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Promoting Inhibitory Control in Preschool Children Through Music-Movement Activities in the Classroom

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ABSTRACT

Executive function (EF) is an early cognitive skill that rapidly develops during the preschool years. One of the common EF issues in young children is inhibitory control. This study investigates the impact of music-movement activities on children's inhibitory control. We designed the music-movement training (MMT) program for preschoolers to practice monitoring and controlling their actions. A quasi-experimental, pretest-posttest design was used to investigate the effectiveness of the MMT program on children's EF. Preschoolers age 4–5 years old were assigned to receive the 45-minute MMT, three times/week, for eight weeks (n = 39; 21 boys, mean age 4.36 ± 0.42 years), or regular classroom activities (n = 40; 17 boys, mean age 4.49 ± 0.29 years). After training, the MMT group showed greater improvement in the performance of inhibitory control tasks as compared to the control group, but showed no significant change in working memory and cognitive flexibility. In conclusion, music-movement activities may be helpful for teachers to enhance inhibitory control in preschool children. We suggest that the preschool curriculum should emphasize more music-movement activities by integrating them into everyday learning activities.

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KEYWORDS
Classroom activities; executive function; inhibitory control; music-movement training; preschoolers

Preschool age is a pivotal period for executive function (EF) development, which is an important skill for school readiness and academic success later in life (see Diamond, 2013, for a review). However, the national survey on EF development in Thai children between 2 to 6 years old (N = 2,965) revealed that almost 30% of preschoolers show signs of delayed EF development (Chutabhakdikul et al., 2017). Fortunately, several lines of evidence demonstrated that EF is a trainable skill (Diamond et al., 2007; Flook et al., 2010; Lakes & Hoyt, 2004) and one potential approach for improving EF in young children is music training. Previous studies reported that music instrumental training can enhance EF development in school-age children (Bolduc et al., 2020; Degé et al., 2022). Yet studies concerning the effect of music-movement training in the classroom on EF among preschoolers are still scarce. The objective of this study was to investigate the effects of music-movement training on the three core domains of EF – working memory, cognitive flexibility, and inhibitory control – in preschool children. The knowledge gained from this study will provide empirical evidence about the effect of music-movement training in the classroom on young children's EF skills, and the possibility of implementing music-movement training in a kindergarten classroom to enhance EF in young children.

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Executive function and child development

Executive function (EF) is a high-level cognitive process for controlling our thoughts, actions, emotions, and cognition, as well as for guiding goal-directed behaviors (Carlson, 2005; Nigg, 2017). Over the decades, EF has been recognized as a key to success in life (Ackerman & Friedman-Krauss, 2017). It helps individuals to select the most advantageous choice when confronted with the complex and heterogeneous demands of life events. EF is essential for human well-being throughout the life span. For example, EF is highly correlated with physical and mental health, school and job success, marital harmony, quality of life, and public safety (see Diamond, 2013, for a review). In contrast, poor EF is associated with both externalizing problems (i.e., hyperactivity, impulsivity, aggression, social problems) and internalizing problems (i.e., anxiety, depression, fearfulness; Tiberio et al., 2016).

EF skills depend on complex neural circuits in which the prefrontal cortex (PFC) plays a prominent role. The human PFC has a long developmental trajectory as compared to other animals. It develops rapidly during the preschool years, continues into adolescence, and fully develops when reaching adulthood (Anderson et al., 2008; Garon et al., 2008). Developmental psychology research has found that preschool is an important period for EF development, as children gradually improve their performance in various EF tasks during this period (Diamond, 2012; Roman et al., 2014; Roskam et al., 2014; Zelazo, 2006).

In young children, EF is composed of three core domains: 1) working memory – the capacity to hold, update, and manipulate information in the mind; 2) inhibitory control – the ability to suppress inappropriate responses; and 3) shift/cognitive flexibility – the ability to flexibly shift between ideas and activities (Garon et al., 2008; Miyake et al., 2000). These EF components are the foundation for higher-level EF crucial for academic success, such as reasoning, planning, and problem-solving (Miyake et al., 2000). Importantly, inhibitory control is a precursor for self-regulation (SR), which is also important for determining goal-directed behavior at a later age (Bridgett et al., 2013; Petersen et al., 2015; Zhou et al., 2012). EF and SR are positively associated with social and emotional well-being in all children (Spinrad & Eisenberg, 2015).

