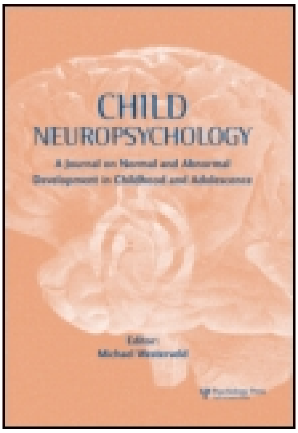

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Processing of musical structure by high-functioning adolescents with autism spectrum disorders

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Processing of musical structure by high-functioning adolescents with autism spectrum disorders

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Enhanced pitch perception and memory have been cited as evidence of a local processing bias in autism spectrum disorders (ASD). This bias is argued to account for enhanced perceptual functioning (Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006) and central coherence theories of ASD (Frith, 1989; Happé & Frith, 2006). A local processing bias confers a different cognitive style to individuals with ASD (Happé, 1999), which accounts in part for their good visuospatial and visuoconstructive skills. Here, we present analogues in the auditory domain, *audiotemporal* or *audioconstructive* processing, which we assess using a novel experimental task: a musical puzzle. This task evaluates the ability of individuals with ASD to process temporal sequences of musical events as well as various elements of musical structure and thus indexes their ability to employ a *global* processing style. Musical structures created and replicated by children and adolescents with ASD (10–19 years old) and typically developing children and adolescents (7–17 years old) were found to be similar in global coherence. Presenting a musical template for reference increased accuracy equally for both groups, with performance associated to performance IQ and short-term auditory memory. The overall pattern of performance was similar for both groups; some puzzles were easier than others and this was the case for both groups. Task performance was further found to be correlated with the ability to perceive musical emotions, more so for typically developing participants.

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Findings are discussed in light of the empathizing-systemizing theory of ASD (Baron-Cohen, 2009) and the importance of describing the strengths of individuals with ASD (Happé, 1999; Heaton, 2009).

Keywords: Perception of structure; Musical structure; Music cognition; Global processing; Autism spectrum disorders.

Autism spectrum disorders (ASD) include autism or autistic disorder, Asperger's syndrome, and pervasive developmental disorder not otherwise specified (PDD-NOS; Klin, McPartland, & Volkmar, 2005). Combinations of three criteria characterize ASD: impairments in social interaction, impairments in verbal and nonverbal communication, and restricted, repetitive, and stereotyped patterns of behavior, interests, and activities (American Psychiatric Association [APA], 2000). Behaviors targeted by this last diagnostic criterion include "encompassing preoccupation with one or more stereotyped and restricted patterns of interest that is abnormal either in intensity or focus [and] persistent preoccupation with parts of objects" (American Psychiatric Association, 2000, p.75). Among the theories that have accounted for this behavior, two frequently cited theories are "Weak Central Coherence" theory (WCC), first introduced in 1989 by Frith, and the "Enhanced Perceptual Functioning" theory (EPF) proposed by Mottron and Burack in 2001. Both theories were revised and presented in the same issue of the *Journal of Autism and Developmental Disorders* in 2006 (Happé & Frith, 2006; Mottron, Dawson, Soulières, Hubert, & Burack, 2006). With this revision, WCC was renamed central coherence (CC). Both theories acknowledge the increasing evidence supporting enhanced *local*, or piecemeal processing of experimental stimuli in ASD. Whether *local* processing has a positive, negative, or null impact on *global* processing in ASD remains an open question.

In line with these theories, Happé (1999) proposed that autism, traditionally described in terms of cognitive *deficits*, should be thought of rather as a different cognitive *style.* Individuals with this processing style tend to focus on details and this has an impact on many spheres of life ranging from solving problems (learning, school, work) to reciprocal social interaction. In proposing this, Happé reviewed evidence at the perceptual, verbal-semantic, and visuospatial and visuoconstructive levels.

At a verbal-semantic level, individuals with ASD do not always rely on context to choose the correct pronunciation of homographs (e.g., "In her eye there was a big tear" vs. "In her dress there was a big tear"; Frith & Snowling, 1983; Hala, Pexman, & Glenwright, 2007; Joliffe & Baron-Cohen, 1999). Examples of a different cognitive style in ASD at the perceptual level include better performance of individuals with autism on tasks of visual illusions, that is, they do not succumb to the illusion as often as controls (Happé, 1996). Good performance of individuals with autism on the Embedded Figure task (Joliffe & Baron-Cohen, 1997) and the block design task (Shah & Frith, 1993) are viewed as evidence of a different cognitive style for visuospatial and visuoconstructive processing. Superior performance of children and adults with high-functioning autism or Asperger's syndrome on the block design, object assembly, and digit span subtests has been reported, relative to the other subtests of the Wechsler intelligence scales (Happé, 1994; Lincoln, Courchesne, Kilman, Elmasian, & Allen, 1988; Spek, Scholte, & van Berckelaer-Onnes, 2008). Digit span requires short-term auditory memory whereas block design and object assembly involve a combination of visuospatial and visuoconstructive processing. In these latter two tasks, parts must be physically arranged in space and put together to form the desired whole figure. A peak in performance on the block design subtest has been observed in 21% of high-functioning individuals with ASD (Caron, Mottron, Berthiaume, & Dawson, 2006) to 38% (Siegel, Minshew, & Goldstein, 1996) and has been interpreted within the context of both central coherence and enhanced perceptual functioning theories. Interestingly, Caron and colleagues (2006) reported more unusual preoccupations and sensory interests (tastes, textures, etc.) for high-functioning individuals with ASD who presented a peak performance on the block design task than for those who did not present such a peak. Auditory sensitivity has also been described in ASD. Children with ASD show aversion of sounds that are not disturbing to others (*auditory allodynia)* and moreover, exhibit *odynacusis*, a lowered pain threshold to loud sounds (Levitin, Cole, Lincoln, & Bellugi, 2005).

The current study assesses perceptual processing in ASD in the auditory domain and thus evaluates if the cognitive style and relative strengths shown by individuals with ASD for visuospatial and visuoconstructive processing are also present in the auditory domain. The experimental task can be thought of as an assessment of two skills that we propose to call *audiotemporal* and *audioconstructive* processing. Visuospatial processing refers to the ability to make sense of the visual environment and, more specifically, of the spatial relations among visual stimuli; visuospatial processing is a necessary component for successful visuoconstructive processing. In our auditory analogue, we regard audiotemporal processing as the ability to integrate elements of a melody across time and to correctly organize temporal sequences of musical events. (We rejected the term "audiospatial" processing in order to avoid confusions with auditory spatial location). Audioconstruction is the process by which these sequences are properly ordered requiring consideration of several elements of musical structures such as melody, harmony, contours, rhythm, etc. As with its visual analogue, audioconstructive processing entails audiotemporal processing. An exception to the analogy is that in the visual domain, the spatial and temporal relationship amongst objects (or visual events) can be independent but this is not the case in music, as music is necessarily manifest across time.

