J. Child Psychol. Psychiat. Vol. 41, No. 8, pp. 1057–1065, 2000
Cambridge University Press

0021–9630/00 $15.00+0.00

Local and Global Processing of Music in High-functioning Persons with Autism: Beyond Central Coherence?

L. Mottron
Hôpital Rivière-des-Prairies and Université de Montréal, Canada

I. Peretz
Université de Montréal, Canada

E. Ménard
Hôpital Rivière-des-Prairies and Université de Montréal, Canada

A multi-modal abnormality in the integration of parts and whole has been proposed to account for a bias toward local stimuli in individuals with autism (Frith, 1989; Mottron & Belleville, 1993). In the current experiment, we examined the utility of hierarchical models in characterising musical information processing in autistic individuals. Participants were 13 high-functioning individuals with autism and 13 individuals of normal intelligence matched on chronological age, nonverbal IQ, and laterality, and without musical experience. The task consisted of same-different judgements of pairs of melodies. Differential local and global processing was assessed by manipulating the level, local or global, at which modifications occurred. No deficit was found in the two measures of global processing. In contrast, the clinical group performed better than the comparison group in the detection of change in nontransposed, contour-preserved melodies that tap local processing. These findings confirm the existence of a "local bias" in music perception in individuals with autism, but challenge the notion that it is accounted for by a deficit in global music processing. The present study suggests that enhanced processing of elementary physical properties of incoming stimuli, as found previously in the visual modality, may also exist in the auditory modality.

Keywords: Autistic disorder, cognition, development, idiot savants, memory, music, neuropsychology, perception.

Abbreviations: ADI-R: Autism Diagnostic Interview-Revised; AP: absolute pitch; HDH: hierarchisation deficit hypothesis; HFA: high-functioning autism; TD: typically developing; WCC: weak central coherence.

The study of musical processing in individuals with autism is relevant for both clinical and theoretical reasons. First, there are clinical indications of atypical auditory processing in persons with autism. These observations justify inquiry of the mechanisms that underlie auditory processing in this group. It is well documented that very young autistic children exhibit aversive reactions to noises; indeed, these children often cover their ears with their hands when in the presence of speakers. In addition, they might cover their ears when exposed to specific, low-intensity sounds to which the majority of individuals would remain insensitive. These behaviours are usually described in terms of a hypersensitivity to sound, and they comprise part of the "restricted interest and repetitive behaviours" area of the diagnostic criteria for autism (American Psychiatric Association, 1994; Lord, Rutter, & Le Couteur, 1994).

Requests for reprints to: Laurent Mottron, Clinique spécialisée de l'Autisme, Hôpital Rivière-des-Prairies, 7070 boulevard Perras, Montréal, Québec, H1E1A4, Canada (E-mail: Mottronl@istar.ca).

Previous research with this population suggests that, within the auditory modality, different reactions are triggered by verbal speech and by musical stimuli. For example, a spontaneous orientation towards musical stimuli, as opposed to nonmusical, verbal stimuli has been reported (Blackstock, 1978). Moreover, although a significant proportion of autistic individuals have a language impairment (American Psychiatric Association, 1994), the ability to process musical material, such as the reproduction of musical pieces (Applebaum, Egel, Koegel, & Imhoff, 1979) remains preserved or even enhanced. Recently, Heaton, Hermelin, and Pring (1998) found that children with autism were more accurate than typically developing boys in their ability to associate tones with pictures, but were equivalent to the latter group in associating linguistic material with pictures.

The presence of special musical abilities in "savant" autistic individuals provides additional evidence for the notion that persons with autism process musical stimuli differently from control participants. In fact, a small proportion of persons with autism exhibit exceptional pitch-processing abilities (Mottron, Peretz, Belleville, & Rouleau, 1999). In addition, they often possess an exceptional long-term memory for musical material (Sloboda, Hermelin, & O'Connor, 1985). This performance may even exceed that of trained musicians, and lies in contrast to autistic individuals' average or often impaired treatment of linguistic material.

Although the continuity between "savant" and nonsavant persons with autism is a matter of debate, savant capabilities in music are informative for the study of nonsavant autistic individuals. Indeed, the outstanding musical operations exhibited by autistic savant musicians are observed at a lower level in nonsavant autistic individuals. For instance, a parallel can be drawn between the enhanced pitch processing reported in nonsavant persons with autism (Heaton et al., 1998) and the special ability known as absolute pitch (AP), which is frequently found in savant persons with autism (Miller, 1999). Savant persons with AP might therefore represent extreme cases of above-average perception of pitch in autism.

Musical processing in nonsavant persons with autism is also relevant to multimodal cognitive models of autism. Recently, there have been theoretical attempts to account for cognitive deficits in unrelated areas (e.g., visuospatial, music, language, memory) in persons with autism by positing multi-modal deficits that apply to various sensory modalities, and, a fortiori, to several cognitive operations in the same modality. Each of these "modules" is characterised by functional autonomy in normal adults (Fodor, 1983), and may be selectively impaired in adult brain-injured subjects. However, in individuals with autism, the boundaries between modules do not seem to exist, as there are deficits in several apparently unrelated areas that seem to be caused by the same underlying mechanism (Mottron & Burack, in press).

