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Correspondence and requests for materials should be addressed to D.Z.Y. (dyao@uestc.edu.cn) or W.Y.M. (weiyi.ma@mq.edu.au)

* These authors contributed equally to this work.

A Longitudinal Study on Children's Music Training Experience and Academic Development

Hua Yang[1,2*], Weiyi Ma[1,3,4*], Diankun Gong[1], Jiehui Hu[1,3] & Dezhong Yao[1]

[1]Key Laboratory for NeuroInformation of Ministry of Education, School of Life Science and Technology, University of Electronic Science and Technology of China, [2]Department of Composition, Sichuan Observatory of Music, [3]School of Foreign Languages, University of Electronic Science and Technology of China, [4]ARC Centre of Excellence in Cognition and its Disorders, Macquarie University.

This study examined the relation between long-term music training and child development based on 250 Chinese elementary school students' academic development of first language (L1), second language (L2), and mathematics. We found that musician children outperformed non-musician children only on musical achievement and second language development. Additionally, although music training appeared to be correlated with children's final academic development of L1, L2, and mathematics, it did not independently contribute to the development of L1 or mathematical skills. Our findings suggest caution in interpreting the positive findings on the non-musical cognitive benefits of music learning.

Music learning appears to have non-musical cognitive benefits[1,2]. Thus, it offers us a unique perspective to understand the functional specificity for higher-level cognitive activities, a key question in cognitive science that still remains unresolved[2]. One way to address the functional specificity of music cognition is to study the transfer effect of the benefits of music learning, which is taken as evidence for the view that music is the product of a domain general cognitive architecture[1,2].

Music and language. Both music and language are systems of auditory communication and share many commonalities acoustically and cognitively[1,2]. Behavioral research showed that music experience was related to enhancements of various language abilities. For example, compared with non-musicians who received no formal music training, musician adults[3] and children[4] had better verbal memory (but not visual memory); furthermore, children who continued music training showed greater improvement in verbal memory one year later, while those who had discontinued music training did not improve[4]. However, the musician women tested by Chan et al.[3] also had more education than their non-musician counterparts, while the musician boys tested by Ho et al.[4] had higher verbal IQs (one-tailed test) than the non-musician boys. Musicians also scored higher on recall of unfamiliar spoken and sung lyrics[5] and on a verbal sequencing test than non-musicians[6]. Practicing a musical instrument in childhood was associated with later verbal ability[7]. Additionally, years of music training predicted the ability to discriminate the order of tones and syllables[8]. Furthermore, a meta-analysis of 25 correlational studies revealed an association between music training and reading skills[9]. An intervention based on singing and rhythm games also improved phonological awareness in children with dyslexia[10]. Music is also related to second language (L2) perception. For example, English-speaking musicians imitated Mandarin lexical tones better than their non-musician counterparts even when the task required categorical rather than pure auditory perception[11]. Furthermore, English speakers' performance on pitch contour perception predicted their ability to use pitch in a Mandarin word-learning task under experimental conditions[12].

The relation between music experience and language is also supported by neuroscience findings. Using Frequency Following Response (FFR), a brain wave that is elicited pre-attentively and encodes the waveform of the *f*0 of an auditory stimulus in a phase-locked manner[13], Wong et al. found that English-speaking musicians' FFR responses to Mandarin lexical tonal contours were more robust and faithful than non-musicians'[14]. Furthermore, compared with non-musicians, musicians had a more robust subcortical representation of the acoustic stimulus in the presence of noise[15]. The enhancement of subcortical encoding of speech could happen as early as three years of age[16]. Furthermore, musicians' subcortical representation of speech was related to the amount of music training received[17]. In addition, both musician adults[18] and children[19] showed more advanced pitch contour processing of sentences than non-musicians as revealed by EEG recordings. This enhancement was also evident in L2 processing[20]. In a longitudinal study, the 8-year-old children, who were randomly assigned to receive music training, outperformed their age-matched controls both in terms of accuracy and their electrophysiological responses to speech stimuli[21].

However, a meta-analysis on six experimental studies did not reveal a robust causal relation between music training and reading ability[9]. Furthermore, a recent experimental study found that music training did not improve 4-year-olds' receptive vocabulary knowledge[22]. However, the finding does not argue against the relation between formal long-term music training and language development because children tested in that study were exposed to only 6 weekly 45-minute sessions[22].