Strategies for enhancing executive function in children

EF is a trainable skill and preschool is an important period for training EF. Various interventions have been proven to have benefits for enhancing EF in preschool children (Diamond et al., 2007; Flook et al., 2010; Lakes & Hoyt, 2004). In 2012, Adele Diamond proposed that a program or intervention that successfully improves EF should support children's EF in both direct and indirect ways. The direct way is to build EF through the practice of newly learned skills again and again until the child excels in those skills. Achieving this short-term goal requires children's focused attention, holding complex sequences of action in mind, controlling emotions, and being flexible to changing circumstances. Meanwhile, the indirect way to support children's EF means the program or intervention helps improve physical fitness and joyfulness, with support and encouragement from adults. The empirical findings indicated that several types of programs successfully promote EF in preschool children, such as the Tools of the Mind curriculum (Diamond et al., 2007), traditional martial arts (Lakes & Hoyt, 2004), physical exercise (Chaddock et al., 2011), mindfulness training (Flook et al., 2010), Buddhist-integrated education (Lertladaluck et al., 2021), etc. One potential approach for improving EF in young children is music training (Hannon & Trainor, 2007; Moreno et al., 2011).

Music and child development

Music has beneficial effects on child development, ranging from improved cognition to social-emotional development (Chobert et al., 2014; Gerry et al., 2012; Miendlarzewska & Trost, 2013; Schellenberg, 2011; Strait et al., 2012). For instance, music instrumental training improves academic achievement (Hoch & Tillmann, 2012), language development (Kraus et al., 2014; Slater et al., 2014), and prosocial behaviors (Schellenberg et al., 2015). When children play musical instruments, they use multisensory integration as well as sensory-motor coordination (Zatorre et al., 2007). A previous study reported that music lesson training enhances both unisensory and multisensory cortical processing (Paraskevopoulos et al., 2014). Although these processes are specific to each type of musical instrument, continuous practice of music gave the musician's brain a remarkable ability for sensorimotor synchronization (SMS), which indicates a highly interconnected neural processing between the motor and the sensory cortex (Gebel et al., 2013). SMS is an essential for higher cognition, such as language, cognition (Moseley & Pulvermuller, 2018), and executive function (Chmielewski & Beste, 2016; Muckschel et al., 2016).

Music instrumental training and EF development

Music is an organized sound that requires more precise auditory processing than ordinary language perception. Various components of music (i.e., pitch, frequency, and rhythm) act as predictive cues that guide children's focus attention toward music when listening. In 2011, Aniruddh Patel proposed the "OPERA Hypothesis," which postulates that musical training benefits the neural encoding of speech in many ways (Patel, 2011). One mechanism is that music engagement shares neural resources (i.e., attention networks) with speech and language (Patel, 2012). This hypothesis supports the associations between musical training, speech, and language abilities. In addition, musical training improves auditory discrimination associated with reading abilities and phonemic skills (Lamb & Gregory, 1993), suggesting that the prefrontal executive control also may be a shared resource between musical and linguistic domains (Slevc & Okada, 2015; Thaut et al., 2019). Altogether, these lines of evidence support the association between music training and the executive function required for reading and language processing.

In the adult musician, music instrumental training for several years alters the brain's structure and functioning correlated with an enhancement of executive functioning (Zuk et al., 2014). Music instrumental training also improves EF among school-age children (Hannon & Trainor, 2007; Moreno et al., 2011). For example, children who received music instrumental training showed greater performance compared to the untrained group in various cognitive domains, such as working memory (Lee et al., 2007; Roden et al., 2012; Saarikivi et al., 2019), inhibitory control and attention (Chmielewski & Beste, 2016; Muckschel et al., 2016), and cognitive flexibility (Zuk et al., 2014). These lines of evidence indicated that the deliberate practice of musical instruments has a positive impact on EF development in school-age children.

However, the significant effects on the structural and functional brain change require repetitive practice for several years (D'Souza et al., 2018; Habibi et al., 2018; Jaschke et al., 2018; Sachs et al., 2017). Therefore, music instrumental training might not be the best choice for music intervention in preschool children since they have limited attention span (Mahone & Schneider, 2012) and as yet do not have fully developed gross and fine motor skills (National Association for the Education of Young Children, 2005). Another limitation of implementing music instrumental training in kindergarten classrooms is teachers without music expertise and limited budget to provide musical instruments to all kindergarten classrooms. For these reasons, music instrument training in young children is still limited, and not all children have a chance to learn music due to individual differences in socio-economic status (Linnavalli et al., 2018; Schellenberg, 2020).

Classroom music activities and EF development in preschoolers

A previous study reported that classroom music activities that do not mainly focus on playing musical instruments might be an alternative approach for enhancing EF in preschool children. For example, Shen and colleagues examined the effects of classroom music activities (i.e., music theory, singing, dancing, and role-playing) on EF in 4-year-old children (N = 61). They found that after 12 weeks of training, children in the music training group show a greater score in all components of EF than those in the control group (i.e., inhibitory control, working memory, and cognitive flexibility; Shen et al., 2019). Moreover, the sustained effect can be observed during the 12-week follow-up period after training.