Few studies have assessed global processing of music but there is evidence of enhanced local processing of music in ASD. Individuals with ASD exhibit superior abilities in associating pitches (single tones) with arbitrary labels and remembering these associations, which can be seen as related to absolute pitch abilities (Heaton, Hermelin, & Pring, 1998). However, Altgassen, Kliegel, and Williams (2005) failed to replicate Heaton and colleagues' (1998) findings for identification of single pitches. Nonetheless, individuals with ASD have been shown to discriminate pitches (Bonnel et al., 2003) and subtle changes in pitch direction (Heaton, 2005) with greater accuracy than controls, abilities believed to reflect an enhanced local processing style. Similarly, they can identify alterations of a single interval in a contour-preserved melody (Mottron, Peretz, & Ménard, 2000) as well as within a melody where absolute pitch values and timing of pitch direction changes are modified (Foxton et al., 2003), which indicates good local and global processing. In tasks of chord disembedding, where participants have to segregate individual pitches from a chord (group of simultaneously sounded tones), individuals with ASD outperform typicals when they can rely on memory to complete the task (i.e., a pitch-label association that has been previously learned) but fail to show an advantage when "novel" pitches are presented in a consonant (Heaton, 2003) or dissonant chord (Altgassen et al., 2005), the latter having weaker Gestalt properties and often associated to global processing.

Enhanced local processing of music has been reported in autism and Asperger's syndrome. Children with Asperger's syndrome perform slightly better than children with autism at disembedding consonant chords (Altgassen et al., 2005). Young adults with autism discriminate pure tones more accurately than young adults with Asperger's syndrome (Bonnel et al., 2010). In addition to strengths mentioned for pitch perception and memory, individuals with ASD can distinguish happy, sad (Heaton, Hermelin, & Pring, 1999), and scary (Quintin, Bhatara, Poissant, Fombonne, & Levitin, 2011) melodies, and they can associate emotional states to music (Heaton, Allen, Williams, Cummins, & Happé, 2008).

Studies of music perception in ASD that employ short strings of single pitches do not necessarily inform us on how individuals with ASD process real music and, thus, lack ecological validity (Heaton, Williams, Cummins, & Happé, 2007). Therefore, Heaton and colleagues sought to assess higher level musical processing in ASD using chord progressions consisting of eight chords. Participants judged the relatedness of the final chord to the rest of the series. At both the local and global levels, there were no differences between participants with and without ASD in judging whether or not the last chord of the series represented a correct ending. In other words, participants with ASD did not differ from typicals when judging how musical sentences created by the experimenters should be completed. In comparison to previous studies, Heaton and colleagues rightfully claim to have evaluated higher level musical processing because their stimuli varied many aspects of musical structure at once, that is, pitch, contour, and melody. Their task also relies on musical expectancy.

Implicit knowledge of regularities in western musical structure is thought to develop by mere exposure and to promote similar musical expectancies for most individuals (Tillmann, 2005). Musical expectancy in the general population is independent of musical expertise (Bigand & Poulin-Charronnat, 2006). In tasks of musical production or improvisation, local (note-to-note) sequences exist within the global musical structure expectation (harmony, melody, etc.) of the musical piece or phrase and expectancy is thought to evolve dynamically as the music is played (Schmuckler, 1989, 1990).

Few studies have assessed musical production or improvisation in ASD. Frith (1972) asked children to play tone sequences on four notes of a xylophone. Lower functioning children with autism created sequences with greater regularity (more repeating subunits) and using fewer notes than lower functioning controls; musical productions of children with autism were less creative than controls, independently of level of functioning (Frith, 1972).

In the visual domain, children with ASD have difficulty sequencing shapes based on size (McGonigle-Chalmers, Bodner, Fox-Pitt, & Nicholson, 2007) arranging sequences of pictures (Baron-Cohen, Leslie, & Frith, 1986) and of goal-directed actions involving objects (Zalla, Labruyere, & Georgieff, 2006). They obtain lower scores on the subtests of the Kaufman Assessment Battery for Children and Wechsler Intelligence Scale for Children-Revised (WISC-R) measuring sequential processing than the subtests measuring simultaneous processing (Allen, Lincoln, & Kaufman, 1991). Mixed findings are reported regarding procedural learning of motor sequences in ASD. High-functioning children with ASD can learn perceptuo-motor sequences as measured by the alternating serial reaction time task (Barnes, Howard, Howard, Gilotty, Kenworth, Gaillard, et al., 2008) but have difficulty learning a simpler serial reaction time task (Mostofsky, Goldberg, Landa, & Denckla, 2000). However, procedural sequence learning on the latter task can be acquired through extensive behavioral training, even for children with autism who have a lower level of functioning (Gordon & Stark, 2007). Individuals with ASD also exhibit alternative approaches to completing the rotary pursuit, a task where participants learn to monitor the movement of a geometric figure (Gidley Larson & Mostofsky, 2008). Thus, there is emerging evidence of a reduced ability to order temporal sequences of events in the visual and visuomotor domains in ASD but little is known about this ability in the auditory domain, which relies on audiotemporal processing.

Research Question and Hypothesis

The study is designed to probe audiotemporal and audioconstructive processing in ASD. We propose a task (with two conditions: creation and replication) where participants attempt to create or re-create coherent musical sequences from shorter subsequences. The task is a musical puzzle that participants have to solve by physically placing the pieces (musical segments) in the order that sounds best to them (first condition) and then by replicating a musical template (second condition). The scoring scheme for the musical puzzle, which will be described below, accounts for the coherence of the musical structures produced by the participant, where the maximum possible score corresponds to the most coherent global musical whole.

The task is conceived as an analogue to both visuospatial and visuoconstructive tasks currently described in the literature, and both conditions require the ability to attend to the specific timely sequence or order of notes (audiotemporal) and to manipulate that sequence appropriately within the musical context of harmony, melody, contour, etc. (audioconstructive). (However, we acknowledge, given the temporal nature of auditory stimuli, that the entire stimulus cannot be present at once in its entirety as is the case with visual stimuli.)

Like Heaton and colleagues (2007), we aim to assess processing of higher level musical structure in ASD and to do so in an ecologically valid fashion. Here, we present an experimental task in which many structural attributes of music, that is, pitch, contour, melody, rhythm, and even instrumentation, are included and where task completion relies, in part, on musical expectancy. We have therefore evaluated the participant's musical training and experience and its impact on task performance.

We hypothesize that audiotemporal and audioconstructive processing in ASD will be as good as that of controls, given the cognitive style of individuals with ASD and the strengths they present in auditory processing. We believe these strengths will trump the difficulties with temporal sequencing of stimuli previously reported in ASD in the visual domain, and thus that participants with ASD will be able to correctly order musical events. Given prior evidence of accurate perception of musical emotions in ASD, performance on a task evaluating such ability will be compared to performance on the musical puzzles herein proposed. To our knowledge, this is the first study in which musical structures produced by individuals with ASD are assessed for coherence and compared to their ability to replicate a musical exemplar, in contrast with the passive music listening tasks typically used in experiments evaluating musical processing in ASD.

METHOD

Participants

Twenty-seven typically developing participants (TD) and 29 participants with ASD completed the experimental task but only 24 participants with TD and 24 with ASD (3 with autism, 10 with Asperger's syndrome, and 11 with pervasive developmental disorder not otherwise specified) were retained for analyses based on responses to developmental questionnaires. Parents filled out the Social Responsiveness Scale (SRS; Constantino et al., 2003) and the Social Communication Questionnaire (SCQ; Rutter, Bailey, & Lord, 2003) to verify diagnosis in the case of adolescents with ASD and to ascertain that participants with

Table 1 Descriptive Statistics of Participants' Characteristics.