Music and mathematical skills. Many explanations could be proposed for the potential relation between music and mathematical skills (e.g., music rhythm is based on mathematical relations). However, the evidence for the mathematical benefits of music still remains mixed. Research showed that the first-graders who received both visual arts and music training over the course of seven months outperformed their control counterparts on mathematics[23]. However, this study did not disentangle music and visual arts training. A meta-analysis of six experimental studies testing the effect of music training on mathematical skills showed a small but significant effect size[24]. However, only two of the six studies showed a significant positive effect of music training. Additionally, practicing a musical instrument in childhood was not associated with later mathematical development[7]. Thus, the hypothesis that music training is related to enhancements of mathematical skills still needs further evaluation.

In summary, past research has shown that music experience may be related to L1, L2, and mathematical development. However, children's academic development is also associated with other variables (e.g., parents' education[25–27]), which in turn are possibly related to music training. Thus, it is unclear whether music training independently contributes to academic development. Additionally, most studies on the academic benefits of music learning on child development are based on data collected within a relatively short period of time (e.g., 1 year in[4]). Therefore, the developmental trajectory of musician and non-musician children still needs further exploration. Finally, the finding of the developmental benefits of music learning is largely based on children raised in Western cultures, thus leaving the universality of the finding open to question.

This study examined whether children's experience of music training is related to academic enhancements of L1, L2, and mathematics. We recorded 250 Chinese primary school students' academic performance on L1 – Chinese, L2 – English, and mathematics at the end of each semester from semester 1 to semester 11, and their performance on a music achievement test at the end of each semester from semester 2 to semester 11. Based on the self-reported music training experience, 77 children, who started to receive formal music training out of school around the beginning of semester 3, were categorized as musician children, while the other 173 children, who had not received formal music training throughout this study, were categorized as non-musician children.

Results

Was music training related to enhancements of musical development? If music training did benefit child development in this study, it should at least enhance children's musical development. A multilevel model analyzed children's performance on the music achievement test with time (i.e., 11 semesters) as the repeated measure and group (musician vs. non-musician) as the between-subject variable. Results showed a significant time × group interaction ($F(1,10) = 6.15$, $p < .001$), suggesting that children's performance differed according to their music training experience. Then, when mother's educational experience (in years) was included in the multilevel model as a covariate, the time × group interaction remained significant ($F(1,10) = 6.17$, $p < .001$). Then, separate ANCOVAs compared musicians' and non-musicians' performance at each semester when mother's educational experience was held constant. Results showed that musicians' performance was better at semesters 3, 5, 6, 7, 9, 10, and 11 (p's $< .05$), and marginally better at semester 4 than non-musicians' ($p = .060$) (Figure 1). However, the pre-training performance at the music achievement test (i.e., semester 2) did not differ between musicians and non-musicians ($p = .15$).

Was music training related to enhancements of academic development? Three separate multilevel models analyzed children performance on L1, L2, and mathematic, respectively, with time (i.e., 11 semesters) as the repeated measure and group (musician vs. non-musician) as the between-subject variable. Only the analysis on L2 revealed a significant time × group interaction ($F(1,10) = 1.91$, $p < .05$), suggesting that children's performance on L2 differed according to their music training experience. Then, mother's educational experience (in years) was included in the multilevel model as a covariate. The time × group interaction remained significant ($F(1,10) = 1.88$, $p < .05$). Then, separate ANCOVAs compared musicians and non-musicians' performance on L2 at each semester when mother's educational experience was held constant. Results showed that musicians' performance on L2 was better at semesters 7, 10, and 11 (p's $< .05$), and marginally better at semester 6 ($p = .084$) than non-musicians' (Figure 2). Furthermore, the pre-training performance on L2 did not differ between musicians and non-musicians at either semester 1 ($p = .48$) or 2 ($p = .22$). Thus, results showed that music training was related to enhancement of L2 performance rather than L1 or mathematic performance in this study (Figures 3a, 3b).

Did music training independently contribute to children's final academic performance? This analysis focused on children's school performance recorded at semester 11. Non-musicians were included in the analysis with their music experience indicators (duration of training in months [DT], weekly amount of training in hours [WA]) equal to zero. First, bivariate correlational analysis examined whether children's final school performance of L1, L2, and mathematics was related to DT, WA, mother's education, IQ, and pre-training performance. Then, regression analysis explored whether the relevant factors independently contributed to children's final school performance.