Another study examined the effect of music training on EF in 4-year-old children (N = 39). In their study, the intervention consisted of music activities (e.g., pitch copy, melody recognition, musical phrasing, and musical anticipation). The training was done in a group context and taught by specialist music teachers. They found that, after 8 weeks of the musicianship class, the music training group had better planning and inhibition skills than the active control group (e.g., art or nursery free play; Bowmer et al., 2018). In addition, a recent study reported that music intervention inspired by the Music Play Program combined with the active music engagement approach could enhance inhibition control, phonological processing, and gross and fine motor skills in children age 5 to 6 years old (Bolduc et al., 2020).

These previous researchers propose that classroom music activities had a unique effect on EF development in their study. This approach enables children to recognize and memorize music rules and symbols through integration in singing, rhythmic activities, role-playing, and music appreciation. Moreover, this process requires regulation and suppression according to changes in activities rules such as musical symbols and rhythm. Additionally, children cooperate with other children, and they are required to adjust their behavior to perform appropriately. This process requires a high degree of working memory, inhibitory control, and cognitive flexibility (Shen et al., 2019).

Even though there are many approaches to enhancing EF in young children, a classroom music movement program is one potential approach. The program emphasizes many factors that support children's EF (e.g., optimal training intensity, repetitive practice with gradually more complex activities to challenge young children, and enhanced intrinsic motivation via the aesthetics and qualities of music). All these factors are unique to promoting EF through music and movement (Diamond & Ling, 2016; Shen et al., 2019). Although music activities are commonly implemented in all kindergarten classrooms, studies concerning the effect of music-movement activities specifically designed to improve EF in preschoolers still have very little evidence, especially empirical evidence from cognitive tasks (Linnavalli et al., 2018).

The current study

According to the national survey on EF development in Thai children, it is necessary to have an intervention to resolve EF issues in young children, especially those who show delayed EF development (Chutabhakdikul et al., 2017). The current study examines the effect of classroom music-movement activities on the development of EF in preschool children. We designed a music-movement training (MMT) program that allows young children to practice attention on music elements, along with movements that require multisensory integration and sensorimotor synchronization. All of these characteristics have been reported as a brain training strategy suitable for preschool children (Nozaradan et al., 2015; Pecenka et al., 2013; Zuk et al., 2014). These activities allow children to practice working memory, inhibitory control, and cognitive flexibility, while also feeling joyful about participating in music-movement activities with friends; support from teachers allow them to practice repetitively until achieving goals, from easy to more difficult steps.

We hypothesize that the MMT program could have some benefits for improving EF in preschool children. This study aims to investigate the effects of music-movement training on the three core domains of EF: working memory, cognitive flexibility, and inhibitory control in preschool children. The knowledge gained from this study will provide empirical evidence about the effect of music-movement training in the classroom on EF skills in young children, and the possibility of implementing music-movement training in a kindergarten classroom to enhance EF in preschoolers.

Methods

Participants

Preschool children, age 4–5 years old, were recruited from two child development centers in the Nonthaburi province of Thailand. Both child development centers have similar school sizes (approximately 120 children) and class sizes (<25 children per class). Both child development centers used the national preschool curriculum and have no special music-movement training or other EF training activities. All children are healthy and had no history of seizures or neurodevelopmental disorders, no gross and fine motor disabilities, and no color blindness. Eighty-seven children agreed to participate in this study; however, 8 children dropped out of the program during the posttest session. As a result, data from 79 children (38 boys, mean age 53.10 ± 4.35 years) were analyzed. Participation by all the children in this study was approved by their parents, who provided the legal guardian's informed consent before the experiment began. The study protocol was approved by the University Central Institutional Review Board (MU-CIRB COA No. 2017/004.1801) and was in accordance with the 1964 Helsinki declaration and its later amendments.

The music-movement training (MMT) program

The MMT program was designed based on the developmental approach to the music education concept of Orff Schulwerk (Shamrock, 1997). The MMT program did not focus on playing musical instruments but rather encouraged children to play with rhythm and control their body movements while listening to the music made by equipment commonly found in the classroom (e.g., rhythm stick, box, and bottle). Children participate in music-movement activities by singing, moving, and playing with the rhythm in a natural environment that requires coordination among visual, motor, and auditory systems. All activities in the MMT program were specifically designed to encourage young children to practice monitoring and controlling their thoughts, minds, and body movements while paying attention to a variety of musical rhythms. During the MMT training, children need to monitor and control their body movements to follow the challenge rules, which also require higher cognitive brain function to complete the tasks (D'Souza et al., 2018; Habibi et al., 2018). The program is simple and the teacher can apply it to all kindergarten classrooms without previous music knowledge. Furthermore, it is a cost-effective approach that does not require any expensive equipment, so the MMT program can be integrated into school activities in all kindergarten classrooms.