Group	Age (yr:mo)	VIQ	PIQ	# of inst.	years of train.	DS	LNS	SRS-T	SCQ
ASD ($n = 24$: 5 girls, 19 boys)									
Mean	13:8	91	97	0.96	1.97	9	7	77	19
SD	1:11	21	16	0.91	3.15	4	4	12	5
Range	10–19	62–132	63–129	0–3	0–12	2–19	1–14	43–90	14–29
TD ($n = 24$: 10 girls, 14 boys)									
Mean	12:7	110	108	1.29	2.83	10	10	47	3
SD	2:4	14	14	0.86	2.83	2	3	5	2
Range	7–17	81–133	75–137	0–3	0–11	7–14	3–18	37–55	0–6
Levene's F	1.34	3.21	0.48	0.01	0.001	7.81**	5.63*	9.65**	13.36**
t	1.73	3.81**	2.43	1.48	1.09	1.46	2.87**	11.64**	15.82**

Note. VIQ = verbal IQ; PIQ = performance IQ; both measured with the WASI; # of inst. = number of instruments played, past and/or present; years of train. = number of years of formal musical training; DS = digit span sequencing subtest and LNS = letter-number sequencing subtest of the WISC-IV, scaled scores reported; SRS-T = Social responsiveness scale, T-scores reported; SCQ = Social communication questionnaire, raw scores reported.

*$p < .05$. **$p < .01$. All *p*s are two-tailed.

TD did not show signs of ASD. Of the initial 29 participants with ASD, 2 were excluded because their full-scale IQ (see measures below) was below 65 and 3 more were excluded because they scored in the typical (non-ASD) range on both SRS and SCQ. Of the remaining 24 participants with ASD, 2 had a full-scale IQ below 70 but their VIQ was above 70 in both instances. Thus, the sample comprises high-functioning participants within the spectrum of ASD. Of the remaining 24 participants with ASD, 2 had SRS T-scores below 60 (43 and 59) but their SCQ score were high enough (22 and 20, respectively) for them to remain in the retained ASD group. Of the initial 27 participants thought to have TD, 3 were excluded because they presented a neurodevelopmental or psychiatric disorder that interfered with testing, attention deficit/hyperactivity disorder (ADHD) for example. None of the profiles for the remaining 24 adolescents with TD indicated ASD or other potential confounds. SRS T-scores and SQC scores were significantly different between groups (see Table 1).

Participants with TD were recruited through word of mouth, advertisements placed at the university and posted in four schools in Montreal (two elementary schools and two high schools). Participants with ASD were recruited through a specialized autism clinic at the Montreal Children's Hospital and a school offering special education for children with ASD. All participants with ASD had received a diagnosis by a specialized medical team (child psychiatrist, developmental psychologist, etc.) that conformed to the *Diagnostic and Statistical Manual of Mental Disorders*, text revision (DSM-IV-TR; APA, 2000) criteria. Given the mean age (see Table 1) of the participants and for brevity, we will refer to the participants as adolescents instead of children and adolescents from this point on.

Measures

In addition to the SRS and SCQ mentioned above, verbal, performance, and full-scale IQ scores (VIQ, PIQ, and FSIQ) were obtained using the Wechsler Abbreviated

Scale of Intelligence (WASI; Wechsler, 1999). Because the experimental task requires use of temporal auditory memory, auditory processing and working memory were assessed. We used the digit span and letter-number sequencing subtests of the Wechsler Intelligence Scale for Children, 4th edition (WISC-IV; Wechsler, 2003). The number of musical instruments that participants knew how to play as well as their number of years of musical training and experience were obtained by combining information from the Salk and McGill Musical Inventory (Levitin et al., 2004) completed by parents and a semi-structured interview conducted with the participants (Queen's University Music Questionnaire – Revised, based on Cuddy, Balkwill, Peretz, & Holden, 2005). There were no differences between groups for chronological age, performance IQ, number of instruments played, years of musical experience, and digit-span scaled score (see Table 1).

Materials

The apparatus used in the experiment was a modified version of the children's toy MusicBlocks^{TM} (Neurosmith, Los Angeles, CA, USA). The toy is a musical puzzle consisting of five plastic cubes, each playing a segment of a melody when inserted into any of five square slots inside a molded plastic base that contains a loudspeaker (see Appendix 1). The child's task, in normal play, is to experiment with different placements and orientations of the cubes to result in a "correct" ordering, that is, a complete musical phrase with the five segments playing in their proper order. A cube plays the same sound regardless of what slot it is placed in. This is so that the child can hear the sound that each cube makes (regardless of *where* it is in the sequence of slots) and then position the cube accordingly. In normal play, various markings on the cubes (combinations of colors and shapes) can reliably be used to visually determine the correct ordering of the cubes. In order to ensure that our participants were using purely auditory, and not visual cues, we modified the toy by covering the cubes with opaque white paper, in order to mask the identity of the cube. We then added random designs that could not be used to determine the correct order but could be used as a memory aid for the participants to identify each cube during the execution of the task.

The "correct" melodies and corresponding cube (segments) order employed were those identified by the manufacturer and corresponded to the experimenters' own judgments about correctness. The shortest melody lasted 19 seconds and the longest was 30 seconds. Five different melodies without lyrics were employed. Of the dozens of possible melodies provided by Neurosmith, we selected "Jumpin' Jive," "Bach," "Sounds of the Orchestra," "Bravo Opera," and "Mozart," which correspond to Puzzles 1, 2, 3, 4, and 5, respectively, in Figures 1 and 2. The melody labeled "Mozart" is an adaptation of Mozart's Eine Kleine Nachtmusik - I Allegro (first eight bars and two additional bars adapted to end the excerpt); "Bach" is an adaptation of Bach's Two Part Invention #13 in A minor (first five bars with ending adapted); "Bravo Opera" is a musical adaptation of Verdi's La Donna è Mobile from the opera Rigoletto (first eight bars of the theme). "Jumpin' Jive" and "Sounds of the Orchestra" were created by Neurosmith. The melodies and the segments corresponding to each cube can be heard online: http://Quintin2012.levitinlab.com/

The task was validated with a separate group of 21 participants (19–39 years old; 9 men and 12 women) recruited through word of mouth and advertisements placed at the university in order to evaluate how normal healthy adults respond to the tasks and to infer probable reactions in adolescents with typical development and ASD.

Experimental Task

Participants were seated at a table facing the experimenter, with the MusicBlocks™ toy within reach and one set of cubes at a time, which were placed in front of the toy in a random fashion. None of the participants reported having played with this toy before. A demonstration video can be viewed online: http://Quintin2012.levitinlab.com/

In the first condition (creation), participants arranged the cubes in the order they thought sounded best without an external referent, a condition similar to what children would typically do with this toy. In the second condition (replication), participants heard two times a melody (exemplar), which had been previously recorded from the musical toy, and were immediately asked to reconstruct it with the cubes. A third presentation of the melody was given if participants had not completed the puzzle after 2 minutes, but they were not informed beforehand that this might happen. The most coherent musical sequence, or the maximum score for each puzzle (see below and Appendix 2), corresponded to the melody proposed by the manufacturer. After adapting the task, the most coherent sequence consisted of a different cube order for each puzzle (trial) with one exception due to the melody selection and apparatus limitation (see score sheet in Appendix 2), thus eliminating the possibility that participants would associate a particular visual sequence with the correct answer. The same five puzzles (trials) were presented in both conditions. The creation condition (five puzzles) was always first and the replication condition (five puzzles) was always second. A practice trial was included before the replication condition and was not scored. The puzzles (trials) were presented in three different orders (see Order A in Appendix 2), which were the same for each condition. The two puzzles with similar cube order (based on the visual symbols) were never presented consecutively. Once the musical puzzles were completed, we asked participants a series of questions about the strategies they used to accomplish the task.