According to Frith (1989), Frith and Happé (1994), and Happé (1996, 1999), the visual and mnemonic characteristics often found in autism can be accounted for by a deficit in the normal tendency to integrate elements into a higher level of organisation. This deficit produces "a specific imbalance in integration of information at different level" (Frith & Happé, 1994, p. 121), regardless of modality. According to one of the latest versions of the "weak central coherence" (WCC) model (Happé, 1999, pp. 217–8), this results in "detailed focused processing in which features are perceived and retained at the expense of global configuration and contextualized meaning". WCC predicts good performance when attention to local information is advantageous and poor performance on tasks requiring integration of stimuli in context. An independent but similar model, the hierarchisation deficit hypothesis (HDH), has been proposed by Mottron and Belleville (1993) on the basis of atypical processing of several types of complex multilevel visual stimuli. It states that local and global levels, despite functioning normally, might not be hierarchically distinguished in persons with autism, yielding an absence of a global advantage, and global interference in conditions in which typically developing subjects show these effects.

The WCC hypothesis was derived mainly from findings in the visuospatial domain, such as the high level of performance on embedded figures and the block design subtest of the Wechsler Intelligence Scale (Shah & Frith, 1983, 1993; Wechsler, 1974, 1981).

In support of Frith's hypothesis, Mottron and Belleville (1993) found locally oriented graphic construction and visual perception in a savant autistic draughtsman. Also, Happé (1996) reported that nonsavant persons with autism were insensitive to visual illusions, which require both intact local and global perception. Finally, the finding of a local bias in graphic construction among autistic individuals provides additional evidence of this aspect of Frith's hypothesis (Mottron, Belleville, & Ménard, 1999).

A locally oriented information processing style has also been reported in the auditory modality, supporting the multi-modal aspect of Frith's hypothesis. Frith (1989) suggests that this general bias towards local processing might account for autistic individuals' exceptional abilities in pitch labelling (AP), pitch being considered a local element. Evidence for this notion was provided by Heaton et al. (1998). In their study, 10 boys diagnosed with autism (chronological age, CA: 7–13, IQ 55–127) and 10 CA-matched typically developing children were presented with four isolated tones and four line drawings of animals. In the familiarisation session, participants were exposed to pairs of tones and animal names and were told "this is the animal's favourite sound". In the pitch identification procedure, children were asked to point to the drawing that corresponded to the presented tone, immediately and then again 1 week after the learning procedure. Results revealed that, in both recall conditions, the clinical group outperformed the group of typically developing boys in their ability to associate tones with pictures. Heaton et al. concluded that the enhanced pitch processing ability found in individuals with autism resulted from a local processing bias, using pitch processing as an example of a local feature in music. However, using isolated pitches to measure local processing in music is problematic because local and global are reciprocally relative concepts and cannot be used in isolation. A global level must be included in the experiment as a basis for comparison of the two levels. For an enhanced memory of isolated pitches to be relevant to a model of hierarchical information processing, it is mandatory that larger sound units such as intervals or melodies be used, as opposed to isolated pitches. Only in this case can a behaviour, such as favouring pitch over melodic contour, be interpreted as resulting from a local bias.

In the current study, hierarchical musical processing was assessed in nonsavant persons with autism. Melodies were employed in this study, as they contain three types of features that can be classified along a local vs. global dimension (Dowling, 1978; Peretz & Morais, 1993). First, each individual *pitch* included in a melody has an absolute height value (expressed in frequency). Second, pairs of individual pitches are separated by *intervals* (which can vary in size, expressed here in semitones). Finally, the direction that intervals take comprises the melodic *contour*. The latter characterises pitch direction independently of the specific pitch values.

These three levels form an embedded, hierarchical structure: a minimum of two pitches is needed to produce an interval, and it is the direction taken by several intervals that produces a contour. A local vs. global gradient can be determined from this hierarchical structure: absolute pitch consideration, for instance, is a more locally (or less globally) oriented type of processing than relative pitch or interval recognition, which in turn requires a more local type of processing than contour processing.

The respective contribution of local and global levels to musical processing can be addressed with "same-different" tasks; for instance, using melodies modified at the pitch/interval vs. contour level (Dowling, 1978). Modification of a single note preserves a melodic contour if it does not modify the ascending vs. descending direction of melody intervals. Such a modification simultaneously transforms the absolute pitch value of a given note in a melody, while also modifying the value of the intervals directly preceding and following the modified note. A melodic modification violates contour when it modifies the direction of intervals (see Fig. 1). This last modification adds a contour transformation to the previous transformations.

Pitch and interval recognition play a role in melody recognition in contour-preserved as well as contour-violated conditions. Nevertheless, compared to contour-violated conditions, contour-preserved conditions selectively suppress the role that contour plays in recognition. Therefore, a better ability to recognise melodies whose contour has been modified as opposed to those whose contour has been preserved can be taken as a measurement of global processing.

Musical material presents an advantage over other stimuli in that certain local features of a melody can be selectively suppressed through transposition. In transposed melody conditions, each absolute pitch value is transformed, while the intervals and contour remain the same. Consequently, a capacity to recognise two transposed melodies as identical constitutes a second and independent assessment of global processing. Conversely, in a system relying mainly on AP, such as persons with autism possess according to WCC predictions, the identification of melodies should be more difficult following changes in pitch level (via transposition), ultimately resulting in a bias toward "different" responses.

