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The Effects of Music Training on Categorical Perception of Mandarin Tones in 4- to 5-Year-Old Preschoolers

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Date: 2019-11-28T00:00:00+00:00

Abstract

Previous studies have shown that musical training can enhance adults' ability to perceive Mandarin tonal categories. Can such training enhance young children' s ability to perceive tonal categories? Is the training effect influenced by the duration of training? This study conducted musical training with 40 kindergarten children aged 4-5 years, divided into a music group and a control group with 20 participants each, to longitudinally investigate the effects of musical training and training duration on the enhancement of children' s tonal category perception ability. The experiment adopted a pretest-midtest-posttest design. The music group received musical training primarily consisting of glockenspiel performance, three times per week, 30 minutes each session; the control group did not engage in any organized training activities. The results revealed that 12 months of musical training enhanced the degree of children' s tonal category perception, as evidenced by the music group children's category boundary width being significantly smaller than that of the control group, whereas this advantage was not significant after 6 months of training. Furthermore, 12 months of musical training also enhanced children' s sensitivity to distinguishing acoustic differences within-category stimuli, while showing no significant improvement in the ability to discriminate between-category stimuli. The findings of this study support the OPERA (Overlapping Precision Emotion Repetition Attention) hypothesis of musical learning, demonstrating that musical training has cross-domain transfer effects and can enhance 4-5-year-old children' s ability to perceive Mandarin tonal categories, but only long-term sustained training can truly promote children' s fine-grained processing of pitch.

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Full Text

The Effects of Music Training on Categorical Perception of Mandarin Tones in 4- to 5-Year-Old Children

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Abstract
Previous research has demonstrated that music training enhances categorical perception of Mandarin tones in adults. The present study investigated whether music training can similarly improve tonal categorical perception in young children, and whether training effects are modulated by duration. Forty 4- to 5-year-old preschoolers were randomly assigned to either a music training group (n = 20) or a control group (n = 20). Using a pretest-midtest-posttest design, the music group received 30-minute music training sessions three times weekly for 12 months, focusing primarily on small carillon performance, while the control group engaged in no structured training activities. Results revealed that 12 months of music training enhanced children' s categorical perception of tones, as evidenced by significantly narrower boundary widths in the music group compared to controls. However, this advantage was not significant after 6 months of training. Furthermore, 12 months of music training improved children' s sensitivity to acoustic differences within tonal categories, but did not significantly enhance discrimination between categories. These findings support the OPERA hypothesis (Patel, 2014), demonstrating that music training has cross-domain transfer effects that can improve Mandarin tone categorical perception in 4- to 5-year-old children, though only long-term, sustained training appears to promote refined pitch processing.

Keywords: music training; cross-domain transfer; categorical perception of tonal contrast; 4- to 5-year-old children
Classification Number: B844.12

Received: 2019-08-22
Supported by National Social Science Foundation Project (14BYY144), Hunan Provincial Social Science Foundation General Project (18YBA071), and Changsha University of Science and Technology Young Teacher Growth Program (2019QJCZ092).

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1 Introduction

Two contrasting perspectives exist regarding the role of music training in language development. One view holds that music training has minimal impact on language development, while the other posits that music training can fa-

cilitate language acquisition. These divergent viewpoints reflect different understandings of the relationship between music training and language learning. The former perspective suggests that music training does not participate in language processing and that music and language learning are independent processes (Peretz, 2009; Peretz & Coltheart, 2003). In contrast, the latter view proposes that music training has cross-domain transfer effects, with music and language learning sharing certain processing mechanisms (Asaridou & McQueen, 2013; Patel, 2008, 2014). The cross-domain transfer effect of music training is built upon the multi-sensory nature of music learning, whereby long-term music training enables musicians to more accurately connect motor representations related to sound with auditory representations, thereby facilitating cognitive processing in the language domain (Lee & Noppeney, 2011).

With the advancement of cognitive science, revealing the role of music training in language learning has become a research hotspot in music training-related fields. Based on the support of multi-sensory representations in music training for language processing, Patel (2014) proposed the OPERA (Overlap, Precision, Emotion, Repetition, Attention) hypothesis, arguing that music and language learning are not independent but rather share numerous perceptual and cognitive processing mechanisms. Because music learning demands more precise sound representations, involves more repetitions, expresses stronger emotions, and requires more focused attention, it can enhance language processing levels. In other words, comprehensive training in musical pitch, melody, rhythm, and emotional expression during music training implicitly opens up perceptual channels for pitch, duration, and prosody in language learning, naturally enhancing individuals' ability to perceive and process phonetic feature changes. Research has found that adult musicians demonstrate superior processing advantages for phonetic elements such as pitch, timbre, or duration compared to non-musicians (Hutka, Bidelman, & Moreno, 2015; Marie, Kujala, & Besson, 2012; Schön, Magne, & Besson, 2004), and that adult musicians also show better speech perception performance in noisy backgrounds (Başkent & Gaudrain, 2016; Du & Zatorre, 2017). A series of empirical studies with child participants have also supported the OPERA hypothesis, with some research indicating that music training can improve phonological awareness in preschool children (Degé & Schwarzer, 2011). François, Chobert, Besson, and Schön (2013) examined speech segmentation abilities in 8-year-old children and found that children who received two years of music training showed significantly better speech segmentation abilities than those who received the same duration of painting training. Nan et al. (2018) used behavioral experiments and EEG techniques in a Chinese context to longitudinally track the neural mechanisms of piano learning transfer to language domains in 4- to 5-year-old Mandarin-speaking children, finding that piano learning could predict children' s consonant discrimination abilities at the behavioral level and tonal discrimination abilities at the neural level. In segmental-level language processing, the influence of musical experience on children' s speech perception has received substantial empirical support. At the suprasegmental level, Nan et al. (2018) found neurophysiological evidence that

