



Impaired Categorical Perception of Mandarin Tones and its Relationship to Language Ability in Autism Spectrum Disorders

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Abstract

While enhanced pitch processing appears to be characteristic of many individuals with autism spectrum disorders (ASD), it remains unclear whether enhancement in pitch perception applies to those who speak a tone language. Using a classic paradigm of categorical perception (CP), the present study investigated the perception of Mandarin tones in six- to eight-year-old children with ASD, and compared it with age-matched typically developing children. In stark contrast to controls, the child participants with ASD exhibited a much wider boundary width (i.e., more gentle slope), and showed no improved discrimination for pairs straddling the boundary, indicating impaired CP of Mandarin tones. Moreover, identification skills of different tone categories were positively correlated with language ability among children with ASD. These findings revealed aberrant tone processing in Mandarin-speaking individuals with ASD, especially in those with significant language impairment. Our results are in support of the notion of impaired change detection for the linguistic elements of speech in children with ASD.

Index Terms: categorical perception, Mandarin tones, ASD, language ability

1. Introduction

Simply defined, autism spectrum disorders (ASD) is a group of neurodevelopmental disorders with core deficits in social communication and interaction, combining with restricted repetitive behaviors and reliance on a routine before three years of age [1]. ASD has been divided into different subtypes, of which Autistic Disorder (or autism) and Asperger's syndrome (AS) are the most commonly studied. Although the symptomatology of autism and AS is similar, individuals with AS function at the higher end of the spectrum [2]. Furthermore, a diagnosis of AS is only given without significant language and/or cognitive delay [3]. However, language onset is significantly delayed in the group of autism, and research on language development showed considerable variability. While between 25% and 50% of children with autism never acquire a functional language [4], relatively well-developed language abilities are also observed in some individuals [5].

The "enhanced pitch processing phenomenon" has drawn researchers' attention to the issue of atypical perception in

children with ASD. There is a relatively high occurrence of absolute pitch (AP) ability among the ASD population [6]. Moreover, several studies have found children with ASD are generally more accurate than typically developing (TD) children at melodic contour discrimination [7-9], and at identifying the pitch of isolated pure-tone stimuli in various pitch discrimination and categorization tasks [5, 10]. Furthermore, Heaton et al. [11] investigated the ability of ASD and TD children to discriminate varied pitch differences between pairs of words, non-words, and non-speech pitch contour analogues. Results indicated ASD subjects were more proficient at discriminating pitch from both speech and non-speech stimuli relative to controls. The enhanced pitch processing across different domains of music, non-speech and speech can be explained by the Weak Central Coherence (WCC) theory, which emphasized the enhanced processing of local information or detail in children with ASD [12-13].

The above-mentioned studies have all focused on pitch processing in individuals with ASD from non-tonal language backgrounds (e.g., English, Finnish, French, etc.). It remains unclear whether the enhancement in pitch perception operates universally regardless of the language background of the participants. Especially, pitch changes play a unique role in building up lexicon in tonal languages, since they form phonological contrasts at the syllabic level that differentiate word meaning [14]. For example, in Mandarin, /ma/ means "mother" when spoken with a high-level tone (Tone 1), and the same syllable means "hemp" when it is pronounced with a middle-rising tone (Tone 2). Consequently, the pitch information in tonal languages performs as a language-specific processing in speech.

It has been well documented that the unique linguistic role of lexical tones requires the language-specific psychological representations for the categorical perception (CP) of pitch patterns in tonal languages (e.g., [15-20]). Especially for Mandarin tone perception, there is ample evidence that Mandarin adult listeners not only showed a sharp boundary (steeper slope) between the level tone and the rising or falling tone in the identification function, but also exhibited a prominent discrimination peak around the categorical boundary position, indicating a typical categorical perception of Mandarin tones (e.g., [15, 17, 18, 20]). Moreover, our previous work [21] has revealed a significant increase in the perceptual acuity of Mandarin tones in TD six-year-old

preschoolers, resulting in an adult-like performance in both the identification and the between-category discrimination tasks.

