and control group respectively (standard deviations were 8.0 and 8.3 for the autistic and control group respectively). Paired t tests revealed that the chronological ages and the Standard Progressive Matrices raw scores of the two groups did not differ significantly ($t(11) = 0.10$ and $t(11) = 0.17$, respectively). Chronological age is required together with Standard Progressive Matrices raw score to determine a value of general IQ. As our groups were pairwise matched in both of these measures it can be concluded that the groups were not significantly different

---

[2] It is important to note that the three experiments presented here are *not* assessing absolute threshold in children with and without autism but rather group differences in the ability to discriminate between auditory and tactile stimuli.

in terms of general IQ. Performance of the two groups was also matched on a simple two-choice speeded Reaction Time (RT) task in order to ensure that there were no differences in basic motor control between the groups, as such differences could have produced artifactual results. All participants were musically untrained.

Apparatus

The stimuli were produced with a Tucker-Davis System II, using TDT DD1 16-bit digital-to-analogue converter (50-kHz sampling rate). The stimuli were recorded onto a TDK CD-R74 640 MB compact disc and were played to the participants through Sennheiser HD414 headphones using a SLTE-266TZ lap-top computer. The computer screen was shielded from the participant using a cardboard screen and participants responded by pressing the mouse button on the computer.

Stimuli

Each stimulus consisted of two tones (tone A and tone B). These tones were presented in an ABA sequence in which each tone was of 80 ms duration and tones were separated by a 20 ms pause. This sequence was repeated across the 30-s period and each sequence presentation was separated by pause of 120 ms. Tone A was fixed in frequency throughout each stimulus but Tone B decreased in frequency, in equal intervals, with each sequence presentation until the two tones were identical. There were four different stimulus starting frequencies: (1) Tone A fixed at 250 Hz and Tone B starting at 750 Hz, (2) Tone A fixed at 500 Hz and Tone B starting at 1,500 Hz, (3) Tone A fixed at 1,000 Hz and Tone B starting at 3,000 Hz, 4) Tone A fixed at 2,000 Hz and Tone B starting at 6,000 Hz.

Design

Each stimulus starting frequency sequence (i.e. combination of fixed A and starting point B) was presented four times, yielding 16 trials in total. The trials were randomised in blocks of 4 with equal representations of each stimulus sequence in each block. Presentation of the order of blocks presentation was counter-balanced across participants within each group.

Procedure

Participants were told that they would hear sequences of two alternating tones and that while one tone would stay the same, the other would change in frequency and become lower until the two tones were identical. They were asked to press the button when they thought that the two tones had become identical. The time from the start of the trial to the point at which the participant responded was recorded from a computer timer, associated with the CD player, in seconds. After the instructions participants were given three practice trials to familiarise them with the task. These were test stimuli sequences and the same stimuli were used for practice for each child. On the first practice trial the sequence was played for its entire duration to enable participants to see how they had to respond. On the following two practice trials participants were asked to respond just as in the test trials. The test trials immediately followed the practice trials and each trial block was separated by a 5-min interval.

Results

Except where otherwise stated, a significance level of $p < 0.05$ was adopted for all statistical comparisons in this experiment and likewise for those that follow. The RT data were analysed using a mixed ANOVA, with one between-subject factor of group (control or autistic), and one within-subject factor of starting frequency (1–4). Most interestingly this analysis revealed a significant main effect of group, $F(1, 22) = 5.43$, reflecting that the individuals with autism

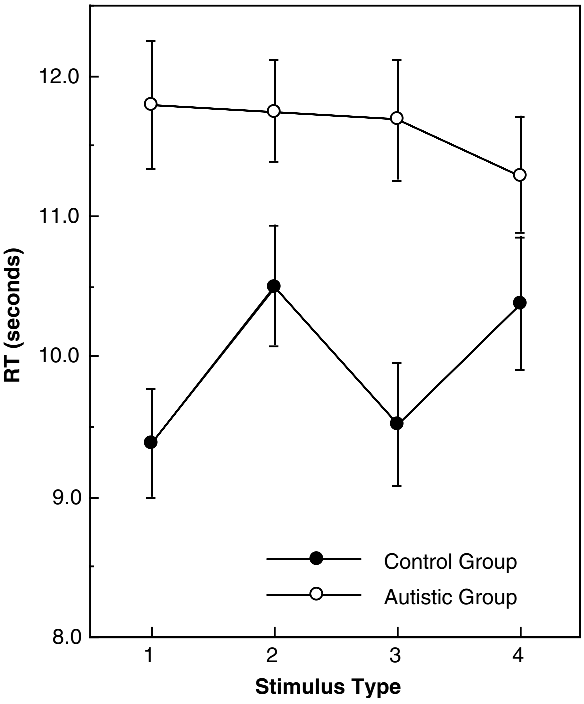

Fig. 1 This graph shows the mean RT for the participants to judge that the two notes in the converging sequence had become identical in frequency, as a function of the various starting frequencies used. The data from the control group is depicted by the filled circles and that from the autistic group by the hollow circles. Each data point shows the mean RT ± SEM (Standard Error of the Mean). The autistic group judged the two notes to be different until significantly later in the converging sequence than controls, regardless of starting frequency

indicated that the two tones were identical significantly later in the sequence than the typically developing children. The mean response time was 9.94 and 11.63 s for the control and autistic groups respectively (see Fig. 1).

