Research Note

Benefits of Music Training in Mandarin-Speaking Pediatric Cochlear Implant Users

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Purpose: The aims of this study were to assess young (5- to 10-year-old) Mandarin-speaking cochlear implant (CI) users' musical pitch perception and to assess the benefits of computer-based home training on performance.

Method: Melodic contour identification (MCI) was used to assess musical pitch perception in 14 Mandarin-speaking pediatric CI users; the instrument timbre and the contour length were varied as experimental parameters. Six subjects received subsequent MCI training on their home computer in which auditory and visual feedback were provided.

Results: MCI performance was generally poor (grand mean = 33.3% correct) and highly variable, with scores ranging from

9.3% to 98.1% correct; there was no significant effect of instrument timbre or contour length on performance ($p > .05$). After 4 weeks of training, performance sharply improved. Follow-up measures that were conducted 8 weeks after training was stopped showed no significant decline in MCI performance. For the 6 trained subjects, there was a significant effect of contour length for the training and follow-up measures.

Conclusion: These preliminary data suggest that although baseline MCI performance initially may be poor, training may greatly improve Mandarin-speaking pediatric CI users' melodic pitch perception.

Whereas musical rhythm perception is quite good for cochlear implant (CI) users, musical pitch and timbre perception is much poorer (for a review, see McDermott, 2004). Due to limited spectro-temporal resolution, CI devices are unable to transmit the fine-structure cues that are important for complex pitch perception, making some aspects of music perception—such as melody recognition and timbre recognition (Shannon, Fu, & Galvin, 2004; Smith, Delgutte, & Oxenham, 2002)—difficult. CI users must use electrode place cues to derive spectrally based pitch information. Because there are only 12 to 22 electrodes, the coarse spectral resolution does not support harmonic pitch. Uneven distributions of auditory neurons may further worsen pitch perception due to spectral mismatch between the acoustic information and the location of healthy neurons (see, e.g., Baskent & Shannon, 2003). Temporal pitch cues may be derived from temporal envelopes used to modulate pulse trains delivered to each

electrode, but these pitch cues are limited to approximately 300 Hz (see, e.g., Fraser & McKay, 2012). Previous studies with English-speaking adult CI users have shown that their melodic pitch perception is generally poor (Galvin, Fu, & Nogaki, 2007; Gfeller et al., 2007; Kang et al., 2008; Kong, Cruz, Jones, & Zeng, 2004; Nimmons et al., 2008).

Poor pitch perception may also contribute to poor performance by English-speaking CI users in difficult speech tasks such as talker identification and sentence recognition in fluctuating noise (Shannon et al., 2004). Perception of voice pitch, or *fundamental frequency* (F0), is also important to tonal languages such as Mandarin Chinese (Fu, Zeng, Shannon, & Soli, 1998). In Mandarin Chinese, there are four lexically meaningful tones: Tone 1 (flat, with high F0), Tone 2 (rising F0), Tone 3 (falling–rising F0), and Tone 4 (falling F0). Whereas the F0 contour is the strongest cue for Chinese tones (Abramson, 1978), other acoustic cues, including duration and amplitude (Fu, Hsu, & Horng, 2004; Fu et al., 1998), vary with F0. When all cues are available, tone recognition by Mandarin-speaking CI users is often quite good (Hsiao, 2008; Tao et al., 2014; S. Wang et al., 2012; W. Wang, Zhou, & Xu, 2011). Intuitively, the importance of pitch cues to both tonal language and music perception would suggest that performance in these listening tasks would be related. Indeed, W. Wang et al. (2011) found that for adult Mandarin-speaking CI users, lexical tone

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recognition was significantly correlated with performance on a melodic pitch–interval discrimination task in which listeners had to discriminate between two melodies that differed in terms of the pitch of one of the component notes. On average, CI users needed more than a five-semitone difference to discriminate the modified melody, whereas normal-hearing listeners needed less than one semitone. S. Wang et al. (2012) also found a significant correlation between lexical tone recognition and familiar melody recognition in adult Mandarin-speaking CI users; mean pitch discrimination thresholds were much higher for CI users (9.1 semitones) than for normal-hearing listeners (2.9 semitones). In these studies, even though speech perception was better than music perception, the CI users who had better speech perception scores also tended to have better music perception scores.