In sum, a better recognition of melody modification in the contour-violated than in the preserved contour condition for nontransposed and transposed melodies, as well as a capacity to discriminate melodies despite the presence of transposition, are two indicators of the integrity of global musical processing. On the other hand, enhanced performance in the detection of contour-preserved modifications would demonstrate a bias toward local music processing. The extent to which this local bias is maintained or lost in the transposed condition provides information about the role of AP in task performance.

In what sense are intervals actually "local" and contours "global"? First, contours are large units that embed smaller units (or intervals) hierarchically. Second, contour, more than intervals, is used by typically developing nonmusicians, as contour-violated modifications are reliably easier to recognise than contour-preserved modifications (Peretz & Morais, 1987). This advantage for contour over intervals parallels the advantage of large embedding letters over small embedded letters in visual hierarchical stimuli (Robertson & Delis, 1986). Third, contour and intervals are processed by asymmetrical and independent brain structures with the same lateralisation as global and local levels in the visual modality. The right hemisphere primarily represents the melody in terms of its contour, and the left hemisphere in terms of its intervallic structure. For instance, asymmetrical hemispheric processing of local and global aspects of melodies has been confirmed by Peretz (1990) with right vs. left brain-injured patients, using the same types of task. This parallels the finding that the right hemisphere contributes more to global aspects of visual stimuli, and the left hemisphere to local components in the visual modality—a reliable finding obtained from ERP (evoked-response potential) and fMRI techniques (Fink et al., 1997; Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998).

The predictions regarding performance differ based on the particular manipulation performed on the melodies. In the nontransposed condition, the clinical and comparison groups should exhibit the same level of performance when the comparison and target melodies are identical. When they differ, the comparison group is expected to exhibit a global superiority effect as indicated by better discrimination of contour-violated than contour-preserved melodies. The clinical group, however, is not expected to show this contour superiority effect following the absence of global bias predicted by the HDH hypothesis.

In the transposed condition, typically developing children should be able to discriminate the melodies despite the presence of a change in pitch level between the two melodies to be discriminated. They should be able to recognise "same" transposed melodies and, for the "different" condition, they should show superior detection in the contour-violated than the contour-preserved condition. However, an overall decrease in performance level is expected in comparison to the nontransposed condition due to the lack of absolute pitch cues for discrimination. Transposition should be much more problematic for individuals with autism, since the WCC model predicts a propensity to rely on absolute pitch rather than relative pitch. If this bias generalises to melodies, individuals with autism are likely to judge all melodies in the transposed condition as "different", hence resulting in an abnormally high number of false alarms on the "same" trials. Moreover, in the "different" condition, because of their tendency to focus on more elementary properties of melodies according to the WCC model, the clinical subjects are expected to differentiate contour-preserved and contour-violated melodies at a similar level.

Method

Participants

Two groups of participants completed the study. The first was a clinical group comprised of 13 participants with high-functioning autism (HFA, $N = 12$) or Asperger syndrome ($N = 1$). The diagnosis of autism was obtained through administration of a standardised interview, the Autism Diagnostic Interview-Revised (ADI-R) (Lord, Rutter, & Le Couteur, 1994), and clinical observations in which DSM-IV (American Psychiatric Association, 1994) criteria for autism were explicitly checked.

The ADI-R is conducted with a parent or close relative of the person believed to be autistic. It compiles information about the first 4 to 5 years of life as well as the current age of the individual, in the four areas relevant for a diagnosis of autism. All but one participant scored above the ADI cutoff for autism. However, this participant satisfied the DSM-IV criteria for Asperger syndrome.

Clinical participants were recruited from the database of the Rivière des Prairies' specialised clinic for diagnosis and assessment of pervasive developmental disorders. At the time of testing, all participants were students or employed in regular jobs, and lived either with their families or alone. None of the participants were taking medication.

The second group was comprised of 13 typically developing participants, matched to the clinical group on chronological age, nonverbal IQ (WAIS-WISC), and laterality. Typically developing participants were selected on a matching basis from

Table 1
Characteristics of HFA Individuals and Typically Developing Participants (TD)

	Age		Laterality		Nonverbal IQ	
Group	Mean	*SD*	Mean	*SD*	Mean	*SD*
HFA	16.73	6.90	66.54	46.26	106.69	11.13
TD	15.33	3.41	42.31	85.75	105.54	11.24

the database of the clinic. The maximum score difference for nonverbal IQ was of ± 10 points on the child and adult versions of Weschler Scales of Intelligence (Wechsler, 1974, 1981). The stringent exclusion criteria did not allow matching for gender: two girls were included in the clinical group and none in the typically developing group. Typically developing participants with any of the following characteristics were excluded: (1) any past or present neurological or psychiatric disorders, (2) medication interfering with the central nervous system, (3) neurodevelopmental cognitive disorders, (4) learning disabilities, (5) poor school attendance, and (6) any first-degree relatives with autism, neuropsychiatric disorders, or neurodevelopmental cognitive disorders.

All participants were of normal intelligence (Full Scale IQ > 80), and older than 10 years. Based on findings from a pilot study, this age appears to be the youngest at which typically developing participants succeed on the task. Only participants without musical experience, a fortiori without musical "special abilities" were included in the study, as musical expertise produces a local bias in musical processing (Bever & Chiarello, 1977). Both groups were paid for their participation. Table 1 shows the individual values, means, and standard deviations for chronological age and nonverbal IQ. No statistical differences were found in a *t*-test conducted between the two groups on these variables.