Both audiotemporal and audioconstructive processing are necessary for the successful completion of both conditions; although the creation condition places a higher demand on audioconstructive than audiotemporal processing, and the opposite can be said of the replication condition. (Note that we are not adding additional terminology to distinguish constructive and *re*constructive processing, as in the case in the visual domain, that is, the term "visuo*re*construction" is not employed to avoid redundancy with visuoconstructive processing.)

We scored the participant's performance in the same ways for both conditions. The first score tallied the number of cubes placed in the correct *location*. (We defined "correct location" as the cube position specified by the manufacturer for proper completion of the melody, and in all cases, the experimenters verified and agreed that this was the optimal configuration). Note that this melody was presented to participants as an exemplar in the replication condition. For each puzzle, this score ranged form 0 to 5 because there were five cubes per puzzle. However, due to the combinations of "drawing with replacement," not all scores were possible — it is mathematically impossible, for example, to have exactly four correct placements: one misplaced cube (X), means that it needs to be in a different location than it is, which means that whatever cube (Y) is in X's location it is also in the wrong location. Thus, the only possible scores per trial were 0, 2, 3, and 5. The "correct locations" total scores for the five trials ranged from 0 to 25 with some discontinuities, for example, a total score of 24 would have been impossible.

The second score tallied the number of correct local adjacent placements, or *connections*; a score of 1 was assigned when two cubes were placed in "correct" consecutive order regardless of absolute location. Possible scores for each puzzle were of 0, 1, 2, and 4. Thus, the "correct connections" total score ranged from 0 to 20 (with some discontinuities, as before) and a score of 20 was perfectly correlated with error-free performance in the "correct location" score.

We then summed the "correct location" and "correct connection" scores into a total score that ranged from 0 to 45. The analyses presented below were performed on this total score, which we considered an index of the global coherence of the musical structures produced by the participants. We computed a separate score where we tallied the subunits, that is, consecutive correct connections independently of location, included within each of the 10 musical structures (5 puzzles x 2 conditions) generated by participants. This yielded the following possibilities: absence of correct connections, one correct connection (duo of cubes), two nonconsecutive correct connections (two duos of cubes), two consecutive connections (trio of cubes), one connection and two consecutive connections (one duo and one trio of cubes), three consecutive connections (quartet of cubes), or four consecutive connections (quintet of cubes).

Procedure

Participants were tested individually in a soundproof room. The musical puzzle task lasted approximately 30 minutes and was included as part of a larger experimental protocol that lasted approximately 3 hours including breaks. Informed consent was obtained from the parents of all participants and assent was obtained from the participants themselves. Participants and parents were debriefed at the end of each session. Participants received a $20 gift certificate for a music store as compensation and parking was also paid for. The research received ethical approval from both McGill University and McGill University Health Center Research Ethics Boards.

Design and Analysis

The experiment uses a repeated-measures mixed-factorial design, with diagnostic group (ASD, TD) as the between-subjects factor (A), task condition (B; creation and replication) as the within-subject (S) factor, and the five different puzzles as a repeated measures within each condition. Thus, the design is $A \times (B \times S)$. The performance on the two task conditions (creation and replication) was compared using *t*-tests. Multivariate analyses of variance and covariance were then performed to assess group differences (ASD, TD) on task performance (the total score ranging from 0 to 45). We also analyzed group differences using a test of minimal-effect and have compared effect sizes to those previously reported in the literature. This was followed by repeated measures analyses of variance (ANOVA) and calculations of intraclass correlations to evaluate patterns of performance between groups. Strategies reported by participants in order to complete the tasks were examined and compared between groups with a Mann-Whitney *U* test. Correlations between performance on the musical task and an emotion perception task were calculated.

RESULTS

Musical Puzzle

The results obtained are presented in Table 2. As can be observed, a wide range of scores was obtained for both groups in both conditions, which suggests there were neither

Table 2 Descriptives and Comparison of Participants' Responses.

	Creation Condition			Replication Condition					
	Location (0–25)	Connection (0–20)	Total (0–45)	Location (0–25)	Connection (0–20)	Total (0–45)	$t(23)$ $\mu_{\text{replication}} - \mu_{\text{creation}}$	95% C.I.	Cohen's d
ASD ($n = 24$)									
Mean	7.71	7.17	14.88	14.21	11.17	25.36	7.47**	7.59 to 13.41	2.20
SD	3.96	3.78	7.39	6.41	4.26	10.48			
Range	3–19	1–14	4–33	2–25	3–20	5–45			
TD ($n = 24$)									
Mean	8.75	7.67	16.42	17.21	12.79	30.00	7.97**	10.06 to 17.11	2.35
SD	2.94	3.14	5.20	5.20	4.48	9.53			
Range	3–15	2–14	5–27	7–25	4–20	12–45			
$F(1, 46)$			0.70			2.56			
p			.41			.12			
95% C.I. $\mu_{\text{TD}} - \mu_{\text{ASD}}$			−2.17 to 5.26			−1.20 to 10.48			
Cohen's d			0.24			0.46			

Note. Cohen's d: effect size is small if $d = 0.20$, medium if $d = 0.50$, large if $d = 0.80$ (Cohen, 1992); Location = score for "correct locations"; Connection = score for "correct connections."

$^{**}p < .001$.

floor effects nor ceiling effects for task performance. Two-tailed paired-sample *t*-tests revealed a significantly more accurate performance on the replication condition compared to the creation condition and this was the case for both groups combined, $t(47) = 10.79$, $p < .001$, 95% C.I. $\mu_{\text{replication}}$ -μ_{creation}: 9.80 to 14.29, $d = 0.29$, as well as for each group considered separately (see *t* and *p* values in Table 2). ANOVAs revealed that the difference scores for the performance on the two conditions (replication - creation) did not differ significantly between groups, $F(1, 46) = 1.95$, $p = .17$ (two-tailed), 95% C.I. $\mu_{\text{TD}} - \mu_{\text{ASD}}$: -1.36 to 7.5, $d = 0.41$. The average time to complete the musical puzzles did not differ between groups for both the creation, Mean ± *SD*; ASD: 104 ± 45 s, TD: 112 ± 38 s, $F(1, 46) = 0.37$, $p = .55$, 95% C.I. $\mu_{\text{TD}} - \mu_{\text{ASD}}$: -17 to 31, $d = 0.18$, and replication conditions, ASD: 86 ± 42 s, TD: 82 ± 32 s, $F(1, 46) = 0.21$, $p = .65$, 95% C.I. $\mu_{\text{TD}} - \mu_{\text{ASD}}$: -27 to 16, $d = 0.13$.