Using a classic paradigm of CP, perceptual performance of the Mandarin tone continuum ranging from Tone 1 to Tone 2 in Mandarin-speaking children with ASD was investigated in the current study, with three basic research concerns. First, we tried to detect whether the perception of Mandarin tones in children with ASD showed basic characteristics of CP, and further compared the degree of CP in children with ASD with age-matched TD controls. Second, we aimed to address whether enhanced auditory discrimination to pitch differences in children with ASD would be applicable to lexical tone processing in speakers of a tonal language. Third, in order to explore the relationship between perceptual acuity and language ability, perceptual performance was considered with respect to participant performance on standardized tests of language ability.

2. Methods

2.1. Participants

The participants included 11 children with ASD (all boys) and 14 typical development children as controls (8 boys). The average chronological ages of the two groups (see Table 1) were not different from one another ($t = 0.99, p = 0.34$). All the 25 child participants were native Mandarin speakers, and had no history of hearing or neurological impairment. The consent form was obtained from each child’s parent.

The 11 individuals with ASD had all been diagnosed based on *Diagnostic and Statistical Manual of Mental Disorders* (DSM-5) criteria [1] and *The Childhood Autism Rating Scale* (CARS) [22] by pediatricians and child psychiatrists with expertise in diagnosing ASD. Of these, nine children were diagnosed with Autistic Disorder, and two were diagnosed with Asperger’s syndrome (with better language ability). Assessed by the local administrant hospital, all the 11 children with ASD had Nonverbal IQ scores above 70 using the Raven’s Standard Progressive Matrices Test [23].

Table 1: *The chronological ages and developmental ages of language ability among participants*

	ASD		Control	
	Mean	SD	Mean	SD
Chronological Ages	7.57	1.04	7.25	0.21
(Range, in year)	(6.08–8.75)		(7.08–7.88)	
Developmental Ages	3.66	1.23	N/A	
(Range, in year)	(2.17–5.72)			

In order to explore the relationship between perceptual acuity and language ability, all children with ASD completed *The Psychoeducational Profile-Third Edition* (PEP-3), which is designed to assess the development of communication, motor skills and the presence of maladaptive behaviors in children with ASD [24]. Specifically, some subtests of PEP-3 (e.g., Expressive Language and Receptive Language) mainly focus on assessing developmental level of language ability in young children with ASD. The raw scores of these subtests can be converted to into developmental ages of language ability (based on a large TD sample). The characteristics of all the participants are presented in Table 1.

2.2. Materials

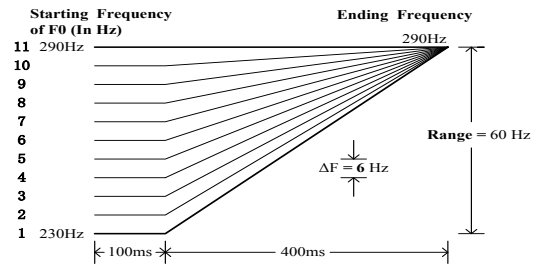


Figure 1: *Schematic diagram of the pitch contours.*

The Mandarin syllable /i/ with the high-level tone (Tone 1 in Mandarin, around 290 Hz) was recorded by a female native Mandarin speaker (22050 Hz sampling rate, 16-bit resolution). Based on the natural speech template with Tone 1, all the 11 stimuli were re-synthesized by applying the pitch-synchronous overlap and add (PSOLA) method implemented in Praat [25], and the procedures for synthesizing these stimuli followed those described in Peng et al. [20]. In Mandarin, the monosyllable /i/, when produced with the high-level tone (Tone 1), is a homophone with different meanings such as “clothes”, and is coded as stimulus #11; when with the mid-rising tone (Tone 2), it is another homophone with different meanings such as “aunt”, which is coded as the stimulus #1. Figure 1 shows schematic diagram of the pitch contours of the 11 stimuli along the tone continuum. All the 500-ms tone stimuli were presented binaurally at 70 dB SPL.