music training enhanced Mandarin-speaking children' s sensitivity to typical tone perception; however, at the behavioral level, does long-term music training also affect the more refined categorical perception of tones in Mandarin-speaking children? This constitutes the first important question addressed in this study.

Additionally, does the effect of music training on children' s speech perception depend on training duration? Existing research presents divergent views on this question. Moreno et al. (2009) used EEG technology to find that 6 months of music training could improve pitch perception levels in 4- to 5-year-old children. However, other research suggests that short-term training has no significant effect on pitch processing. Chobert, Francois, Velay, and Besson (2014) found that 12 months of music training affected duration and voice onset time perception in 8- to 10-year-old children but had no significant effect on pitch. Strait, Parbery-Clark, O' Connell, and Kraus (2013) used EEG technology to find that at least one year of music training was required to enhance speech discrimination abilities in noisy backgrounds in 3- to 5-year-old children, with two years of community music training showing more significant effects than one year. The relationship between children' s pitch perception abilities and music training duration remains controversial. However, most previous studies have used non-tonal language speakers as participants, and non-tonal language speakers experience certain difficulties in tone perception (Hallé, Chang, & Best, 2004). Therefore, the second important question in this study is to investigate the effect of music training duration on Mandarin tone perception in tonal language-speaking children.

To address these questions, we selected categorical perception of tones as our experimental paradigm for two main reasons. First, research on categorical perception based on pitch cues focuses on the process of children' s refined pitch processing. Children aged 4-5 years are in a stage of rapid development in categorical perception (Chen, Peng, Yan, & Wang, 2017). Mandarin Chinese is a tonal language where pitch and its variations determine the semantic information of characters. Previous research has shown that Mandarin-speaking children can master Mandarin tones relatively well by age 3, with correct perception rates for the four Mandarin tones reaching 90% (Wong, Schwartz, & Jenkins, 2005). Therefore, using typical tone perception as experimental material might result in ceiling effects for 4- to 5-year-old children. Categorical perception of speech manifests as discontinuous, discrete categorical perception of a speech stimulus; humans are more sensitive to differences between categories than to differences within categories (Liberman, Harris, Hoffman, & Griffith, 1957). Research indicates that infants begin to form concepts of native language phonetic categories at 6 months of age (Kuhl et al., 2006), but these differ significantly from adult patterns, with such differences persisting through school age and even adolescence (Hazan & Barrett, 2000). Xi, Jiang, Zhang, and Shu (2009) used identification experiments to find that 5-, 6-, and 7-year-old children all showed categorical characteristics when perceiving tones, but 5-year-olds' categorical perception abilities were significantly lower than those of 6- and 7-year-olds. Chen et al. (2017) used identification and discrimination experiments to com-

pare tonal categorical perception among 74 Mandarin-speaking children aged 4-7 years and adults, finding that children in all three age groups showed categorical characteristics in tone perception, with 6-year-olds' identification rates for tone categories approaching adult levels and significantly higher than 5-year-olds, but discrimination accuracy significantly lower than the adult group. Ages 3-6 represent a critical period for early music training in children (Miyazaki & Ogawa, 2006; Takeuchi & Hulse, 1993). Children' s cerebral cortex thickness peaks at age 6 (Shaw et al., 2006), before which brain plasticity and sensitivity are strongest (Lenroot et al., 2009; Pascual-Leone, Amedi, Fregni, & Merabet, 2005). Therefore, conducting music training with 4- to 5-year-old children to examine whether it can improve their categorical perception of tones clearly helps us more comprehensively understand the role of music training in children' s language development.