Materials

Twelve melodies, originally used by Peretz (1987) with university students, served as the basic set of stimuli. The melodies were tonal in that they all started and ended on the tonic, and only included diatonic notes. Each contained nine tones, with each tone lasting 350 msec, except for the final one that lasted twice as long. The melodies were computer generated on a TX81Z Yamaha synthesiser approximating the timbre of a piano. Three types of modification were applied to each of these 12 basic melodies.

One modification consisted of transposing each melody to a near key, either by raising each pitch by a perfect fifth or by diminishing each pitch by a fourth (as in Fig. 1, example B). The other modification consisted of creating a contour-violated alternate melody of each basic melody by changing the pitch of one tone so that it modified the pitch direction of the surrounding intervals (see C in Fig. 1, for an example of these contour changes; i.e., the interval directions surrounding the critical pitch were modified from +, + to −, +), while maintaining the original key. The serial position of this modified pitch varied across melodies; it either fell at the beginning of the melody, in the middle, or at the end, while avoiding the first and last tone positions. The third manipulation consisted of creating a contour-preserved alternate melody of these contour-violated melodies by modifying the same critical pitch to the same extent (in terms of semitone distance), yet maintaining the original contour and key (see D in Fig. 1).

Average departures from the tonic were made equivalent across the contour-violated and contour-preserved melodies, with a mean of 4.4 and 4.5 scale degrees, respectively. Thus, the change affected an important scale degree (i.e. a member of the tonic triad, as in C) or a less important scale degree (i.e. a nonmember of the tonic triad, as in D) equally often across the contour-violated and contour-preserved melodies.

The average interval sizes for the two intervals surrounding the changed pitch were also made equivalent across the contour-violated and the contour-preserved melodies, with means of 2.2 and 3.3 vs. 4.0 and 3.6 semitones for the preceding and following interval of the changed pitch in the contour-violated and contour-preserved melodies, respectively. The interval sizes for each of the 12 melodies were submitted to an ANOVA using manipulation (contour-violated vs. contour-preserved) and interval position (preceding vs. following) as within-item factors. No main effects or interactions were obtained. Thus, although the interval sizes were, on average, slightly larger in the contour-preserved melodies than in the contour-violated melodies, this difference was not significant.

Two sets, each consisting of 2 practice trials and 48 experimental trials, were constructed with these melodies. Each trial consisted of a warning signal and a target melody followed, after a 2 sec silent interval, by a comparison melody. Duration of the inter-trial interval was 5 sec. A first set, prepared for the nontransposed condition, was constructed in such a way that it included 24 trials of identical melodies and 24 trials of different melodies. When different, the comparison was the contour-violated alternate melody (for example, A followed by C in Fig. 1) in 12 trials and the contour-preserved alternate melody in the remaining 12 trials (e.g. A followed D of Fig. 1).

The second set, prepared for the transposed condition, was similar to the nontransposed condition in that it maintained the same comparison melodies; the only modification was that each target melody (either same or different) was replaced by its transposed version (for example, B followed by C or D in Fig. 1). Therefore, on each trial of this latter set, the target melody was always higher or lower in pitch level than the comparison melody. Melody pairs in each set were recorded on tapes in a different random order.

Figure 1. Example of basic melody (A), its transposed version (B), its contour-violated (C), and its contour-preserved (D) transformations.

Procedure

All participants were presented with the nontransposed condition first, followed by the transposed condition, in one session of 45 minutes with a 10 minute break between conditions. On each trial of both conditions, participants were instructed to judge whether the two successive melodies were the "same" or "different". For the transposed version, they were further instructed to disregard the fact that the melodies were played at different pitch levels, as if they were to judge whether a melody sung by a man was the same as or different from a subsequent melody sung by a woman (or vice versa). Participants received feedback regarding the accuracy of their responses only on the practice trials.

Participants were tested individually with a Hitachi tape recorder that delivered the stimuli at a comfortable level through two built-in speakers. The responses were made orally and recorded by the experimenter. Data from one participant in each group were discarded because the performance of this individual was considered to be at chance level, as computed through a binomial test, in the nontransposed condition (with less than 30 correct responses out of 48 trials).

Results

The responses on "different" trials were classified as hits if an alternate comparison melody was correctly judged as "different", and responses on "same" trials were classified as false alarms if an identical comparison melody (irrespective of pitch level) was incorrectly judged as "different". The mean proportions of hits and false alarms obtained in each condition for the contour-violated and contour-preserved melodies in the clinical and control groups are presented in Table 2.

As can be seen, the overall pattern of performance was similar in the two groups, with the clinical group generally obtaining higher hit scores. The rate of false alarms was very similar in all conditions for both groups. This was confirmed by a preliminary ANOVA in which group (clinical vs. control) was the between-subjects factor and condition (nontransposed vs. transposed) the within-subjects factor (all F being inferior or equal to 1). Therefore, for each participant, the proportion of false alarms was subtracted from his/her hit score in order to obtain a single discrimination score in each condition.

The discrimination scores were submitted to an ANOVA in which group (clinical vs. control) served as the between-subjects factor and condition (nontransposed vs. transposed) and melodic change (contour-violated vs. contour-preserved) as within-subjects factors.