2.3. Procedure

For the young children to complete the whole identification task and discrimination task, the experimental designs were modified following those described in Chen et al. [21]. No feedback was given to the child participants during the practice and testing blocks.

The identification task was tested on the first day. A training session was firstly provided to guarantee that all the children could follow the instructions. The experimenter taught them to point at the left picture on a computer screen (a car driving on a level road) representing the F0 direction of stimulus #11 after playing the sound #11 several times, and point at the right picture (a car driving on a rising road) representing the F0 direction of stimulus #1 after playing the sound #1 several times. For TD controls, the 11 stimuli were repeated eight times; for children with ASD, the 11 stimuli were repeated only five times in the testing block to reduce the task difficulty, totaling 55 testing trials in a random order.

The discrimination task was conducted on the next day. In the training part, the experimenter instructed them to point at the left picture (a happy face with two identical eyes) representing the same pairs after playing sounds (11-11 or 1-1) several times, and point at the right picture (a sad face with two different eyes) representing the different pairs after playing the sounds (11-1 or 1-11) several times. Only after the children succeeded in pointing at the matched picture each time they heard the training sound pairs (11-11; 1-1; 11-1; 1-11) would they progress to formal experiment. For the testing part, 29 pairs were presented in a random order, with a 500 ms inter-stimulus interval (ISI). Of the 29 testing pairs, 18 pairs consisted of two different stimuli separated by two steps (i.e., 12 Hz) (different pairs), in either forward (1-3, 2-4... 8-10, 9-

11) or reverse order (3-1, 4-2 ... 10-8, 11-9), and 11 pairs consisted of the 11 stimuli on the continuum each paired with itself (same pairs). For children with ASD, the 29 testing pairs were repeated twice, resulting in 58 pairs in total; for controls, the 29 pairs were repeated five times, totaling 145 testing pairs.

2.4. Data analyses

The identification score was calculated as the percentage of responses with which participants identified that stimulus as being either ‘Tone 1’ or ‘Tone 2’. Boundary position and boundary width were assessed by using Probit analyses [26]. The boundary position, defined as the 50% crossover points, and the boundary width as the linear distance between the 25th and 75th percentiles were analyzed according to the procedures described in Peng et al. [20].

In order to calculate the obtained discrimination scores, we divided the discrimination pairs into nine comparison units, each consisting of all the pairs in four types of pairwise comparisons (AB, BA, AA, and BB) for stimuli A and B separated by two steps (cf. Peng et al., [20]). The discrimination accuracy (P) for each comparison unit was calculated according to the formula described in Xu et al. [19]. Moreover, based on the position of category boundary, we further divided the discrimination accuracy into between-category comparisons (P_{bc}) and within-category comparisons (P_{wc}) for each subject (cf. [27]).

3. Results

3.1. Identification and discrimination curves

All the child participants completed the identification task. However, two children with ASD failed to accomplish the discrimination task and were thus excluded from discrimination analysis. Identification and discrimination curves for children with ASD and TD controls are shown in Figure 2. The discrimination peak was well aligned with the position of categorical boundary for TD controls. However, for children with ASD, no prominent peak exhibited along the discrimination curve ($F(8, 72) = 0.23; p = 0.99$).

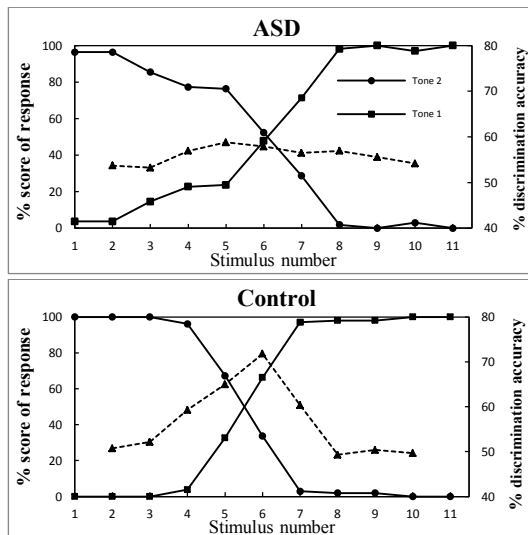


Figure 2: Identification curves (solid lines) and discrimination curves (dashed lines). The left y-axis indicates the percentage score of Tone 2 or Tone 1

responses, while the right y-axis means the percentage of discrimination accuracy.