Second, exploring the relationship between music training and categorical perception of tones in 4- to 5-year-old children contributes to understanding issues in music learning and language auditory processing. Most existing research has used cross-sectional comparisons to reveal differences in categorical perception of tones between musicians and non-musicians. Wu et al. (2015) compared 32 musicians with 32 non-musician adults on categorical perception characteristics of Mandarin Tones 1-4, finding that musicians showed significantly higher accuracy in discriminating within-category differences than control participants, with no significant differences in discriminating between-category differences or in identifying boundary positions and widths. When identifying changes in musical pitch and linguistic pitch, Mandarin-speaking musicians showed larger mismatch negativity brain responses compared to adult controls without music training experience (Tang, Xiong, Zhang, Dong, & Nan, 2016). Some researchers have found that musicians show significantly higher categorical perception in discriminating pure tone pitches than non-musician adults (Sares, Foster, Allen, & Hyde, 2018). These cross-sectional findings support the facilitative effect of music training on categorical perception of tones but cannot disentangle innate from acquired factors. Some evidence suggests that musicians' acquired learning experience is more likely the main factor in music training effects. For example, both vocalists and instrumentalists significantly outperformed controls in imitating foreign accents, but vocalists performed significantly better than instrumentalists, which is related to vocal performance exercising the vocal-motor system (Christiner & Reiterer, 2015). Compared to cross-sectional studies, longitudinal studies typically require more time, resources, and effort, but they are essential because only longitudinal studies can ultimately reveal causal relationships (Nan, 2017). Therefore, this study combined cross-sectional comparison (music group vs. control group) with longitudinal tracking (6 months vs. 12 months of training) to investigate the relationship between music training, training duration, and categorical perception of tones.

This study tested both music and control groups on categorical perception of tones at 6 and 12 months of training. We selected instrumental performance rather than formal singing or music games because previous research has found

that instrumental performance involves interaction among multiple sensory and motor channels, is more complex, and has more obvious facilitative effects on auditory perception (Herholz & Zatorre, 2012), and that multi-modal music training can improve participants' pre-attentive processing levels for different stimuli (Chen & Wang, 2019). Each test included identification and discrimination tasks. The identification task examined children' s boundary position and boundary width data when discriminating speech stimuli; based on each participant' s identification boundary position, the discrimination task further focused on within-category and between-category discrimination accuracy. Our experimental hypothesis was that 4- to 5-year-old children would show categorical characteristics in tone perception (as demonstrated in existing literature, see Chen et al., 2017; Xi et al., 2009), and that music training would increase their degree of categorization. This paper explores how music training and training duration affect the development of categorical perception of tones in 4- to 5-year-old children.

2 Methods

2.1 Participants

Participants were 46 children from two natural classes in a public kindergarten affiliated with a university. The two classes were randomly assigned to music and control groups. After excluding 3 children from each group due to absence or extracurricular instrumental learning, 40 children remained, with 20 in the music group (13 boys, 7 girls) and 20 in the control group (11 boys, 9 girls). At the start of the experiment, participants' mean age was 4.3 (±0.41) years, with no significant age difference between the two groups. Parents signed informed consent forms.

To avoid intelligence factors influencing music training effects, all participants completed an intelligence test (Weiß & Osterland, 1977) before the pretest, following Degé and Schwarzer (2011). Testing was conducted in 5 groups of 8 children each, with each group tested for 60 minutes. No significant difference was found between the two groups of the same age on intelligence test scores ($F(1,39)=0.274$, $p=0.603$). Results are shown in Table 1 .

Table 1 Mean and standard deviation of age and intelligence test scores for both groups

Group	Age (months)	Intelligence Score
Music	51 (2.91)	110.25 (4.48)
Control	50.8 (3.0)	111.95 (3.95)

2.2 Experimental Design

The experiment employed a 2×3 design (music group/control group; pretest/midtest/posttest). Group (music/control) was a between-subjects

variable, while test type (pretest/midtest/posttest) was a within-subjects variable. Neither the music nor control group had participated in similar training before. The music group received music training in sessions of 20 children each, three times per week, 30 minutes per session, for 12 months, totaling 110 training sessions. The control group received no organized training and participated in normal class activities. Both groups completed tonal categorical perception tests before training, after 6 months of training, and after 12 months of training. This experiment used a double-blind design: the music group teacher conducted music instruction and guidance without knowledge of the training purpose; pretest, midtest, and posttest were administered by an experimenter who did not know participants' group assignments using homogeneous test tasks; participant data were entered and processed by another experimenter using anonymous, ungrouped data.

2.3 Materials and Procedure

2.3.1 Tone Categorical Perception Test Original speech samples for creating experimental stimuli were natural monosyllables dā (Tone 1) and dá (Tone 2) produced by a female Mandarin speaker (22050 Hz sampling rate, 16-bit, mono). Following Peng et al. (2010) and Chen et al. (2017), we used Praat (Boersma & Weenink, 2009) to create a Tone 2 to Tone 1 continuum from starting point dá to endpoint dā with 60 Hz intervals, with equal pitch steps of 7.5 Hz. During processing, all speech parameters except pitch were held constant: intensity was 70 dB and duration was 500 ms. Specific speech stimuli were synthesized using Praat (see Figure 1 [Figure 1: see original paper]). This yielded 9 speech experimental stimuli, which were used for all three tests.

Each test included both identification and discrimination tasks, with stimulus presentation controlled by E-prime 2.0. Before formal testing, participants completed 6 identification trials and 4 discrimination trials as practice to familiarize themselves with the procedure. Only those achieving over 90% accuracy on stimuli at the continuum endpoints proceeded to the formal test.

