CROSS-DOMAIN PITCH RECOGNITION ABILITIES OF MANDARIN-SPEAKING PRELINGUALLY DEAF CHILDREN WITH COCHLEAR IMPLANTS*

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ABSTRACT

The study focused on how Mandarin-speaking children with cochlear implants (CIs) perceived domain-specific pitch information (linguistic pitch vs. musical pitch), under different pitch contexts (context with both segment and pitch information vs. context with mere pitch information). The results showed that when provided with linguistic information involving both segment and pitch, the cochlear-implanted (CI) children were likely to achieve desirable accuracy in identifying different Mandarin lexical tones, though consuming more reaction time (RT) compared with normal-hearing (NH) peers. However, if there was only pitch information available, CI children underperformed their NH counterparts. Furthermore, though they had domain-general barriers in perceiving the subtle pitch variations, comparatively CI children showed a more profound deficiency in pitch recognition under music-domain than linguistic-domain. Finally, RT measurement was found to be negatively correlated with the chronological age, while positively correlated with the age at implantation.

Keywords: Cochlear-implanted children, pitch perception, language and music.

1. INTRODUCTION

Normal-hearing people can recognize more than 90% of the tone through extracting the fundamental frequency from the complex sound signals [7]. But most hearing-impaired children failed even with the help of implanted cochlea [15]. Although cochlear implantation can help hearing-impaired children restore part of their auditory sensation, linguistic disorders still frequently emerge when it comes to daily communication [3, 13, 14]. It was reported that CI children have a lower capacity for recognizing tones and intonations [8, 11, 16], as well as decoding pragmatic and affective meanings [4, 6, 12, 17], in which pitch is a vital element. Therefore, in order to improve the intelligibility and naturalness of language production performance by CI children, it is urgent to well understand their perception performance in various pitch events.

Previous studies have mostly focused on the description of the inefficiency of CI children in pitch perception but barely provide a deep analysis into the internal and external factors that induce the pitch perceptive weaknesses. Besides, though correlations between language and music laid down a theoretical basis for studying pitch perception from a cross-domain perspective [1, 9, 10], there is still a handful of studies investigating the cross-domain pitch perception by Mandarin-speaking children. Therefore, the main purpose of the current study was to obtain a comprehensive understanding about CI children's pitch perception defects from a cross-domain perspective. Only by figuring out what induces the weaknesses of their pitch perception in essence, can clinicians and therapists design and put forward effective intervention in point. The study focused on cross-domain pitch recognition performance (linguistic pitch vs. musical pitch) of the CI children under different phonetic contexts (context with both segment and pitch information vs. context with mere pitch information). By comparing their linguistic and music pitch perception performances, it can be understood whether the CI children's deficit in pitch perception is domain-specific or domain-general; by comparing pure pitch and pitch with intact information, it can be examined how the Mandarin-speaking CI children perceive the Mandarin tones, in terms of bottom-up processes (cortex acoustic analysis) or top-town (stored knowledge gained from linguistic experience). In this way, the following three research questions were expected to be addressed:

1) Are there any differences between the CI children's and the NH children's ability in cross-domain pitch perception in terms of, pitch context and pitch movement?

2) Are there any differences between the CI and the NH group in pitch perception confusion pattern?

3) How the cochlear usage and musical experience impact the CI Children's pitch perception performance?

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2 METHOD

2.1 Participants

Totally 11 monolingual Mandarin-speaking CI children (7 boys and 4 girls), aged from 6;9 to 11;10 (M ± SD = 9.54 ± 2.88 years), and 20 NH children (10 boys and 10 girls) aged from 5;2 to 10;3 (M ± SD = 7.23 ± 1.96 years), were recruited to take part in the experiment. They were matched in hearing age, language background and education to avoid possible further deviation in the experiment results.

2.2 Audio Recording

Recordings were collected in a sound-proof booth where the noise was 15.6 dB. The recorder is a native Mandarin-speaking female qualified with a Mandarin Proficiency Test certificate of 2nd Grade, Level A. She was seated in front of a laptop, with a Sennheiser head-worn microphone situated approximately 2cm from the mouth. For music stimuli, the piano note C4 (Middle C) was played and recorded with a fundamental frequency of 261.63 Hz. All audios were saved in the wav. format, 16 bits, 44100 Hz.

2.3 Materials and Design

2.3.1 Linguistic Pitch Event

The subtypes of linguistic pitch events include the Mandarin tone and the Mandarin pure tone. Three Mandarin tones were chosen as the experimental materials for perception, namely, T1 (high level), T2 (middle rising) and T4 (high falling). Tone 3 was not included in that CI children are reported to strategically rely more on “creaky voice” instead of pitch to realize the low-dipping property of Tone 3 [5]. Mandarin pure tones were the sinusoidal carrier waves of the lexical tones, being regarded as partially lexical. Specifically, they are comprised of a sine wave and the fundamental frequency shape extracted from recorded Mandarin tones through the LPC manipulation [2].

2.3.2 Non-Linguistic Pitch Event

The subtypes of non-linguistic pitch events include the musical (piano) note and the musical pure note. We generated the musical stimuli in the form of a pair of notes with different pitch directions in accordance with lexical tones’ pitch trend. The F0 of the head note was set to the value of the minimum F0 in the first 250 ms of lexical tone, and that of the tail note was modified to the maximum F0 in the latter 250 ms. As with Mandarin pure tones, musical pure notes were the sinusoidal analogues of the musical notes.

2.4 Procedures

All children were brought to participate in a 3 AFC picture-choice task in a visual-world paradigm. Before the formal experiment, they were invited for a session for five trials under instruction. Stimuli were played on a computer screen in a volume reported as audibly comfortable to the participants. At the end of the audio, they were asked to choose one of the three pictures, which represented respectively T1, T2 and T4, shown on the computer screen. Their response accuracy and reaction time were recorded.

3 RESULTS AND DISCUSSION

3.1 Linguistic Pitch Event Perception

In Mandarin lexical tone perception, the groups showed no significant differences both in perception accuracy and reaction time (ACC: $\beta = 0.01$, $p = 0.89$; RT: $\beta = -2.054.98$, $p = 0.19$). It seemed that the CI Children could make the comparable performance as those typically developing children when identifying Mandarin lexical tones, though they had longer reaction time. With regard to the Mandarin pure tone perception, the “group” factor unfolded a significant main effect both on the perception accuracy and the reaction time (ACC: $\beta = 0.27$, $p = 0.01$; RT: $\beta = -2382.33$, $p < 0.05$). CI children were more likely to have obstacles than the NH children when the segmental information was missed. In other words, if the only available attribute was the speech pitch contour, hardly can the CI children match them with the familiar linguistic pitch contour in their mother tongue. In addition, the interaction effect between group and tone type was found significant ($\beta = 0.208$, $p < 0.05$). For the NH children, the identification for a flat tone was far easier than that for a falling tone. Conversely, the CI children performed undesirably in perceiving flat tone but much better in falling tone, though generally worse than the NH children. Since the CI children relied much on larger F0 range to perceive the pitch changes, the detection of flat tone came to be more troublesome.

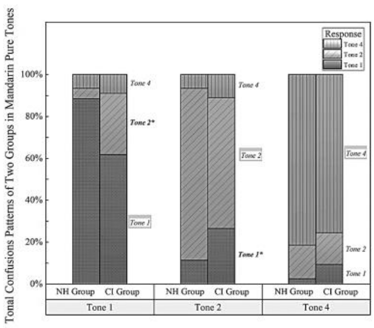

Figure 1: Confusion Patterns for Responses in Mandarin Pure Tones of CI Group and NH Group

Tonal identification errors were also examined to investigate the tonal confusion of the two groups. It showed there was no significant difference between the CI and the NH group in perceiving Mandarin lexical tones ($\chi 2 = 24.557$, $p = 0.80$); while significant difference in perceiving Mandarin pure tone ($\chi 2 = 54.422$, $p < 0.001$). Kenward-roger method in linear mix model was further applied to investigate the details in the perception of Mandarin pure tone (see Figure 1).

Generally speaking, all the children can correctly perceive most of the tones, for both groups showed ACC above the chance level 33.3%, which indicated that the cochlear device did facilitate those hearing-impaired children to perceive the linguistic pitch variations. However, when there was merely natural pitch contour modulated in the sine wave without any segmental information, the CI children performed much worse than the NH peers. Among all the Mandarin pure tones, the most confusing error pair was T1-T2. The CI children frequently recognized flat pure tone as rising pure tone or vice versa by mistake.

3.2 Non-Linguistic Pitch Event Perception

Musical notes consisted of two sequential equal-long piano notes which retained the identical pitch direction and pitch range of their corresponding linguistic pitch. Different from the perception result of Mandarin lexical tones, significant group effect was found in musical notes perception in terms of ACC, though not RT (ACC: $\beta = 0.33$, $p<0.01$; RT: $\beta = -311.64$, $p = 0.58$). It showed that the accuracy of CI children was significantly far from satisfactory than that of NH children. The musical correlates maintained the same pitch direction and pitch range of the linguistic tones, but the changes in musical pitch were discrete instead of continuous, which demanded more precise resolution in frequencies. The intrinsic hearing loss and imperfect "artificial ear" of the CI children caused the incapability in resolving frequency precisely, thus constraining them to perceive the musical note pitch correctly.

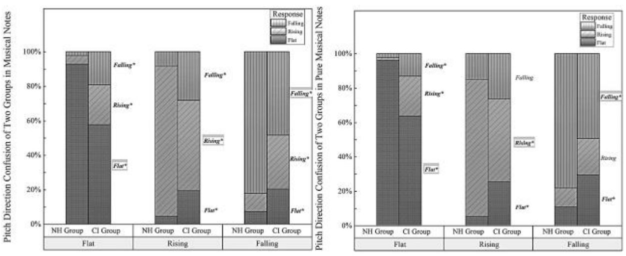

Figure 2: Confusion Patterns for Responses in Linguistic Pitch Event Perception of CI Group and NH Group; Pitch Direction Confusion of Two Groups in Musical Notes (the left figure); Pitch Direction Confusion of Two Groups in Pure Musical Notes (the right figure)

Musical pure notes excluded the musical timbre and thus took a stricter form of pitch that required elementary ability in acoustic processing. The Results were quite similar to that of musical notes, in which group effect was found significant (ACC: $\beta = 0.28$, $p<0.01$; RT: $\beta = -161.88$, $p = 0.83$). It indicated that different from linguistic timbre, which exerted an enormous impact on the pitch perception of Mandarin tones, for the CI children, the timbre of musical instrument had little effect on their pitch perception. In other words, with or without instrument information, CI children achieved the same accuracy performance.

The Chi-square test showed that the CI children displayed different confusion patterns from their NH counterparts in identifying musical pitch (musical notes: $\chi 2 = 126.59$, $p < 0.001$; musical pure notes: $\chi 2 = 112.56$, $p < 0.001$). In musical notes perception, two groups performed significantly differently in the accuracy of the nine target-response pairs. In musical pure notes, the CI children were also vulnerably trapped into the "pitch change trick", in which they mistakenly perceived those pitch with subtle variances as pitch with dynamic movement, either going up or falling down. But with regard to the rising pitch, the CI children would be less likely to take the rising pitch as a falling one or vice versa. The above results confirmed that CI children were more sensitive to large pitch range not only in linguistic domain, but also in music domain.

3.3 Asymmetrical Patterns Between Different Pitch Event Perception

Figure 3 presented the different ACC and RT performance between the CI and the NH group in the cross-domain pitch perception tasks. Pitch event 1 to 4 in the figure represented respectively Mandarin lexical tone, Mandarin pure tone, musical note and musical pure note.

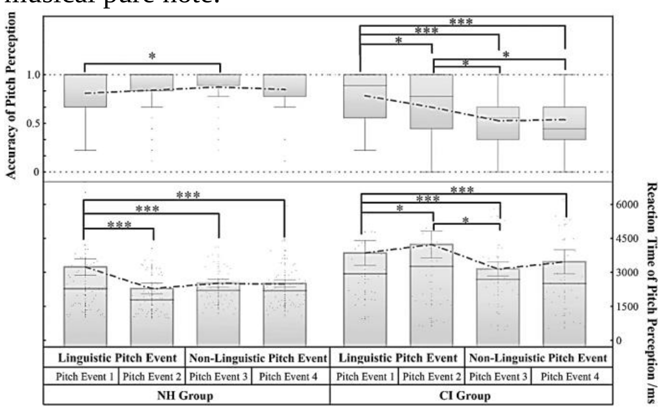

Figure 3: Patterns in Linguistic and Non-Linguistic Pitch Event Perception of Two Groups

Compared to the NH children, the CI children performed diversely in different pitch events. First, the CI children perceived Mandarin lexical tone significantly better than the other three pitch events. Secondly, their perception accuracy of linguistic pure tone was lower than lexical tone but higher than musical pitch perception, which revealed that though the lack of segmental information would somewhat hinder CI children from recognizing the pitch information, they still retained the ability to take advantage of pitch contour to achieve tone recognition. Moreover, they demanded more RT time to organize and coordinate the cognitive resources to process the natural pitch contour in daily life. Finally, it seemed that the perception consistency only resided in non-linguistic pitch events, for the instrumental timbre helped little to perceive pitch information under the music domain. Comparing with linguistic pitch perception, non-linguistic pitch perception of the CI group was extremely poorer. This further reflected the biased development of pitch recognition ability between the music and the linguistic domain.

3.4 Factors Influencing CI Children's Pitch Perception

The former analysis revealed the internal deficiency of CI children in sensing subtle pitch variation in both linguistic and non-linguistic domains and their weaknesses in detecting discrete pitch in music domain. It was attributed not only to their intrinsic bottom-up defect, but also to their insufficient language experience and thus impaired the top-down modulation of speech contour. In this section, other external factors, including musical training, chronological age and cochlear device usage were investigated to fully explain the pitch perception ability of the CI children.

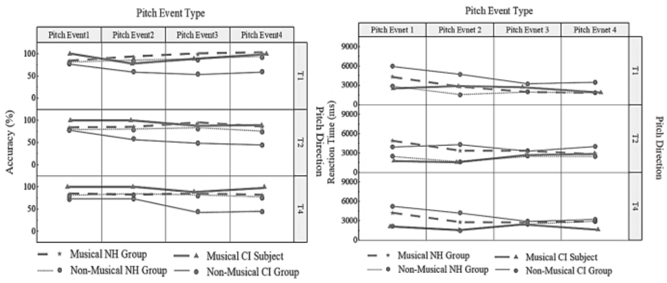

Figure 4: Pitch Perception of Musically Trained and Untrained Children

In our data, half of the NH group (10 children) had received formal musical training. The LMM results showed that the musical training had little influence on normally-developing children in pitch perception but only a difference in the reaction time of Mandarin lexical tone perception (ACC: $\beta = 0.05$, $p = 0.62$; RT: $\beta = 1961.71$, $p<0.05$). As for the CI group, there were 10 non-musically trained subjects. Only one 9-year-old CI boy received 2 years of piano training. Conversely, one-sample T-test indicated that the trained child performed extremely differently in both pitch perception accuracy and reaction time, compared with those non-musical training CI peers (ACC: $t = 16.02$, $p < 0.001$; RT: $t = -12.17$, $p < 0.001$). Furthermore, the musical CI subject showed comparable perception performance to the 20 NH participants, no matter in language or music. The results may not substantiate but indicate the possible positive impact of musical training on the CI children's ability in pitch perception in both music and language.

Spearman coefficients were calculated between the chronological age, age at implantation, length of CI device and pitch perception results. It was found that the chronological age and the age at implantation were closely related to the CI children's reaction time ($\rho = -0.43$, $p < 0.001$; $\rho = 0.29$, $p < 0.001$). The elder the CI children were, the shorter reaction time they demanded in recognizing the pitch. Those who received cochlear implantation earlier could reach faster speed in their way of working out pitch in musical pure notes and pitch with the falling trend.

4. CONCLUSION

In conclusion, CI children could achieve desirable accuracy in identifying different Mandarin tonal pitches, though consuming more reaction time. On the one hand, results in different pitch contexts proved that CI children's top-down regulation was rather weak when perceiving the linguistic pitch contour. They relied more on the segmental information in words. The deficiency in extracting stored pitch knowledge was possibly attributed to the inadequate linguistic experience, causing them failing to internalize the linguistic pitch contour. Therefore, the study further confirmed the significance of linguistic input and experience in the development of pitch awareness and pitch memory. On the other hand, the cross-domain comparison indicated that the CI children may apply domain-specific mechanisms when perceiving the music-domain and linguistic-domain pitch information. The linguistic mechanism took charge of processing continuous coarse pitch contour, while music mechanism dealt with discrete and precise pitch and thus, had higher requirements for the CI children's pitch perception competence. Several important factors were responsible for the CI children's deficiency in pitch perception performance. The case study of the CI boy proved that musical training could potentially strengthen his ability both in language and music. In addition, earlier implantation of cochlear devices may benefit the CI children when processing the pitch information.

5. ACKNOWLEDGEMENT

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