3.2. Position and width of categorical boundary

The mean boundary positions for children with ASD and controls were 5.65 and 5.57 respectively. Results of one-way ANOVA revealed that the perceptual boundary position was not significantly different between the two groups ($F(1, 23) = 0.07; p = 0.80$). Moreover, the average boundary widths for children with ASD and controls were 2.16 and 1.07 respectively. One-way ANOVA showed that the average boundary width for children with ASD was significantly wider than controls ($F(1, 23) = 14.49; p < 0.001$). The distribution of boundary width for two groups is shown in Fig. 3.

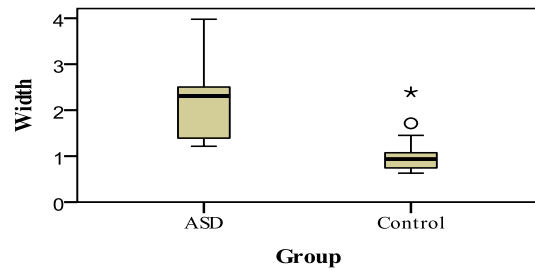


Figure 3: Distribution of boundary width.

3.3. Discrimination accuracy

The overall discrimination accuracies of nine comparison units were divided into two category types: between-category comparison (P_{bc}) and within-category comparison (P_{wc}), as shown in Figure 4. A 2 (category type) \times 2 (group) two-way Analysis of Variance (ANOVA) was conducted. The analysis confirmed a significant main effect of category type, $F(1, 21) = 19.48, p < 0.001$, with no significant main effect between two groups, $F(1, 21) = 1.78, p = 0.20$. However, there was a significant interaction between category type and group, $F(1, 21) = 5.83, p < 0.05$, indicating that the influence of category type on the discrimination accuracy was statistically distinguishable between two testing groups.

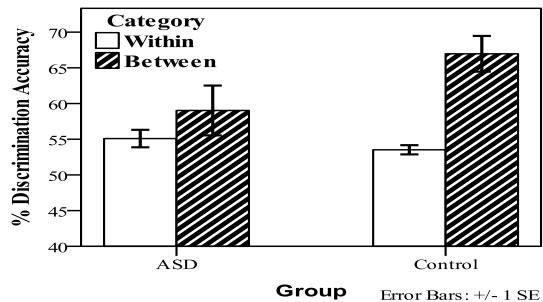


Figure 4: Between-category and within-category discrimination accuracy for two groups.

Simple main effects were then tested on the influence of category type (within vs. between) within each group. For the TD controls, category type showed a significant effect ($F(1, 26) = 27.06, p < 0.001$), indicating that between-category comparisons led to a higher accuracy (66.96%) than within-category comparisons (53.52%) for TD controls. In contrast, no significant effect of category type was found for children with ASD ($F(1, 16) = 1.13, p = 0.30$). Moreover, an

independent-samples t-test showed that TD children performed better than ASD children in terms of between-category discrimination ($t = -1.90, p < 0.05, df = 21$; see Fig. 4). However, the two groups showed similar sensitivity to the within-category discrimination ($t = 1.24, p = 0.23, df = 21$).

3.4. Correlation between identification acuity and language ability

A Spearman correlation analysis was conducted between boundary widths and developmental ages of language ability in children with ASD, and the corresponding scatterplot is shown in Fig. 5. A strong negative correlation between the boundary width and developmental age of language ability ($r = -0.81, p < 0.01$) was found in children with ASD.

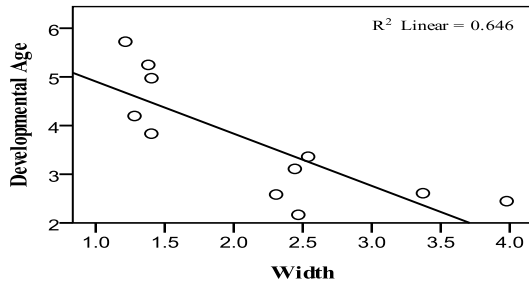


Figure 5: Correlations between the boundary width and developmental age of language ability.

4. Discussion

The current study examined CP of Mandarin tones in six- to eight-year-olds with ASD. The CP of tones was greatly impaired in terms of two aspects. On the one hand, compared with controls, the boundary width was much wider for children with ASD (i.e., more gentle slope), meaning that it was not sensitive for children with ASD to identify the change from one tone category to the other. On the other hand, no prominent discrimination peak was shown along the curve for children with ASD. Taken together, the present results showed an impaired CP of Mandarin tones for children with ASD.

It has been well documented that superior pitch perception is characteristic of many individuals with ASD at melodic contour discrimination (e.g., [7-9]), and at perceiving the pitch of non-speech pure-tone stimuli (e.g., [5, 10]). Moreover, for non-tonal language speakers with ASD (e.g., [11]), hypersensitivity to pitch information has also been observed in speech words. As for tone language speakers with ASD, however, Yu et al. [28] investigated the pitch processing in Mandarin-speaking children with autism using event-related potential measures and found enhanced neural discriminatory sensitivity only in the nonspeech conditions but not for speech stimuli, implying domain specificity of enhanced pitch processing. The present study further discovered impaired tone processing in speech for Mandarin-speaking individuals with ASD, in terms of both the tone identification and between-category discrimination performance.

The different performance of speech pitch perception between non-tonal and tonal language speakers with ASD can be explained by the phonological status of pitch information in the speech stimuli. For tonal language users, the pitch difference constitutes a phonemic contrast, and the reduced sensitivity to lexical tones in the children with ASD is likely attributable to troubles in the proper and typical acquisition of

lexical tones. While growing up, the Mandarin-speaking children are frequently exposed to spoken language input in their surrounding environment, which provides highly variable pitch information for different tone categories. To establish stable representations of the phonological categories for the lexical tones, the listeners need to develop enhanced sensitivity for between-category contrasts, which is shown clearly in TD Mandarin-speaking children even as early as age four [21]. However, the current results showed that there was no difference in discriminating within- and between-category tone pairs for Mandarin-speaking children with ASD, thus preventing the formation of CP of tones.

Furthermore, previous researches have demonstrated that individuals with ASD attend to and even prefer musical and non-speech stimuli over speech [29-31]. This may consequently result in an attention bias toward the musical or non-speech sounds and a diminished interest in linguistic or social stimuli in children with ASD. For example, Jiang et al. [32] investigated the perception of melodic contour and speech intonation in a group of Mandarin-speaking individuals with ASD, who showed superior melodic contour identification relative to controls. However, they performed worse than controls on the perception of speech intonation. WCC theory [33] proposes that the coherence at verbal/semantic levels is weak, and many experiments supporting this hypothesis have observed a reduced ability to process language elements in children with ASD (for a review, see [34]). To the best of our knowledge, the present study is the first attempt to discover a strong correlation between tone identification acuity and language ability in tone language speakers with ASD. The present results indicated that the better identification acuity (the narrower width or the sharper boundary) tended to be generated by Mandarin-speaking ASD children with an older developmental age of language ability.

5. Conclusions

We have examined CP of Mandarin tones in six- to eight-year-olds with ASD and its age-matched TD controls. A typical CP of Mandarin tones was found among TD controls, while the child participants with ASD exhibited a much wider boundary width, and showed no improved discrimination for pairs straddling the boundary. These results indicated an impaired CP of Mandarin tones in children with ASD, reflecting a reduced perceptual ability to process linguistic pitch information in speech. Moreover, Mandarin-speaking ASD children with better language ability also exhibited higher identification acuity of different tone categories, emphasizing the importance of language-related processing of pitch information among tonal language speakers with ASD.

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