Finally, there was no significant effect of stimulus type ($F < 1$) and no interaction between group and starting frequency ($F < 1$); indicating that the individuals with autism showed enhanced discrimination ability across the various frequency pairs employed. In summary Experiment 1 showed that children with autism are superior to matched controls at discriminating between auditory stimuli.

Experiment 2

Method

Participants

These were identical to those in Experiment 1.

Stimuli

Four different grades of 'Wet and Dry' sandpaper, ranging from type 1, the finest to type 4, the most coarse, were used. Each stimulus consisted of a pair of 12 cm by 10 cm rectangles of sandpaper, which were mounted side by side on an A4 card divider. These dividers were presented in A4 folders.

Design

The four different types of sandpaper yielded 10 different combinations of pairs of stimuli as shown in Table 1. Of the 10 stimulus types, there were four pairs of the same sandpaper grade presented together and six pairs in which different kinds of sandpaper were presented together, with these six pairs varying in terms of the grain similarity. Each discrimination pair was presented six times in the session and, to allow equal representation of each discrimination pair to each hand, the 10 combinations were presented three times on each side. Trials were randomised in blocks of 20, with equal representation of all experimental factors (discrimination pair and side) in each block. The order in which these blocks were presented was counter-balanced across participants within each group using a Latin square design. Participants were required to respond verbally whether each pair were the same or different.

Table 1 Here the various combination of sandpaper types used in Experiment 2. Sandpaper types ranged from 1, the finest, through to 4, the roughest

Stimulus type	1	2	3	4
1	1:2	1:2	1:3	1:4
2	–	2:2	2:3	2:4
3	–	–	2:3	2:4
4	–	–	–	4:4

Procedure

Before testing, the participant was asked to feel two pieces of sandpaper (type 1 and type 4) and to indicate which was rough and which was smooth. This was to ensure that the participant understood the concepts of rough and smooth. The participant was then told that they would be presented with pairs of pieces of sandpaper and asked to judge whether these felt the same or different. On trials where a 'different' response was given participants were asked to indicate which piece was rougher in order to verify that the child was discriminating rather than guessing. Participants sat opposite the experimenter and were asked to close their eyes or look at the experimenter. This, together with covering of the tactile samples with the A4 folder lid, was to eliminate the participants' use of visual clues to assist performance and so that the experimenter did not know which trial was being presented and so could not influence the participants' decisions. A second experimenter recorded the participants' responses. When participants were asked to justify a different response, this response was only counted as correct if the participant also correctly identified which of the stimuli were rougher.

Results

The ability of individuals in each group to discriminate each of the sandpaper stimuli was assessed using the measure of sensitivity d' (Signal Detection Theory). This parameter measures sensitivity as a function of the probability of hits [P(H) = hits/(hits+misses)] and the probability of false alarms [P(FA) = false alarms/(false alarms+correct rejections)], and is independent of the bias toward either category. It is defined by the formula: $d' = z[P(H)] - z[P(FA)]$ (For more details on Signal Detection Theory see Macmillan & Creelman, 2004).

ANOVA of the d' was conducted with one between-subject factor of group (control or autistic) and one within-subject factor of sandpaper type (1–4). Critically, this analysis revealed no main effect of group ($F < 1$) thus, the ability to discriminate between the pairs of sandpaper was comparable across the two groups (see Fig. 2). Furthermore there was no interaction between group and stimulus type ($F < 1$), showing that not only were the two groups performing comparably overall but they also shared similar levels of discrimination ability across all the stimulus pairs. However, there was a main effect of stimulus type, $F(3, 66) = 18.67$.

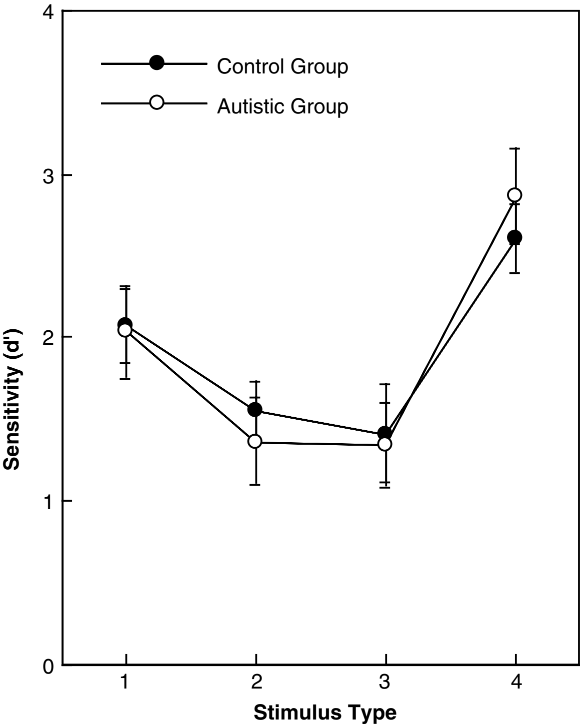

Fig. 2 This graph shows the sensitivity of the groups of children both with and without autism to detecting differences between each of the sandpaper types. The data from the control group is depicted by filled circles and that from the autistic group by hollow circles. Each data point shows sensitivity ± SEM. The two groups performed at an identical level regardless of stimulus type

Neuman-Keuls pairwise comparisons revealed that stimulus 4 was the most difficult to discriminate and that stimulus 1 was more difficult to discriminate than either stimulus 2 or stimulus 3. Similarly, ANOVA of the probability of hits using the same factors as above found a significant main effect of stimulus, $F(3, 66) = 31.87$, but no effect of group ($F < 1$) or stimulus by group interaction, ($F < 1$). Neuman-Keuls pairwise comparisons revealed that stimulus 4 was the most difficult to discriminate and that stimulus 1 was more difficult to discriminate than either stimulus 2 or stimulus 3. In summary, this experiment revealed no differences between the individuals with and without autism in the ability to discriminate between tactile stimuli.

Experiment 3

Method

Participants

Two groups of children participated: a group of 13 children with autism, and a group of 13 developmentally normal children. The details for recruitment, diagnosis and matching were the same as those described in Experiments 1 and 2. The mean age of each group of children was 10 years, 0 months with a standard deviation of 11 months. The mean Raven's Standard Progressive Matrices raw scores were 34.5 and 35.9 for the autistic and control group, respectively, (standard deviations were 7.6 and 5.7 for the autistic and control group respectively). Paired t tests revealed that the chronological ages and the Standard Progressive Matrices raw scores of the two groups did not differ significantly ($t(12) = 0.67$, $p = 0.514$ and $t(12) = 1.04$, $p = 0.318$, respectively). All participants were right handed.

Apparatus

The apparatus consisted of a wooden disk of 13.8 cm diameter and 0.6 cm depth with an 11.8 cm long perpendicular wooden handle attached to the centre of the disk. In the edge of the disk at 0.3 cm depth there were eight equidistant 0.1 cm diameter holes (i.e. at each 45° interval). In each of these small holes a piece of synthetic fibre was mounted such that it projected out from the disk parallel to the disk's surface. The eight pieces of synthetic fibre were of equal length (3.0 cm) but of differing diameter (0.1, 0.12, 0.15, 0.22, 0.25, 0.30, 0.35 and 0.40 mm).

Design

There were eight different diameters of synthetic fibre and thus eight different pressures to be applied to the participant. Null trials were also incorporated with each trial set, on which no pressure was applied to the participant. Thus, in total, there were nine trials in each complete set of trials. The full set of trials was repeated eight times generating a total of 72 trials. These were split into 4 separate blocks giving 18 trials per block and trial order was randomised using a computer algorithm such that there would be equal representation of each trial type in each block but a different order of stimulus presentation within each block.

Procedure

Participants sat opposite the experimenter and were asked to roll up their sleeve and place their right arm on a table. They were then shown that when the experimenter pressed lightly on their arm with a pen that they could feel it. The point of pressure application on the participant's arm was at the junction of the proximal two-thirds and distal third of the right inside forearm. While watching the experimenter, the participants were then asked to say when the pen was touching them. Participants were then asked to close their eyes and turn their head away (this meant the participants eyes were oriented 180° away from the stimulus being presented) so the exercise could be repeated without visual clues to assist performance. The experimenter asked the participant three times whether they could feel something now, the pressure was applied on the first and third but not the second occasion. The experimenter told them that now they would do exactly the same thing but this time using pieces of string rather than the pen. Participants were asked to again close their eyes and look away and to answer yes or no every time they were asked, ‘Can you feel something now?’ Participants were reminded that sometimes there would be something touching their arm and sometimes there would not be anything. Then the first of the four test blocks was initiated. On each trial, the end of a fibre was placed on the skin and pressure was applied until the fibre began to bend. The stimuli were presented quickly with approximately 5 s between trials in a block. A second experimenter recorded the responses of each participant and verified that the participants eyes remained closed. At the end of each block there was a 2-min pause during which the participant could open their eyes and rest.

Results

From the participants’ responses, the probability of hits [or $P(H) = \text{hits}/(\text{hits} + \text{misses})$], the probability of false alarms [$P(FA) = \text{false alarms}/(\text{false alarms} + \text{correct rejections})$], and d′ (Macmillan & Creelman, 2004), were calculated using the formula: $d' = z[P(H)] - z[P(FA)]$.

ANOVA of d′ was conducted with one between-subject factor of group (control or autistic) and one within-subject factor of stimulus type (1–8). Critically, as in the previous experiment, this analysis revealed no main effect of group ($F(1, 24) = 1.52$, $p = 0.2298$), thus, the ability to detect the stimuli was comparable across the two groups (see Fig. 3). Furthermore there was no interaction between group and stimulus type ($F < 1$), showing that not only were the two groups performing comparably overall but they also shared similar levels of detection ability across all the stimulus types. However, there was a main effect of stimulus type, $F(7, 168) = 160.15$. Neuman-Keuls pairwise comparisons revealed that sensitivity was lower to the pressure exerted by each of the 0.1, 0.12, 0.15 and 0.22 mm diameter thread relative to all thicker fibres. There was no difference in sensitivity between the pressure exerted by the 0.25, 0.30, 0.35 and 0.40 mm threads. Similarly, analysis of the probability of hits using the same ANOVA revealed no main effect of group ($F < 1$), no interaction between group and stimulus ($F < 1$) but a significant effect of stimulus $F(7, 168) = 178.84$). Thus, the present study showed that there was no difference between the two groups in detection of the various degrees of tactile pressure exerted and hence no difference in tactile discrimination ability.

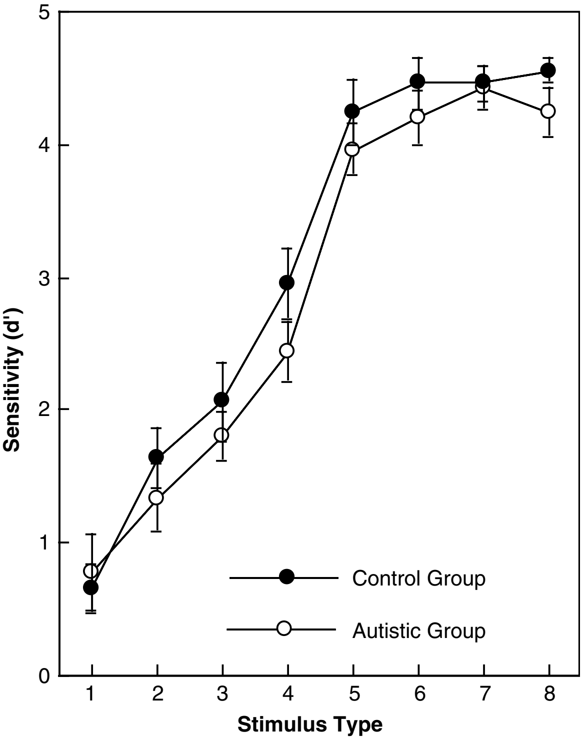

Fig. 3 This graph shows the sensitivity of the groups of children both with and without autism to the pressure exerted by each of the variously diametered fibres. The data from the control group is depicted by filled in circles and that from the autistic group by hollow circles. Each data point shows the sensitivity ± SEM. The two groups performed at an identical level regardless of stimulus type

General discussion

The first main result of the present study was that children with autism were later than matched controls to indicate that two alternately played notes of converging frequency sounded the same. This result suggests that the children with autism perceived the two tones to differ from one another until later in the sequence than controls. The further along in the trial the closer the tones actually were suggesting that children with autism were superior to controls at discriminating between the sounds. Thus, Experiment 1 provides an initial indication that enhanced discrimination in autism extends from the visual to the auditory modality.

The results of Experiment 1 are unlikely to be artifacts of behavioural abnormalities, such as perseveration, impulsivity, or poor motor control in the autism group for two reasons. Firstly, the groups of participants were prematched for their performance on a speeded two-choice RT task, and the autistic group showed no evidence of slowed responding, impulsivity, or perseveration, on this task. Secondly, in Experiment 1, participants were required to make a single button press when they judged the sounds to be identical and all participants followed these instructions, with the autism group waiting until later in the sequence to respond than controls. In contrast with this observed behaviour perseverative, responding should have produced repeated responding and impulsivity should have given rise to earlier responses than controls. Overall, based on these preliminary findings, it seems reasonable to suggest that enhanced auditory discrimination ability might be a feature of autism. It would be interesting to determine how far this phenomenon generalises to other aspects of auditory stimuli by assessing discrimination of loudness of sounds and of sound frequencies outside the range used in the present experiment.

As in the visual modality, it is possible to speculate how enhanced discrimination in the auditory modality might underlie many of the auditory-perceptual anomalies characteristic of autism, such as enhanced pitch processing and hypersensitivity (see Introduction). To determine whether this is the case, future experiments should investigate the relationship between levels of enhanced discrimination and measures of reported perceptual anomalies. In addition, such a disturbance could have implications far beyond these perceptual/attentional abnormalities. Indeed, any disturbance in stimulus processing would fundamentally alter the quality of the information that the child receives from the environment and would have profound effects on psychological processing and development. For example, it is possible to speculate how enhanced auditory discrimination might contribute to the language delay observed in autism. Typically developing neonates can discriminate between speech sounds of many different languages, including ones they have never been exposed to (Werker, Gilbert, Humphrey, & Tees, 1981) but exposure to a specific language results in a reduction in the ability to perceive differences between speech sounds that do not differentiate between words in that language (Werker et al., 1981). It is argued that through exposure to language, neonates group together variants of phonemes into categories of sounds that distinguish between words, such that all the variants in the category come to be perceived as that one phoneme and subsequently discrimination between exemplars of that phoneme becomes difficult (Iverson & Kuhl, 1995; Kuhl, 1991). Enhanced auditory discrimination in autism would predict a reduction in the categorisation of speech sounds into phonemic units and a preservation of the ability to discriminate between speech sounds that do not distinguish between words in the language until later in development than normal. If, as Kuhl argues (1991), categorisation of sounds into phonemic units is a pre-requisite for the development of language, a disruption of this process could potentially contribute to late language onset. Relating measures of language delay with levels of enhanced auditory discrimination would assess this idea.[3]

One obvious question raised by the present study concerns the mechanisms underlying enhanced auditory discrimination. Initial steps taken towards elucidating this mechanism in the visual modality (O'Riordan, 2000) have suggested that enhanced discrimination in autism does not stem from top–down attentional differences. By a process of elimination, it was suggested that perhaps differences in early perceptual processing underlie enhanced visual discrimination in autism, but future research will be required to demonstrate that this is the case. It seems plausible that similar mechanisms may underlie enhanced discrimination in the auditory and visual modalities. In support of this idea, levels of performance on tasks, which may reflect visual and auditory discrimination, have been found to correlate (Heaton et al., 1998). Alternatively, some have suggested that enhanced discrimination in autism may be symptomatic of a general superiority of low-level perceptual processing rather than an isolated enhanced processing capacity (Mottron & Burack, 2001).

The second main finding of the present study is that, at variance with the results in the visual and auditory modalities, tactile discrimination performance was comparable in autism and normal development in two separate experiments. There are several potential ways that this unexpected finding might be reconciled with the many anecdotal reports of unusual tactile processing in autism. The first possibility that must be considered is whether the lack of group differences in the tactile discrimination tasks were artifacts of poor task sensitivity. This seems unlikely, as performance levels varied across the stimulus types in both experiments. Thus, overall the set of stimuli chosen should have enabled detection of either enhanced or impaired performance in the autistic group. A second possibility is that enhanced discrimination is present in different modalities in different individuals with autism and that the children used in the present study simply did not have tactile disturbances. However, this notion seems unlikely as comparable tactile processing was found in two separate sets of children with and without autism in the present study and has also been found in other studies (Minshew, Goldstein, & Siegel, 1997). A third possibility is that perhaps reports of unusual tactile processing (i.e. hypersensitivity and proprioceptive seeking behaviour) in autism are not accounted for by an enhanced discrimination

---

[3] To highlight that a simple difference in low-level perception could have far reaching ramifications is not to negate the possibility that hyper-perceptual discrimination may itself result from a failure of development of some other process or related neural structure, either within or outside the perceptual processing system.

ability, but rather some other disturbance. It is possible that there are differences between light touch discrimination examined in this study and proprioceptive/kinesthetic functions that should be investigated in future experiments. A lack of relationship between perceptual anomalies and enhanced discrimination could also obviously also be true of perceptual disturbances in any modality, even those modalities in which a superior discrimination ability has been found. This is because although an enhanced discrimination ability could potentially underlie hypersensitivity the link has yet to be explicitly determined. Fourthly, it is possible that unusual tactile processing (hypersensitivity or proprioceptive seeking behaviours) in autism might reflect a focus on this modality rather than something unusual about it per se precisely because of the disturbances in the other modalities. Fifthly, it is possible that unusual tactile processing is a feature of low mental age rather than a specific feature of autism (e.g. Frith, 1989). Sixthly, another way in which the results presented here and findings of unusual tactile processing in autism might be reconciled is by consideration of active versus passive tactile stimulation. It is possible that one form of tactile stimulation evokes unusual reactions in individuals with autism while the other does not and our tasks selectively assessed the unaffected form. However, while Experiment 2 was clearly an active tactile task where participants controlled their own manipulation of textures to recruit as many receptors as needed, in Experiment 3, participants were in a passive role where the tactile stimuli were applied by the experimenter so it is possible that both active and passive touch were assessed here. However, future experiments should explicitly dissociate between active and passive stimulation in autism. Finally, the present study only assessed pressure discrimination and there are other aspects of tactile processing, such as pain and temperature, which also need to be investigated before it can be concluded that individuals with autism have normal tactile discrimination abilities in general. However, the results of the present study do provide an initial indication that tactile pressure discrimination is comparable in autism and normal development.

Clearly further experiments are required to fully elucidate the nature of tactile processing in autism. However, taking this initial indication of enhanced auditory and visual discrimination in the absence of any abnormality in tactile discrimination may help generate hypotheses regarding a neuro-developmental theory of autism. For example, the maturation of distinct perceptual modalities in mammals follows a fixed developmental pattern: first olfaction, then tactile, taste, auditory, and visual perception (Gottlieb, 1971). Thus, while tactile perception is virtually mature at birth and, if anything, sensitivity to gentle tactile stimuli reduces with growth (Werner & Bernstein, 2001), auditory and visual acuity only become comparable to that of adults from six months onwards (Gwiazda & Birch, 2001; Werner & Bernstein, 2001). This pattern is adaptive and consistent with the changing perceptual needs of developing infants, who naturally rely on proximal senses at an early stage, when only an impression of the immediate vicinity is necessary for existence and for the stimulation of further perceptual, cognitive, and social development (Hainline, 1998). At this early stage, extremely fine acuity, fine stereoscopic discriminations of depth, and accurate sound localisation are not necessary and it has been argued, in the visual modality at least, that such sophisticated processing might even *impede* development (Hainline & Abramov, 1992; Turkewitz & Kenney, 1982). An infant's ability to process complex visual and auditory stimuli later increases to help them cope with the richer perceptual (and social) stimuli that they come into contact with as they begin to explore their broader environment. In the context of autism, these notions may support speculation regarding the developmental stage at which a neuropathological insult responsible for the behavioural and psychological abnormalities associated with this disorder must take place, or at least find expression. Based on the results presented here and elsewhere (Minshew et al., 1997) of comparable tactile perception in autistic and normally developing children, it may be suggested that the greatest impact of the neuropathological insult might take place at a time when the neuronal mechanisms underlying tactile perception are already nearly or fully established, but auditory and visual perception are still immature. This hypothesis would also be compatible with the notion of cognitive impairments, in autism, affecting the sphere of language and social functions, rather than praxic and constructional abilities, which are preserved in individuals with this disorder (Minshew et al., 1997 although see Mari, Castiello, Marks, Marraffa, & Prior, 2003).

In summary, the present study suggests that the enhanced ability of individuals with autism to discriminate between stimuli extends from the visual to the auditory but not to the tactile modality. It is certainly not the case that these are the only disturbances in autism (Russell, 1997), nor are they necessarily the only stimulus processing disturbances. However, these visual and auditory disturbances may relate to the numerous reports of unusual reactions to incoming stimuli in autism and further have far reaching consequences for all aspects of development. It is difficult to imagine a world experienced through such a perceptual apparatus, but a simple perceptual difference could lead to disturbances in any psychological system that relies upon it for its input. Such perceptual differences must be fully understood if we are to unravel the etiology of the autistic disorder.

Acknowledgments During the period of this work, Michelle O'Riordan was supported by a Dorothy Hodgkin, Royal Society Fellowship and a Research Fellowship from St. John's College, Cambridge. We are extremely grateful to Professor Brian Moore and his co-workers, particularly Geoff Moore, for providing the stimuli used in Experiment 1 and for useful discussion. We are also grateful to Simon Baron-Cohen and Greg Davis for useful discussion. The authors would also like to thank Kate Sheppard and Anna Shiel for collecting some of the data as part of a final year project, the parents and teachers for allowing us to visit the schools to conduct this research, and to the children for taking part.

References

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

Baranek, G. T., Foster, L. G., & Berkson, G. (1997). Sensory defensiveness in persons with developmental disabilities. *Occupational Therapy Journal of Research, 17*, 173–185.

Bettison, S. (1996). The long-term effects of auditory training on children with autism. *Journal of Autism and Developmental Disorders, 27*(3), 347–348.

Blackstock, E. G. (1978). Cerebral Asymmetry and the development of early infantile autism. *Journal of Autism and Developmental Disorders, 8*, 339–353.

Bruneau, N., Roux, S., Adrien, J. L., & Barthélémy, C. (1999). Auditory associative cortex dysfunction in children with autism: Evidence from late auditory evoked potentials (N1 wave-T complex). *Clinical Neurophysiology, 110*, 1927–1934.

Bryson, S. E., Wainwright-Sharpe, J. A., & Smith, I. M. (1990). Autism: A developmental neglect syndrome? In J. T. Enns (Ed.), *The development of attention: Research and theory*. Amsterdam: North-Holland.

Chess, S. (1977). Follow-up report on autism in congenital rubella. *Journal of Autism and Childhood Schizophrenia, 7*, 69–81.

Collet, L., Roge, B., Descouens, D., Moron, P., Duverdy, F., & Urgell, H. (1993). Objective auditory dysfunction in infantile autism. *Lancet, 342*, 923–924.

Courchesne, E., Kilman, B. A., Galambos, R., & Lincoln, A. J. (1984). Autism – processing of novel auditory information assessed by event-related brain potentials. *Electroencephalography and Clinical Neurophysiology, 59*(3), 238–248.

Dahlgren, S. O., & Gillberg, C. (1989). Symptoms in the 1st 2 years of life – a preliminary population study of infantile-autism. *European Archives Of Psychiatry and Neurological Sciences, 238*(3), 169–174.

Dawson, G., Finley, C., Phillips, S., Galpert, L., & Lewy, A. (1988). Reduced P3 amplitude of the event-related brain potential: Its relationship to language ability in autism. *Journal of Autism and Developmental Disorders, 18*, 493–504.

Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism and Developmental Disorders, 28*, 479–485.

Duncan, J., & Humphreys, G. W. (1989). Visual-search and stimulus similarity. *Psychological Review, 96*(3), 433–458.

Frith, U. (1989). *Autism: Explaining the enigma*, Oxford: Basil Blackwell.

Geldard, F. A. (1972). *The human senses* (2nd ed.). New York: John Wiley and Sons Inc.

Gillberg, C. (1990). Autism and pervasive developmental disorders. *Journal of Child Psychology and Psychiatry, 31*(1), 99–119.

Gillberg, C., Ehlers, S., Schaumann, H., Jacobsson, G., Dahlgren, S. O., Lindblom, R., Bagenholm, A., Tjuust, T., & Blidner, E. (1990). Autism under age three years: A clinical study of 28 cases referred for autistic symptoms in infancy. *Journal of Child Psychology and Psychiatry, 31*, 921–934.

Gottlieb, G. (1971). Ontogenesis of sensory function in birds and mammals. In E. Tobach, L. R. Aronson & E. F. Shaw (Eds.), *The biopsychology of development* (pp. 67–128). New York: Academic Press.

Grandin, T. (1992a). Calming effects of deep touch pressure in patients with autistic disorder, college students and animals. *Journal of Child and Adolescent Psychopharmacology, 2*, 63–72.

Grandin, T. (1992b). An inside view of autism. In E. Schopler & G. Mesibov (Eds.), *High-functioning individuals with autism*. New York: Plenum Press.

Grandin, T. (1997). A personal perspective on autism. In D. J. Cohen & F. R. Volkmar (Eds.), *Handbook of autism and pervasive developmental disorders* (2nd ed.). New York: John Wiley and Sons, Inc.

Gwiazda, J., & Birch, E. E. (2001). Perceptual development: Vision. In E. B. Goldstein (Ed.), *Handbook of perception*. Blackwell.

Hainline, L. (1998). How the visual system develops: Normal and abnormal development. In A. Slater (Ed.), *Perceptual development: Visual, auditory and speech perception in infancy*. Hove, Sussex: Psychology Press Ltd.

Hainline, L., & Abramov, I. (1992). Assessing visual development: Is infant vision good enough? In C. Rovee-Collier & L. P. Lipsitt, (Eds.), *Advances in infancy research*. New Jersey: Norwood.

Hayes, R. (1987). Training for work. In D. J. Cohen & A. M. Donnellan (Eds.), *Handbook of autism and pervasive developmental disorders*. Silver Springs, MD: Winston.

Heaton, P., Hermelin, B., & Pring, L. (1998). Autism and pitch processing: A precursor for savant musical ability? *Music Perception, 15*(3), 291–305.

Heller, M. A. (1991). Introduction. In M. A. Heller & W. Schiff, (Eds.), *The Psychology of Touch* (pp. 1–19). Lawrence Erlbaum Associates.

Iverson, P., & Kuhl, P. K. (1995). Mapping the peceptual magnet effect for speech using signal detection theory and multidimensional scaling. *Journal of Acoustic Society of America, 97*, 553–562.

Jolliffe, T., & Baron-Cohen, S. (1997). Are people with autism or Asperger's Syndrome faster than normal on the Embedded Figures Task? *Journal of Child Psychology and Psychiatry, 38*, 527–534.

Kanner, L. (1943). Autistic disturbance of affective contact. *Nervous Child, 2*, 217–250.

Khalfa, S., Bruneau, N., Roge, B., Georgieff, N., Veuillet, E., Adrien, J. L., Barthélémy, C., & Collet, L. (2001). Peripheral auditory asymmetry in infantile autism. *European Journal of Neuroscience, 13*(3), 628–632.

Kootz, J. P., Marinelli, B., & Cohen, D. J. (1980). Sensory receptor sensitivity in autistic children: Response times to proximal and distal stimuli. *Archives of General Psychiatry, 38*, 271–273.

Kuhl, P. (1991). Human adults and human infants show the perceptual magnet effect for the prototypes of speech categories, monkeys doe not. *Perception and Psychophysics, 50*, 93–107.

Lincoln, A. J., Courchesne, E., Harms, L., & Allen, M. (1995). Sensory modulation of auditory stimuli in children with autism and receptive developmental language disorder: Event-related brain potential evidence. *Journal of Autism and Developmental Disorders, 25*, 521–539.

Lockyer, L., & Rutter, M. (1969). A five to fifteen year follow-up study of infantile psychosis, III. *British Journal of Psychiatry, 115*, 865–882.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism diagnostic interview-revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders, 24*, 659–685.

MacMillan, N.A., & Creelman, C.D. (2004). *Detection theory: a user's guide* (2nd ed.). Lawrence Erlbaum Associates.

Mari, M., Castiello, U., Marks, D., Marraffa, C., & Prior, M. (2003).The reach-to-grasp movement in children with autism spectrum disorder. *The Philosophical Transactions of The Royal Society: Biological Sciences, 358*, 393–403.

Minshew, N. J. (1996). Brief report: Brain mechanisms in autism: Functional and structural abnormalities. *Journal of Autism and Developmental Disorders, 26*(2), 205–209.

Minshew, N. J., Goldstein, G., & Siegel, D. J. (1997). Neuropsychologic functioning in autism: Profile of a complex information processing disorder. *Journal of International Neuropsychological Society, 3*, 303–316.

Mottron, L., & Burack, J. A. (2001). Enhanced Perceptual Functioning in the Development of Autism. In J. A. Burack, T. Charman, N. Yirmiya & P. R. Zelazo (Eds.), *The development of autism: Perspectives from theory and research*. New Jersey: Lawrence Erlbaum Associates.

Mottron, L., Peretz, I., & Menard, E. (2000). Local and global processing of music in high-functioning persons with autism: Beyond central coherence? *Journal of Child Psychology and Psychiatry, 41*(8), 1057–1065.

Muller, R. A., Behen, M. E., Rothermel, R. D., Chugani, D. C., Muzik, O., Mangner, T. J., & Chugani, H. T. (1999). Brain mapping of language and auditory perception in high-functioning autistic adults: A PET study. *Journal of Autism and Developmental Disorders, 29*, 19–31.

NASC. (1978). National society for autistic children definition of the syndrome of autism. *Journal of Autism and Developmental Disorders, 8*, 162–167.

O'Neill, M., & Jones, R. S. P. (1997). Sensory-perceptual abnormalities in autism: A case for more research. *Journal of Autism and Developmental Disorders, 27*(3), 283–293.

O'Riordan, M., Plaisted, K., Driver, J., & Baron-Cohen, S. (2001). Superior visual search in autism. *Journal of Experimental Psychology: Human Perception and Performance, 27*(3), 719–730.

O'Riordan, M. A. (2000). Superior target detection in autism does not result from differential levels of target excitation or distractor inhibition. *Cognition, 77*, 81–96.

O'Riordan, M. A., & Plaisted, K. C. (2001). Enhanced discrimination in autism. *Quarterly Journal of Experimental Psychology, 54A*(4), 961–979.

Ornitz, E. M. (1974). The modulation of sensory input and motor output in autistic children. *Journal of Autism and Developmental Disorders, 4*, 197–215.

Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998a). Enhanced discrimination of novel, highly similar stimuli by adults with autism during a perceptual learning task. *Journal of Child Psychology and Psychiatry, 39*, 765–775.

Plaisted, K., O'Riordan, M., & Baron-Cohen, S. (1998b). Enhanced visual search for a conjunctive target in autism: A research note. *Journal of Child Psychology and Psychiatry, 39*, 777–783.

Plaisted, K. C. & O'Riordan, M. A. (in preparation). Autistic children show enhanced perceptual learning – further evidence of reduced generalisation in autism.

Rapin, I. (1997). Autism. *New England Journal Of Medicine, 337*(2), 97–104.

Raven, J., Court, J., & Raven, J. (1992). *The standard progressive matrices*, Oxford: Oxford Psychology Press.

Rosenhall, U., Nordin, V., Sandstrom, M., Ahlsen, G., & Gillberg, C. (1999). Autism and hearing loss. *Journal of Autism and Developmental Disorders, 29*, 349–366.

Rumsey, J., & Hamberger, S. (1988). Neuropsychological findings in high functioning men with infantile autism, residual state. *Journal of Clinical and Experimental Neuropsychology, 10*, 201–221.

Russell, J. (Ed.) (1997). *Autism as an executive disorder*. Oxford: Oxford University Press.

Schopler, E. (1965). Early infantile autism and receptor processes. *Archives of General Psychiatry, 13*, 327–335.

Shah, A., & Frith, U. (1983). An islet of ability in autism: A research note. *Journal of Child Psychology and Psychiatry, 24*, 613–620.

Shah, A., & Frith, U. (1993). Why do autistic individuals show superior performance on the block design test? *Journal of Child Psychology and Psychiatry, 34*, 1351–1364.

Thivierge, J., Bedard, C., Cote, R., & Maziade, M. (1990). Brain-stem auditory evoked-response and subcortical abnormalities in autism. *American Journal Of Psychiatry, 147*(12), 1609–1613.

Turkewitz, G., & Kenney, P. (1982). Limitations on input as a basis for neural organisation and perceptual development: A preliminary theoretical statement. *Developmental Psych-biology, 15*, 357–368.

Weisenberger, J. M. (1991). Curtaneous perception. In E. B. Goldstein (Ed.), *Handbook of Perception* (pp. 535–566). Blackwell.

Werker, J. F., Gilbert, J. H. V., Humphrey, K., & Tees, R. C. (1981). Developmental aspects of cross-language speech perception. *Child Development, 52*, 349–355.

Werner, L. A., & Bernstein, I. L. (2001). Development of audition, somesthesis, taste & olfaction. In E. B. Goldstein (Ed.), *Handbook of perception* (pp. 670–708). Blackwell.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). A modified feature integration model for visual search. *Journal of experimental psychology: Human perception and performance, 15*, 419–433.