Title: Evidence for intact melodic and rhythmic perception in children with ASD

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List of abbreviations:

ADI-R	Autism Diagnostic Interview - Revised
ADOS	Autism Diagnostic Observation Schedule
ASD	Autism Spectrum Disorder
IQ	Intelligence Quotient
PIQ	Performance Intelligence Quotient
TD	Typical Development
VIQ	Verbal Intelligence Quotient
MBEMA	Montreal Battery for the Evaluation of Musical Abilities
WASI	Wechsler Abbreviated Scale of Intelligence
PPVT	Peabody Picture Vocabulary Test
SCQ	Social Communication Questionnaire
SRS	Social Responsiveness Scale

Abstract

Background:

Autism spectrum disorder (ASD) is a complex neurodevelopmental condition characterized by socio-communicative difficulties and restricted patterns of behavior. Despite these challenges, some individuals with ASD have preserved or even enhanced sensory skills, for example in the case of music. As such, music provides a key way to study sensory processing and individual differences in ASD. However, current studies of music perception in ASD have mixed results.

Methods:

This study sought to examine music perception in terms of melodic pitch, rhythm, and memory in school-age children with ASD compared to typically-developing (TD) children. Music perception was investigated as a function of verbal and non-verbal IQ, age, and ASD social symptom severity.

Results:

Children with ASD performed similar to TD children on melodic pitch perception, rhythm perception and melodic memory. Melodic pitch perception in particular was strongly associated with non-verbal cognitive abilities in the ASD group. Similar effects of age on performance were observed in ASD and TD; in particular, rhythm discrimination increased with age in both groups. Music perception in ASD was not associated with ASD social symptom severity.

Discussion:

These findings provide further evidence for intact melodic and rhythmic perception in children with ASD. In addition, music perception abilities were related to non-verbal cognitive ability and age in ASD, and not with ASD social symptom severity. This research provides a better understanding of individual differences in auditory processing, helps to better define phenotypes in ASD, and can guide future studies on the effects of music therapy in ASD.

Keywords: Autism spectrum disorder, auditory, music, perception, cognition, development.

Introduction

Problems in social and communication skills as well as atypical sensory processing are core symptoms of Autism Spectrum Disorder (ASD) (American Psychiatric Association, 2013). Importantly, while many individuals with ASD have impairments in processes required for speech perception, such as auditory filtering, phoneme categorization, and multisensory integration (DePape et al., 2012), they often have preserved or even enhanced auditory skills (Ouimet et al., 2012) including pitch discrimination (Heaton, 2003, 2005) and pitch memory (Stanutz, Wapnick, & Burack, 2014). However, compared to studies on social cognition and language, as well as sensory processing in other sensory domains like vision, research on auditory perception in ASD remains limited.

Music has been used to study auditory perception in typical development (Rajendran et al., 2017; Wang, 2013) as well as disorders such as dyslexia (Partanen et al., 2012; Serrallach et al., 2016) and schizophrenia (Hatada, 2014). Music offers a particularly accessible means of examining auditory perception in ASD because it is nonverbal, familiar, and produces a similar or greater affinity as in TD children (Darrow & Armstrong, 1999; Lai et al., 2012). There are also examples of musical savants in the ASD spectrum (Mottron, Dawson, Soulières, 2009). In addition, while music can be composed and performed to convey emotional content, musical passages with low emotional valence provide a useful, familiar type of stimulus to measure perception of auditory pitch and temporal structure (Peretz & Zatorre, 2005). For these reasons, music bears great potential for studying auditory perception in ASD, including evaluating models of perceptual processing in this disorder (Mottron, 2006) as well as applications in a therapeutic context (Geretsegger et al., 2014). However, studies of musical perception in children with ASD generally have not examined different dimensions of musical perception such as melody and rhythm within the same participants, nor directly measured the influence of individual differences in cognitive abilities, age or symptom severity.

Accordingly, the present study sought to assess music perception across a range of music tasks in children with ASD versus typical developing children (TD), as a function of differing cognitive abilities, age and social symptom severity. Our ultimate goal was to better characterize auditory perception in children with ASD, and for these results to help guide auditory-based interventions to improve features of ASD such as communication and social functioning.

Music perception in ASD versus TD

While sensory processing in ASD has received considerable research attention, work on auditory music processing in ASD remains less extensive. Music perception may be spared in ASD and could be a motivating non-verbal tool to help develop social and communication skills in ASD. Some work has found enhanced music-related perception particularly in terms of pitch processing in ASD. For example, both children and adults with ASD have shown enhanced judgments of pitch difference, direction and identification (Jones et al., 2009; Bonnel et al., 2010; Bonnel et al., 2003; O'Riordan & Passetti, 2006; Heaton, Williams, Cummins & Happé, 2008; Heaton, Hermelin, & Pring, 1998). However, the stimuli used in these studies are intentionally simplistic and lack the pitch structure of musical melodies. Other studies have found enhanced judgments of pitch in a melodic context, such as classification of pitch contour (Jiang et al., 2015) and detection of a pitch change in a melody (Heaton, 2005; Stanutz, Wapnick, & Burack, 2014; Mottron, Peretz & Ménard, 2000). Enhanced pitch memory has also been found in children with ASD for long-term melodic memory (Stanutz, Wapnick, & Burack, 2014), long-term pitch memory (Heaton, Williams, Cummins & Happé, 2008), disentangling pre-exposed pitch tones from chords (Altgassen et al. 2005), and memory for unlabelled pre-exposed pitch tones (Heaton, 2003), and there is a greater incidence of absolute pitch in ASD (Bouvet et al., 2016; Mottron et al., 2013; DePape at al., 2012; Masataka, 2017). Such findings of enhanced processing in these music areas are consistent with the Enhanced Perceptual Functioning model of ASD that predicts enhanced processing of local (detailed) sensory features in ASD versus TD (Mottron et al., 2006), with intact processing of global (whole) sensory features.