Although the means presented in Table 2 tend to be slightly higher for the TD group, there was no significant difference between groups for the total scores for the creation and replication conditions as per a multivariate analysis of variance (see *F* and *p* values in Table 2). We can interpret these results to say that participants with ASD and TD did not perform differently on the musical puzzle task but traditional null hypothesis testing does not allow us to say that they performed similarly. To evaluate the absence of group differences further, we performed a minimum-effect test where H_o, group differences account for less than 1% of the variance in the scores on the musical puzzle task, that is, a "minimum effect," and H_I, group differences account for more than 1% of the variance in the scores, that is, a "meaningful effect," according to the procedure detailed in Murphy and Myors (1999). In this procedure, the observed *F* values, $F_{\text{creation}} = 0.70$, $F_{\text{replication}} = 2.56$ (see Table 2), are compared to critical values of a noncentral *F* distribution, $F_{\text{NC}}(1, 40) = 5.64$, $F_{\text{NC}}(1, 50) = 5.93$, $\alpha = .05$ (see Table 1 in Murphy & Myors, 1999). The results of this analysis indicate that the hypothesis of a minimum-effect between groups is not rejected. We thus conclude with $p < .05$ that there are no meaningful differences between the two diagnostic groups. (Note that one can gain greater confidence in findings of no group difference using this method because tests of minimum-effect are less sensitive to sample size; Murphy & Myors, 1999).

To further assess the absence of differences between diagnostic groups, Cohen's *d*, a measure of effect size, was calculated. Cohen's *d* of 0.20 is considered as a small effect size, 0.50 is medium, and 0.80 is large (Cohen, 1992). For comparison, we calculated effect sizes for previous findings assessing auditory processing in ASD reviewed in the introduction (Table 3) based on the procedure detailed in Thalheimer and Cook (2002). Of the previously reported effect sizes associated to nonsignificant findings, two were smaller and five were greater than our $d = 0.24$ (creation condition) and four were smaller and three were greater than $d = 0.46$ (replication condition). Our observed small effect sizes, in comparison to previously reported effect sizes, further support the conclusion of no intergroup differences.

Multivariate analyses of covariance were performed wherein the following variables were entered one at a time as potential covariates: gender, chronological age, number of instruments played, years of musical training, verbal IQ, performance IQ, digit span forward (raw score) and backward (raw score), and letter-number sequencing (scaled score). When the total score for the creation condition was considered as the dependent variable, the effect of years of musical experience as a covariate approached significance, $F(1, 45) = 3.21$, $p = .08$, $d = 0.53$, but the group effect remained nonsignificant, $F(1, 45) = 0.34$, $p = .56$, 95% C.I. $\mu_{\text{TD}} - \mu_{\text{ASD}}$: -2.6 to

Table 3 Comparison of Effect Size (Cohen's *d*) with Previous Studies.

Study	*n* per group controls, ASD	Mean age (rounded in years) controls, ASD	Findings	*F* or *t*	Cohen's *d*
Previous results					
Heaton et al., 1998	10, 10	9, 8	ASD > controls	$F = 12.26^*$	1.65
Mottron et al., 2000	13, 13	15, 13	ASD ≅ controls	$F = 3.01$, *ns*	0.71
			ASD > controls		1.24
				$t = 3.04^*$	
			ASD ≅ controls		0.51
				$t = 1.255$, *ns*	
Foxton et al., 2003	15, 13	18, 18	ASD ≅ controls	$F = 0.02$, *ns*	0.06
			ASD > controls		.66
				$t = 1.69^{\dagger}$	
Altgassen et al., 2005	13, 17	9, 9	TD > controls	$F = 0.93$, *ns*	0.36
			ASD > controls	$F = 0.82$, *ns*	0.35
			ASD > controls	$F = 0.17$, *ns*	0.16
Heaton, 2005	13, 13	10, 10	ASD > controls	$F = 10.35^*$	1.32
	(2 control groups of 13)		ASD > controls	$F = 4.92^*$	0.91
Heaton et al., 2007	10, 10	11, 12	ASD ≅ controls	$F = 3.03$, *ns*	0.56
Current results	26, 26	13, 14	Creation: ASD ≅ controls	$F = 0.70$, *ns*	0.24
			Replication: ASD ≅ controls	$F = 2.56$, *ns*	0.46

Note. $^*p < .05$. $^{\dagger}p = .052$.

4.7, $d = 0.17$. When the total score for the replication condition was considered as a dependent variable, the effect of performance IQ, $F(1, 45) = 4.22$, $p = .05$, $d = 0.61$, digit span forward, $F(1, 45) = 5.19$, $p = .03$, $d = 0.67$, and letter-number sequencing, $F(1, 44) = 6.66$, $p = .01$, $d = 0.76$, were significant but the group effect was not significant in these analyses, with p values of .39, .07, and .52, respectively. When chronological age was considered as a covariate, its effect was not significant, $F(1, 45) = 3.01$, $p = .09$, $d = 0.51$, but the diagnostic group effect was significant, $F(1, 45) = 4.05$, $p = .05$, 95% C.I. $\mu_{TD} - \mu_{ASD}$: -0.01 to 11.76, $d = 0.59$. There was a mildly significant interaction effect between group and chronological age, $F(2, 45) = 3.096$, $p = .055$, 95% C.I. $\mu_{TD} - \mu_{ASD}$: 0.33 to 11.81, $d = 0.52$.

Given that there were no differences between the groups for scores summing performance on all musical puzzles, analyses were performed to compare groups for each of the five musical puzzles separately (Figure 1) and thus assess the pattern of responses of both groups where a difference may perhaps lay. Repeated measures analyses of variance were performed with the diagnostic group as the between-subject factor and, instead of the total score, the sum of "correct location" and "correct connection" for each puzzle as the within-subject factor, which we shall refer to as the "puzzle factor." These ANOVAs revealed that there was again no effect of diagnostic group for both the creation, $F(1, 46) = 0.70$, $p = .41$, and replication conditions, $F(1, 46) = 2.55$, $p = .12$. Significant effects were found for the "puzzle factor" for both the creation, $F(4, 184) = 12.46$, $p < .01$, and replication conditions, $F(4, 184) = 11.41$, $p < .01$, indicating that some musical puzzles were solved more accurately than others, and this was equally the case for both groups as revealed by the lack of interaction effect between the "puzzle factor" and the diagnostic group factor on both the creation, $F(4, 184) = 1.23$, $p = .30$, and replication conditions, $F(4, 184) = 0.91$, $p = .46$. This is illustrated in Figure 1. For instance, scores on Puzzle 1 were lower than scores on Puzzle 5, independently of presentation order. Controlling for potential covariates listed above yielded the same results reported previously for the multivariate analyses of variance on the total score.

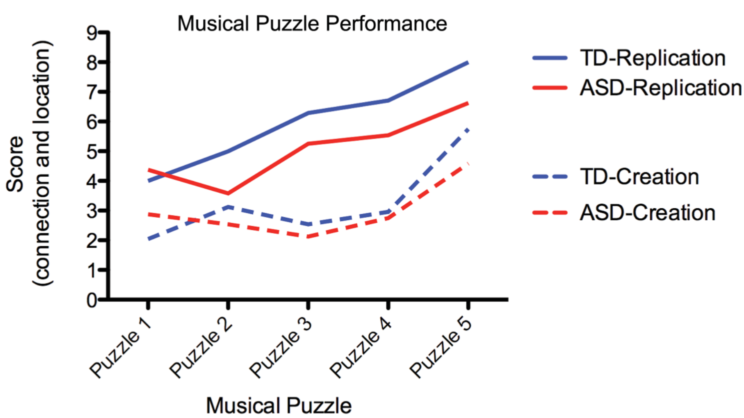

Figure 1 Score for each of the five puzzles for both groups (ASD and TD) and for both conditions (creation and replication).