Each test was conducted over two days: Day 1 completed the identification experiment (approximately 5 minutes), and Day 2 completed the discrimination experiment (approximately 10 minutes). In the identification experiment, each stimulus was repeated 5 times and played randomly, so each participant heard 45 identification stimuli. Since no participants had received pinyin training, the experiment used a picture selection method (Figure 2 [Figure 2: see original paper]): participants pressed the 1 key to select the left picture (a car driving on a flat road) when identifying the stimulus as Tone 1, and pressed the 2 key to select the right picture (a car driving uphill) when identifying the stimulus as Tone 2.

In the discrimination experiment, researchers paired stimuli separated by two steps (15 Hz) to form stimulus pairs (i.e., 1-3, 3-5, 5-7, 7-9, 2-4, 4-6, 6-8, 3-1, 5-3, 7-5, 9-7, 4-2, 6-4, and 8-6), while also pairing identical stimuli (1-1, 2-2, 3-3, 4-4,

5-5, 6-6, 7-7, 8-8, and 9-9). The two stimuli within each pair were separated by 200 ms. Each stimulus pair was repeated 4 times and played randomly, so each participant heard 92 discrimination stimulus pairs. The discrimination experiment also used a picture selection method (Figure 3 [Figure 3: see original paper]): participants pressed the 1 key to select the left picture (two identical cars) when judging the two stimuli as the same, and pressed the 2 key to select the right picture (two different cars) when judging them as different. Three 10-second breaks were provided during testing.

Both experiments used a forced-choice format with two alternatives. After each stimulus or stimulus pair was played, participants were required to respond as quickly as possible by pressing a key, with no feedback provided.

2.3.2 Data Processing Methods Following Peng et al. (2010) and Chen et al. (2017), this study quantitatively analyzed three important parameters affecting phonemic categorical perception: boundary position, boundary width, and discrimination accuracy.

The identification task examined boundary position and boundary width for children in both music and control groups. Boundary position refers to the stimulus number value corresponding to the 50% identification rate where the two identification function curves intersect (i.e., at the crossover point of the two curves). Boundary width refers to the linear distance between 25% and 75% identification rates, a value determined by the mean and standard deviation in probit analysis (Peng et al., 2010). Both boundary position and boundary width were obtained through Probit analysis (Finney, 1971). A narrower boundary width indicates a faster transition rate from one tonal category to another near the boundary position and higher degree of categorization.

The discrimination task analyzed discrimination accuracy. We regrouped all discrimination stimulus pairs, with each group including four types of stimulus pairs: AA, BB, AB, and BA. For example, group 2-4 contained stimulus pairs 2-2, 4-4, 2-4, and 4-2. Adjacent groups contained overlapping AA or BB stimuli (e.g., stimulus pair 5-5 existed in both groups 3-5 and 5-7), resulting in 7 stimulus pair groups: 1-3, 2-4, 3-5, 4-6, 5-7, 6-8, and 7-9. Discrimination accuracy for each group was calculated using the formula from Xu, Gandour, and Francis (2006): P = P('S' /S) × P(S) + P('D' /D) × P(D). In this formula, P('S' /S) represents the percentage of "same" judgments after hearing identical stimulus pairs, and P('D' /D) represents the percentage of "different" judgments after hearing different stimulus pairs. P(S) represents the percentage of identical stimulus pairs within each group, and P(D) represents the percentage of different stimulus pairs. In this experiment, both P(S) and P(D) were 50%.

Additionally, based on each participant's identification boundary position, Chen et al. (2017) further divided discrimination test accuracy into within-category and between-category discrimination accuracy. For example, if a participant' s identification boundary position was 4.8, the average discrimination accuracy

of the two groups crossing this boundary (groups 3-5 and 4-6) represented that participant' s between-category discrimination accuracy, while the average accuracy of the remaining five groups represented within-category discrimination accuracy. Following this method, this experiment compared within-category and between-category discrimination accuracy between music and control groups. All data were collected via E-prime 2.0 and processed in SPSS 20.0 for Windows.

2.4 Music Training Procedure and Scoring Criteria

One week after the pretest, children in the music group began receiving music training. Following Chobert et al. (2014), this study adopted a combined Kodály and Orff music education approach, designing a series of music training intervention courses suitable for 4- to 5-year-old children' s musical development from four stages: listening, discriminating, playing, and performing. Due to space limitations but needing to ensure all music group children received training of identical duration, intensity, and content, researchers decided to use the small carillon for training tasks. Currently, most kindergartens in China offer small carillon courses. Similar to the piano, the small carillon is a fixed-pitch instrument with 32 notes (16 high and 16 low notes), featuring clear timbre, stable intonation, and simple operation, making it suitable for children' s music 启蒙 teaching.

The course was conducted three times per week, with all music group participants together for 30 minutes each session, for 12 months, totaling 40 weeks (approximately 110 sessions). The first session each week introduced new material, while the second and third sessions were practice sessions where teachers guided children in repeated practice of the new content, identifying and solving problems to ensure music group children maintained basically equivalent small carillon performance levels by the end of training. To ensure consistent training time, music group children were uniformly scheduled for collective training in the morning, with no encouragement for home practice.