Music. Children's final music achievement was related to WA ($r = .34$, $p < .001$), DT ($r = .36$, $p < .001$), mother's education ($r = .17$, $p < .05$), and pre-training music achievement (i.e., semester 2) ($r = .32$, $p < .001$). Then, a regression model analyzed the unique contribution of WA, DT, mother's education, and pre-training music achievement to children's final music achievement. Results showed that WA, mother's education, and pre-training music achievement independently contributed to children's final music achievement (p's $< .05$) [Table S1 in SOM]. Thus, music training (i.e., WA) was indeed related to enhancement of musical development in this study.

L2. Children's final L2 performance was related to WA ($r = .19$, $p < .01$), DT ($r = .15$, $p < .05$), mother's education ($r = .17$, $p < .01$), and IQ ($r = .20$, $p < .01$). Then, a regression model analyzed the unique contribution of WA, DT, mother's education, and IQ to children's final performance on L2. Results showed that WA, mother's education, and IQ independently contributed to children's final performance (p's $< .05$) [Table S2 in SOM]. Thus, music training (i.e., WA) was indeed related to enhancement of L2 performance in this study.

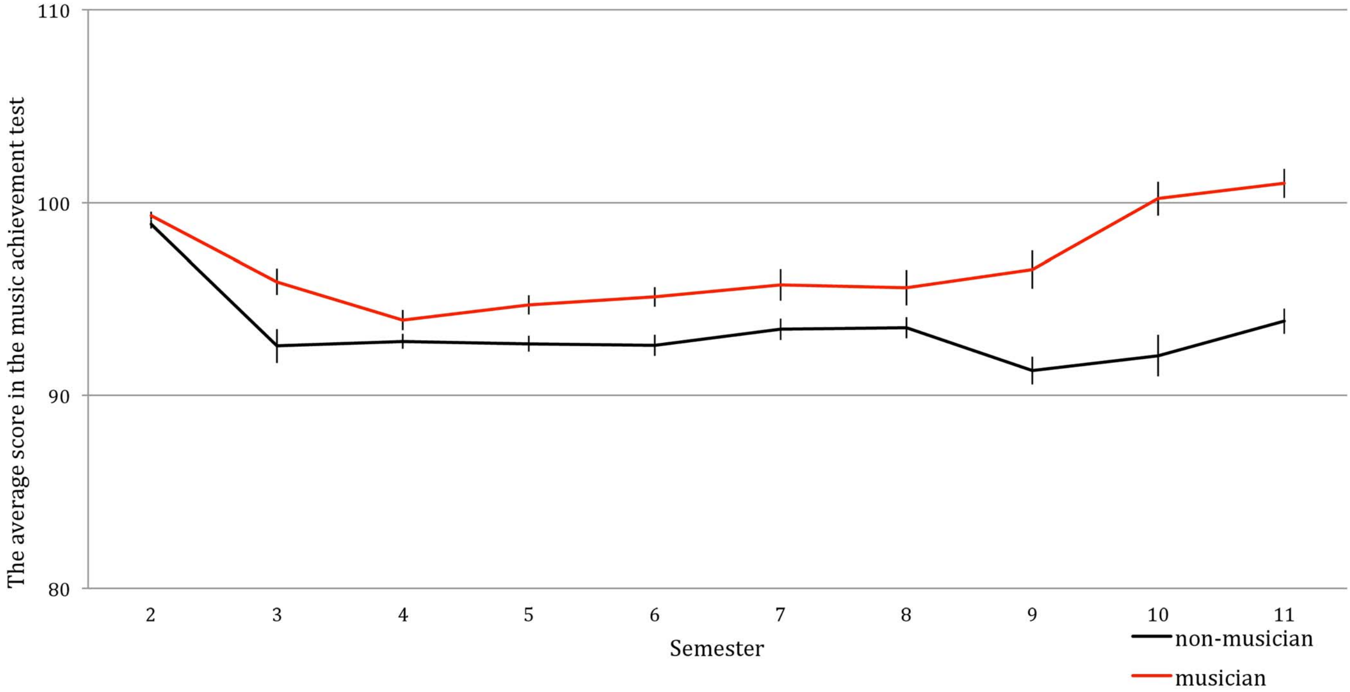


Figure 1 | Children's music achievement development. Independent samples *t* tests showed that musician children's musical aptitude was better than non-musicians' at semesters 3, 5, 6, 7, 8, 9, 10, and 11 (p's $< .05$), and marginally better at semester 4 ($p = .09$). There was no significant between-group difference at semester 2.