Note. N.B.: Puzzles were presented in three different orderings, for example, order A was 2-3-4-1-5. "Jumpin' Jive," "Bach," "Sounds of the Orchestra," "Bravo Opera," and "Mozart" correspond to Puzzles 1, 2, 3, 4, and 5, respectively (see under "Materials"). To view this figure in color, please see the online version of the Journal.

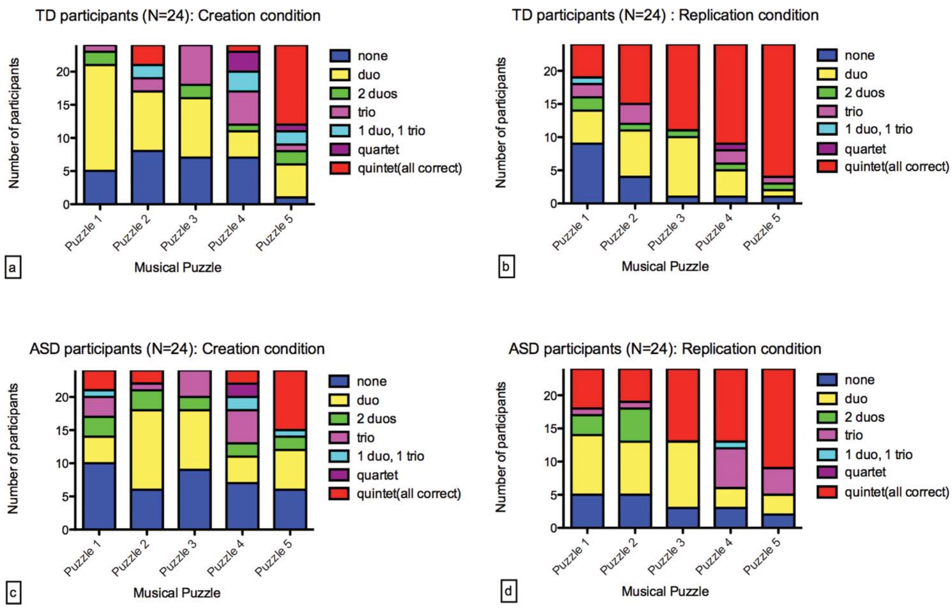

Figure 2 Number of participants generating subunits within musical structures for all musical puzzles.
Note. TD participants in 2a and 2b; ASD participants in 2c and 2d; creation condition in 2a and 2c; replication condition in 2b and 2d. To view this figure in color, please see the online version of the Journal.

Furthermore, subunits (one duo, two duos, trio, duo and trio, quartet, quintet of cubes, or absence of subunits) included within the musical structures created were consistent between groups (Figure 2). Intraclass correlations revealed that this was the case for four of the five puzzles in the creation condition, ICC coefficients: .81 to .96, all p values $< .01$, and all puzzles in the replication condition, ICC coefficients: .75 to .97, p values $< .01$ to .01. The between-group subunit inconsistency found for one puzzle (#1) in the creation condition, ICC coefficient: .38, $p = .16$, was due to the fact that 4 participants with ASD versus 16 with TD created duos and 10 participants with ASD versus 5 with TD did not create any subunits.

Next, we analyzed the strategies the participants said they used to solve the musical puzzles. Their answers were classified into five categories (Table 4): (a) music: participants reported listening for qualities inherent to the music (melody, pitch, instruments, rhythm, etc.); (b) beginning-end: participants reported finding which cubes should begin and/or end the musical puzzle and then found the order of the three middle cubes by trial and error; (c) cube per cube: others reported that they would find which cube should begin the puzzle and than move on to finding the second and so on; (d) a combination of (a) and (b) or (c); (e) other: the participants repeated the task instructions or gave an answer that did not fit in the previous categories. Classification of answers by two judges (E.M.Q. and A.B.) was consistent as measured by Cohen's kappa coefficient for interrater agreement ($\kappa = .89$; 95% C.I. : 0.81 to 0.94). The number of participants per category was not different between groups as revealed by a two-tailed Mann-Whitney U test, $z = .21$, $p = .83$.

Table 4 Classification of Participants' Self-Reported Strategies to Solve the Musical Puzzles.

	ASD	TD
	(number of participants)	
a. Music	6	7
b. Beginning-end	4	5
c. Cube per cube	5	2
d. a and b or a and c	3	4
e. Other	6	6
Total (*n*)	24	24

Musical Puzzle Task Performance and Recognition of Musical Emotions

Finally, Kendall's Tau correlations were performed to assess the relationship between performance on the musical puzzle task and performance on a separate emotion recognition task in which participants chose, by means of a forced-choice procedure, which of four emotions (happy, sad, scared, and peaceful) best described 30-second musical clips (none of which were used in the present experiment; Quintin et al., 2012). When VIQ was controlled for, there was no difference between groups on the emotion recognition task. The same participants completed the emotion recognition task and the musical puzzle task, with the exception of 4 additional participants (2 with ASD and 2 with TD) who did not complete the musical puzzle task. There was a significant correlation between the score on the emotion recognition task and the total score for both the creation, *Kendall's* $\tau = .27$, $p = .01$, and replication conditions, *Kendall's* $\tau = .32$, $p < .01$, when both groups were combined. When groups were analyzed separately, the same correlation patterns were found only for participants with TD for the creation, *Kendall's* $\tau = .35$, $p = .03$, and replication conditions, *Kendall's* $\tau = .44$, $p < .01$. However, there was no significant relationship between emotion recognition and performance on the musical puzzle for participants with ASD for either the creation, *Kendall's* $\tau = .14$, $p = .36$, or the replication conditions, *Kendall's* $\tau = .14$, $p = .35$. (All correlations were performed for two-tailed significance.)

DISCUSSION

The aim of this study was to assess processing of musical structure in ASD in light of the theories of Enhanced Perceptual Functioning (Mottron et al., 2006) and Central Coherence (Happé & Frith, 2006) that strive to describe the cognitive profile of individuals with ASD in terms of cognitive style rather than cognitive deficits (Happé, 1999). These theories suggest that individuals with ASD often show enhanced detail-oriented processing that confers an advantage in solving visuospatial and visuoconstructive tasks. We thus sought to assess if the cognitive style of individuals with ASD would also confer an advantage in the auditory domain. We employed a musical puzzle that we believe taps into auditory analogues of visuospatial and visuoconstructive processing, which we refer to as audiotemporal and audioconstructive processing. The musical structures of short melodies created by adolescents with ASD were not significantly different from those created by typically developing adolescents in terms of global coherence. For both groups, the presence of a musical exemplar favored production of musical structures with greater global coherence. Both groups also showed similar response patterns for the various puzzles presented, indicating that some puzzles were easier and others were more difficult and this was equally the case for both groups. This finding complements previous research that failed to show impairments for musical expectancy in ASD (Heaton et al., 2007). Future research could compare multiple exemplars of different musical genres to evaluate if musical genre influences the ease with which individuals with ASD produce musical structures because some genres, such as jazz, are thought to have less fixed or predictable musical structures. For instance, the melody in Puzzle 1, a puzzle for which scores were low, was a jazz melody whereas the other melodies were from the classical repertoire.