The specific training arrangement was as follows: (1) Listening: listening to music and singing scores to perceive musical pitch, dynamics, and tempo; (2) Discriminating: focusing attention on pitch changes in notes; (3) Playing: performing small carillon pieces with background music; (4) Performing: increasing piece difficulty and length, with simple body movements added during transition sections without playing tasks (approximately 10-15 seconds per piece) to make the form more lively and performances more complete (see Table 2 for specific curriculum). Training teachers had received Kodály and Orff music education method training, were familiar with training procedures, key points, and difficulties, and guided children to learn music with interest and progression through encouragement.

After the first 6 months and after 12 months of training, music group children were assessed by their instructor. Each assessment included two parts: small car-

illon performance and scale imitation singing. The small carillon performance test evaluated whether children had mastered the learned pieces to meet stage teaching requirements. Teachers judged from three aspects: accuracy, completeness, and fluency, with 10 points for each aspect and a total maximum score of 30 points.

Scale imitation singing examined the effect of music training on children' s pitch accuracy. Test materials were untrained melodies within the length of children' s short-term memory, with a test range of 11 notes from G3 to B4. Teachers used an "echo game" design, playing complete demonstrations on piano in a quiet, separate classroom before prompting children to begin testing. In groups of three notes, children imitated and sang the heard melody, with each child given two complete imitation opportunities. Teachers recorded the tests and judged each note in the test song as accurate (scored as 1) or off-pitch (scored as 0), with a total maximum score of 30 points.

Table 2 Music Training Curriculum for 4- to 5-Year-Old Children

Month	Objectives & Content	Key Points & Difficulties	Training Abilities	Teaching Tools
Month 1	Recognize small carillon, listen to music and sing scores (2 new lessons + 4 practice sessions)	Key: Listening, singing scores; Difficulty: Accurate singing	Listen and sing	Small carillon
Months 2-4	Perceive pitch, dynamics, and tempo (9 new lessons + 18 practice sessions)	Key: Identify 32 notes, perceive different pitches; Difficulty: Identify 32 notes and strike designated notes according to beat	Focus on perceiving pitch differences between notes	Small carillon, African drum (accompaniment)
Months 5-6	Play simple pieces with music (8 new lessons + 16 practice sessions)	Key: Distinguish 32 notes, accurately strike designated notes among different notes; Difficulty: Sing scores and play with background music	Perceive pitch, duration, dynamics, and play with background music melody and beat	Small carillon

Month	Objectives & Content	Key Points & Difficulties	Training Abilities	Teaching Tools
Months 7-12	Play complete longer pieces with music (18 new lessons + practice sessions)	Key: Repeated practice with music to improve accuracy, fluency, and completeness; Difficulty: Sing scores and play with background music	Perceive pitch, duration, dynamics, play with background music beat, and use small hammers with simple movements during transition sections to make performances more complete	Small carillon

3 Results

3.1 Music Training Performance

The music group completed 12 months of training. After 6 months of training, music group children were individually assessed by their instructor. Small carillon performance and scale imitation singing each accounted for 50% of the total score (see Table 3). To demonstrate that music group children met stage requirements and made progress, we first conducted a paired-samples t-test on the music group children' s total scores from the two assessments, revealing a significant difference ($t(19)=12.120$, $p<0.001$). Subsequently, to examine the effect of music training on children' s musical pitch perception ability, we conducted a paired-samples t-test on scale imitation singing scores from the two assessments, also revealing a significant difference ($t(19)=9.568$, $p<0.001$).

Table 3 Mean and standard deviation of music training scores

Assessment	Small Carillon Performance	Scale Imitation Singing	Total Score
6 months	25.15 (1.95)	23.45 (1.64)	48.60 (2.23)
12 months	27.75 (1.83)	27.80 (1.50)	55.56 (2.43)

3.2 Tone Categorical Perception Test Results

This study first conducted descriptive statistics on boundary position and boundary width in the identification test for both groups (see Table 4) and plotted

identification curves for both groups at different test times. Additionally, we conducted statistics on average discrimination accuracy in the discrimination test and plotted average discrimination accuracy curves for the three test times. Results (Figure 4 [Figure 4: see original paper]) showed that in all three tests, both groups exhibited categorical boundaries and discrimination peaks, indicating that children in this age range show categorical characteristics in tone perception, consistent with previous literature (Chen et al., 2017; Xi et al., 2009). Based on this, this study conducted further statistical analysis on boundary position, boundary width, and discrimination accuracy (including within-category and between-category discrimination rates) for both groups at different test times.