Previous studies have used melodic pitch discrimination or recognition of familiar melodies without rhythm cues to characterize English-speaking CI users' melodic pitch perception (see, e.g., Gfeller et al., 2007; Kang et al., 2008; Nimmons et al., 2008). *Melodic contour identification* (MCI) has been used to characterize CI users' functional pitch perception (Galvin, Eskridge, Oba, & Fu, 2012; Galvin et al., 2007; Galvin, Fu, & Oba, 2008; Galvin, Fu, & Shannon, 2009). Different from simple melodic pitch discrimination, the MCI task requires listeners to integrate changes in pitch direction over a longer time course; by manipulating the pitch ranges of the contours, the functional pitch perception may be better observed over different frequency regions of the CI. Different from familiar melody recognition, the MCI task requires no previous experience with the contours or any modification to rhythm cues because the stimulus duration and interstimulus intervals are kept constant. As such, the MCI task may better reflect CI users' functional pitch perception. Different from the aforementioned studies by W. Wang et al. (2011) and S. Wang et al. (2012), Tao et al.'s (2014) study of young Mandarin-speaking CI users showed no correlation between lexical tone recognition and MCI performance. In that study, mean tone recognition performance was 81% correct, but mean MCI performance was quite poor (23% correct), possibly due to the difficulty of the listening task and the limited musical experience of the subjects.

It is possible that the poor MCI performance observed in young Mandarin-speaking CI users by Tao et al. (2014) may have been improved with training, similar to findings with English-speaking adult CI users with postlingual deafness (Galvin et al., 2007, 2012). Indeed, music training has been shown to improve CI users' music perception and appreciation. Gfeller et al. (2002) found that moderate training improved CI users' timbre perception and sound-quality ratings. Galvin et al. (2007, 2012) found that computer-based training at home greatly improved CI users' MCI performance; performance gains were largely retained 1 month or more after training was ceased. In a survey study, Looi and She (2010) also reported that the more time CI users spent listening to music (i.e., "passive" training), the more enjoyment they received; the surveyed CI users expressed great

interest in receiving some sort of "active" music training. Chen et al. (2010) found that, in Chinese pediatric CI users, the duration of musical training was positively correlated with pitch-perception accuracy. Yucel, Sennaroglu, and Belgin (2009) found that pediatric CI users who received structured music training (e.g., using a take-home keyboard) developed significantly better music perception skills than the control group that received no explicit training. Taken together, these studies suggest that music training may benefit CI users' music perception, which may in turn improve their quality of life. In everyday speech perception, CI users may receive regular feedback during conversation and make use of contextual cues and visual information. Music perception may require more explicit training. As CI users' understanding of pitch and timbre information with their implant improves, music appreciation may also improve as the stimulation patterns become more familiar. We find it interesting that active speech training has been shown to improve CI users' speech perception even after years of experience with their device (see, e.g., Fu & Galvin, 2007, 2008; Stacey et al., 2010). Given the substantial improvements in MCI performance with MCI training observed in previous studies with adult English-speaking CI users (Galvin et al., 2007, 2012), it is possible that similar training may also improve Mandarin-speaking CI users' music perception. Active music training may improve Mandarin-speaking CI users' melodic pitch perception, which, given the correlations between music and lexical tone perception observed in W. Wang et al. (2011) and S. Wang et al. (2012), may also benefit tonal language perception.

The aims of this study were to assess young Mandarin-speaking CI users' musical pitch perception and to assess the benefits of training on performance. Different from Tao et al. (2014), which included older subjects with postlingual deafness, the present study recruited younger CI subjects with prelingual deafness. As such, age at testing, duration of deafness, age at implantation, and previous acoustic hearing experience were more homogeneous for the present study subjects. Musical pitch perception was assessed using the MCI task, as in previous studies (Galvin et al., 2007, 2012; Tao et al., 2014). Also different from Tao et al. (2014), MCI performance was assessed using multiple instrument timbres (in which the spectral and temporal envelopes differed) and multiple contour lengths (in which the overall pitch range differed). We hypothesized that timbre and pitch range would significantly affect MCI performance, with poorer performance associated with greater timbre complexity and reduced pitch range. We also hypothesized that training would greatly improve MCI performance in these pediatric Mandarin-speaking CI users, similar to previous findings with adult English-speaking CI users (Galvin et al., 2007, 2012).

Method

Subjects

Fourteen pediatric CI users with congenital deafness participated in the study. Subjects were recruited from

National Cheng Kung University Hospital in Taiwan. Subjects were required to be at least 5 years old at the time of testing, to have at least 2 years of experience with their device, and to be native speakers of Mandarin Chinese. All subjects were unilateral CI users and were tested with their clinically assigned processors and settings; once set, these were not changed during testing. All were paid for their participation, and the subjects' parents provided informed consent in compliance with the institutional review board at National Cheng Kung University Hospital. Table 1 contains demographic information for the 14 subjects. Gender was equally distributed across subjects (seven boys and seven girls). The mean age at testing was 7.8 years (range = 5.5–9.7 years). The mean age at implantation was 2.9 years (range = 1.7–5.1 years). The mean amount of CI experience was 4.9 years (range = 2.3–7.7 years). The mode of communication for all subjects was oral communication. None of the subjects had enrolled in any explicit musical training class.

Stimuli

Stimuli consisted of nine melodic contours similar to those in the two studies by Galvin et al. (2007, 2008): rising, rising–flat, rising–falling, flat–rising, flat, flat–falling, falling–rising, falling–flat, falling). The contours were composed of either three or five notes of equal duration (250 ms, with 50 ms of silence between each note); the frequencies of the notes corresponded to musical intervals. The lowest note in any contour (the “root note”) was A4 (440 Hz). All notes in the contours were generated relative to the root note according to

$$f = 2^{x/12} f_{ref},$$

where f is the frequency of the target note, x is the number of semitones relative to the root note, and f_{ref} is the frequency of the root note. The spacing between notes in each

contour was varied to be one, two, three, four, five, or six semitones. The musical “instruments” were either a five-tone complex or a piano sample (MIDI sampling and re-synthesis; Microsoft GS Wavetable Synth, Redmond, WA); the piano sample was the same as that used in Galvin et al. (2008). The frequency components for the five-tone complex were F0 (0 dB), 2F0 (–3 dB), 3F0 (–6 dB), 4F0 (–9 dB), and 5F0 (–12 dB). Stimuli were normalized to have the same long-term root-mean-square amplitude. For each test condition, the stimulus set consisted of 54 contours (9 melodic contours $\times$ 6 semitone spacings). There were three stimulus sets in total: five-note/five-tone complex (5 TONE), three-note/five-tone complex (3 TONE), five-note/piano (5 PIANO).

Testing Procedures

All stimuli were presented in sound field at 70 dBA (i.e., at a comfortably loud level). Subjects were seated in a sound-treated booth, directly facing a single loudspeaker 1 m away. During testing, a stimulus set was randomly selected, and a stimulus was randomly selected from among the 54 melodic contours in the stimulus set; once selected, the stimulus was not presented again during the test run. All 54 contours within the stimulus set were presented during each test run. The participant responded by clicking on one of the nine response choices shown onscreen; response boxes were labeled in Mandarin Chinese and included an illustration of the contour pitch direction. Subjects were allowed to preview all nine melodic contours a few times; the root note of the preview stimuli was different from that of the test stimuli. A short test run was also conducted to make sure the subjects understood the task before the formal test was performed. Subjects were allowed to repeat each stimulus up to three times; no trial-by-trial feedback was provided. Subjects were told to guess if they were unsure of the answer but were cautioned against choosing the same response for every stimulus. MCI performance for

Table 1. Cochlear implant (CI) participant demographic information.

Participant	Gender	Age test (years)	Age implant (years)	CI experience (years)	Etiology	Device	Strategy
S1	M	9.7	2.0	7.7	hereditary	Nucleus 24	ACE
S2	M	6.8	4.0	2.8	unknown	Nucleus 24	ACE
S3	F	6.9	3.7	3.2	unknown	HiRes 90k	Fidelity 120
S4	F	7.3	2.9	4.4	unknown	Nucleus 24	ACE
S5	F	5.5	1.7	3.8	hereditary	HiRes 90k	Fidelity 120
S6	M	8.8	5.1	3.7	hereditary	Nucleus 24	ACE
S7	M	7.9	2.3	5.6	unknown	Nucleus 24	ACE
S8	F	9.2	2.3	6.9	Mondini	Nucleus 24	ACE
S9	F	9.4	2.0	7.4	large vestibular aqueduct	Nucleus 24	ACE
S10	M	9.3	2.7	6.6	unknown	Nucleus 24	ACE
S11	M	6.8	3.8	3.0	recurrent high fever in neonatal period	HiRes 90k	Fidelity 120
S12	M	7.3	5.0	2.3	unknown	HiRes 90k	Fidelity 120
S13	F	7.5	1.8	5.7	hereditary	Nucleus 24	ACE
S14	F	6.3	1.5	4.8	unknown	HiRes 90K	Fidelity 120

Note. ACE = advanced combination encoder.

each condition was tested at least twice (six times for the 5 TONE condition), typically over 2-day sessions (one test session per day), each of which lasted approximately 2 hours.

Training Procedures

After completing baseline test measures, six of the 14 subjects received MCI training, using custom training software loaded onto their home computers; see Fu, Galvin, Wang, & Nogaki, (2005) and Galvin et al. (2007, 2012) for general descriptions of the training software and procedures. Subjects were asked to train at home for a half hour per day, every day for a period of 10 weeks; the total amount of training completed by each participant is shown in Table 2. The average training frequency was 5 days per week (range = 3 to 7 days) and three training sessions per day (range = two to six sessions). The average training time for each training session was 12 minutes (range = 9–18 minutes). Only the 5 TONE stimuli were used for training. To avoid directly training the same root note used for testing (A4; 440 Hz), the root note of the training stimuli was randomly varied from trial to trial to be any note between A3 (220 Hz) and A5 (880 Hz) except A4 (440 Hz). Thus, 23 root notes were used for training. During training, a contour was randomly selected from the stimulus set and played; once selected, the stimulus was not presented again during the training run. The participant responded by clicking on one of the response boxes shown onscreen, similar to the testing procedure. If the participant answered correctly, video feedback was provided, and a new contour was played. If the participant answered incorrectly, audio and video feedback was provided, allowing the participant to compare the incorrect with the correct response twice, after which time a new contour was played. When performance achieved a criterion level (80% correct), the level of difficulty was adjusted for the next training block by reducing the semitone spacing within the contours from a maximum of six semitones to a minimum of one semitone. Subjects returned to the lab after the 4th, 8th, and 10th week of training for retesting of baseline conditions: 5 TONE (the trained condition, except that different root notes were used for training), 3 TONE, and 5 PIANO. Subjects returned to the lab 1, 2, 4, and 8 weeks

after the 10-week training block for follow-up assessment to evaluate whether any performance gains with training had been retained. Thus, the training subjects participated in this study for a minimum of 18 weeks.

Results

Figure 1 shows mean MCI performance for individual subjects (averaged over six test runs) and mean MCI performance across subjects ($N = 14$) for the 5 TONE, 3 TONE, and 5 PIANO stimuli. There was great variability in MCI performance across subjects, with scores ranging from chance level (S11–S14) to nearly perfect (S1). Mean MCI performance ($N = 14$) was 34.5% ($SE = 8.3$) for the 5 TONE stimuli, 33.0% ($SE = 7.8$) for the 3 TONE stimuli, and 32.4% ($SE = 7.5$) for the 5 PIANO stimuli. Because there was not a normal distribution, a repeated measures analysis of variance (ANOVA) was performed on ranked data, with stimulus (5 TONE, 3 TONE, and 5 PIANO) as the factor. Results showed no significant effect of stimulus, $\chi^2(2, N = 14) = 2.873$ ($p = .238$). Test run data for the 5 TONE stimulus were analyzed to examine any procedural learning effects. Because there was not a normal distribution, an ANOVA was performed on ranked data, with baseline test run (one, two, three, four, five, and six) as the factor. Results showed no significant effect of test run, $\chi^2(5, N = 14) = 7.378$ ($p = .194$), suggesting that there was no procedural learning during testing. The relationships between (a) MCI performance and age at testing and (b) MCI performance and age at implantation were examined; *CI experience*, defined as the difference between age at testing and age at implantation, was excluded as a relevant demographic characteristic. Pearson correlations were not significant between (a) MCI performance and age at testing or (b) MCI performance and age at implantation (all $ps > .05$).

Figure 2 shows mean MCI performance as a function of test week for the six training subjects. Note that subjects were trained only with the 5 TONE stimulus. Pre-training baseline performance was averaged across all pre-training test runs because no procedural learning effects were observed. For the six training subjects, mean baseline performance across all conditions was 26.3% correct

Table 2. Melodic contour identification (MCI) performance for different stimuli, before, during, and after training.

Subject	Total hours trained	5 TONE (trained)			3 TONE			5 PIANO		
		B	T	F	B	T	F	B	T	F
S3	12.0	77.0	95.0	98.6	68.5	82.1	87.0	65.9	86.4	93.0
S5	29.0	33.8	94.4	95.8	27.8	77.4	86.8	27.8	80.4	96.7
S7	26.0	18.2	96.5	98.1	14.8	79.8	84.7	16.7	92.4	96.7
S10	54.0	18.1	48.8	61.1	16.7	33.3	36.1	13.5	63.0	54.2
S12	23.0	17.3	88.9	97.7	9.3	91.4	91.7	13.6	82.7	96.7
S14	33.0	10.8	95.7	97.1	11.1	59.3	70.1	12.6	81.0	94.9
Average	29.5	29.2	86.5	91.4	24.7	70.5	76.1	25.0	81.0	88.7

Note. B = mean pretraining baseline performance; T = mean performance during training; F = mean follow-up performance.

Figure 1. Individual and mean ($n = 14$) melodic contour identification (MCI) performance with the 5 TONE, 3 TONE, and 5 PIANO stimuli. The asterisks indicate subjects who participated in the subsequent MCI training. Error bars indicate 1 standard error. The dashed line shows chance-level performance (11.1% correct).

($SE = 5.0$; range = 9.3%–77% correct); in comparison, mean baseline performance for the eight subjects who received no training was 38.9% correct ($SE = 6.6$; range = 10.5%–97.2% correct). Because the distribution was not normal, a Kruskal–Wallis one-way ANOVA was performed on ranked baseline data, with participant group (training, no training) as the factor. Results showed no significant difference between participant groups ($H = 1.99$; $p = .158$).

Figure 2. Mean baseline, training, and follow-up MCI performance for the 5 TONE (black circles), 3 TONE (grey triangles), and 5 PIANO stimuli (white squares). Baseline performance (Test Week 0) is shown at left. Training performance (Test Weeks 4–10) is shown in the gray shaded area. Follow-up performance (Test Weeks 11–18) is shown at right. Error bars indicate 1 standard error. The dashed line shows chance-level performance (11.1% correct).

Four weeks after training began, mean performance sharply increased for all stimuli (mean across all stimuli = 71.2% correct; $SE = 4.8$; range = 13%–98.1% correct). A two-way ANOVA was performed, with test week and stimuli type (5 TONE, 3 TONE, and 5 PIANO) as factors. There was a significant effect for test week, $F(7, 70) = 28.5$, $p < .001$, and stimuli, $F(2, 70) = 13.3$, $p = .002$; there were no interactions, $F(14, 70) = 1.1$, $p = .387$. Post hoc Tukey pairwise comparisons showed that pretraining baseline performance was significantly poorer than all other test weeks ($p < .05$); there were no significant differences among the remaining test weeks. Similarly, performance with the 3 TONE stimuli was significantly poorer than that with the 5 TONE or the 5 PIANO stimuli ($p < .05$); there was no significant difference between the 5 TONE and the 5 PIANO stimuli.

Table 2 shows individual mean MCI baseline, training, and follow-up performance for the three contour conditions; performance was averaged within the baseline, training, and follow-up test periods. There was a wide range in the number of training hours completed (12–54 hours). Linear regression analysis showed that the gains in performance during or after training were not significantly correlated to the subjects' total hours trained (all $ps > .05$). For example, the subjects who spent the most (S10) or least (S3) amount of time training exhibited similar training benefits. For the six training subjects, MCI performance was also compared with the demographic factors of age at testing and age at implantation. Pearson correlations were not significant between age at testing and baseline or post training performance, or between age at implantation and baseline or post training performance ($p > .05$ in all cases).

Discussion

In general, baseline MCI performance by Mandarin-speaking pediatric CI users was relatively poor (mean across all conditions = 33.1% correct). There was large variability in MCI performance, consistent with Galvin et al. (2007, 2008, 2012). There was no significant effect of instrument timbre (5 TONE vs. 5 PIANO) or contour length (5 TONE vs. 3 TONE) for the 14 subjects shown in Figure 1. Thus, the hypothesis that instrument timbre and contour length would affect MCI performance was not supported by the present data, most likely due to the overall poor performance of the present subjects. These data are also somewhat in contrast to Galvin et al. (2008), who found poorest performance with the piano and generally better performance with the organ (which was similar in timbre to the present 5 TONE and 3 TONE stimuli). However, for the six trained subjects, there was a significant effect of contour length, because performance during and after training was poorer with the 3 TONE stimuli than with the 5 TONE or 5 PIANO stimuli. Thus, after a period of training, the present data support the hypothesis that contour length would affect MCI performance. The maximum pitch range, given a rising contour with six-semitone spacing, would be two octaves (24 semitones) with the 5 TONE or 5 PIANO stimuli, but only one octave with the 3 TONE stimuli. As such, the stimulation patterns with the 3 TONE stimuli would have spanned fewer electrodes, making the task more difficult. Also, the extra notes in the 5 TONE and 5 PIANO stimuli would have provided additional information to the contour, which might have been especially helpful for the combination contours (e.g., rising-flat, falling-flat, rising-falling). Alternatively, training with five-note stimuli may have provided less of a benefit when only three notes were used for testing stimuli.

Mean baseline MCI performance (33.1% correct) with the present pediatric Mandarin-speaking CI users was much poorer than that observed in previous MCI studies with English-speaking adult CI users with postlingual deafness (e.g., 53.3% correct in Galvin et al., 2007; 54.2% correct for the piano stimuli in Galvin et al., 2008; and 54.1% correct in Galvin et al., 2012). Although discrepancies may be due to test environment and/or stimuli (different pitch ranges, different instruments, different semitone spacing), differences between participant groups (adults with postlingual deafness vs. children with prelingual deafness) may have contributed to differences in MCI performance. The pediatric subjects in the present study all had congenital deafness and had little music experience before or after implantation.

Mean performance sharply improved for all outcome measures after 4 weeks of training with the 5 TONE stimuli. Thus, the present data support the hypothesis that home training would significantly improve performance. Some subjects (S5, S10) required a longer learning period, with performance steadily improving during the training. Note that different pitch ranges were used for training and testing. Although mean performance during the training period improved with the trained 5 TONE stimuli (mean

improvement = 57.3 points; $SE = 11.1$), strong improvements were also observed with the 3 TONE (mean improvement = 45.8 points; $SE = 10.9$) and 5 PIANO (mean improvement = 56.1 points; $SE = 8.2$) stimuli. This suggests that subjects were able to learn to identify changes in pitch direction despite differences in the root note, instrument timbre, and contour length between the training and test stimuli. The improved performance during the training period was largely retained after training was stopped. Performance gains with MCI training were larger in this study than those with previous MCI studies with English-speaking adult CI users with postlingual deafness (Galvin et al., 2007, 2012). It is interesting to note that the present mean training score (79.4% correct, across all conditions) was comparable to that in Galvin et al. (2007; 78% correct). The greater improvement for the present subjects was most likely due to the poorer baseline performance, which in turn was most likely due to the prelingual deafness, pediatric status of the subjects. The amount of training completed by the present subjects was not associated with performance gains, and performance asymptoted after 4 weeks of training, suggesting that after completing a sufficient amount of training, subjects learned all that they could, given the present training methods and stimuli.

Speech performance was not measured in the present study. Previous studies have shown a correlation between lexical tone recognition and music perception in Mandarin-speaking CI users (S. Wang et al., 2012; W. Wang et al., 2011), presumably because pitch perception is important to both listening tasks. Such a correlation was not observed between tone recognition and MCI performance in Tao et al. (2014); although mean tone recognition performance was good (81% correct), mean MCI performance with the piano was quite poor (23% correct), similar to the baseline performance with the 5 PIANO in this study (25% correct; $SE = 8.1$). The large improvements in MCI performance with training observed in the present study suggest that the poor MCI performance observed in Tao et al. (2014) may have also improved with training. If so, a stronger relationship between MCI and tone recognition might have emerged, similar to correlations between music perception and tone recognition observed in W. Wang et al. (2011) and S. Wang et al. (2012). Given the extensive time commitment for the training, only six of the present subjects were available. A greater number of subjects would certainly have provided greater statistical power to see the effects of melodic contour stimuli and training on performance. Still, the present preliminary data indicate a wide range of MCI performance among Mandarin-speaking pediatric CI users that can be greatly improved with computer-based training. Given the poor baseline MCI performance and training benefits observed in this study, future research should incorporate some music training when comparing lexical tone recognition and music perception in Mandarin-speaking CI users. More important, future research should explore whether music training can benefit tonal language perception.

Conclusions

MCI was tested in pediatric Mandarin-speaking CI users; the benefits of training on performance were also evaluated in a subset of subjects. Major findings include the following:

1. Mean MCI performance was poor (33.1% correct across all conditions), with great intersubject variability.
2. There were no significant correlations between MCI performance and CI subjects' age at testing or age at implantation.
3. Training greatly improved MCI performance (mean improvement of 53.1 percentage points across all conditions). Performance gains with training were largely retained 8 weeks after training was stopped. Training with one stimulus also improved MCI performance with untrained stimuli.

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