However, enhanced musically-relevant processing in ASD has not always been replicated. For example, no performance differences were observed between ASD and TD on tasks of melodic global-local perception (Foster et al., 2016), pitch direction discrimination (Germain et al., in press), pitch identification (Altgassen et al., 2005), or in studies involving harmonic priming (DePape et al., 2012), music structure processing (Bhatara et al., 2013) or contour discrimination (Jiang et al., 2015). Individuals with ASD also appear to perform the same as TD children in auditory-motor rhythm synchronization (Tryfon et al., 2017), although some studies have reported that people with ASD have reduced specialization in categorizing simpler meters that are prevalent in Western music over more complex meters (DePape et al., 2012). This range of performance may be explained by various factors including different tasks used across the studies, along with the differing cognitive abilities, age and symptom severity of the ASD participants. In the present study, by measuring performance on several different dimensions of musical perception in the same participants using realistic, ecologically valid musical stimuli, and by directly evaluating potential influences of cognitive ability, age and severity together, many of these potential points of inconsistency among existing studies may be addressed.

Verbal and non-verbal cognitive abilities and music perception

One challenge to understanding music perception differences in ASD is to discern how cognitive abilities, which vary widely from impaired to above average in the ASD population, may influence music perception. Studies on the association between perception and cognition in ASD are key to better understanding individual differences in ASD; however, few such studies exist. Both verbal and non-verbal cognitive profiles in ASD are highly variable (Black et al., 2009; Charman et al., 2005; Farley et al., 2009; Joseph et al., 2002; Koyama et al., 2007). For example, individuals with ASD often display uneven cognitive profiles relative to TD individuals (e.g., either having non-verbal or verbal IQ substantially higher than the other domain; Black et al., 2009; Joseph et al., 2002).

In TD, better performance on auditory tasks has been related to improved receptive language ability (Grube et al., 2012; Mayer et al., 2016), but the status of such a link between auditory perception and verbal skills in ASD is not clear. For example, Mayer et al. (2016) did not find any significant association between auditory pitch discrimination and receptive vocabulary in ASD. In terms of non-verbal cognitive ability, some studies have revealed a correlation between non-verbal reasoning (as measured by the Block Design task), and auditory skills such as pitch discrimination (Mayer et al., 2016), pitch memory (Stanutz, Wapnick, & Burack, 2014), and melodic memory ability (Heaton et al., 1998; Heaton, Williams, Cummins, & Happé, 2008; Stanutz et al., 2014). However, these findings have not always been replicated (Heaton, Hudry, Ludlow, & Hill, 2008; Meilleur et al., 2015).

Our lab recently found significant variability in performance on pitch and melodic discrimination tasks in both ASD and TD children that was predicted by non-verbal, but not verbal skills (Chowdhury et al., 2017). However, the stimuli in the Chowdhury et al. study were designed to investigate auditory global/local perception, and as such were not designed as naturalistic (ecologically valid) music stimuli. Additionally, that study did not include individuals with lower IQ. Overall, non-verbal IQ seems to be positively related to aspects of musical perception such as melodic pitch discrimination. In contrast, verbal IQ does not appear to be linked with music discrimination ability in ASD (although it does correlate with emotional recognition in music in ASD; Heaton et al., 2008). Novel aims of the present work were to examine music perception within ASD in association with verbal and non-verbal cognitive abilities using ecological musical tests of melody, rhythm and memory ability.

Age and music perception

In addition to verbal and non-verbal cognitive abilities, other variables such as age may contribute to differences in music perception ability in ASD. Age predicts music perception ability in TD children from 6-8 years olds (Peretz et al., 2013). In ASD, developmental trends have been detected in auditory global-local processing whereby children with ASD perform better at younger ages (Foster et al., 2016). Similarly, one study also reported an improvement of fine pitch discrimination abilities from 5 to 14 years in TD children, whereas in ASD they were enhanced in childhood (6-14 years) and remained stable across development (Mayer, Hannent & Heaton, 2016). In addition, developmental differences have been found in ASD for auditory short-term memory, which continues to develop to adulthood in TD, but stops prematurely in persons with ASD (Erviti et al., 2015). Overall, some aspects of music-related auditory perception, and in particular fine-grained pitch processing, appear to develop differently in ASD versus TD, but further study across a range of music tasks is required to better understand these developmental effects.

ASD symptom severity and music perception

In addition to studying how development affects music perception in ASD, it is important to investigate how music perception might be linked to clinical severity in ASD. Findings from such studies can help to design more effective sensory and music-based interventions in ASD that are better tailored to the individual. Despite this, there has been surprisingly little study on the connection between sensory perception and symptom severity in ASD. One recent study revealed a significant relationship between neural electrophysiological (EEG) response during an audiovisual reaction time task and the severity of ASD symptoms, in a group of children and adolescents with ASD (Brandwein et al., 2015). While EEG responses on the audio-visual task predicted ASD severity, behavioral reaction time (RT) did not, indicating that EEG is a particularly sensitive metric to predict ASD symptoms. Moreover, the EEG neural responses and RT data did not predict auditory/visual sensitivities, as assessed by parent responses on the Short Sensory Profile (SSP) (McIntosh et al., 1999), a questionnaire on which parents/caregivers rate their child's reactions, preferences, and tendencies when confronted with everyday sensory stimuli and situations (Brandwein et al., 2015). No study has yet examined the potential link between music perception and ASD social symptom severity.

Objectives and hypotheses

The main objective of the present study was to examine music perception across a range of music abilities in school-age children with ASD (in comparison to TD, and within ASD), and to measure how this music perception may vary based on cognitive abilities, age and ASD social symptom severity. While there is evidence that individuals with ASD have intact detection of emotional content in music (Heaton et al., 2008), the present study intentionally used a musical test battery that measures perception of musical structure in brief melodies having negligible emotional content (Gosselin, Paquette & Peretz, 2015) in order to avoid potential confounds with atypical processing of emotion in ASD (Hill, Berthoz & Frith, 2004). The first specific aim was to test the hypothesis that children with ASD have intact or enhanced processing relative to TD across a range of ecologically valid music tasks including melodic pitch perception, rhythm discrimination and melodic memory. The second aim was to test the hypothesis that music perception in ASD is related to non-verbal cognitive abilities, but not necessarily to verbal abilities (Chowdhury et al., 2017). The third aim was to test the hypothesis that performance improves on music tasks as a function of age in ASD and TD, but with a possibly attenuated age effect in ASD (Foster et al., 2016; Mayer, Hannent & Heaton, 2016; Erviti et al., 2015). The final aim was to test the hypothesis that music perception in ASD is associated with social symptom severity in the same direction as any group differences in performance.

Methods

Participants

41 boys with ASD and 23 TD boys participated in the present study (mean age: 10.1, SD: 1.8 years, range: 6-12 years). Participants were recruited from laboratory databases and through the local community. Individuals with ASD were diagnosed by expert opinion (American Psychiatric Association, 2000, 2013), and diagnoses were supported by standard diagnostic measures (Autism Diagnostic Observation Schedule [ADOS] Lord et al., 1989; Autism Diagnostic Interview-Revised [ADI-R], Lord, Rutter, & Lecouteur, 1994) where available. The Social Communication Questionnaire [SCQ] (Rutter, Bailey & Lord, 2003), a questionnaire version of the Autism Diagnostic Interview-Revised [ADI-R] (Lord, Rutter, & Couteur, 1994), was used as an additional screen, with a minimum SCQ score of 13 required for inclusion of individuals with ASD and a maximum score of 12 for TD individuals. Participants from the TD group were not recruited if a family history of ASD was reported during screening. Exclusion criteria for all children were a gestational age of 35 weeks or less and hearing impairment. Other global exclusion criteria included missing IQ scores, or a verbal IQ score of 145 and above (see "Cognitive measures" below). This study was approved by our University ethics committees. All guardians provided written informed consent. All participants received a t-shirt or a gift card as compensation for their time.

Materials & Design

Montreal Battery for the Evaluation of Musical Abilities (MBEMA)

In the present study, the abbreviated Montreal Battery for the Evaluation of Musical Abilities MBEMA (Peretz et al., 2013) was used to assess a range of music perception abilities in ASD and TD school-age children. The abbreviated MBEMA is an ideal test battery for this purpose because it is an objective, short (~20 minutes) and child-friendly test battery of music perception that can be used in both TD, special populations and across cultures (Peretz et al., 2013). Additionally, the stimuli in the abbreviated MBEMA are designed to focus on discrimination of musical structure and do not cover emotion discrimination (Gosselin, Paquette & Peretz, 2015), making the task well suited to measure such discrimination of musical structure in ASD without a potentially confounding influence of emotional valence in the materials.

The abbreviated MBEMA has been described in detail elsewhere (Peretz et al., 2013) but briefly includes three types of tests: 1) melodic pitch (involving either a scale, interval, or contour pitch change), 2) rhythm, and 3) memory. In total, the task includes 30 unfamiliar melodies. 20 of these melodies are used on both the melodic pitch and rhythm tests, whereas the memory test uses 10 of the same melodies as the other two tests plus the remaining 10 melodies.

Melodies are presented in different keys and timbres to make the tests as engaging as possible. In the melodic pitch test, participants are asked to make a same-different judgement between two short melodies that may differ in the pitch of one note; this pitch change alters either the scale, interval or melodic contour. This test contains 10 “same” and 10 “different” trials. In the rhythm test, participants are asked to make a same-different judgement between two short melodies that may differ in rhythmic grouping. This test also contains 10 “same” and 10 “different” trials. In the memory test, participants are presented with a series of single melodies, 10 of which they heard in the previous tests, and 10 of which are new melodies. For each melody, participants are asked if they heard it before or not (see Figure 1).

The abbreviated MBEMA was administered on a laptop computer using Presentation software (Neurobehavioral Systems, http://www.neurobs.com). Responses were recorded using the left and right buttons of a computer mouse. The stimuli were presented to the participants in a quiet room at a comfortable volume. Accuracy scores on the abbreviated MBEMA were calculated as the percentage of correct responses in each task.

Figure 1

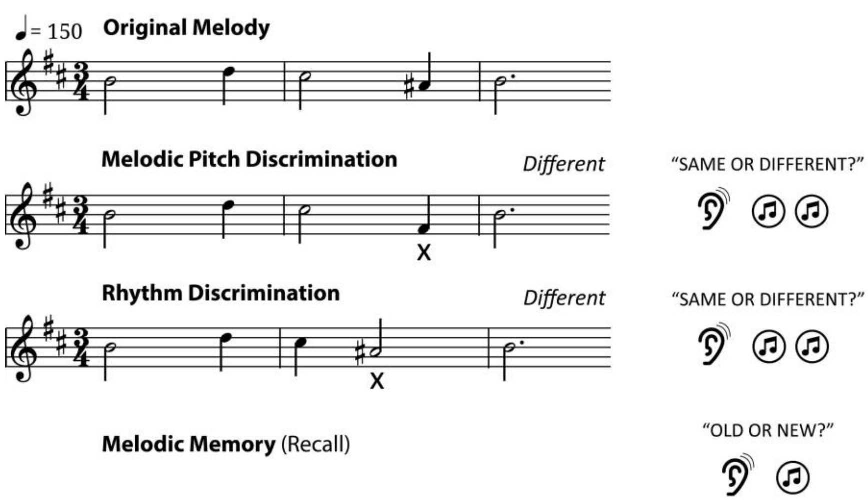

Figure 1. Example of one music stimulus as used in the three subtests of the MBEMA (adapted from Peretz et al., 2013). The standard stimulus is represented in the original, followed by a melodic alternate (violating the interval, contour or scale) and a rhythm alternate. The X indicates the changed note. The example can be heard at www.brams.umontreal.ca/short/mbea-child

Cognitive measures

An estimate of IQ abilities was obtained by the Wechsler Abbreviated Scale of Intelligence II (WASI-II; Wechsler, 2013) which provides Full-Scale (FSIQ), Verbal (VIQ) and Performance (PIQ) scores. The VIQ sub-scale includes the Similarities subtest of verbal reasoning and concept formation, as well as the Vocabulary subtest of word knowledge and verbal concept formation. The PIQ sub-scale measures non-verbal cognitive abilities via the Blocks sub-test which assesses the ability to analyze and synthesize abstract visual stimuli, and the Matrix Reasoning Task which assesses the ability to identify the missing element that completes a pattern. Two participants in the ASD-vs-TD sample and three in the ASD-only sample had already taken the Wechsler's Intelligence Scale for Children IV or V (WISC-IV; Wechsler, 2003; WISC-V; Wechsler, 2014), in which case we used their WISC verbal composite score if it was recorded within 2 years of testing date. We ran the same analyses for each sample separately excluding these participants and it did not affect the results. Receptive vocabulary was measured using the Peabody Picture Vocabulary Test (PPVT-4) (Dunn & Dunn, 2007), where participants are presented with a word and four pictures and then asked to choose which picture best corresponds to a spoken word.

Symptom Severity

Symptom severity in ASD was measured using total t-scores from the Social Responsiveness Scale (SRS-2) (Constantino et al., 2003). The SRS-2 is a norm-referenced parent-reported questionnaire used to identify the existence and severity of social symptoms characteristic of ASD.

Procedures and Analysis

Definition of samples of participants

In order to examine the effect of IQ, age and social symptom severity on music perception in ASD and TD children three overlapping samples of participants were defined here (see Table 1). First, in order to minimize possible confounds due to differences in IQ level, an ASD-vs-TD sample included 19 ASD and 21 TD participants (with available VIQ and PIQ data) that were group-matched on VIQ (minimum VIQ criterion of 90, mean VIQ 115.0). This also resulted in this ASD-vs-TD sample being group-matched on FSIQ and PIQ. Participants were included in the ASD-vs-TD sample only if their mean global MBEMA accuracy score (averaged across all three MBEMA subtests) was above chance. The chance score threshold was global MBEMA accuracy score > 64%, which was determined by permutation test on global MBEMA accuracy scores. This criterion resulted in the exclusion of 4 ASD and 2 TD children, leaving the ASD-vs-TD sample with 19 ASD and 21 TD. Enrolment in musical training (≥1 year private lessons) was matched between groups (ASD: 5 with training, 14 without; TD: 4 with training, 17 without; $\chi^2 = .03$, $p = .86$).

The VIQ matching in the ASD-vs-TD sample served to avoid a confound between cognitive ability (including potential comorbidity with language disorders such as Specific Language Impairment; Tager-Flusberg & Helen, 2015) and ASD diagnosis, but also resulted in the exclusion of some individuals with lower verbal ability in the ASD group. Thus, to test our hypotheses in a more representative ASD sample, an ASD-only sample included 35 ASD participants with no minimum IQ requirement (VIQ range 55-136), and no chance cut-off criterion for global MBEMA scores, and who had available data on all of the following: VIQ, PIQ, receptive vocabulary, and social symptom severity scores.

In order to examine within-group effects in a TD sample, sample 3 (“TD only”) included 23 TD participants (with available VIQ and PIQ data) with no minimum VIQ requirement (VIQ range 91-142), and no chance cut-off criterion for global MBEMA scores.

Table 1

Participant characteristics

	ASD-vs-TD			ASD-only	TD-only
	ASD (n=19)	TD (n=21)		ASD (n=35)	TD (n=23)
	Mean (SD, Range)	**Mean** (SD, Range)	**Group difference**	**Mean** (SD, Range)	**Mean** (SD, Range)
Age	10.4 (1.6, 7-12)	9.8 (1.8, 7-12)	t(38)=1.13 p=.268 d=.35	10.3 (1.8, 6-12)	9.7 (1.8, 7-12)
FSIQ[a]	118.6 (14.5, 97-144)	122.2 (11.2, 100-141)	t(33)=-0.87 p=.386 d=-.28	103.3 (18.7, 62-144)	120.6 (11.97, 100-141)
VIQ[a]	114.8 (13.3, 91-136)	115.1 (12.0, 95-142)	t(34)=-0.07 p=.941 d=-.02	95.9 (22.3, 55-136)	113.4 (12.93, 91-142)
PIQ[a]	119.4 (17.0, 91-148)	122.9 (15.41, 95-149)	t(36)=-0.66 p=.510 d=-.21	111.8 (17.3, 72-148)	121.9 (15.2, 95-149)
SCQ	19.5 (5.2, 13-35)	4.2 (2.5, 0-9)	t(25)=11.62 p<.0001* d=3.80	20.5 (5.0, 13-35)	4.0 (2.53, 0-9)
PPVT-4				95.6 (24.3, 42-145)	
SRS-2				69.4 (9.3, 55-90)	

Note. *SD=standard deviation; IQ=intelligence quotient; FSIQ= Full-Scale IQ, PIQ=Performance IQ, VIQ = Verbal IQ; SCQ= Social Communication Questionnaire; PPVT-4 = Peabody Picture Vocabulary Test 4; SRS-2 = Social Responsiveness Scale 2.*

[a] *was measured using the Wechsler Abbreviated Scale of Intelligence (WASI)*

**p<0.05*

Statistical analyses

Linear fixed effects models were used to evaluate the effect of group, PIQ (WASI-IV), VIQ (WASI-IV), age and their interactions on accuracy on the MBEMA tasks in the ASD-vs-TD sample, as shown below.

$$\text{Accuracy}_{\text{Task}} = \beta_0 + \beta_1\text{*Group} + \beta_2\text{*PIQ} + \beta_3\text{*VIQ} + \beta_4\text{*Age} + \beta_5\text{*PIQ*Group} + \beta_6\text{*VIQ*Group} + \beta_7\text{*Age*Group}$$

where $\text{Accuracy}_{\text{Task}}$ is performance on one MBEMA task (melody, rhythm or memory). The model was tested for each MBEMA task separately in each analysis. PIQ and VIQ are not necessarily well correlated in ASD research (Joseph et al., 2002; Mayes & Calhoun., 2003; Tager-Flusberg & Joseph., 2003), but out of caution for potential violation of multicollinearity, the correlation between PIQ and VIQ was calculated and verified to be acceptably low (r=.36). Additionally, the variance inflation factor (VIF; Fox and Monette, 2012) was calculated to confirm low multicollinearity among predictors in the model (VIF ≤ 3.1).

The ASD-only sample was utilized to examine whether music perception performance was related to receptive vocabulary and social symptom severity within the ASD group. For each MBEMA task we used a linear fixed effects model to test the effects of VIQ (WASI-IV), PIQ (WASI-IV), age, social symptom severity (SRS-2) and receptive vocabulary (PPVT-4) on MBEMA subscore:

$$\text{Accuracy}_{\text{Task}} = \beta_0 + \beta_1{*}\text{PIQ} + \beta_2{*}\text{VIQ} + \beta_3{*}\text{Age} + \beta_4{*}\text{SRS} + \beta_5{*}\text{PPVT}$$

PPVT and VIQ scores had a correlation of r=.74, so out of caution a supplementary analysis was tested with the PPVT term removed, and the same results were found for VIQ, PIQ, Age and SRS. Additionally, calculation of the VIF confirmed low multicollinearity among predictors in the full model (VIF ≤ 2.5).

The TD-only sample was utilized to examine whether music perception performance was related to cognitive ability and age. For each MBEMA task we used a linear fixed effects model to test on the effect of VIQ (WASI-IV), PIQ (WASI-IV) and age:

$$\text{Accuracy}_{\text{Task}} = \beta_0 + \beta_1{*}\text{PIQ} + \beta_2{*}\text{VIQ} + \beta_3{*}\text{Age}$$

Calculation of the VIF confirmed low multicollinearity among predictors in the model (VIF ≤ 1.1).

All continuous variables were mean-centered. Analyses were performed in R software (R Development Core Team, 2011) and significance was assessed using type III sum of squares at $p < 0.05$. Results are noted when p values pass a Bonferroni correction for multiple comparisons across the three MBEMA tests, i.e. $p < 0.0167$. Effect sizes are reported as partial eta-squared (η_p^2; Lakens, 2013).

Results

Music perception tests

The MBEMA results for the ASD-vs-TD sample are shown in Figure 2. The accuracy scores did not differ between the ASD and TD group for melodic pitch discrimination ($F(1,32)=0.67$, $p=.41$, $\eta_p^2=.02$), rhythm discrimination ($F(1,32)=1.18$, $p=.29$, $\eta_p^2=.01$) or melodic pitch memory ($F(1,32)=0.03$, $p=.86$, $\eta_p^2<.01$).

[INSERT FIGURE 2 HERE]

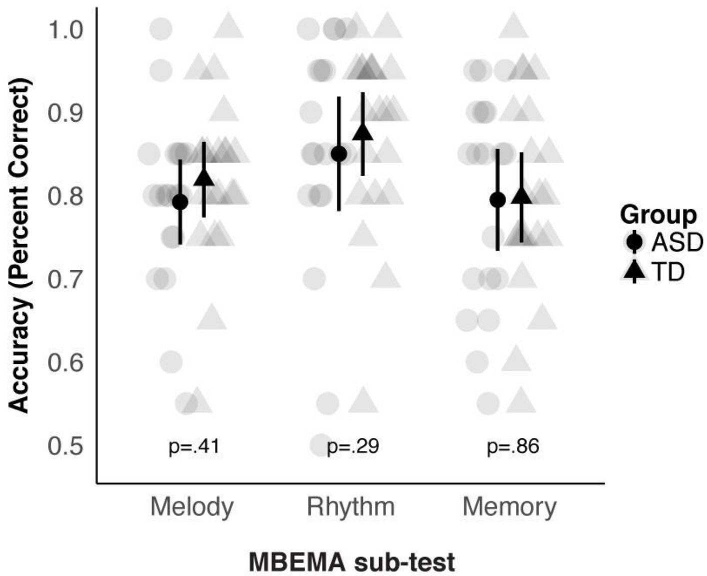

Figure 2. Results of the Montreal Battery of Evaluation of Musical Abilities (MBEMA): Mean task accuracy is equivalent between ASD and TD on each music perception task (ASD-vs-TD sample, all $p>.05$, bars represent +/- 1 standard error)

Cognitive measures and music perception

In the ASD-vs-TD sample, there was a main effect of verbal IQ on rhythm discrimination ($F(1,32)=4.29$, $p=.046$, $\eta_p^2=.12$) that did not pass the Bonferroni correction. There were no significant main effects of verbal IQ on melodic pitch discrimination ($F(1,32)=1.11$, $p=.75$, $\eta_p^2=.03$) or melodic memory ($F(1,32)=0.35$, $p=.56$, $\eta_p^2=.01$). There were no significant VIQ*Group interactions on melodic pitch discrimination ($F(1,32)=.59$, $p=.45$, $\eta_p^2=.02$), rhythm discrimination ($F(1,32)=3.25$, $p=.08$, $\eta_p^2=.09$) or melodic memory ($F(1,32)=0.35$, $p=.56$, $\eta_p^2=.01$) in the ASD-vs-TD sample. There were no significant main effects of PIQ on melodic pitch discrimination ($F(1,32)=2.60$, $p=.12$, $\eta_p^2=.08$), rhythm discrimination ($F(1,32)=.84$, $p=.37$, $\eta_p^2=.03$) or melodic memory ($F(1,32)=2.02$, $p=.16$, $\eta_p^2=.06$). There were no significant PIQ*Group interactions on melodic pitch discrimination ($F(1,32)=1.50$, $p=.23$, $\eta_p^2=.04$), rhythm discrimination ($F(1,32)=0.71$, $p=.40$, $\eta_p^2=.02$) or melodic memory ($F(1,32)=2.02$, $p=.16$, $\eta_p^2=.06$) in the sample.

In the ASD-only sample, there was a main effect of PIQ on melodic pitch discrimination ($F(1,29)=17.78$, $p<.001$, $\eta_p^2=.38$; Figure 3a) and melodic memory ($F(1,29)=4.30$, $p=.047$, $\eta_p^2=.13$), and an effect of VIQ on rhythm discrimination ($F(1,29)=5.38$, $p=.03$, $\eta_p^2=.16$); however, these last two results did not pass the Bonferroni correction. There was no significant effect of PIQ on rhythm discrimination ($F(1,29)=4.16$, $p=.0504$, $\eta_p^2=.13$) and no significant effect of VIQ on melodic pitch discrimination ($F(1,29)=.54$, $p=.47$, $\eta_p^2=.02$; Figure 3b) or melodic memory ($F(1,29)=1.92$, $p=.18$, $\eta_p^2=.06$). There was no significant effect of receptive vocabulary on melodic pitch discrimination ($F(1,29)=0.35$, $p=.56$, $\eta_p^2=.01$), rhythm discrimination ($F(1,29)=0.84$, $p=.37$, $\eta_p^2=.03$) or melodic memory ($F(1,29)=0.06$, $p=.80$, $\eta_p^2<.001$).

In the TD-only sample, there was no significant effect of PIQ or VIQ on melodic pitch discrimination (PIQ: $F(1,19)=1.01$, $p=.33$, $\eta_p^2=.01$; VIQ: $F(1,19)=.32$, $p=.58$, $\eta_p^2=.02$), rhythm discrimination (PIQ: $F(1,19)=.56$, $p=.46$, $\eta_p^2=.03$; VIQ: $F(1,19)=0.62$, $p=.44$, $\eta_p^2=.06$) or melodic memory (PIQ: $F(1,19)=.10$, $p=.76$, $\eta_p^2=.01$; VIQ: $F(1,19)=1.44$, $p=.25$, $\eta_p^2=.07$).

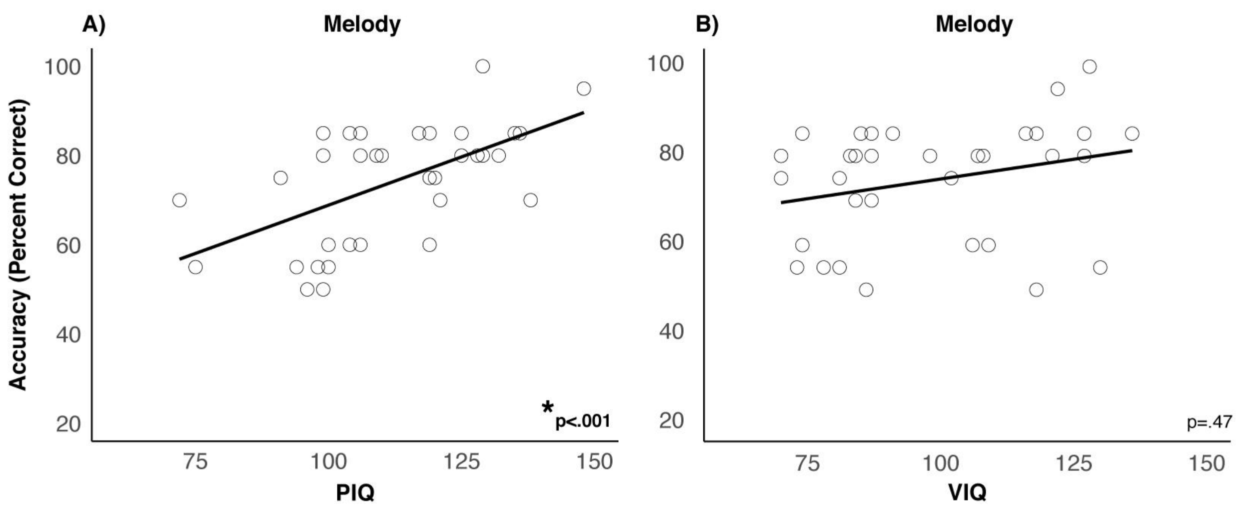

Figure 3. A) Melodic pitch discrimination increases with performance IQ (PIQ) in ASD (ASD-only sample, $F(1,29)=17.78$, $p<.001$); B) No significant relationship between melodic pitch discrimination and verbal IQ (VIQ) in ASD (ASD-only sample, $F(1,29)=.54$, $p=.47$, $p=.47$).

Age and music perception

In the ASD-only sample, there was a significant main effect of age on melodic pitch discrimination ($F(1,29)=7.36$, $p=.01$, $\eta_p^2=.20$, Figure 4a) and rhythm discrimination ($F(1,29)=11.95$, $p=.002$, $\eta_p^2=.29$, Figure 4b), but not on melodic memory ($F(1,29)=0.05$, $p=.83$, $\eta_p^2<.01$). In the TD-only sample, there was a significant main effect of age on rhythm discrimination ($F(1,19)=7.79$, $p=.01$, $\eta_p^2=.29$, Figure 4c), but not on melodic pitch discrimination ($F(1,19)=3.05$, $p=.10$, $\eta_p^2=.14$) or melodic memory ($F(1,19)=4.27$, $p=.053$, $\eta_p^2=.18$). In the ASD-vs-TD sample, there was no significant main effect of age on accuracy scores for melodic pitch discrimination ($F(1,32)=0.79$, $p=.38$, $\eta p^2=.02$), rhythm discrimination ($F(1,32)=1.63$, $p=.21$, $\eta_p^2=.02$) or melodic memory ($F(1,32)=.34$, $p=0.56$, $\eta_p^2=.01$). There was no significant Age*Group interaction on melodic pitch discrimination ($F(1,32)=0.41$, $p=.53$, $\eta_p^2=.01$), rhythm discrimination ($F(1,32)=.01$, $p=.91$, $\eta_p^2<.001$) or melodic memory ($F(1,32)=.10$, $p=.75$, $\eta_p^2<.01$) in the ASD-vs-TD sample.

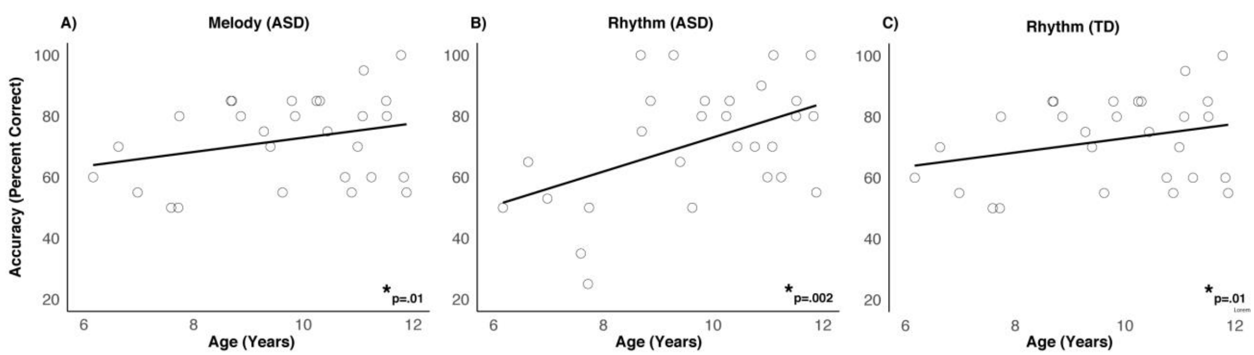

Figure 4. Melodic pitch discrimination and rhythm discrimination increase with age in ASD and TD. A) Melody task (ASD-only sample, p=.01); B) Rhythm task (ASD-only sample, p=.002); C) Rhythm task (TD-only sample, p=.01);

ASD social symptom severity and music perception

There was no significant effect of social symptom severity on the MBEMA tests of melodic pitch discrimination ($F(1,29)=0.03$, $p=.85$, $\eta_p^2<.01$; Figure 5a), rhythm discrimination ($F(1,29)=0.004$, $p=.95$, $\eta_p^2<.01$; Figure 5b) or melodic memory ($F(1,29)=0.90$, $p=.34$, $\eta_p^2=.05$; Figure 5c) in the ASD group.

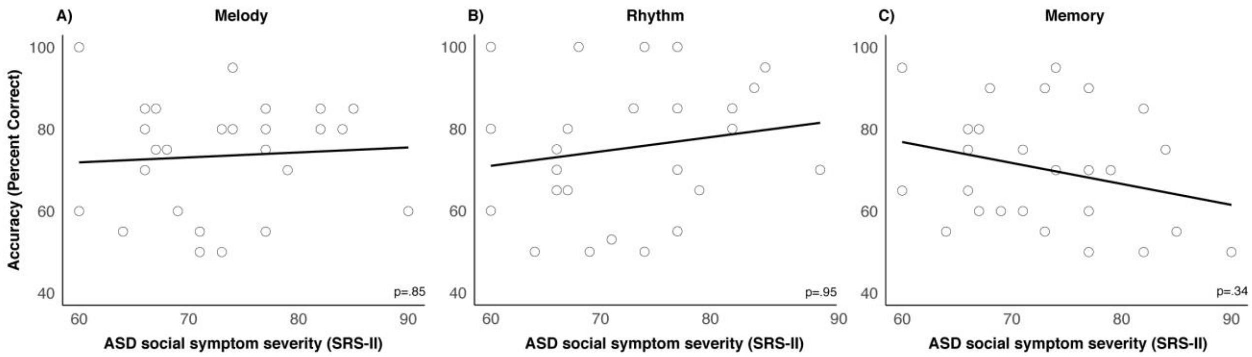

Figure 5. ASD social symptom severity (SRS-II) is not related to music perception in ASD (all p≥.34, 60-66 = mild, 66-75 = moderate, 75-90 = severe symptoms; Constantino et al., 2003)

Discussion & Implications

The main objective of the present research was to better characterize music perception abilities in ASD versus TD children, and to examine how music perception may vary as a function of cognitive abilities, age and ASD social symptom severity. Taken together, findings suggest that music perception is intact in children with ASD and that music perception is related to non-verbal cognitive ability and age in ASD, and not with ASD social symptom severity.

Basic discrimination of musical melody, rhythm and memory are intact in ASD

The first aim of this study was to investigate music perception across a range of music tasks in ASD versus TD. It was hypothesized that the ASD group would exhibit similar or enhanced performance versus TD in melodic pitch discrimination, rhythm discrimination and melodic memory. Results showed no performance differences between ASD and TD on either melodic pitch discrimination, rhythm discrimination or melodic memory. These findings are consistent with previous research that found similar pitch discrimination abilities in children with ASD compared to TD (Germain et al., in revision; Jiang et al., 2015, Stanutz, Wapnick, & Burack, 2014; Bhatara et al., 2013; DePape et al., 2012). The present finding that ASD performed the same as TD on the rhythm discrimination task is consistent with previous findings of intact auditory-motor rhythm synchronization in ASD (Tryfon et al. 2017). However, these findings are inconsistent with previous work showing deficits in rhythm processing in ASD, particularly in meter categorization (DePape 2012). This discrepancy could be due to differences across tasks; for example, meter was not manipulated in the rhythm tasks of the MBEMA. Performance on the melodic memory task was similar in ASD and TD, consistent with with a previous study by Heaton (2003) using a similar melodic memory recall task. The present findings provide further evidence that basic musical discrimination and recall for melody and rhythm are intact in children with ASD.

Music perception is related to non-verbal cognitive abilities in ASD

The second aim of this research was to examine whether cognitive abilities are related to music perception. Both verbal and non-verbal IQ scores were tested for relationships with the three measures of music perception (melody, rhythm and memory). Among the IQ results, we found the relationship between PIQ and melody perception in the ASD group was significant and passed Bonferroni correction. This is a strong effect, with a partial eta squared value indicating more than 35% of the melody score variance explained by PIQ in the ASD group. The relationship between PIQ score and melody perception is consistent with previous research showing a relationship between non-verbal skills, such as the block-design task, with local pitch direction (Chowdhury et al., 2017) and pure tone pitch discrimination (Meilleur et al., 2014) in ASD. It has been proposed that such links between auditory pitch perception and non-verbal IQ in ASD may reflect more effective allocation of attentional resources in individuals with higher non-verbal abilities (Mayer, 2016).

Although the rhythm and memory tasks did not have significant relationships with PIQ score in the ASD group, effect sizes showed about 13% of task variance was explained by PIQ for both tasks, suggesting that the relationship with PIQ is not entirely specific to the melody task. Future research with larger samples may be expected to find significant relationships between cognitive ability in ASD and the rhythm and memory tasks as well. Conversely, IQ effect sizes were considerably lower in the TD group and none approached statistical significance.

No analyses showed task performance relationships with VIQ that passed Bonferroni correction. However, both the ASD-vs-TD and ASD-only analyses showed a relationship between VIQ and rhythm task performance that explained 12-16% of task performance variance in the ASD group. While these results do not stand on their own, they indicate that for the relationship found between PIQ and musical perception performance in the ASD group, the degree of specificity of this effect to PIQ (vs VIQ) remains an open question.

Taken together, melodic music perception was strongly associated with non-verbal cognitive abilities in the ASD group and not in TD, though we are cautious not to suggest that this relationship in ASD is exclusive to melodic (vs rhythm or memory) perception or to non-verbal (vs verbal) cognitive abilities. Music perception, being a form of non-verbal ability, may overlap with other non-verbal aspects of cognition. Individuals who obtain high results on psychometric tests tend to score highly on musical judgment tests (Lynn & Gault, 1986; Lynn, Wilson, & Gault, 1989), and twin studies suggest that music aptitude and intelligence have genetic factors in common (Swaminathan, Schellenberg & Khalil, 2017; Mosing, Pederssen et al, 2014).

Music perception ability increases with age in both ASD and TD children

The third aim of this work was to examine if age affects music perception in children with ASD in a similar way to TD children. Rhythm discrimination accuracy increased with age in ASD and TD for the ASD-only and TD-only samples, as did melodic pitch discrimination in the ASD-only sample. These are strong effects, with partial eta squared values indicating 20-29% of the score variance explained by age. Although the melody and memory tasks did not have significant relationships with age in the TD group, effect sizes showed 14-18% of task variance explained by age for both tasks, suggesting that the effect of age may not be restricted to melody and rhythm in ASD and rhythm in TD. Future research with larger samples may well find the effect of age to be more general across these tasks.

The present results coincide with findings from Peretz and colleagues (2013) that music perception performance increases with age in TD. Note that no relation between the music tasks and age was found for the abbreviated version of MBEMA in Peretz et al. (2013). Our sample size was smaller than Peretz et al. (2013) but our age range was twice as wide, so our findings provide evidence that for children aged from 6-12 years old the abbreviated MBEMA is capable of detecting age related differences in music perception in TD similar to those found when using the full MBEMA (Peretz et al., 2013). Furthermore the abbreviated MBEMA can capture these differences for clinical populations, in particular for ASD. Music perception was not related to age in the ASD-vs-TD sample, and it may be that this more restricted sample did not allow enough range in performance to detect such a relationship, since some ASD participants at younger ages were excluded for performing at chance.

Clinical severity does not affect music perception in children with ASD

The fourth aim of the present work was to examine if ASD social symptom severity was related to music perception in ASD. This study provides the first evidence that these are not significantly related in ASD. Moreover, the present results suggest that music perception appears to be a special ability in ASD that remains intact across a wide range of clinical severity. Moreover, these results appear to be true across a range of musical abilities including melodic pitch and rhythmic perception as well as melodic memory. These results coincide with previous behavioral results showing that basic auditory processing does not predict symptom severity in ASD (Brandwein et al., 2015). Although no relationship between social symptom severity and music perception was found here, results may be different at wider extremes of ASD severity and functioning. Thus, the present findings motivate future work to examine the relationship between music perception and clinical symptomatology at differing ranges of ASD severity and in lower functioning individuals with ASD.

Study implications, limitations and future directions

This study provides a better characterization of auditory and musical profiles in children with ASD. In turn, this work helps to better define individual differences in ASD and to refine sensory phenotypes. To enhance the generalizability of results, future studies should include more representation of female ASD participants and individuals across a wider range of age and ASD severity. As the present tasks focused on perception of musical structure without explicit emotional content, future studies can complement this work by evaluating whether using stimuli with emotional valence modulates this discrimination in children with ASD (e.g. by varying modes, tempo and dynamics as in Gosselin, Paquette & Peretz, 2015), as well as directly evaluating judgments of emotional content (as in Heaton et al., 2008) and physiological correlates of emotional response such as chills and skin conductance. Furthermore, while comorbidity with language disorders such as Specific Language Impairment (SLI; Tager-Flusberg &

Helen, 2015) was likely mitigated in our ASD-vs-TD analysis by setting a lower limit on VIQ, the present results do not preclude the potential for impairment in musical perception in individuals with greater symptom severity, including the presence of concurrent disorders. Finally, this work motivates future studies to examine the efficacy of musical interventions in ASD to improve clinical outcomes.

Conclusions

The present study provides new evidence for intact music perception abilities in children with ASD across a range of music tasks including melody and rhythm discrimination as well as melodic memory. This research extends previous work in important ways by demonstrating a relationship between music perception and non-verbal cognitive ability in ASD in particular, and providing a better understanding of the connection between music perception, development and clinical profiles in ASD.

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Conflicts of interest

The authors declare no conflicts of interest.

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