Our a priori hypothesis was that adolescents with ASD would perform the task as well as TD adolescents. This hypothesis was confirmed, and results indicated no significant group differences for creation and replication of musical structures. Although individuals with ASD may present a different cognitive style (Happé, 1999), it does not seem to affect global processing of musical structures differently than in the typical listener. Heaton (2009) proposed that enhanced perceptual functioning can lead individuals with ASD to pay attention to music and perhaps motivates listening to music, which in turn fosters learning of higher order musical structure and of the rules or expectancies of western musical harmony. Here, the strategies participants reported using to solve the musical puzzles were similar in both groups. Findings reported suggest that *what* adolescents with ASD have learned concerning musical structures is similar to peers their age. Nonetheless, further research is required to evaluate if *the way* in which rules of musical structures are learned differs for individuals with ASD.

Many potential factors (covariates) were considered in order to account for task performance. Although some covariates were found to have significant effects, group effects were not significant when these specific covariates were controlled for. When chronological age was entered as a covariate, the group effect reached significance in the replication condition; although chronological age did not have a significant effect. Out of many factors considered, years of musical experience had the greatest effect for the creation condition (a trend) whereas performance IQ, digit span forward, and letter-number sequencing had a greater effect for the replication condition.

Although musical expectancy, which includes expectancy of melody, contour, rhythm, etc., is generally independent of musical expertise (Bigand & Poulin-Charronnat, 2006), a greater effect of years of musical experience in comparison to other potential covariates suggests that the ability to produce coherent musical structures may be somewhat linked to prior musical experience for the participants in this study (both ASD and TD). In this case, musical experience refers to formal musical training or instruction. The association may thus lie in the training itself, which fuels a greater knowledge of musical structures, and/or in the fact that adolescents who receive musical training spend more time involved in musical activities, such as practicing an instrument, attending music theory class, etc. In addition, the creation condition is somewhat akin to musical composition/improvisation and it can be thought that participants who play an instrument have had more opportunities to experiment with musical composition/improvisation.

Performance IQ, digit span forward, and letter-number sequencing were associated to the replication condition. Recall that, in the replication condition, participants heard the musical exemplars twice before attempting to order the pieces of the puzzle to reproduce the musical exemplar. Although participants were not explicitly instructed to memorize the exemplar, they had to rely on auditory memory to some extent to complete the experimental task; hence, the association between the musical puzzle task performance and digit span forward and letter-number sequencing, two auditory memory tasks. Of particular interest is the effect of performance IQ (PIQ) for the replication condition. PIQ was measured with the block design and matrix reasoning subtests of the WASI, which are visuospatial and visuoconstructive tasks. The significant effect of PIQ as a covariate suggests that there may be commonalities between visuospatial-visuoconstructive and audiotemporal-audioconstructive tasks and/or the types of processing and reasoning required to solve these tasks. Although further research is needed, it seems as though the strengths of individuals with ASD in the former domain (visual) generalize to the latter (auditory), which supports the view of a different cognitive style in ASD (Happé, 1999). In the visual domain in ASD, spared visuospatial and visuoconstructive abilities exist in parallel to difficulties for temporal sequencing of visual stimuli and procedural learning of motor sequences. However, audiotemporal processing of music, which includes temporal sequencing of auditory events, does not seem impaired in ASD. Audiotemporal and audioconstructive processing seem to be strengths within the cognitive profile found in ASD; a claim that is further supported by the fact that, even though there was a significant difference between groups in terms of verbal IQ, VIQ was not retained as one of the significant covariates for task performance on either the creation or replication condition. The findings reveal the ability of adolescents with ASD to perform audiotemporal-audiocontructive processing as well as controls despite their lower level of verbal ability. Thus, the experimental task seems to have tapped into the types of processing that we thought it would elicit, that is, audiotemporal-audiocontructive processing, and that seem to be associated to auditory memory and PIQ but not verbal ability. Alternatively, auditory memory and PIQ can also be viewed as compensatory mechanisms employed by adolescents with ASD to succeed on the experimental task. It would be particularly instructive to test whether this finding would hold for lower functioning individuals with ASD and with those who are said to be nonverbal.

The findings also suggest that the experimental task can be used to assess audiotemporal-audioconstructive processing in typically developing children. We believe that the musical puzzle and similar tasks could complement neuropsychological assessments based on adaptations of Luria's model (1973), which is still often referred to today (Strauss, Shermann, & Spreen, 2006; Tupper, 1999), since most dimensions of cognitive functioning described by the model are typically assessed with visual tasks. Adaptations of the musical puzzle for congenitally blind children, for instance, could be used to assess cognitive functioning since auditory processing, such as localization of sound in the auditory space, is thought to be preserved in this population (Lessard, Paré, Lepore, & Lassonde, 1998).

Although findings suggest good audiotemporal-audioconstructive processing in ASD, participants with ASD did not outperform controls. Thus, this type of processing may constitute a relative strength in comparison to the cognitive profile of individuals with ASD but it does not seem to be a special skill as could have been expected based on previous research (Bonnel et al., 2003, 2010; Heaton et al., 1998; Mottron et al., 2000). In any case, exploring what people with ASD are *good* at is important to understand the disorder (Happé, 1999). It is also possible that audiotemporal-audioconstructive processing could be a special skill for only a subgroup of individuals with ASD that were not represented here. Special skills may be more difficult to pinpoint in ASD as a results of the wide variability and heterogeneity within the cognitive profile of ASD that parallels the broadening of diagnosis criterion and the increase in the number of diagnoses (Fombonne, 2009). The

ASD group, for instance, did not show a peak performance for the block design subtest of the WASI. Even though the WASI only has four subtests, a peak on the block design could have been expected given prior evidence of block design peak in ASD on the Wechsler scales (Caron et al., 2006; Happé, 1994; Siegel et at., 1996). There were, however, 3 participants with ASD and 6 with TD who did show a block design peak, but these were too few to proceed to analyses. Based on an adaptation of Caron and colleagues' procedure (2006), we considered a block design peak as a T-score greater than 60 on this subtest if it was also the highest T-score of the four WASI subtests. Chronological age and level of intellectual functioning may also account for the absence of a special skill in the ASD group. For instance, individuals for whom a block design peak was reported by Caron and colleagues (2006) tended to be older (23.28 $\pm$ 7.4 years old) than the participants in the present study and have a higher IQ (VIQ: 98.9 $\pm$ 21.5, PIQ: 108.9 $\pm$ 10.0). Age is a factor to consider in future studies of musical processing in ASD. Indeed, we did find a mildly significant interaction effect between group and chronological age. Conducting a similar experimental procedure with younger children with ASD would help to address this issue.

