DO CHILDREN WITH DYSLEXIA HAVE A GENERAL AUDITORY PROCESSING DEFICIT, PHONOLOGICAL PROCESSING DEFICIT OR SEMANTIC DEFICIT: INSIGHTS FROM LINGUISTIC AND NON-LINGUISTIC TONE PERCEPTION IN CANTONESE-SPEAKING CHILDREN WITH DYSLEXIA

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ABSTRACT

Previous research hypothesized that children with dyslexia might have a general auditory processing deficit or phonological processing deficit. Recent studies showed that tone-speaking children with dyslexia had special difficulties with lexical tone identification. Tone identification ability uniquely predicted word reading ability and dyslexia.

This study compared discrimination of non-linguistic pitch contours that resembled Cantonese lexical tones, discrimination of Cantonese lexical tones, and identification of Cantonese lexical tones in (1) Cantonese-speaking children with dyslexia, (2) age-matched peers and (3) reading-matched children. Children with dyslexia performed poorer than age-matched children in all tasks. Their ability in pitch and tone discrimination was comparable to that of younger reading-matched peers but their tone identification was poorer than age-matched and reading-matched peers and uniquely predicted their literacy skills and dyslexia. The results suggest that children with dyslexia are delayed in general auditory processing and phonological processing and have core deficits in semantic access.

Keywords: pitch perception, lexical tone perception, dyslexia, general auditory deficit, Cantonese

1. INTRODUCTION

Children with dyslexia exhibit difficulties with word encoding and decoding. The general auditory processing deficit theory [1, 2] and the phonological processing deficit theory [3, 4] have been put forward to explain the reading difficulties in children with dyslexia. The former proposes that children with dyslexia have difficulties processing acoustic signals, particularly those that are brief with rapid transition [5, 6, 7], not specifically to speech sounds. The latter theory, on the other hand, postulates that children with dyslexia have special difficulties processing linguistic speech sounds as displayed by their difficulties with phonological awareness and manipulating speech sounds [8, 9].

Studies that examined pitch perception in English-speaking children with dyslexia supported the general auditory processing deficit theory. Children with dyslexia required higher threshold than age-matched controls in discriminating pure tones of different frequencies [10, 11]

Yet, recent studies that examined Mandarin and Cantonese lexical tone identification showed speech specific phonological deficits in children with dyslexia. Children with dyslexia identified lexical tones poorer than their age-matched peers [12, 13]. Interestingly, children's lexical tone identificaiton ability predicted word reading abiltiy and dyslexia better than other linguistic tasks such as initial syllable deletion [12, 13]. It remains unclear whether non-linguistic pitch perception or tone discrimination also predicts word reading and writing abilities.

To test the two theories of dyslexia, this study examined non-linguistic pitch discrimination, linguistic tone discrimination, and lexical tone identification in three groups of Cantonese-speaking children: children with dyslexia, age-matched typically-developing children, and younger reading-matched children. If the general auditory processing deficit theory deficit is correct, children with dyslexia would perform poorer than typical children in all the three tasks given that accurate pitch percpetion is the basis for accurate lexical tone perception. If the phonological processing deficit theory is right, children with dyslexia would perform comparably in the pitch discrimination task but poorer in the lexcial tone discrimiantion and identificaiton tasks than the typical children. In addition, if children with dyslexia performed poorer than age-matched children but comparable to the reading-matched peers, their difficulties would be indicative of a delay related to their reading development, whereas if childern with dyslexia performed poorer than both age-matched and reading-matched children, their difficulties would be more indicative of a disorder.

Cantonese was selected because it has one of the most complex tonal systems with six full tones and three checked tones. The six full tones consist of three level tones (high, mid and low level tones), two rising tones (high and low rising tones) and a falling tone (low falling tone). The three checked tones only occur in syllables with a final voiceless plosive (/-p/, /-t/, /-k/) and are considered as allotones of the three level tones. They are 2/3 shorter than their full tone counterparts [14]. Thus the nine Cantoense tones are contrastive in pitch levels, pitch shapes and pitch durations (See [14] for detailed acoustic information of the nine tones).

The research questions of the current study were: (1) Do Cantonese-speaking children with dyslexia demonstrate non-linguistic pitch perception deficits? (2) Do Cantonese-speaking children with dyslexia display lexical tone perception deficits? (3) What are the relationships among pitch perception, lexical tone perception and word reading and writing abilities in children?

2. METHOD

2.1. Participants

75 children participated in the study. Thirty (15 8-year-olds (D08), 15 10-year-olds (D10)) received formal diagnosis of dyslexia (D group). Another 30 typically-developing children (15 8-year-olds (CA08), 15 10-year-olds (CA10)) formed the age-matched control group (CA group). Fifteen 10-year-old children whose non-verbal IQ and word reading ability matched those of the ten-year-old children with dyslexia formed the reading-matched control group (RM group, mean age =8.3 years).

2.2. Measures

Tasks that were used to measure children's abilities:

2.2.1. Language ability

Language ability was measured by the Cantonese Expressive Language Scales [15].

2.2.2. Non-verbal intelligence

Non-verbal intelligence was measured by the Raven's Colored Progressive Matrices [16].

2.2.3. Memory capacities

Forward and backward digit span tests were used to measure short-term and working memory.

2.2.4. Literacy skills

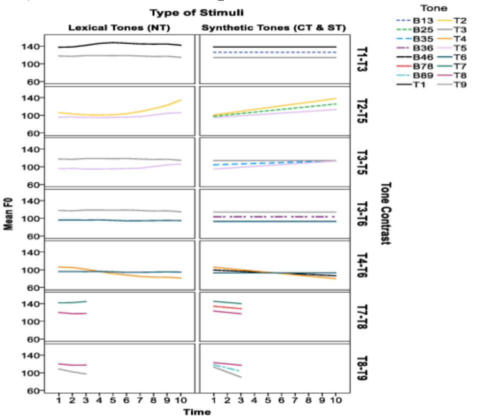
Literacy skills were measured by a Chinese word reading task adopted from [17], a Chinese word reading fluency taskn, and a word dictation task.

2.2.5. Lexical tone perception abilities

Children's lexical tone perception abilities were measured by a Cantonese tone discrimination task and a Cantonese tone identification task.

In the tone discrimination task, natural productions of the nine Cantonese tones in the syllables /ji/ (for full tones) or /jip/ (for entering tones) by a male speaker were low passed filtered at 5K Hz and normalized to 72 dB. The tones of these productions had been correctly identified by five judges in filtered stimuli that retained the pitch information but eliminated the lexical identity. The nine natural productions formed seven tone minimal pairs covering the most confusing tonal contrasts for children based on previous research [18, 19]. The seven tone pairs were used to construct a 28-trials AXB tone discrimination experiment with an ISI of 500 ms. Children determined which production was different from the other two. The left panels in Figure 1 show the F0 contours of the seven pairs of naturally produced lexical tones.

Figure 1: Fundamental frequency contours of the naturally produced tones (NT), the synthetic complex tone (CT) and the synthetic speech tones (ST) for the tone and pitch discrimination tasks.



Note. "B" indicates F0 contours mid-way between a pair of tones. For example, B13 indicates an F0 contour mid-way between Tone 1 (High-level) and Tone 3 (Mid-level).

In the tone identification task sixty-five monosyllabic words familiar to pre-school children formed 36 minimal pairs, 2 for each of the 18 tone pairs formed by the 9 tones. There were 8 trials for each tone pair. In each trial, 4 pictures representing the target word and 3 words that differed from the target word by the initial consonant, the vowel or the tone only were presented on the screen. Upon hearing the target word in a carrier phrase, children selected the corresponding picture.

2.2.6. Pitch perception abilities

Children's pitch perception abilities were measured in an AXB pitch discrimination task. Sixteen synthetic complex tones (CT) were generated using the Pitch Synchronous Overlap Add (PSOLA) re-synthesis tool in Praat. Nine of them were constructed using the mean fundamental frequency (F0) (for the level tones), or the minimum and maximum F0 (for the contour tones) of the naturally produced lexical tones used in the lexical tone identification task described above. Seven additional synthetic tones were generated by having the onset and offset F0 of the tones mid-way between seven easily confused tone pairs. Each synthetic tone composed of 500 harmonics and was low-pass filtered at 5K Hz and normalized at 72 dB. Durations of synthetic tones were set at 470 ms and 150 ms, respectively. Another set of synthetic speech tones (ST) was created by applying the F0 contours of the CT stimuli to the syllables of /ji/ and /jip/.The right panels in Figure 1 show the F0 contours of the two sets of synthetic stimuli.

2.3. Procedures

Each child attended one or two one- to three-hour sessions, depending on the number of breaks the child needed. Parents completed a language background questionnaire. All children passed a hearing screening and completed the measures described in section 2.2 above.

3. RESULTS

In all statistical analysis, multiple comparisons were corrected with Bonferroni adjustments.

3.1. Comparisons of age, non-verbal intelligence, memory capacities, and reading and writing abilities between 8- and 10-year-old children with dyslexia (D) and their age-matched peers (CA)

Two analyses of variance (ANOVAs) with participant group (D, CA) and age group (08, 10) as between-subject factors were conducted. One used age and the other used scores in Colored Raven's test as between-subject factors. The results showed no significant difference in age between children with dyslexia and their age-matched peers, and no significant difference in non-verbal IQ between 10-year-old children with Dyslexia and their age-matched peers. However, 8-year-old children with Dyslexia had lower non-verbal IQ scores than their age-match peers ($p<.001$, $r = -0.547$).

Two multivariate analyses of variance (MANOVAs) using participant group (D, CA) and age group (08, 10) as between-subject factors were conducted. One used the scores in the digit span tests and the other used the scores in the reading and writing tasks as the dependent variables. The results showed no significant differences in the memory capacities in the children. However, children with dyslexia performed significantly poorer than their age-matched typically-developing peers in all the three reading and writing tasks (all $p < .001$, ηp^2 ranged from .43 to .56), confirming the reading and writing deficits in children with dyslexia.

3.2. Pitch and tone discrimination in 8- and 10-year-old children with dyslexia and their age-matched peers

A four-way mixed ANOVA with participant group (D and CA) and age group (08, 10) as between-subject factors, sound type (CT, ST, NT) and tonal contrast (T1-T3, T2-T5, T3-T6, T3-T5, T6-T4, T7-T8, T8-T9) as within subject factors, and accuracy scores in the discrimination tasks as the dependent variable was used. The results showed main effects of participant group, sound type, and tone pair (all $ps<.001$, $\eta p^2=.187-.318$), and significant interaction effects of sound type x participant group ($p=.023$, $\eta p^2=.074$) and tone pair x sound type ($p<.001$, $\eta p^2=.076$). Pairwise comparisons showed that children with dyslexia performed poorer than age-matched children in the discrimination of all the sound types ($ps \leq .001$, r ranged from -0.414 to -0.572) and all the tone pairs (all $ps \leq .001$).

3.3. Tone Identification in 8- and 10-year-old children with dyslexia and their age-matched peers

A three-way mixed ANOVA with participant group (D, CA) and age group (08, 10) as between subject factors, tone type (full, entering) as within subject factor and tone identification accuracy as the dependent variable was conducted. The results showed main effects of participant group, age group, and tone type and significant interaction effect of participant group x tone type. Pairwise comparisons showed that eight-year-old children performed poorer than 10-year-old children ($p=.023$, $\eta p^2=0.089$), identification of entering tones were more difficult than full tones ($p < .001$, $\eta p^2=.407$), children with dyslexia performed poorer than age-matched children in identifying tones in both tone types ($p =.015$, $r=-.498$ for entering tones, $p < .001$, $r=-.508$ for the full tones), with the identification of the entering tones poorer than the full tones ($p <.01$, $r=.417$).

3.4. Relationships between tone perception skills and literacy skills

Results of partial correlation analysis showed that after controlling for age and non-verbal IQ, scores in

CT discrimination significantly correlated with reading fluency (r^2=.094); ST discrimination significantly correlated with word dictation (r^2=.133), NT discrimination significantly correlated with both reading fluency (r^2=.092) and word dictation (r^2=.091). Tone identification performance significantly predicted performance in all the three reading and writing tasks (r^2=.125, .102, .125 for word reading, reading fluency, word dictation, respectively), suggesting that tone identification was better than pitch and tone discrimination in predicting reading and writing skills.

Results of hierarchical regression analyses supported that lexical tone identification was the most important predictor of word reading and writing. It accounted for unique variance in word reading (R^2 change = 0.06, p = 0.01) and writing skill (R^2 change = 0.05, p = 0.02) after controlling for age, nonverbal IQ, and other predictor variables (CT, ST and NT).

Results of logistic regression demonstrated that among the predictors tested (i.e., age, nonverbal intelligence, discrimination of CT, ST and NT and lexical tone identification), NT discrimination (B = 5.961, p = .014) and lexical tone identification (B = 27.371, p = .007) were the only variables that significantly predicted children with dyslexia.

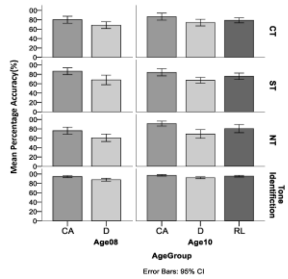
3.5. Differences in age, non-verbal intelligence, memory capacities, and reading and writing abilities among 10-year-old children with dyslexia (D), their age-matched (CA) and reading-matched (RM) peers

Using the three 10-year-old groups -- 10-year-olds with dyslexia (D10), 10-year-old age-matched typical children (CA10), and 10-year-old reading-matched children (RM10) -- as a between subject factor, two MANOVAs and two ANOVAs were performed on the same measures described in 3.1. As expected, the results showed that RM10 was significantly younger than D10 and CA10 (p<.001, ηp^2=.744) while there was no significant difference in age between D10 and CA10. The three groups of children performed comparably in the two digit span tests and the Colored Raven's test, indicating comparable memory capacities and non-verbal intelligence in the three groups of 10-year-old children. As expected, children with dyslexia (D10) performed poorer than typically developing children (CA10) in all the three reading and writing tasks (p< .001, ηp^2=.304-.441), but comparably to reading-matched children (RM10).

3.6. Pitch and tone discrimination and tone identification in the three groups of 10-year-old children

Results of a three-way mixed ANOVA using the 10-year-old participant groups (D10, CA10, RM10) as between subject factor, sound type (CT, ST, NT) and tonal contrast (T1-T3, T2-T5, T3-T6, T3-T5, T6-T4, T7-T8, T8-T9) as within subject factors and accuracy as independent variable showed that 10-year-old children with dyslexia were poorer than age matched peers (p=.001), but comparably to reading-matched children in all the 3 discrimination tasks.

Figure 2: Accuracy of the 3 participant groups on the experimental tasks.



Results of a two-way mixed ANOVA using participant group (D10, CA10, RM10) as between subject factor, tone type (full, entering tone) as within subject factor, and tone identification accuracy as dependent variable showed that 10-year-old children with dyslexia performed significantly poorer than both the age-matched and reading matched children (ps<.001, .003). No difference was found between the two groups of typical children.

4. SUMMARY

Though pitch discrimination, lexical tone discrimination and lexical tone identification all correlated with Chinese word reading and/or writing abilities in children, lexical tone identification is the best predictor of reading and writing abilities and dyslexia.

Cantonese-speaking children with dyslexia perform poorer than age-matched typical peers in pitch discrimination, lexical tone discrimination, and lexical identification. Their pitch discrimination and lexical tone discrimination skills are comparable to those of younger children with similar reading abilities. However, their lexical tone identification abilities are significantly poorer than reading-matched children.

The findings suggest that Cantonese-speaking children with dyslexia are delayed in general auditory processing and phonological processing skills, as indicated by their poorer pitch and tone discrimination than age-matched peers. They appear to have special difficulties accessing lexical information, as indicated by their poorer lexical tone identification than lexical tone discrimination and their poorer tone identification abilities than younger reading-matched children.

5. REFERENCES

[1] Tallal, P. (1984). Temporal or phonetic processing deficit in dyslexia? That is the question. *Applied Psycholinguistics*, 5(2), 167–169.

[2] Tallal, P. (2004). Improving language and literacy is a matter of time. Nature Reviews. *Neuroscience*, 5(9), 721–728.

[3] Farmer, M. E., & Klein, R. M. (1995). The evidence for a temporal processing deficit linked to dyslexia: A review. *Psychonomic Bulletin & Review*, 2(4), 460–493.

[4] Mody, M., Studdert-Kennedy, M., & Brady, S. (1997). Speech perception deficits in poor readers: Auditory processing or phonological coding? *Journal of Experimental Child Psychology*, 64(2), 199–231.

[5] Haggerty, R., & Stamm, J. S. (1978). Dichotic auditory fusion levels in children with learning disabilities. *Neuropsychologia*, 16(3), 349–360.

[6] McCroskey, R. L., & Kidder, H. C. (1980). Auditory fusion among learning disabled, reading disabled, and normal children. *Journal of Learning Disabilities*, 13(2), 69–76.

[7] Tallal, P. (1980). Auditory temporal perception, phonics, and reading disabilities in children. *Brain and Language*, 9(2), 182–198.

[8] Christmann, C. A., Lachmann, T., & Steinbrink, C. (2015). Evidence for a general auditory processing deficit in developmental dyslexia from a discrimination paradigm using speech versus nonspeech sounds matched in complexity. *Journal of Speech, Language, and Hearing Research*, 58(1), 107–121.

[9] Ho, C. S. H., Chan, D. W. O., Tsang, S. M., & Lee, L. H. (2000). The Hong Kong test of specific learning disabilities in reading and writing (HKT-SpLD). Hong Kong, China: Chinese University of Hong Kong and Education Department, HKSAR Government.

[10] Halliday, L., & Bishop, D. (2006). Auditory frequency discrimination in children with dyslexia. *Journal of Research in Reading*, 29, 213–228.

[11] Banai, K., & Ahissar, M. (2004). Poor frequency discrimination probes dyslexics with particularly impaired working memory. *Audiology and Neurotology,* 9(6), 328–340.

[12] Tong, X., Tong, X., & King Yiu, F. (2018). Beyond Auditory Sensory Processing Deficits: Lexical Tone Perception Deficits in Chinese Children With Developmental Dyslexia. *Journal of learning disabilities*, 51(3), 293-301.

[13] McBride-Chang, C., Tong, X., Shu, H., Wong, A. M.-Y., Leung, K., & Tardif, T. (2008). Syllable, phoneme, and tone: Psycholinguistic units in early Chinese and English word recognition. *Scientific Studies of Reading*, 12(2), 171–194.

[14] Wong, P., & Chan, H. Y. (2018). Acoustic characteristics of highly distinguishable Cantonese entering and non-entering tones. *The Journal of the Acoustical Society of America*, 143(2), 765-779.

[15] Hong Kong Education and Manpower Bureau. (2006). Cantonese Expressive Language Scales (CELS). Hong Kong.

[16] Raven, J. C. (1960). Guide to the standard progressive matrices: sets A, B, C, D and E. HK Lewis.

[17] Choi, W., Tong, X., & Deacon, S. H. (2017). Double dissociations in reading comprehension difficulties among Chinese--English bilinguals and their association with tone awareness. *Journal of Research in Reading*, 40(2), 184–198.

[18] Wong, P., Fu, W. M., & Cheung, E. Y. (2017). Cantonese-speaking children do not acquire tone perception before tone production—A perceptual and acoustic study of three-year-olds' monosyllabic tones. *Frontiers in psychology*, 8, 1450.

[19] Wong, P., & Leung, C. T. T. (2018). Suprasegmental Features Are Not Acquired Early: Perception and Production of Monosyllabic Cantonese Lexical Tones in 4-to 6-Year-Old Preschool Children. *Journal of Speech, Language, and Hearing Research*, 61(5), 1070-1085.