Table 4 Mean and standard deviation of identification boundary position and boundary width for both groups

Group	Test	Boundary Position	Boundary Width
Music	Pretest	4.84 (0.44)	1.67 (0.29)
Music	Midtest	4.81 (0.49)	1.64 (0.41)
Music	Posttest	4.79 (0.50)	1.17 (0.47)
Control	Pretest	4.81 (0.46)	1.59 (0.32)
Control	Midtest	4.77 (0.36)	1.55 (0.36)
Control	Posttest	4.75 (0.51)	1.51 (0.50)

3.2.1 Boundary Position Results Boundary position results for both groups in pretest, midtest, and posttest are shown in Table 4. A 2 (group: music/control) × 3 (test type: pretest/midtest/posttest) repeated measures ANOVA was conducted on participants' pretest, midtest, and posttest results. Results showed no significant main effect of test type ($F(2,76)=0.21$, $p=0.81$, $^2=0.06$), no significant main effect of group ($F(1,38)=0.20$, $p=0.66$, $^2=0.05$), and no significant interaction between test type and group ($F(2,76)=0.002$, $p=0.99$, $^2=0.01$). These results indicate that music training had little effect on boundary position perception, and that neither music nor control group participants showed significant differences in boundary position across the three test times.

3.2.2 Boundary Width Results The distribution of boundary widths for each group at different test times in the identification experiment is shown in Figure 5 [Figure 5: see original paper]. We first conducted a 2 (group: music/control) × 3 (test type: pretest/midtest/posttest) repeated measures ANOVA on boundary width, which revealed a significant interaction effect ($F(2,76)=3.60$, $p=0.03$, $^2=0.09$). We analyzed the interaction effect from two directions: First, analyzing boundary widths before and after training for both groups showed no significant difference between groups in the pretest ($p=0.79$) or midtest ($p=0.49$), but a significant difference in the posttest ($p<0.001$). Second, simple effects analysis for each group' s three test scores showed that the

music group' s pretest and posttest widths differed significantly ($p<0.001$), as did midtest and posttest widths ($p=0.02$), while pretest and midtest differences were not significant ($p=0.35$). The control group showed no significant differences between pretest and midtest, pretest and posttest, or midtest and posttest (all $ps>0.05$).

These results demonstrate that music training had a significant effect on reducing categorical boundary width, with smaller boundary values indicating higher categorization. No significant differences existed between groups before training or after 6 months of training, but after 12 months of training, the music group' s boundary width was significantly smaller than the control group' s. Notably, the control group showed no significant change in boundary width across the three tests with age, while same-age music group participants showed significant changes in boundary width after 12 months of music training, indicating that the 4- to 5-year-old music group children indeed improved their tonal categorical perception ability by reducing boundary width values through music training, without age-related confounds.

3.2.3 Discrimination Accuracy Results The distribution of discrimination accuracy for each stimulus pair in the discrimination experiment for music and control groups at different test times is shown in Figure 6 [Figure 6: see original paper]. First, we observed that both groups showed discrimination peaks in all three tests, but the peak locations changed. In the pretest, discrimination peaks for both music and control groups fell on stimulus pair 3-5; in the midtest, the music group' s peak fell on stimulus pair 4-6 while the control group remained at 3-5; in the posttest, both groups' peaks fell on stimulus pair 4-6. These results reflect that without music training, age increase causes discrimination peaks to shift rightward in this age range, while music training advances this trend.

Second, we divided discrimination accuracy results into two categories: within-category and between-category discrimination accuracy. Since no significant difference existed between groups in boundary position in the identification experiment, the mean of stimulus pairs 3-5 and 4-6 represented between-category accuracy, while the mean accuracy of the other five groups represented within-category accuracy. Between-category mean accuracy for each group is shown in Figure 7 [Figure 7: see original paper]: music and control groups showed 59.32% and 59.24% in pretest, 59.41% and 59.43% in midtest, and 59.79% and 59.46% in posttest, respectively. A 2 (group: music/control) $\times$ 3 (test type: pretest/midtest/posttest) repeated measures ANOVA on between-category accuracy showed no significant main effect of test type ($F(2,76)=1.37$, $p=0.26$, $^{2}=0.03$), no significant main effect of group ($F(1,38)=0.10$, $p=0.75$, $^{2}=0.01$), and no significant interaction between group and test type ($F(2,76)=0.07$, $p=0.94$, $^{2}=0.002$). These results indicate that music training had no significant effect on between-category accuracy, with music group children showing only slightly higher between-category discrimination accuracy than controls, but not significantly so.

Within-category mean accuracy for each group is also shown in Figure 7: music and control groups showed 52.79% and 52.75% in pretest, 52.74% and 52.91% in midtest, and 56.19% and 53.03% in posttest, respectively. A 2 (group: music/control) × 3 (test type: pretest/midtest/posttest) repeated measures ANOVA on within-category discrimination accuracy revealed a significant interaction between group and test type ($F(2,76)=207.51$, $p<0.001$, $^{2}=0.09$). Simple effects analysis from two directions found no significant group differences in pretest or midtest (both ps>0.05), but a significant group difference in posttest ($p<0.001$). The music group showed no significant difference between pretest and midtest ($p>0.05$), but significant differences between posttest and pretest and between posttest and midtest (both ps<0.001). The control group showed no significant differences across the three tests (all ps>0.05). These results demonstrate that children who received 12 months of music training showed significantly higher within-category discrimination accuracy than children without music training, while 6 months of music training had no significant effect on within-category discrimination accuracy. Additionally, 4- to 5-year-old control group children' s within-category discrimination accuracy did not significantly improve with age.

To explore the relationship between music group' s tonal categorical perception ability improvement and 12 months of music training, we conducted a Pearson correlation analysis between the reduction in boundary width (defined as the difference between boundary width before training and after 12 months of training) and the improvement in scale imitation singing scores (defined as the difference between scale imitation singing scores after 6 months and before training). The correlation analysis results are shown in Figure 8 [Figure 8: see original paper], revealing a significant positive correlation ($r=0.567$, $p<0.05$).

4 Discussion

This study selected 4- to 5-year-old kindergarten children for music training tasks and used tonal categorical perception experiments to longitudinally examine whether music training affects children' s Mandarin tone categorical perception ability and how training duration influences training effects. Specific discussions follow.

4.1 Effects of Music Training on Children' s Tonal Categorical Perception

The first question regarding music training is whether it truly improves children' s Mandarin tone categorical perception ability. This study found that in all three test times, both groups' identification curves showed obvious S-shaped categorical perception characteristics, with clear peaks appearing on discrimination curves near boundary positions, proving that categorical characteristics emerge in Chinese children' s auditory processing of tones. Although control group participants showed slight increases in categorization with age, no significant changes occurred in boundary position or width in identification tasks

or in between-category and within-category discrimination accuracy in discrimination tasks, demonstrating that 12 months of age increase during the 4- to 5-year-old period had no significant effect on children' s tonal categorical perception. These results are consistent with previous conclusions that Chinese children show categorical characteristics in tone perception, with categorization abilities gradually approaching adult levels only after age 6 (Chen et al., 2017; Xi et al., 2009). Participants in this study had not yet reached the critical period for tone perception at age 6 when completing the three tests, so age increase had no significant effect on refined pitch processing in this experiment.

After eliminating age-related confounds, this study examined the effect of music training on children' s tonal categorical perception. Results found that 12 months of music training centered on small carillon performance significantly promoted tonal categorical perception, manifested as reduced identification boundary width. Wu et al. (2015) studied adult Mandarin speakers and found that music training could improve within-category discrimination accuracy but could not affect boundary position, boundary width, or between-category discrimination accuracy. This study provides additional evidence from the perspective of children' s native phoneme acquisition for the positive transfer effect of music training on auditory processing. Four- to 5-year-old children' s tonal categorical perception ability is in a developmental stage, making musical pitch processing experience more likely to participate in linguistic pitch processing. Furthermore, previous research suggests that musicians are more sensitive to various forms of acoustic features than non-musician adults, particularly pitch information in music, language, and pure tones (Kuehnis, Elmer, Meyer, & Jaencke, 2013; Marie, Magne, & Besson, 2011; Milovanov et al., 2009; Sadakata & Sekiyama, 2011; Wong & Perrachione, 2007). The discrimination results in this study indicate that music training indeed improved children' s perceptual sensitivity to linguistic pitch acoustic features, manifested as improved within-category discrimination accuracy. However, because between-category differences represent phonological-level contrasts with more robust perceptual space than acoustic-level contrasts, even 12 months of music training could not affect between-category discrimination accuracy. Regarding categorical boundary position, this study found that neither 6 nor 12 months of music training could significantly affect it, because phonetic attributes near boundary positions in native language continua are acquired early and basically mature in children (Zhang, Kuhl, Imada, Kotani, & Tohkura, 2005). Some researchers have found no significant difference in identification boundary positions between 4- to 7-year-old children and adults (Chen et al., 2017). Chen, Zhang, Wang, and Peng (2019) noted that identification boundary position cannot serve as an effective indicator for measuring the degree of phoneme perception categorization. Therefore, we believe that music group children' s categorical perception boundary positions were already fixed before training began, making it difficult for music training to affect boundary position.

These results support the OPERA hypothesis. From the OPERA perspective, music and language share the same sensory and cognitive processes, and mu-

sic involves higher-level processing within this shared neural mechanism than language, thus music training may promote speech perception. When these higher-level neural mechanisms combine with emotion created by music, repetition in music training, and focused attention, they activate neural plasticity and lead to changes in brain structure and function. Nan et al. (2018) used piano training to reveal the neural mechanisms of children' s music learning transfer to language domains, finding that music training enhanced children' s brain neural responses to linguistic tone and musical pitch changes, an effect not observed in reading training or control groups. Similar to the piano, each key on the small carillon corresponds to a fixed note, with adjacent note changes determined by pitch, similar to the pitch cues that cause tonal changes in Mandarin. To further illustrate the contribution of music group children' s musical pitch experience to changes in tonal categorical perception ability, we conducted a correlation analysis between the improvement in scale imitation singing scores and the reduction in boundary width, which showed a significant correlation ($r=0.567$, $p<0.05$).

Furthermore, individual tonal categorical perception is related to pre-attentive processing levels. Research has revealed that non-musician adults show significantly increased MMN amplitude after short-term music training (Lappe, Herholz, Trainor, & Pantev, 2008). In that experiment, participants were divided into two groups: one receiving piano training and the other only auditory training. Within two weeks, they practiced 8 times for 25 minutes each. After training, the piano group showed significantly increased MMN amplitude compared to before training, while the auditory group showed no significant difference. These results indicate that in music training, particularly training combining sensory and motor aspects, is more beneficial for improving pre-attentive processing levels. Additionally, Zhao and Kuhl (2016) conducted a 4-week, 12-session music intervention with 9-month-old infants, having them listen to music in triple meter and move to the beat with caregivers' help. Control group infants did not listen to music but simply played with toys freely. Results showed that the music intervention group was more sensitive to temporal structure changes and evoked larger MMN amplitudes than the control group. In this study' s music training process, teachers not only guided children to recognize scales (high, middle, low), beats, and staff notation, but also encouraged children to sing simple cheerful songs while playing after some training time. This training method combining sensory and motor aspects not only improved children' s precise auditory perception and discrimination abilities for musical pitch, but also cultivated accurate sound judgment and rich emotional expression through production practice. Teachers conducted two practice sessions weekly, with repeated training strengthening music' s cross-domain effects, thereby affecting music group participants' judgments of the two category boundaries.

4.2 Effects of Music Training Duration on Children' s Tonal Categorical Perception

The second question regarding music training is whether 6 months of short-term training and 12 months of music training can improve children's tonal categorical perception ability, and whether long-term sustained training is necessary to realize music training' s facilitative effects.

This study examined the effect of music training duration on children' s Mandarin tone categorical perception. Results showed that 6 months of small carillon training had no significant effect on children' s tonal categorical perception, while 12 months of training produced facilitative effects, indicating that improved refined pitch processing in the language domain indeed requires longer time. Related ERP research has found that 6 months of music training is sufficient to induce behavioral and neural changes (Moreno et al., 2009), suggesting that short-term music training can significantly affect functional organization in children' s brains. However, other research has found that ERP-based results differ from behavioral experiment results. For example, Zheng et al. (2014) found that non-speech stimuli used in ERP experiments could elicit larger categorical effects, possibly because tone perception in the pre-attentive stage is mainly affected by harmonic structure, and non-speech stimuli have simpler and more regular harmonic structures, thus producing larger categorical effects. The test materials in this study were all speech stimuli, so the categorical effects they elicited might be slightly smaller than those elicited by non-speech stimuli. In terms of experimental methods, Nan et al. (2018) suggested that for children, neural response predictive effects might be more sensitive than behavioral test predictive effects, making significant changes easier to observe early on. This experiment used behavioral testing; although music group children did not show significant advantages in tonal categorical perception at 6 months, neural changes might have already occurred. The results provide some 启示 for future research to address this question from the perspective of neural responses.

Furthermore, the effect of music training on pre-attention is also related to training strategies. Vuust, Brattico, Seppanen, Naatanen, and Tervaniemi (2012) used a multi-feature music paradigm to compare jazz musicians, classical musicians, rock musicians, and non-musicians. Results showed that jazz musicians' MMN responses to pitch deviant stimuli were significantly larger than non-musicians' . The authors argued that jazz performance requires strong auditory discrimination and improvisation abilities, making them sensitive to subtle changes in stimulus pitch and intensity. Tervaniemi, Castaneda, Knoll, and Uther (2006) also supported this view, finding that amateur rock musicians showed significantly larger MMN amplitudes evoked by location deviant stimuli than non-musicians. The music training in this study used familiar cheerful children' s songs with slower tempos than rock and jazz, and did not include improvisation training, which may have affected children' s pre-attentive processing levels for different stimuli to some extent. Additionally, most previous research used piano training; due to experimental constraints, the small carillon

used in this study has a narrower range than the piano, so the categorical effects produced by 6 months of short-term training may not be as significant as those from piano training.

5 Conclusion

This study investigated whether music training can improve 4- to 5-year-old children's Mandarin tone categorical perception ability and whether training duration affects training effectiveness. The following conclusions were drawn: (1) Music training can enhance the development of 4- to 5-year-old children' s tone categorical perception ability, specifically manifested as significantly reduced identification categorical boundary width and improved categorical perception ability after 12 months of training, supporting the OPERA hypothesis that music training can promote language development. (2) Training duration affects training effectiveness: 12 months of music training effectively reduced children' s tone categorical boundary width and improved within-category stimulus discrimination accuracy, but this advantage was not significant after 6 months of training, proving that music training for children should be long-term and sustained, as short-term training is difficult to promote refined pitch processing in children.

This study only reported the effects of music training activities centered on small carillon performance on 4- to 5-year-old children' s Mandarin tone categorical perception ability. Future research in this area could be validated through training with multiple instruments and longer-term tracking. Additionally, combining techniques such as event-related potentials (ERP) and functional magnetic resonance imaging (fMRI) could reveal what changes music training causes in children' s nervous systems, whether music training effects can be retained and play stable roles over longer periods, and other questions that require further in-depth research.

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