As noted, central coherence and enhanced perceptual processing theories have mostly accounted for the third diagnostic criterion for ASD, which are restricted, repetitive, and stereotyped patterns of behavior, activities, and interests observed in ASD (American Psychiatric Association, 2000). In an effort to account for all three diagnostic criteria, Baron-Cohen and colleagues (2005) proposed the systemizing-empathizing theory of ASD, which stipulates that these two dimensions are normally distributed among the population and that individuals with ASD show a marked discrepancy between these two dimensions. According to this model, empathizing includes the ability to empathize and sympathize with another person such as perceiving another person's emotions or state of mind and adapting our behavior accordingly. Systemizing is described as an analytical approach to predict how a system works and will behave based on correlations established between input and output (Baron-Cohen, 2002). Machines, mathematics, business, elections, elements of the weather, etc. are examples of systems. Playing a song repeatedly and analyzing musical structure are presented as examples of systemizing (Baron-Cohen, 2009). Stimuli soliciting both dimensions of the empathizing-systemizing (ES) theory can help to refine the theory (Baron-Cohen, 2009). Music, as an experimental stimulus, has been used to increase our understanding of both cognitive (Bonnel et al., 2003, Heaton et al., 1998, Mottron et al., 2000) and emotional processing (Bhatara, Quintin, Levy, Bellugi, Fombonne, & Levitin, 2010; Heaton et al., 1998, 2008; Quintin et al., 2011) in ASD.

Therefore, analyses were performed to assess the relationship between musical-processing abilities and perception of musical emotions in ASD. To our knowledge, it has not been reported that emotional and structural processing of music have been studied for the same group of participants; although it has been reported for one case study (Heaton, Pring, & Hermelin, 1999). When VIQ was controlled for, performance of participants with ASD was not significantly different from controls for an emotional recognition task (Quintin et al., 2011), which had also been completed by the participants in the present study. For both groups combined, performance on the musical puzzle was correlated with emotion recognition. When groups were analyzed separately, however, the correlation between performance on the emotion recognition and musical puzzle tasks was significant for the TD group but not for the ASD group. This warrants further questioning of the association between processing of musical structure, a systemizing ability, and perception of musical emotions, an empathizing ability, in typical development and in ASD.

For instance, participants with ASD in the present study gave judgments that were different from controls for subtle variations of emotional expressivity in piano performances (timing and amplitude) that were experimentally altered to varying degrees (Bhatara et al., 2010). However, Allen, Hill, and Heaton (2009) suggest that adults with ASD exploit music in a similar fashion to the typical listener. Thus, music represents a promising means to test the empathizing-systemizing theory of ASD; although it has its limitations such as impossibility to obtain a complete dissociation between emotional and structural aspects of music (Huron, 2006). Findings presented here and evidence to date (Heaton, 2009 for a review) do not suggest a discrepant cognitive profile for processing of higher order musical structure and processing of musical emotions at a global level in ASD, that is, recognizing or categorizing emotions from musical excerpts.

The present findings demonstrate that real and complex music can be processed globally in ASD and TD. This bridges the gap between studies on music therapy and studies typically assessing processing of local elements of music in ASD. Hence, these findings complement the existing literature and support therapeutic use of music as an efficient means of intervention in ASD (see Whipple, 2004, for a review) because these individuals can process music with as much accuracy as their group of peers. For example, good audiotemporal processing abilities can fuel intervention strategies. Indeed, songs have been shown to help children with ASD learn and accomplish sequences of events such as their morning routines (Kern, Wolery, & Aldridge, 2007). Music therapy has led to increased spontaneous imitation (Kern et al., 2007), joint attention, and nonverbal communication (Kim, Wigram, & Gold, 2008) in ASD. Music has also been posited to stimulate the mirror neuron system in ASD, a system that is thought to be impaired in ASD (Wan, Demaine, Zipse, Norton, & Schlaug, 2010) and associated with empathizing deficits in ASD (Gallese, 2006). We join those (Baron-Cohen, 2009; Happé, 1999) who have outlined the strengths of people with ASD and encourage the use of music therapy to foster positive outcomes.

Supplementary content is available via the ‘Supplementary’ tab on the article’s online page (http://dx.doi.org/10.1080/09297049.2012.653540). The audio and video files referred to in the supplementary material, are available at http://Quintin2012.levitinlab.com/.

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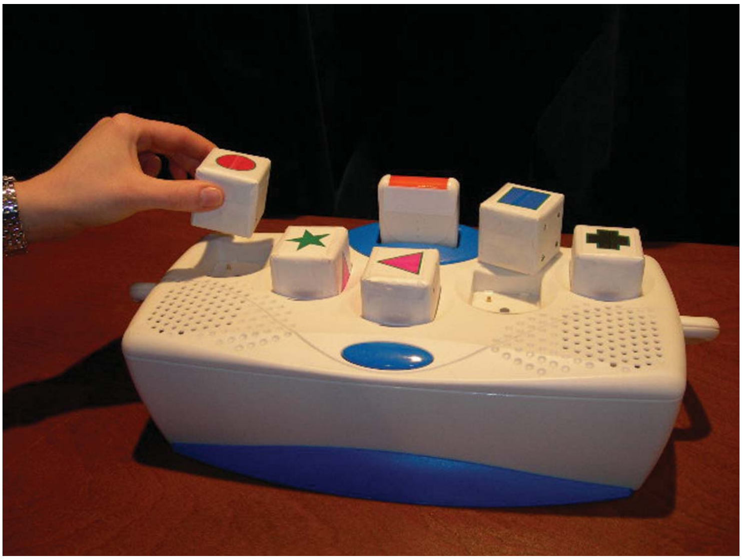
APPENDIX 1

Experimental task (One of the five musical puzzles):
Adaptation of the children's musical toy, MusicBlocks™



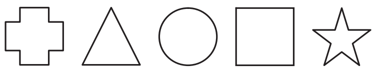
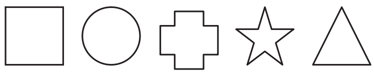
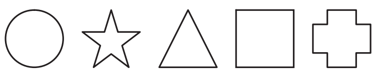
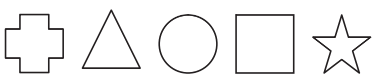
APPENDIX 2

Musical Puzzle (Scoring Sheet, List A)

The experimenter must be seated in front of the participant. In each row marked “answer”, draw the shapes for the participant’s final answer, from the experimenter’s point of view. The order of the shapes on this marking sheet is the correct order from the experimenter’s point of view (i.e., the inverse of the participants’ point on view).

Participant # : _________Date:_________ Time:_________ Experimenter:______

Part 1: Freestyle Creation!

	Cartridge/Song	Order (for the EXPERIMENTER)	ExecutionTime
2.	Bach		
	Answer		
3.	Sounds of the orchestra		
	Answer		
4.	Bravo opera		
	Answer		
1.	Jumpin’ Jive		
	Answer		
5.	Mozart		
	Answer		

Part 2: Replication (with Two Hearings Before Constructions)

	Cartridge/Song	Order (for the EXPERIMENTER)	Execution Time	Replay@ 2 min.
	Nutcracker Trial	○ ☆ △ □ ✙		
	Answer			
2.	Bach	✙ △ ○ □ ☆		
	Answer			
3.	Sounds of the orchestra	□ ○ ✙ ☆ △		
	Answer			
4.	Bravo opera	△ □ ☆ ✙ ○		
	Answer			
1.	Jumpin' Jive	○ ☆ △ □ ✙		
	Answer			
5.	Mozart	✙ △ ○ □ ☆		
	Answer			

Strategy Verification: Ask this question when the task is completed:
1. "If another child/teenager wanted to play the game, what advice would you give him?"
Answer:
If the child describes the game instead of describing the strategy say:
"Yes, but what hints would you give him? Would you have any tricks on how to play the game?"
Answer:
2. "Thanks, is that how you played the game?" Answer: