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Autistic traits and enhanced perceptual representation of pitch and time.

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Abstract

Enhanced basic perceptual discrimination has been reported for pitch in individuals with autism spectrum conditions. We test whether there is a correlational pattern of enhancement across the broader autism phenotype and whether this correlation occurs for the discrimination of pitch, time and loudness.

Scores on the Autism-Spectrum Quotient (AQ) correlated significantly with the pitch discrimination ($r=-0.51$, $p<0.05$) and the time-interval discrimination ($r=-0.45$, $p<0.05$) task that were based on a fixed reference. No correlation was found for intensity discrimination based on a fixed reference, nor for a variable reference based time-interval discrimination. The correlations suggest a relationship between autistic traits and the ability to form an enhanced, stable and highly accurate representation of auditory events in the pitch and time dimensions.

Keywords: Autism-Spectrum Quotient, Sensory processing, Audition, Pitch, Time, Loudness, Enhanced representation

1. Introduction

Autism spectrum conditions (ASC) are characterised by differences in social interaction, social communication and restricted, repetitive behaviours compared with typically developing individuals (American Psychiatric Association, 2013). In addition to the defining traits of ASC, enhanced discrimination of basic perceptual information has been found for visual and auditory stimuli in ASC (Bertone, Mottron, Jelenic, & Faubert, 2005; Plaisted, Saksida, Alcántara, & Weisblatt, 2003). One model, the Enhanced Perceptual Functioning model (Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006), suggests that persons with ASC have enhanced low-level processing of basic perceptual information.

Traits or features of ASC are present both in relatives of those with ASC and in the typically developed population (Baron-Cohen, et al., 2001; Dawson, et al., 2007; Hurley, Losh, Parlier, Reznick, & Piven, 2007). Parents of children with ASC have higher autistic character trait scores than parents of typically developing children, and individuals with ASC score higher than typically developing controls on autistic traits as measured by the Autism-Spectrum Quotient (AQ) (Baron-Cohen, et al., 2001; Bishop, et al., 2004; Kurita, Koyama, & Osada, 2005). The AQ is a self-administered questionnaire designed to measure the extent to which adults with normal intelligence possess traits associated with ASC. The scale is not a diagnostic measure, although it was developed using diagnostic criteria, rather it is a measure of the levels of autistic traits (Baron-Cohen, et al., 2001). In line with a continuum theory of the autism spectrum between persons with ASC and the typically developed population, similarities in processing styles are found in those who score highly on the AQ compared with those with ASC (Almeida, Dickinson, Maybery, Badcock, & Badcock, 2010; Baron-Cohen, et al., 2001; Bayliss & Tipper, 2005; Clark, Hughes, Grube, & Stewart, 2013, Fugard, Stewart, & Stenning, 2011; Grinter, et al., 2009; Grinter, et al., 2009; Stewart & Ota, 2008; Stewart, Watson, Allcock, & Yaqoob, 2009). In this study we test whether autistic character traits are correlated with fundamental aspects of auditory processing.

Superior performance has been found for a range of perceptual tasks across domains. For instance, within the visual domain, enhanced performance has been found across a range of tasks with differing task demands and constraints. In an adapted block design task, where performance was compared between whole and segmented patterns and those with ASC showed reduced interference from the whole picture (Shah & Frith, 1993). Similarly, enhanced performance has been found on the embedded figures task, in which participants are required to find a design which is ‘hidden’ in a larger picture (Shah & Frith, 1983). Tasks such as the block design and the embedded figures require the participant to ignore the ‘gestalt’ of the whole and focus on the local detail in complex designs. Furthermore, children with autism have been shown to perform better than typically developing matched controls on tasks that require the discrimination of highly similar stimuli (Plaisted, O'Riordan, & Baron-Cohen, 1998), in other words depend on a detailed, accurate representation.

In the auditory domain, key findings in individuals with ASC have been: i) enhanced discrimination of pitch, ii) improved ability to categorise tones on the basis of their pitch, and iii) enhanced memory of pitch (Bonnel, et al., 2010; Bonnel, et al., 2003; Heaton &

Heaton, 2003, 2005; Jones, et al., 2009; O'Riordan & Plaisted, 2001). Bonnel et al. (2003) reported higher sensitivity in children with autism in a pitch discrimination and a categorisation task, both using the method of constant stimuli, i.e. fixed levels of difficulty. Bonnel et al. (2010) found enhanced pitch discrimination for participants with autism, but not with Asperger syndrome, and no discrimination-threshold differences were found for intensity. Similarly, O'Riordan and Passetti (2006) found enhanced discrimination of pitch in children with ASC compared with controls. Their design was an adaptive one: two tones alternated in such a way that one tone stayed at the same frequency whilst the other would change until the participant would indicate that the two sounded identical. Children with ASC took longer to indicate that the two tones were identical; the authors argue that this indicated that the ASC participants were able to discriminate between the two tones later in the sequence than controls, and hence to discriminate smaller differences in frequency. The design is not criterion-free and cannot rule out the possibility of a perceptual bias or difference in response time. Jones et al. (2009) compared a group of adolescents with ASC and a typically developing group on auditory discrimination tasks of frequency, intensity and duration. They measured individual thresholds using reference tones fixed in frequency, intensity or duration. The authors found no differences at the group level but that a subset of the ASC group had an enhanced ability to discriminate frequency. However, in contrast, Kargas, López, Reddy and Morris (2014) report deficits in auditory discrimination on tasks of frequency, intensity and duration in adults with ASC compared to age-matched controls.

Few studies have assessed across modalities or features, however recently Meilleur, Berthiaume, Bertone and Mottron (2014) assessed performance across two visual and two auditory tasks. They suggest that a common perceptual factor may drive performance on perceptual tasks in individuals on the autism spectrum.

In the current study we focused on basic perceptual attributes of sounds: an area that lacks systematic testing. Stimulus timing is crucial in the auditory modality for speech and music (Chi, Gao, Guyton, Ru, & Shamma, 1999; Jusczyk, 1999; Klatt, 1976; Liberman, Delattre, Gerstmann, & Cooper, 1956; Rosen, 1992; Scott, 1982). Most relevant is the inter-onset-timing between one event and the next: the perception of the timing of auditory events relies on determining the time between events rather than the duration of an event (Grube & Griffiths, 2009; London, 2004; McAdams & Drake, 2002; Monahan & Hirsh, 1990; Povel & Essens, 1985). Another example of rhythmic sounds in our daily environment is footsteps along the corridor. In order to test the enhanced low-level processing model in the auditory domain in relation to everyday relevance, we tested the perception of pitch and inter-onset-interval timing.

We aimed firstly to demonstrate a significant relationship for the processing of pitch based on previous findings of group differences in ASC, and secondly to show a similar relationship for stimulus timing. We administered one pitch task using a fixed reference, and two timing tasks, using a fixed and a variable reference. We opted to use a fixed reference condition as this method had been used in previous studies on pitch processing (Bonnel, et al., 2010; Jones, et al., 2009). However, for timing we used both a fixed and a variable reference task as we were particularly interested in assessing the discrimination of time, a sound feature, which has been relatively unstudied in this field.

In addition, we administered an intensity discrimination task with a fixed reference. To date there have been no reports of enhanced intensity discrimination either in individuals with ASC or in relation to autistic traits. Intensity does not seem to show similar patterns of neural encoding as pitch and timing, i.e. it is not processed by specific areas or neurons. Intensity is encoded by an increase in neural activity, both firing rate and number of neurons firing, and is context-dependent. In addition, our sensitivity is controlled to a large extent by the ambient sound pressure. Correspondingly, the subjective percept of loudness is less directly related to the physical stimulus and represented in a less "absolute" manner than pitch or time.

The approach is a correlational one in order to show the relationship between autistic character traits and auditory processing. Perceptual ability is strongly related to nonverbal or performance IQ (*r*=.92; Deary, Bell, Bell, Campbell, & Fazal, 2004), therefore a student sample was selected as this group is likely to be more homogeneous for IQ. The auditory discrimination tasks used an adaptive tracking algorithm in order to measure thresholds at the individual level. Autistic character traits were evaluated by means of the AQ.

2. Methods

2.1. Participants

University students were recruited who all had English as their first language (n=24; mean age=22.3, s.d.=3.9; 12 males, 12 females). Questionnaires were distributed in either a classroom or a laboratory setting; the remaining tests were administered in a quiet laboratory room on a one-to-one basis with the experimenter, these took approximately two hours to complete.

All participants gave informed consent, and ethical approval was obtained from the University Ethics Committee.

2.2. Auditory Tests

Stimuli were created and delivered using Matlab 6.5 (The Mathworks), with 44.1 kHz sampling rate and 16 bit resolution. The stimuli were presented at 70 dB rms Sound Pressure Level (except where paradigm required intensity variation) via an external soundcard and closed headphones (Edirol Audio Capture UA-3FX; Sennheiser HD 265). All stimuli were based on 200 Hz pure tones (except where the paradigm required frequency variation) of 100 msec in duration with 20 msec gating times.

Each test included a minimum of 3 practice trials for familiarisation of the participant with the task before starting the 60 test trials. Each trial contained one reference and one target stimulus. The position of the target was randomized with equal probability (50%) across trials, using a pseudo-randomised order that was fixed across subjects. Participants had to indicate which of the two stimuli they perceived as target and responded by pressing the appropriate number key on the keyboard. Each test started with a clear difference between target and reference, and all of them used an adaptive two-down, one-up staircase procedure, with the difference being decreased or increased after 2 consecutive responses correct or 1 incorrect, respectively. A larger step size was used up to the fourth reversal (change from decrease to increase or vice versa), after which a smaller step size was used. Interstimulus and intertrial intervals were 1500 ms each (measured from the end of the first stimulus and the subject's response, respectively). Response time was not limited. The discrimination threshold was calculated as the arithmetic mean of the final six reversals, equivalent to the 70.9% correct point of the psychometrical function (Levitt, 1971). The four tests were run in the order described below. In order to reduce the effects of fatigue, following each task the participant was asked to take a break, stretch, take the headphones off and move around the room. Participants were invited to have a drink or a snack, go for a short walk or use the restroom if required. Fatigue within each task would be observable in the adaptive tracks, and the tracks obtained in the present study demonstrate overall reliable results. Figure 1 illustrates the stimuli and tasks.

2.2.1. Fixed reference frequency discrimination: Participants were asked to discriminate between a 200 Hz reference tone and a target tone with a higher frequency. The task was to indicate which tone sounded higher in pitch. The initial difference was 3.2 semitones; step sizes were 0.3 and 0.75 semitones.

2.2.2. Fixed reference intensity discrimination: Participants were asked to discriminate between a softer reference tone and a louder target tone. The task was to indicate which tone sounded louder. The initial difference in intensity was 7 dB; step sizes were 0.75 and 0.25 dB.

2.2.3. Variable reference interval timing: Participants were asked to discriminate between a shorter reference interval and a longer target interval. Intervals were marked by pairs of tones of 100 ms in duration and 200 Hz in frequency. The task was to indicate which pair of tones had the longer gap between them. Reference stimuli had inter-onset-intervals of 300, 360, 420, 480, 560 or 600 ms, presented at equal probabilities in a pseudo-randomised order that was fixed across subjects. Target stimuli were longer by 90% of the duration of the silent reference interval initially; step sizes were 12% and 6%.

2.2.4. Fixed reference interval timing: This task was the same as the variable interval timing task, except that reference stimuli were of fixed durations. Reference stimuli had inter-onset-intervals of 300 ms. Target stimuli were longer by 30% of the duration of the silent reference interval initially; step sizes were 4% and 1.33%.

2.3. Autism-Spectrum Quotient (AQ; (Baron-Cohen, et al., 2001)): The test consists of 50 items and includes five subscales of 10 questions each: social skill (e.g. “I would rather go to a library than a party”), communication (e.g. “I frequently find that I don’t know how to keep a conversation going”), imagination (e.g. “When I’m reading a story, I find it difficult to work out the characters’ intentions”), attention to detail (e.g. “I usually notice car number plates or similar strings of information”), and attention-switching (e.g. “I frequently get so absorbed in one thing that I lose sight of other things”). Half the questions are worded to elicit an ‘agree’ response and the other half, a ‘disagree’ response.

The test was administered as a pen-and-paper task. Participants were asked to answer the question as quickly as possible by circling their response on a 4-point scale (‘strongly disagree’, ‘disagree’, ‘agree’, ‘strongly agree’). The items were scored on a continuous (Likert) scale (1-4). The total AQ score is calculated by summing the scores for all of the 50 items, and total scores can range from 50-200. Baron-Cohen et al. (2001) scored the AQ using the alternative, binary scoring, that is, the collapsing of the 4-point scale to 0 0 1 1. However, the use of binary scoring removes information about individual differences, whereas the Likert scoring preserves the available detail and can increase reliability and validity (Muniz, Garcia-Cueto, & Lozano, 2005). The Likert scoring system for the AQ is therefore the preferred measure here, similarly as in previous studies on the relationship with performance on cognitive and language tasks (Fugard, et al., 2011; Stewart & Ota, 2008; Stewart, et al., 2009).

2.4. Non-Verbal Intelligence: We used a shortened version of Raven’s Advanced Progressive Matrices (RAPM) (Raven, Raven, & Court, 1998) set II) in order to be able to control for a possible relationship of non-verbal IQ and auditory performance or AQ. In each test item, the participant identifies the missing design which completes a pattern. This version consists of 36 items, which progressively increase in difficulty and where each correct response gives a score of 1, and an incorrect response a score of 0, and the range of possible scores is 0–36. We used a 20-minute time limit rather than select particular items, in order to preserve the progressive nature of the task, using this method shows a high correlation with the full test score; r=0.74 (Hamel & Schmittmann, 2006)). The items were presented by computer using the platform of E-prime (Psychological Software Tools, Pittsburgh, PA).

3. Results

Descriptive statistics for the thresholds for the auditory discrimination tasks, AQ and RAPM are shown in Table 1. Spearman's rank correlation test was carried out to seek relationships between those measures. AQ scores correlated significantly with the auditory discrimination thresholds for the fixed reference frequency discrimination task ($r = -0.51$, $p<0.05$), and the fixed reference interval timing task ($r = -0.45$, $p<0.05$) (Fig. 2). These are medium to large effects, explaining 26% and 20% of the variance, respectively (Cohen, 1988). In both cases, auditory thresholds decreased with increasing AQ, suggesting that autistic character traits predict enhanced perception of pitch and time. There was no significant correlation between AQ scores and the auditory discrimination thresholds for the variable reference timing task ($r = -0.22$, n.s.) or the fixed reference intensity task ($r = -0.01$, n.s.). Furthermore, there was no relationship between AQ and non-verbal IQ scores ($r = 0.24$, n.s.) as measured by the Raven’s task, nor was there any relationship between any of the auditory discrimination tasks and the Raven’s task (fixed timing $r = -0.14$, n.s.; variable timing $r = -0.16$, n.s.; frequency $r = -0.20$, n.s.; intensity $r = 0.07$, n.s.). Therefore, there was no need to control for an effect of IQ in the relationship between AQ and auditory thresholds. For the two significant correlations of AQ with frequency and timing thresholds, we tested whether the correlation was a reliable finding by assessing its validity throughout the sample in an additional analysis using bootstrapping. For all possible (134.596) random combinations of n=18 (out of 24), the mean Spearman’s rho correlation coefficient with AQ was -0.45 (SD, 0.11) for the fixed-reference time interval and -0.50 (SD, 0.09) for the frequency discrimination. The mean correlation coefficients in this bootstrapping analysis demonstrate the robustness of the correlations and their validity across the sample, in other words that they are not driven by a few values at either end.

Table 1

Figure 1

Figure 2

4. Discussion

This study set out to assess whether autistic character traits in typically developing individuals would correlate with basic auditory discrimination thresholds for pitch and time and intensity. Autistic traits were assessed using the Autism-Spectrum Quotient (Baron-Cohen, et al., 2001), allowing the evaluation of each individual's degree of autistic character traits. Auditory performance was measured adaptively at the individual level for the basic discrimination for each of the three perceptual features of pitch, time and loudness. The data demonstrate correlations between autistic character traits and the ability to discriminate pitch and time but not intensity. The dissociation suggests that the correlations observed are not a function of a general sensory or auditory enhancement, but that the demonstrated relationship with AQ is specific to certain perceptual features. Non-verbal intelligence did not correlate with any of the auditory measures or with autistic character traits, which further supports the specificity of the demonstrated relationships.

From first principles, the correlations between autistic traits and time and frequency discrimination might reflect a neural basis at a number of levels of sound analysis: i) sensory encoding of the stimuli, ii) the encoding of the corresponding percept, iii) the encoding into and retrieval from working memory. Interestingly, the relationship with thresholds for time-interval discrimination was demonstrated only for a fixed but not a variable reference stimulus. The frequency discrimination task for which a correlation was also observed had a fixed reference stimulus as well, suggesting the possibility that autistic characteristics may enhance specifically the ability to form a more stable representation (of the reference). It must be noted at this point, that the study is limited in its interpretation for two main factors, i) only timing included both a fixed and a variable reference task; ii) the tasks were run in a set order which may have resulted in fatigue or practice effects, which may in theory affect individuals with different levels of autistic traits differently. However, given that correlations were found for the first and fourth task but not for the second and third, order or fatigue are unlikely to have played a significant role in evoking those. We recommend that future work address these limitations by assessing larger cohorts and including additional tasks to assess the differential effect between a fixed and a variable reference described in the current study.

The fact that we find an AQ-related, enhanced discrimination for both a pitch discrimination and a timing task provides some support for the model of Enhanced Perceptual Functioning (EPF) in ASC (Mottron & Burack, 2001; Mottron, et al., 2006)**,** extends this model across the broader autism phenotype, and suggests the existence of a functional correlate within one or more neural mechanisms in more than one domain. The work is congruent with previous behavioural studies showing augmented pitch processing in individuals with ASC (Bonnel, et al., 2003; Jones, et al., 2009; Mottron, et al., 2006). The work further supports the previously suggested absence for an effect for loudness perception; no correlation between autistic traits and threshold for discrimination of intensity was found here and no effect has been found for individuals diagnosed on the autism spectrum (Bonnel, et al., 2010; Jones, et al., 2009). However, the findings contradict the work by Kargas et al. (2015) who find a deficit in discrimination of frequency, intensity and duration. Kargas et al. (2015) suggest that the differences in their study may be explained by IQ and indeed our participants were matched on performance using the Raven's Matrices however, the participants in the Kargas et al. (2015) study were matched on performance on the Wechsler Adult Intelligence Scale (Wechsler, 1999). Individuals with ASC tend to perform better on the Raven's therefore the difference between the studies may be in part due to the matching criteria.

One novel finding is that of a correlation between AQ and discrimination thresholds for time interval processing. The finding of this effect does not necessarily contradict the absence of enhancement in duration discrimination in individuals with autism found in a previous study (Jones, et al., 2009) or the deficit shown by Kargas et al. (2015). Jones et al. (2009) and Kargas et al. (2015) looked at tone duration discrimination, which may or may not be mediated by the same underlying mechanisms as time interval discrimination (Merchant, Zarco, Bartolo, & Prado, 2008; Rammsayer & Brandler, 2004). Duration discrimination for a filled interval (e.g. a constant tone) as used by Jones et al. (2009) could in theory also be achieved by integration of energy (sound intensity) over time, for which an effect would not necessarily be expected. In the discrimination of empty time intervals as used here, which are, defined by the onsets of consecutive events rather than the on-off duration of individual events this is not possible: the task can only be solved based on the timing. The timing of event onsets as tested here provides salient information in temporal pattern (rhythm) perception with or without a beat (Grube & Griffiths, 2009; McAdams & Drake, 2002; Monahan & Hirsh, 1990; Povel & Essens, 1985), and is relevant in the perception of speech (Rosen, 1992) (Scott et al., 1982) and music (London, 2004).

The absence of an effect in the variable reference task suggests that the locus of the enhancement may lie in the formation of a stable and accurate representation of a repeatedly presented stimulus, rather than the immediate sensory processing. Further support for the proposed formation of a stable representation can be seen in previous work showing related effects but not explicitly addressing this point. Bonnel et al. (2003) for instance looked at pitch perception and reported high sensitivity of the group with ASC in a discrimination (same-different) and a categorization (low-high) task. The categorization task depends highly on an accurate, memorised representation of the reference pitches, which in the comparison group led to a characteristic drop in performance and sensitivity index in comparison with the discrimination task. The identical level of performance between the two tasks in the ASC group is discussed by the authors as a lower sensitivity to difference in task requirements and a more robust sensory memory trace. Possibly and in line with our present conclusion, the absence of a drop in performance for the categorization task in the ASC group could be related to an enhanced ability to form an accurate and stable representation of a repeated reference stimulus, which could also be the basis for a more accurate memory trace. The notion of such an enhancement would include memorised traces of a particular "value" of a sensory feature, e.g. pitch or time. This is further supported by electrophysiological data such as enhanced mismatch negativity (Gomot, Belmonte, Bullmore, Bernard, & Baron-Cohen, 2008; Gomot, Giard, Adrien, Barthelemy, & Bruneau, 2002), an auditory event-related potential in the EEG (electroelencephalogram) that reflects the processing of a mismatch to a memory trace of a physical stimulus feature or some kind of violation of regularity (Naatanen, 2007). The recently emerging pattern of enhanced brain activations in primary areas in individuals with ASC compared with typically developing individuals (in conjunction with the opposite pattern for associative areas) (e.g. Just, Cherkassky, Keller, & Minshew, 2004) fits well with the idea of enhanced low level processing (see Mottron et al., 2006: Principles 4 and 8). Increased activity in sensory and associative cortical areas has been reported in the auditory modality (Samson et al., 2011), whilst in the visual domain increased activity has also been reported in higher-order order areas (Samson et al., 2012). Differences in effects in higher-order areas may in part be due to differences between sensory modalities (auditory versus visual) and in part due to task demands (e.g. low-level sound discrimination vs. sentence comprehension). In the current study, the significant correlation between AQ and fixed reference pitch and fixed reference time discrimination, together with the lack of a significant correlation for a variable reference time discrimination, suggests that the locus of enhancement is the formation of a stable perceptual representation, possibly based on early cortical processes.

There are a number of possible brain bases for the ability to form an enhanced perceptual representation of pitch and time with increasing AQ. Previously suggested possibilities include an augmented sensory representation in the ascending pathway and auditory cortex in autism (Plaisted, et al., 2003). Candidate neural bases for the perceptual representation of pitch are currently debated but are likely to exist in auditory cortex (see Bendor & Wang, 2005 for non-human primate studies; see Griffiths, et al., 2010 for discussion of human studies), whilst the perceptual encoding of single or multiple time intervals as assessed here involves analysis beyond the auditory cortex, including the cerebellum, basal ganglia and pre-frontal cortex (Grube, Cooper, Chinnery, & Griffiths, 2010; Lewis & Miall, 2003; Penhune, Zattore, & Evans, 1998; Teki, Grube, Kumar, & Griffiths, 2011; Xu, Liu, Ashe, & Bushara, 2006). Both pitch and time are highly salient perceptually and can, to a certain extent be encoded in an absolute fashion, i.e. in a way that allows us to remember and judge the pitch and the timing of events based on one (or more) fixed reference points -implicitly or explicitly. The skill of absolute pitch for instance (Griffiths, 2003; Plack, Oxenham, Fay, & Popper, 2005; Schonwiesner, von Cramon, & Rubsamen, 2002) is an example of the absolute encoding of pitch value, coupled with a specific type of verbal labelling (Zatorre, 2003; Zatorre, Perry, Beckett, Westbury, & Evans, 1998). The categorical perception of phoneme-to-phoneme timing of speech sounds, e.g. of voice-onset-time, a common one (Lisker & Abramson, 1964, 1967; Rosen, 1992). Recent data suggest a mechanism for absolute duration encoding based on neuronal "channels" of preferred duration (Becker & Rasmussen, 2007; Heron, et al., 2011; Ivry, 1996). Mechanisms for the representation of stimulus intensity or the corresponding percept of loudness however do not allow such an absolute encoding perceptually. They have been investigated using electroencephalography and brain imaging methods (Jancke, Shah, Posse, Grosse-Ryuken, & Muller-Gartner, 1998; Tanji, et al., 2010; Neuner, Kawohl, Arrubla, Warbrick, Hitz, Wyss, Boers, & Shah, 2014), but the existence of a dedicated encoding of intensity as the basis for an absolute and stable representation of the percept is uncertain. The absence of a correlation with loudness perception in contrast to the presence for those with pitch and time supports the notion that autistic traits relate to the ability to form a stable perceptual representation.

The study is clearly limited in that it assesses a group of university students. The advantage of this participant group is that IQ is relatively homogeneous, and in an study such as this where IQ may correlate with discrimination ability it is important to control as much as possible for IQ. Indeed, we did not find a correlation between IQ and discrimination thresholds. In addition, although we have a good range of AQ scores, and bootstrapping analysis has shown the effect to be robust the sample is not large. However, any findings are limited to this group, and it would be useful to test a larger group, including members from the general population, and to test whether the findings hold in a group with ASC.

The present data demonstrate improved perceptual processing for the two auditory perceptual features of pitch and time. The findings are consistent with the augmented encoding of the corresponding stimulus features and moreover suggest as the locus of enhancement not the immediate sensory processing but the formation of a stabilised percept of pitch and also of time at or beyond early cortex levels in participants with autistic traits. The identification of the neural substrates for the effects of increased AQ and enhanced perceptual representation observed here will require further investigation.

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Table 1: Descriptive statistics on autistic traits measures, Raven's matrices (RAPM) and auditory discrimination performance.

	Mean	SD	Min	Max
Pitch (in semitones)	0.79	0.53	0.13	1.81
Fixed Time-interval (threshold in ms)	13.88	5.66	4.67	23.11
Variable Time-interval (threshold in %)	18.78	9.04	7.00	40.00
Intensity (threshold in dB)	1.37	0.68	0.25	3.08
AQ total	114.0	20.3	77	150
Social Skill	22.1	6.2	11	33
Attention Switching	25.8	5.4	14	36
Attention to Detail	23.5	5.5	15	39
Communication	21.6	5.1	13	33
Imagination	21.0	4.0	16	30
RAPM score (20min)	21.0	4.7	13	28

Figure 1. Auditory discrimination tasks. (a) Time. (b) Frequency. (c) Intensity. Stimuli were presented using Matlab 6.5 (The Mathworks), 44.1 kHz sampling rate and 16-bit resolution, an external soundcard (Edirol UA-3FX) and closed headphones (Sennheiser HD 265). All stimuli were based on pure tones with a frequency of 200 Hz in (plus difference in b), a duration of 100 msec , and an intensity of 80 dB SPL rms (plus difference in c). Inter-onset intervals (in a) were 300 ms and 300-600 ms in the fixed and the variable condition, respectively (plus difference).

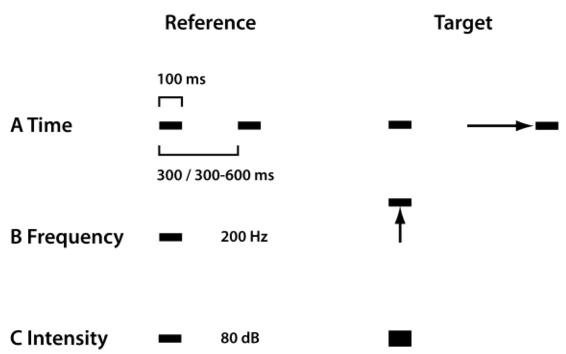

Figure 2. Correlation between AQ scores and auditory discrimination thresholds for fixed-reference stimuli: (a) Time: correlation coefficient r = -0.45 (p<0.05). (b) Pitch: correlation coefficient r = -0.51; both significant at the level of p<0.05 (Spearman's rho).