Main Effects

Overall, the clinical and comparison groups processed the melodies along similar principles. Both groups showed impaired performance when melodies were transposed, as compared to their performance in the nontransposed condition, $F(1, 24) = 15.26$, $p < .001$, suggesting that all subjects used AP to some extent to discriminate the nontransposed melodies. Similarly, both groups displayed an advantage for discriminating contour-violated melodies over contour-preserved melodies, irrespective of the presence of transposition, $F(1, 24) = 25.01$, $p < .0001$. This result indicates that all subjects used contour as a discrimination cue. Finally, the observation that performance was above chance in discrimination of contour-preserved melodies in the transposed condition revealed that all subjects were able to discriminate the melodies on the basis of intervals alone. In sum, all participants made efficient use of AP, interval or scale distance, and pitch direction in melody discrimination. In contrast to the WCC hypothesis, global processing is intact in the auditory modality.

Finally, the analysis failed to confirm the presence of a group effect, $F(1, 24) = 3.01$, n.s., indicating that the generally better performance of the clinical group is statistically unreliable. However, as predicted, there seemed to be a larger difference between the clinical and control group in discriminating the nontransposed contour-preserved melodies (with discrimination scores of 53% and 38% for the clinical and control group, respectively).

Simple Effects

Although this difference was not borne out by an interaction between the group, transposition, and melodic factors, $F(1, 24) = 2.23$, n.s., it was assessed with a one-tailed t-test. This is justifiable for three reasons. First,

Table 2
Mean Proportion (%) of Hits and False Alarms Obtained in the Nontransposed and Transposed Conditions for the Contour-violated and Contour-preserved Melodies in Both Groups

	Transposition condition			
	Nontransposed		Transposed	
	Contour-violated	Contour-preserved	Contour-violated	Contour-preserved
HFA participants				
Hits				
Mean	83	74	69	57
SD	14	12	20	15
False alarms				
Mean	20		16	
SD	10		17	
TD participants				
Hits				
Mean	78	58	62	50
SD	11	16	14	11
False alarms				
Mean	21		20	
SD	12		13	

this particular difference was predicted by the WCC and HDH hypotheses. Second, enhanced local processing has been found in several visual tasks (Mottron, Belleville, et al., 1999; Plaisted, Swettenham, & Rees, 1999) and, finally, enhanced pitch processing is highly compatible with the exceptional pitch-processing abilities exhibited by musical savants with autism (Mottron, Peretz, et al. 1999) and the superior pitch memory exhibited by children with autism (Heaton et al., 1998). The analysis yielded a significant effect, $t(24) = 3.04$, $p < .01$. This advantage of the clinical over the control group for discrimination of contour-preserved melodies was probably due to a more effective use of AP. In effect, when AP was no longer available for discrimination in the transposed condition, the clinical group no longer outperformed the control group, $t\,(24) = 1.255$, n.s., for the contour-preserved melodies in the transposed condition.

General Discussion

The purpose of the present study was to assess global and local processing of musical stimuli in individuals with autism. Global processing was assessed using two independent criteria: a superior recognition of modified melodies in the nontransposed, contour-violated condition over the contour-preserved condition, and a generally normal performance in the transposed condition. Local processing was assessed by examining participants' ability to detect melody modifications in the nontransposed, contour-preserved condition as well as by the presence of a detrimental effect of transposition on recognition of identical melodies.

Consistent with the central coherence hypothesis (Frith, 1989), we expected to find poor performance in global processing, along with an enhanced local bias. In accord with the hierarchical deficit hypothesis (Mottron & Belleville, 1993), we expected to find an absence of the global advantage effect presented by typically developing persons. However, local processing was expected to be similar in the clinical and comparison groups.

Consequences of Normal Global and Isolated Enhanced Local Processing for Weak Central Coherence and Hierarchisation Deficit Hypothesis

Our first finding with respect to *global processing* was that the clinical group possessed the same advantage as the comparison group in the contour-violated condition over the contour-preserved condition. This reveals that, on a task that is successful in eliciting the global advantage found in the literature, persons with autism process hierarchical musical stimuli with a global advantage. Second, persons with autism recognised the identical, transposed melodies and, indeed, did so to the same extent as participants in the control group. This indicates that differences in pitch did not mask the perception of contour similarity (i.e., that persons with autism were able to process the contour of a melody even when the contribution of AP was suppressed, hence constituting a second, strong argument for intact global processing).

It is necessary to address whether intact recognition of transposed melodies and superior recognition of modified melodies in the contour-violated condition, instead of normal global processing, could result from a mere local strategy. Indeed, contour is a succession of ascending or descending pitch directions. Athough contour is, by definition, independent of absolute pitches and pitch interval sizes, it is logically plausible to obtain the representation of a large-scale melodic contour by adding several small-scale units (or "links"), with each link composed of two pitches separated by one interval. As an analogy, the local-by-local graphic construction exhibited by the savant draughtsman EC (Mottron & Belleville, 1993), and by nonsavant individuals with autism, is compatible with normal (Mottron, Belleville, et al., 1999) and occasionally outstanding (Mottron & Belleville, 1995) conservation of global properties (e.g. proportion). Nevertheless, although a chaining strategy could result in the correct reproduction of a melody and allow for the detection of melody modifications, this could not result in a *superior* detection of altered melodies in a condition where contour is modified. If the whole is superior to the sum of the parts, juxtaposition of parts cannot produce an advantage of whole.

The typical global advantage in high-functioning individuals with autism has been reported previously by several authors. Mottron, Burack, Stauder, and Robaey (1999) found faster detection of global rather than local targets in using hierarchical stimuli (large letters into which small letters were embedded) in a divided attention condition. In addition, advantages were found for "good" geometrical figures over "bad" ones in a visual parsing task, an effect that requires intact perception of configural properties. Ozonoff, Strayer, Filloux, and McMahon (1994) and Plaisted et al. (1999), using hierarchical stimuli in a selective attention condition, found similar global advantage and global interference effects in clinical and comparison groups. Therefore, the main claim of the hierarchical deficit hypothesis in autism (i.e. absence of a global advantage, or equivalent local and global processing) at the behavioural level remains unsubstantiated. The finding of intact perception of global music features, based on two independent criteria, also challenges the weak central coherence hypothesis in music perception, in which "coherence" is represented by contour. Along with previous reports of normal global processing in the visual modality, this contradicts one of the two predictions by the weak central coherence hypothesis: impaired global processing.

In terms of *local processing*, we found that persons with high-functioning autism performed better than the comparison group when AP could be used for discrimination, due to a superior detection of modified melodies in the contour-preserved (local) condition, in conjunction with normal processing of global features. A similar circumstance of local bias without global deficit has already been encountered in the visual modality in autism. Plaisted et al. (1999), using hierarchical visual stimuli in a divided attention condition, found an atypical local advantage and local interference effect. Nevertheless, the finding of normal global precedence and global interference, using the same subjects and the same stimuli, but in a selective attention condition, suggests typical global processing. Using graphic reproduction of geometrical figures, we also found that persons with autism used a more local graphic strategy than typically developing participants (Mottron, Belleville, et al., 1999). Nevertheless, the clinical group was able to reproduce complex geometric figures with a very high level of quality in the reproduction of proportion, and in a shorter time than the comparison group. Thus, these individuals could not have been impaired in perceiving global aspects of visual stimuli, and the local bias in graphic construction could not have resulted from global impairment.

Therefore, we are obliged to conclude that although a local bias in autism has been confirmed in the visual and auditory modality with several independent paradigms, it is not necessarily associated with a global deficit. The question then arises: is the concept of locality still helpful, and more generally, do "hierarchical" models of autism (WCC and HDH) maintain their heuristic value in describing this "local bias" in autism as we currently interpret it?

Possible Causes of Superior Pitch Processing

As mentioned previously, the Central Coherence model predicts a local bias that results from an imbalance in the integration of information at different levels (Frith & Happé, 1994). However, even if the presence of local superiority partially supports this model, the absence of a global impairment prevents the conclusion that local superiority derives in this case from a global impairment *within the same modality*. Similarly, if pitch ability resulted from a *general* local bias, persons with AP should show abnormal hierarchical perception in both the auditory and visual modalities. This issue has been addressed by assessing hierarchical perception in the visual and auditory modality in the same participant. Mottron, Peretz, et al. (1999) conducted an extensive study of QC, an adolescent with autism who possessed the special ability of AP. AP in identification and production was confirmed. Nevertheless, no abnormalities were found in the perception of hierarchical (local-global) properties for visual patterns and music. This finding indicated that AP in autism might not result from a multimodal deficit in processing global information. In contrast, the observation of a low threshold for auditory stimuli in AP suggests that exceptional pitch perception might be related to enhanced perception for elementary properties of sounds.

This interpretation has received some support by recent findings that several elementary perceptual functions appear to exist at an abnormally high level in persons with autism. Plaisted, O'Riordan, and Baron-Cohen (1998 a, b) established that high-functioning individuals with autism are superior to typically developing participants in discriminating highly similar stimuli to which they had not been pre-exposed (dots differing in their relative position), although this superiority vanished for pre-exposed stimuli. They are also superior in conjunctive visual search (i.e., in a condition where targets are composed of a conjunction of two features, each of which is shared by a category of distracters). Both our findings and those of Plaisted et al. strongly suggest that over-development of low-level perceptual processing might extend to a possibly large number of basic perceptual functions in autism. However, it remains to be demonstrated whether the same subjects present all of these types of enhancement concurrently.

Enhanced Perceptual Processing: A Compensatory Mechanism?

We discussed elsewhere (Mottron & Burack, in press) the manner in which enhanced perception for elementary properties of incoming stimuli in autism may be interpreted in the more general framework of Paradoxical Functional Facilitation (PFF; Kapur, 1996). PFF furnishes an inventory of the cognitive mechanisms (release of inhibition, suppression of an antagonist function when two systems are typically in competition, functional compensation) by which a neurological deficit may produce enhanced performance. Insights regarding the causal mechanism that produces superior performance in atypical development might indeed be achieved by examining other pathological conditions in which superior performance in basic perceptual processing is produced to compensate for a known deficit. For example, a developmental compensation resulting in a superior ability in the auditory modality has recently been found in congenitally blind persons (Lessard, Paré, Lepore, & Lassonde, 1998). Specifically, visually impaired persons are indeed superior to normal adults in determining spatial localisation of sounds. Better performance in the intact modality might be explained by an increase in neuronal resources devoted to this function, as evidenced, for example, by a larger amount of brain tissue devoted to intact modalities in congenitally blind persons (Sadato et al., 1996). Therefore, it is possible that enhanced perceptual processing results from a compensation mechanism where perception compensates for nonperceptual processes, in the same manner that, for blind persons, enhanced auditory perception compensates for visual impairment.

In our study, the (purported) compensation does not shed light on the cognitive locus of the deficit for which the compensation occurs. Our findings do not help to discriminate among the various candidates for the primary cognitive deficit in autism. In particular, these results do not allow us to discriminate between specific deficits in the processing of social information, such as "theory of mind" (Baron-Cohen, Leslie, & Frith, 1985) and nonspecific deficits in other types of complex operations (executive functions; Ozonoff, Pennington, & Rogers, 1991; complex operations, regardless of type; Minshew, Goldstein, & Siegel, 1997). Considering that enhanced performance in autism has been found mainly for elementary operations (pitch processing, visual search, visual discrimination), and that impaired mentalising and executive operations share properties of complexity (Zelazo & Frye, 1998), a possible framework within which to examine compensatory relations would involve testing basic enhanced processing against deficits in complex operations.

An alternative proposal to the compensation hypothesis attributes the enhanced performance of elementary perceptual modules to an intrinsic, primary property of neuronal networks in autism, the same as those that produce a deficit in higher-order processing. This would modify the primary/secondary causal relationship between enhanced basic operations and impaired complex ones (like theory of mind or executive function deficits), both resulting from an anomaly in neuronal learning properties. Some researchers have suggested that modifying the learning properties of neuronal networks might produce superior discrimination performances (Oliver, Johnson, Karmiloff-Smith, & Pennington, 2000), although application of this line of thought to autism is at its inception and thus remains imprecise in terms of its predictions.

Enhanced Perceptual Processing and Peaks of Performance

According to Morton and Frith's (1995) general description of cognitive models of autism, a single cognitive deficit might explain heterogeneous symptoms in multiple and heterogeneous behaviours. The failure of an elementary operation that is mandatory for several behaviours, either concurrently or as development proceeds, would yield the characteristics described as symptoms of autism. Nevertheless, the claim that a sole cognitive deficit might be responsible for two symptoms of autism as distinct as, for example, theory of mind deficits and over-representation of absolute pitch, is difficult to maintain. This led Frith and Happé (1994) to propose two core deficits, one for the "triadic" symptoms (social, communication, imagination) and one for the "nontriadic" symptoms, which is the "central coherence" deficit. Indeed, this last group of characteristics overlaps with the domains of processing where a "local bias" may be found. We propose to increase the precision of this rather general statement. First, the relation between the two core deficits might be a *compensatory* one. A deficit in "higher" processes might produce a superior development of perceptual modules devoted to elementary visual and auditory features. Second, certain special abilities and peaks of performance in autism relate only indirectly to a deficit in high-level cognitive operations, through the mediation of a *hidden variable*, the enhanced processing of physical aspects of stimuli. For example, peaks in the block design subtest of the WISC (Shah & Frith, 1993) would be related only indirectly to deficits in complex levels of processing, through the mediation of enhanced recognition of simple figures, instead of resulting directly from a central coherence or a hierarchical deficit. Finally, one of the cognitive *deficits*—that which is responsible for the characteristics described in terms of the central coherence deficit—might be in fact the *over-development* of elementary perceptual modules.

In sum, our finding of superior absolute pitch in the presence of normal processing of global music features extends our understanding of local-global processing in this population. First, it confirms that enhanced "local" processing is present in the auditory as well as the visual modality in autism. Second, it refutes the hypothesis of a deficit in the perception of global properties in the auditory modality, and converges with recent findings of normal global perception in the visual modality. Third, recent findings of superior discrimination for highly similar novel stimuli, and superior visual search, in addition to the present finding of enhanced pitch perception, suggest that several basic perceptual operation are enhanced in autism. An important future issue will be to establish if it is processing of novelty and dissimilarity per se that is enhanced, for any type of material, or if autism is characterised by enhanced activity of a restricted and fixed number of elementary perceptual modules.

Acknowledgements—Funding for this project was provided by a Chercheur Boursier du Fonds de la Recherche en Santé du Québec (FRSQ) award to L. Mottron, two research awards from the Medical Research Council of Canada to L. Mottron and I. Peretz, and a studentship award of the FRSQ to E. Ménard. We thank Patricia Jelenic, Catherine VanHalle, and Bernard Bouchard, who helped with the testing and stimuli construction, and J. Boseovki for editing the English version of the manuscript. We are grateful to Sylvie Belleville and Jake Burack for their helpful comments. Special thanks is also extended to an anonymous reviewer for providing useful suggestions regarding data presentation and interpretation.

References

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

Applebaum, E., Egel, A. L., Koegel, R. L., & Imhoff, B. (1979). Measuring musical abilities of autistic children. *Journal of Autism and Developmental Disorders*, *9*, 279–285.

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a "theory of mind"? *Cognition*, *21*, 37–46.

Bever, T., & Chiarello, R. (1977). Cerebral dominance in musicians and nonmusicians. *Science*, *184*, 537–539.

Blackstock, G. (1978). Cerebral asymetry and the development of early infantile autism. *Journal of Autism and Childhood Schizophrenia*, *8*, 339–353.

Dowling, W. J. (1978). Scale and contour: Two components of a theory of memory for melodies. *Psychological Review*, *85*, 341–354.

Fink, G. R., Halligan, P. W., Marshall, J. C., Frith, C. D., Frackowiak, R. S., & Dolan, R. J. (1997). Neural mechanisms involved in the processing of global and local aspects of hierarchically organized visual stimuli. *Brain*, *120*, 1779–1791.