L1. Children's final L1 performance was related to WA ($r = .20$, $p < .01$), IQ ($r = .13$, $p < .05$), and pre-training performance on L1 (the average across semesters 1 and 2) ($r = .20$, $p < .01$). Then, a regression model analyzed the unique contribution of WA, IQ, and pre-training performance on L1 to children's final performance on L1. Results showed that only pre-training performance on L1 indepen-

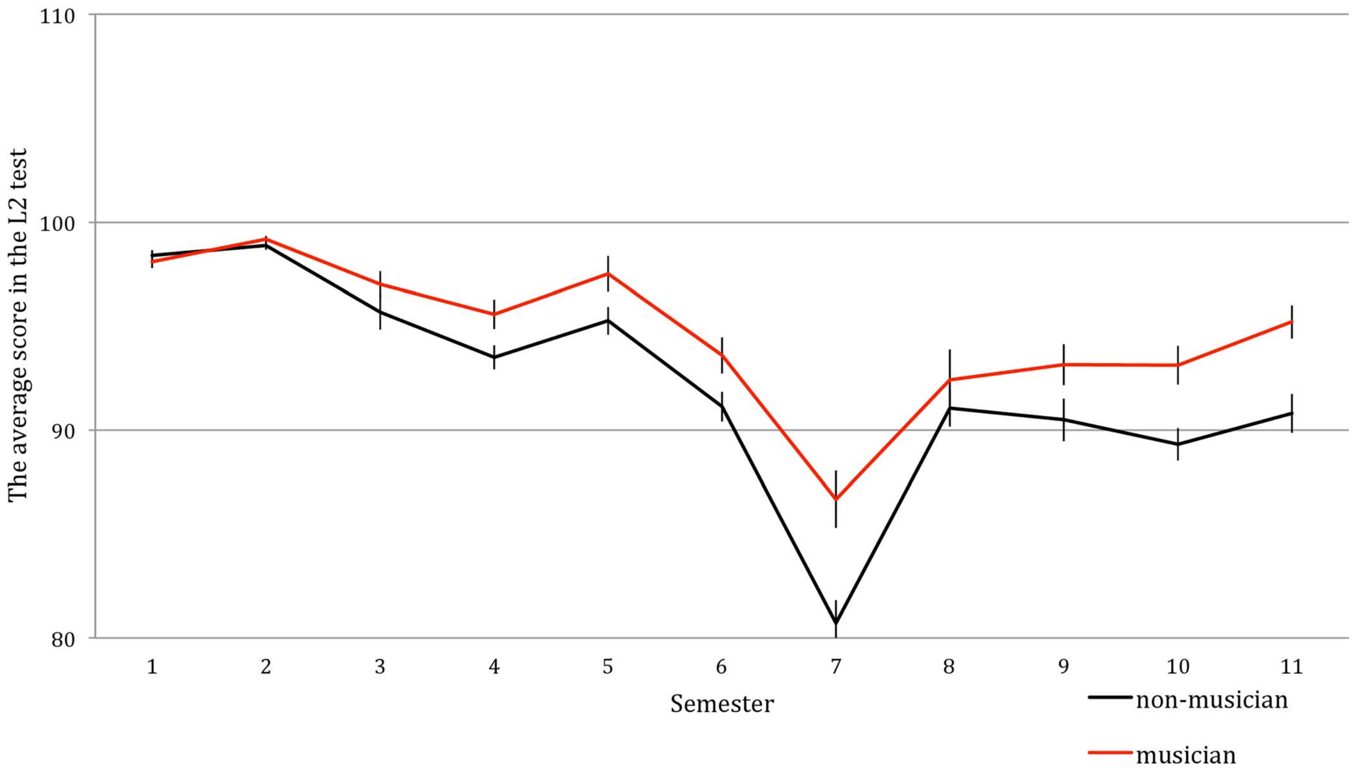
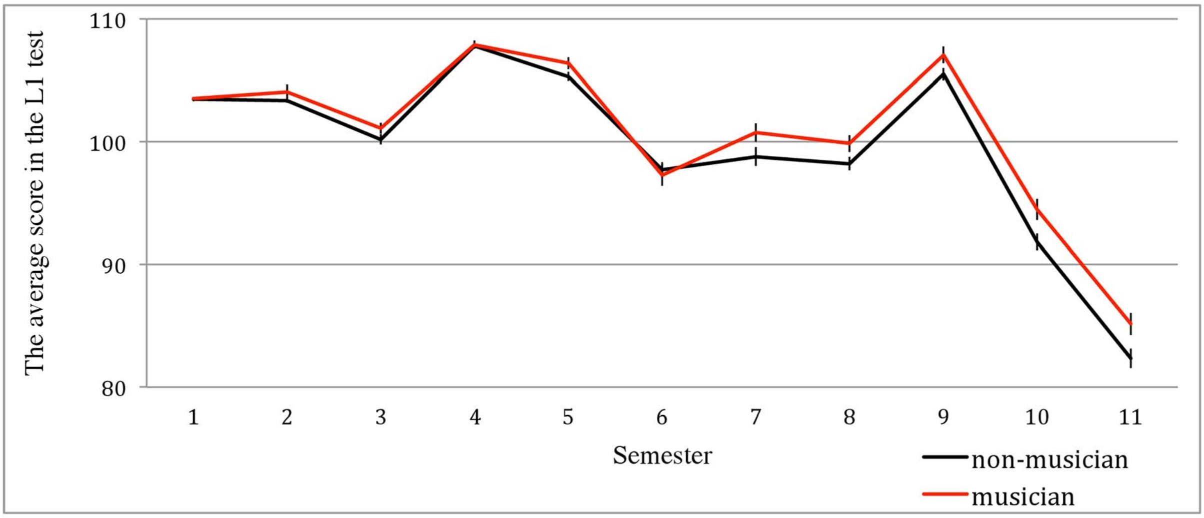


Figure 2 | Children's L2 development. Independent samples *t* tests showed that musician children significantly or marginally significantly outperformed non-musician children on L2 at semesters 4, 5, 6, 7, 9, 10, and 11.There was no significant between-group difference at either semester 3 ($p = .21$) or 8 ($p = .43$).



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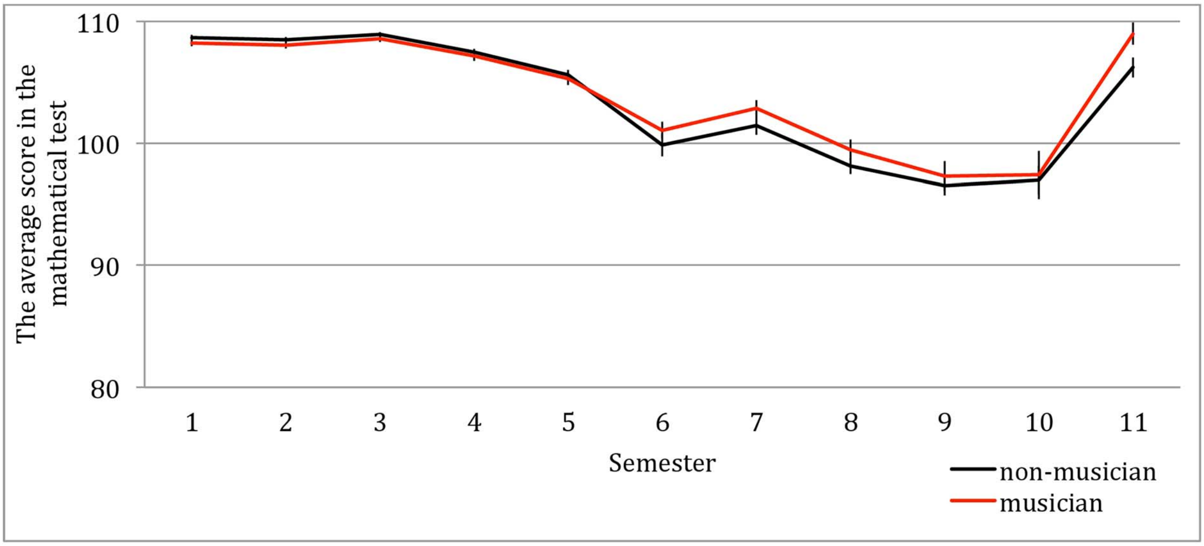

b

Figure 3 | (a) Children's L1 development. Independent samples *t* tests showed that musician children significantly or marginally significantly outperformed non-musician children on L1 at semesters 5, 8, 9, 10, and 11. There was no significance between-difference at semester 3 ($p = .17$), 4 ($p = .76$), 6 ($p = .68$), or 7 ($p = .12$). (b) Children's mathematical development. Independent samples *t* tests showed that musician children significantly outperformed non-musician children on mathematics at semester 11. Although multilevel models did not show significant time × group interactions in the analyses on L1 or mathematics, independent samples *t* tests revealed that musicians outperformed non-musicians at various semesters. The findings suggest caution in interpreting the positive findings on the non-musical cognitive benefits of music learning when children's cognitive development was examined *only* at one specific time point, which may increase the possibility of Type 1 error.

dently contributed to final performance on L1 ($p < .05$) [Table S3 in SOM]. Thus, the results confirmed that music training was *not* related to L1 development in this study.

Mathematics. Children's final mathematical performance was related to WA ($r = .14$, $p < .05$), IQ ($r = .37$, $p < .001$), and pre-training performance on mathematics (the average across semesters 1 and 2) ($r = .27$, $p < .001$). Then, a regression model analyzed the unique contribution of WA, IQ, and pre-training performance on mathematics to children's final performance on mathematics. Results showed that only IQ and pre-training performance on mathematics independently contributed to children's final performance on mathematics (*p's* $< .01$) [Table S4 in SOM]. Thus, the results confirmed that music training was *not* related to mathematical development in this study.

Discussion

Were the results driven by factors rather than music training? Were the findings driven by the possibility that higher achieving children were more likely to receive music training? This explanation is highly unlikely. First, the result that music training was related to only musical and L2 development suggested that the music experience was not associated with overall academic achievement in this study. Second, children's pre-training performance on L1, L2, and mathematics did not have between-group difference. Finally, children's IQ measured by a Raven test at semester 11 did not differ between groups ($p = .26$), which argued against the possibility that higher achieving students were more likely to receive music training.

Furthermore, it is also highly unlikely that the academic benefits of music training observed in this study are due to a general training effect rather than music training specific. Children's painting training experience (weekly amount of time spent on painting in minutes) reported at semester 11 was not related to academic performance. In addition, a general training effect tends to influence multiple cognitive domains indiscriminately; however, we found that music training was only related to musical and L2 development. Finally, musicians outperformed non-musicians on music achievement after the onset of music training, thus, supporting the music specific effect in this study. However, given the fact that a music achievement test differs from a music aptitude test, which measures one's potential to acquire skills and knowledge required for musical activity[28], this study does not allow for an evaluation of the relation between music training and music aptitude. Future longitudinal research should also examine children's music aptitude.

Why was music training related to L2 rather than L1 development in this study? We would propose two explanations. First, both music and language are systems of auditory communication. Thus, music training may have a stronger influence on the auditory aspect of language ability than other aspects, such as grammar, reading, and writing. In this study, the L1 tests assessed a wide range of language abilities, including phonology, word meaning, grammar, reading, and writing, while the L2 tests only assessed listening comprehension and knowledge of phonology and word meaning. Therefore, the test content might make the linguistic benefits of music training more evident in L2 than L1. Second, at 6 to 12 years of age, children are already proficient L1 users, but their L2 abilities are still developing. Thus, the L2 test might be a more sensitive measurement of one's language learning ability than the L1 test in this study. This explanation is supported by the result of a paired sample t test, which showed that children's performance on L2 had a greater standard deviation than their performance on L1 across the 11 semesters ($t = 3.76$, $p < .01$).

Several theoretical frameworks have been proposed to explain the transfer effects from music to language. The most parsimonious account for the transfer effects proposes that music and language share the same auditory processing infrastructure. Music training could enhance the efficiency of this infrastructure, thus, leading to more efficient speech processing. The finding that music training sharpens auditory processing even at the subcortical level supports the view that music-specific experience enhances domain-general auditory mechanisms[17–19]. In this study, the finding that music training was related to enhancements of performance on L2 tests, which were biased towards the auditory aspect of language abilities, also supports this view.

In addition, Patel proposed the OPERA hypothesis, which is an acronym composed from the initial letters of five conditions necessary for transfer to occur: 1) *Overlap*, the fact that training must be related to a common neural circuit, 2) *Precision*, the demands for processing precision should be high in order to trigger top-down tuning, 3) *Emotion*, the importance of the emotional rewards that music offers, 4) *Repetition*, the simple learning principle essential for plasticity to occur, and 5) *Attention*, the importance of engaging focused attention while training[29]. Although this hypothesis mainly concerns the effect of music on brainstem plasticity, it can also serve as a theoretical framework to explain effects of music on language at the behavioral level in this study. Music training may improve selective attention skills, working-memory load, and learning of the acoustic rules that bind musical sounds together. These cognitive skills are also important for language learning. Specifically, categorizing sounds might promote speech perception ability, while matching visual and auditory musical information could facilitate the ability to map linguistic labels onto referent.

We found that the benefit of music training was only related to WA, while past research identified three typical determinants of the influence of music training in musicians: age of training onset, length of continuous training, and amount of practice[30]. Another study also suggested that the benefit of music training could be a function of the amount of practice[31]. Our finding is consistent with the latter one, which is probably because our participants had a similar age of training onset and length of training. A recent study showed that when personality is held constant, the relation between duration of music training and cognitive abilities could disappear[32]. In this study, children with longer WA were also likely to be more conscientious than those with shorter WA. Is the finding in this study modulated by children's personality? We cannot rule out this possibility because we did not measure children's personality. Future research should examine the role that non-musical factors (e.g., personality, attention) play in the transfer effects of music on cognitive abilities.

Furthermore, this study found that children's final IQ did not differ between groups. Actually, evidence for the intellectual benefits of music training still remains mixed. For example, research found that music lessons was associated with IQ in 6- to 11-year-olds, and music learning experience in childhood predicted both academic performance and IQ in young adulthood even when confounding variables (e.g., family income, parents' education) were held constant[33]. In an experimental study, children receiving either keyboard or vocal training over the course of 36 weeks had a larger increase in full scale IQ than the matched group receiving either drama lessons or no lessons[34]. However, two subsequent studies failed to find corresponding IQ effects with music training[21,35]. Furthermore, the association between music training and IQ tends to attenuate when professional musicians were compared to non-musicians[36]. For example, the IQ scores of music majors in college did not consistently differ from those of students from other disciplines[37]. When young musicians who had received music training for at least half of their lives were compared to non-musicians, research did not find significant between-group differences in their IQ[37]. Similarly, when participants who had received an average of 11 years of music training were compared to non-musicians, there was no difference in their general IQ[38]. Schellenberg and Moreno argued that the effect of music training on IQ may be only evident for those who take music lessons in addition to everything else[36]. However, this study did not reveal evidence that music training was related to enhanced IQ.

This study found the relation between music training and academic development in Chinese children, who have drastically different linguistic, educational, and cultural experiences than children living in Western countries, thus, supporting the universality of such benefits. Our findings also suggest caution in interpreting the positive findings on the intellectual benefits of music learning.

Methods

Ethics statement. All participants gave their written, informed consent in compliance with an experimental protocol approved by the Ethics Committee of School of Life Science and Technology, University of Electronic Science and Technology of China. The methods were carried out in accordance with the approved guidelines.

Participants. Two hundred and fifty children (122 females) from Chengdu Normal University Elementary School participated in this study. They were raised in monolingual Chinese-speaking families in Chengdu. All the children entered the school in September 2006, when their mean age was 78 months (SD = 4.30). Additional 20 children, who transferred out of the school in the middle of the study, were not included in the final sample. Both musician and non-musician children were exposed to general music classes in school, typically lasting for 45 minutes per week, but these classes included neither formal instrumental or vocal instruction nor one-on-one instruction. Children completed a self-report at semester 11 about their music training experience. They were asked to report whether they received formal music training out of school, and if they did, when they started receiving the music training, what specific types of music training they received, how often they received music training weekly, how much music training they received weekly. Based on the self-reported music training experience, 77 children, who started to receive formal music training out of school around the beginning of semester 3, were categorized as musician children. The other 173 children, who had not received formal music training throughout this study, were categorized as non-musician children. The musician children had an average duration of training of 43.31 months ($SD = 8.67$, range = 24–48), a weekly frequency of practice (WF) of 1.88 times ($SD = .62$), and a weekly amount of practice (WA) of 3.47 hours ($SD = 1.07$) based on the self-report completed at semester 11 [see the supporting online material (SOM) for details].

Design and materials. We recorded children's academic developmental data from semester 1 to 11.

Academic performance. Children completed standardized tests on L1, L2, and mathematics at the end of each semester from semester 1 to 11. The tests were designed by a government supported educational testing service in Chengdu, which has been providing standardized tests to all the elementary and secondary school students in the region for over three decades. In this study, a single teacher taught a particular subject for all the children in a certain year, thus, eliminating the influence of instructor differences. The instructor graded the test papers based on the standardized grading rubrics provided by the educational testing service. The L1 test assessed children's phonological and word knowledge of Chinese from semester 1 to 4, while reading ability, grammatical knowledge, sentence making, and writing started to be included in the test since semester 5, 6, 7, and 8 respectively. English is a required course at the elementary school. The L2 test assessed children's listening comprehension, phonological and word knowledge of English from semester 1 to 11. We found that music training was related to enhancements of the overall performance on the L2 tests rather than any specific part of the test. The mathematics test assessed children arithmetic skills from semester 1 to 5, while geometry and algebra started to be included in the test since semester 6 and 8 respectively. The highest score was 110 for each test.

Painting training. Children's experience of painting training served as a control variable for us to evaluate whether the academic benefits of music training observed in this study were music specific. If so, painting training should *not* be related to academic enhancements. At semester 11, children were asked to report whether they received formal, one-on-one painting training out of school; if so, what specific types of painting training they received, how often they received painting training weekly, how much paining training (in minutes) they received weekly. Among all the 250 children, 97 of them received painting training. Fifty-three of them were also musician children, while the other 44 children were non-musician children. The painter children had an average duration of painting training of 14.31 months ($SD = 23.67$, range = 10–45), a weekly frequency of practice of 1.24 times ($SD = .76$), and a weekly amount of practice of 1.89 hours ($SD = 1.12$) based on the self-report completed at semester 11. Painter children's painting training (the duration of training, weekly amount of training) was not related to their academic performance of L1, L2, or mathematics at semester 11 (p's $> .54$). When non-painter children were included in the analysis with their painting experience (the duration of training, weekly amount of training) equal to zero, painting training was again unrelated to academic performance of L1, L2, or mathematics at semester 11 (p's $> .37$).

Music achievement. Children's performance on the music achievement test enables us to evaluate whether the finding was driven by *music* training per se. If so, musicians should have a music achievement advantage over non-musicians after the onset of music training. Children were tested on their music ability at the end of each semester since semester 2. The test was designed by the elementary school as an assessment of children's musical development and the pedagogical effectiveness of the general music lesson. The test assessed music pitch identification, melody representation, and singing from semester 2 to 5, while the basic musical theory started to be included in the test since semester 7.

Mother's education. At semester 11, mothers completed a self-report on the years of education they received starting from elementary school. Overall, mothers received 14.50 years of education ($SD = .73$). An independent samples t test showed that mother's educational experience (in years) did not differ between musician ($M = 14.47$ ys, $SD = .62$) and non-musician children ($M = 14.51$ ys, $SD = .78$). Mother's education in years was used because research showed that mother's education was a sensitive predictor of children's academic development[39].

Raven IQ test. Children were tested individually at their school by female native Chinese-speaking research assistants at semester 11. The Standard Progressive Matrices was used. The Raven test is designed to measure the test-taker's nonverbal reasoning ability, which is often referred to as general intelligence[24].

Out-of-school academic engagement. At semester 11, children were asked to report whether they were receiving extra instruction of L1, L2, and mathematics out of school; if so, how much instruction (in minutes) they were receiving every week on each subjects. The amount of extra instruction children received for each subject was not related to their WA, IQ, and academic performance on the corresponding subject at semester 11. Thus, out-of-school academic engagement was not included in the data analysis [See SOM for details].

Data analysis. To examine the influence of music training on L1, L2, mathematical skills, and IQ, we performed the following analyses.

1. A multilevel model analyzed children's performance on music achievement, L1, L2, and mathematics, respectively, with time (i.e., 11 semesters) as the repeated measure and group (musician vs. non-musician) as the between-subject variable. This analysis examined whether there was a significant time $\times$ group interaction.
2. If there was a significant time $\times$ group interaction, separate ANCOVAs compared musicians and non-musicians' performance at each semester with mother's educational experience held constant.
3. Bivariate correlational analysis examined the correlations between children's final school performance and music training experience (DT, WA), mother's education, IQ, and pre-training performance. Analyses 3 and 4 focused on children's final academic performance recorded at semester 11, because the data of WA and children's IQ were recorded only at semester 11. Based on Schellenberg's study[33], non-musician children were included in analyses 4–5 with each of their music experience indicators equal to zero.
4. Regression analysis explored the unique contribution of the factors, which were significantly related to children final school performance as revealed in analysis 3, to children's final school performance on music achievement, L1, L2, and mathematics, respectively.

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Author contributions

H.Y., W.Y.M. and D.Z.Y. designed research; H.Y., J.H.H. and D.K.G. collected data; W.Y.M. and D.Z.Y. analyzed the data and wrote the paper. All authors reviewed the manuscript.

Additional information

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