Fodor, J. A. (1983). *The modularity of mind*. Cambridge, MA: MIT Press.

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

Frith, U. (1991). *Autism and Asperger syndrome*. Cambridge: Cambridge University Press.

Frith, U., & Happé, F. (1994). Autism: Beyond "theory of mind". *Cognition*, *50*, 115–132.

Happé, F. G. (1996). Studying weak central coherence at low levels: Children with autism do not succumb to visual illusions. A research note. *Journal of Child Psychology and Psychiatry*, *37*, 873–877.

Happé, F. G. (1999). Autism: Cognitive deficit or cognitive style? *Trends in Cognitive Science*, *3*, 216–222.

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

Heinze, H. J., Hinrichs, H., Scholz, M., Burchert, W., & Mangun, G. R. (1998). Neural mechanisms of global and local processing. A combined PET and ERP study. *Journal of Cognitive Neuroscience*, *10*, 485–498.

Kapur, N. (1996). Paradoxical functional facilitation in brain-behaviour research: A critical review. *Brain*, *119*, 1775–1790.

Lessard, N., Paré, M., Lepore, F., & Lassonde, M. (1998). Early-blind human subjects localise sound sources better than sighted subjects. *Nature*, *395*, 278–280.

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*, 659–686.

Miller, L. K. (1999). The savant syndrome: Intellectual impairment and exceptional skill. *Psychological Bulletin*, *125*, 31–46.

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.

Morton, J., & Frith, U. (1995). Causal modelling: A structural approach to developmental psychopathology. In D. Cicchetti & D. J. Cohen (Eds.), *Manual of developmental psychopathology, Vol. 1* (pp. 357–390). New York: John Wiley & Sons.

Mottron, L., & Belleville, S. (1993). A study of perceptual analysis in a high-level autistic subject with exceptional graphic abilities. *Brain and Cognition*, *23*, 279–309.

Mottron, L., & Belleville, S. (1995). Perspective production in a savant-autistic draughtsman. *Psychological Medicine*, *25*, 639–648.

Mottron, L., Belleville, S., & Ménard, E. (1999). Local bias in autistic subjects as evidenced by graphic tasks: Perceptual hierarchization or working memory deficit? *Journal of Child Psychology and Psychiatry*, *40*, 743–756.

Mottron, L., & Burack, J. (in press). Enhanced perceptual functioning in the development of persons with autism. In J. A. Burack, T. Charman, N. Yirmiya, & P. R. Zelazo (Eds.), *The development of autism: Perspectives from theory and research*. Hillsdale, NJ: Lawrence Erlbaum.

Mottron, L., Burack, J., Stauder, J. E., & Robaey, P. (1999). Perceptual processing among high-functioning persons with autism. *Journal of Child Psychology and Psychiatry*, *40*, 203–212.

Mottron, L., Peretz, I., Belleville, S., & Rouleau, N. (1999). Absolute pitch in autism: A case study. *Neurocase*, *5*, 485–502.

Oliver, J., Johnson, M. H., Karmiloff-Smith, A., & Pennington, B. (2000). Deviations in the emergence of representation. *Developmental Sciences*, *3*, 1–23.

Ozonoff, S., Pennington, B. F., & Rogers, S. J. (1991). Executive function deficits in high-functioning autistic individuals: Relationship to theory of mind. *Journal of Child Psychology and Psychiatry*, *32*, 1081–1105.

Peretz, I. (1987). Shifting ear differences in melody comparison through transposition. *Cortex*, *23*, 317–323.

Peretz, I. (1990). Processing of local and global musical information by unilateral brain-damaged patients. *Brain*, *113*, 1185–1205.

Peretz, I., & Morais, J. (1987). Analytic processing in the classification of melodies as same or different. *Neuropsychologia*, *25*, 645–652.

Peretz, I., & Morais, J. (1993). Specificity for music. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology, Vol 8* (pp. 373–390). Amsterdam: Elsevier Publishers.

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., Swettenam, J., & Rees, L. (1999). Children with autism show local precedence in a divided attention task and global precedence in a selective attention task. *Journal of Child Psychology and Psychiatry*, *40*, 733–742.

Robertson, L. C., & Delis, D. C. (1986). "Part-whole" processing in unilateral brain-damaged patients: Dysfunction of hierarchical organization. *Neuropsychologia*, *24*, 363–370.

Sadato, N., Pascual-Leone, A., Grafman, J., Ibanez, V., Deiber, M.-P., Dold, G., & Hallett, M. (1996). Activation of the primary visual cortex by Braille reading in blind subjects. *Nature*, *380*, 526–528.

Shah, A., & Frith, U. (1983). An islet of ability in autistic children: 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 task? *Journal of Child Psychology and Psychiatry*, *34*, 1351–1364.

Sloboda, J. A., Hermelin, B., & O'Connor, N. (1985). An exceptional musical memory. *Music Perception*, *3*, 155–170.

Wechsler, D. (1974). *Wechsler Intelligence Scale for Children-Revised*. New York: Psychological Corporation.

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale-Revised*. New York: Psychological Corporation.

Zelazo, P. D., & Frye, D. (1998). Cognitive complexity and control: The development of executive function. *Current Directions in Psychological Science*, *7*, 121–126.

Manuscript accepted 6 April 2000