The MMT program is composed of 24 lessons (45 minutes each), with 3 lessons per week. The total training period of the program is 8 weeks. The class begins with a 10-minute warm-up session, followed by 25 minutes of main activities session, and finally ends with a 10-minute cool-down session (see Figure 1). The warm-up and cool-down activities were constant, while the main activities were divided into three main units. **Unit 1** is moving and freezing activities. In this unit, children were asked to move their body parts faster or slower according to the rhythm of the music. In addition, children had to stop when the music suddenly stopped. **Unit 2** is the leader and follower activities. In this unit, children work together in a small group to play alternative roles, either as the leader or the follower (3–4 per group). The child who is the leader creates the body movement for the song and rhythm, and children who are followers replicate the leader's movement. After that, their roles are switched; the child who was the leader becomes a follower, and a child who was a follower becomes the leader, and so on. **Unit 3** is singing-playing-moving activities. This unit combined singing, playing simple musical instruments (i.e., body percussion, rhythms sticks, maracas, tambourine, drums, etc.), and moving body parts following the rhythm of a song (see Appendices A and B). The MMT program allowed children to monitor and manipulate their thoughts, emotions, and movements to achieve the goal of each lesson. The content of the MMT program was reviewed by early childhood educators who specialize in the Orff Schulwerk curriculum. The Indexes of Item-Objective Congruence (IOC) score is 0.83 for content validity.

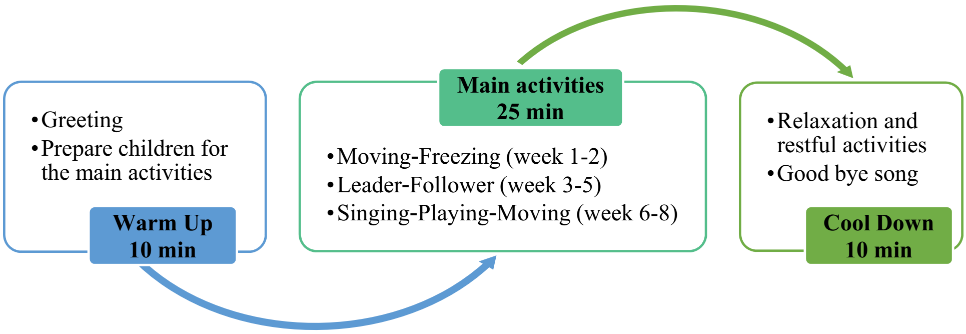

Figure 1. The Music-movement training (MMT) program is divided into 3 steps: 1) 10 minutes of warm-up activities, 2) 25 minutes of main activities, and 3) 10 minutes of cool-down activities. The main activities are composed of moving-freezing activities (8 lessons), leader-follower activities (8 lessons), and singing-playing-moving activities (8 lessons). A total of 24 lessons. Children were trained with 3 lessons of the MMT program per week, over the 8-week period.

Measures

To investigate the effectiveness of the music-movement activities on EF development, cognitive performance tasks to measure three core EF skills were performed. Missing scan task was applied to measure working memory and dimensional change card sort was applied to measure cognitive flexibility. As the MMT program was specifically designed to improve inhibitory control, three tasks were performed to confirm the effect (i.e., cat-mouse task, bird and dragon task, and tapping task).

Missing scan task (MST)

The MST is a computer game for assessing working memory. In 2014, Roman and colleagues reported that the MST is a feasible and valid methodology for assessing working memory in preschool children as young as 3 years of age (Roman et al., 2014). The task was administered through a 13-inch notebook screen displaying the picture of two animals; the experimenter encourages the child to say the name of each animal correctly. The animal picture was displayed for 5 seconds and then one animal disappeared from the screen. The child was asked to say the name of the disappearing animal within 20 seconds. If he/she passes, the next level was introduced with an increasing number of animals. The minimal number of animals is 2 and the maximum number of animals is 10. There are 2 trials for each set; if the child fails at the first trial, she/he still has a chance to try the second trial. The task ended when the child failed at both trials in the same set. In each set, children got 2 points for the correct answer in the first trial and 1 point for the correct answer in the second trial. The total scores range from 0 to 18.

Dimensional change card sort (DCCS)

The DCCS task in this study followed the protocol of Zelazo (2006). It is a method to investigate cognitive flexibility in young children (3–6 years old). This task includes two stimulus cards and 24 response cards (10.75 x 7.00 cm). Each card had two dimensions: shape (rabbit or boat) and color (red or blue). The task has three phases: pre-switch, post-switch, and border phase. In each phase, the child has to match response cards with the stimulus cards by shape or color. The child was asked to sort response cards with stimulus cards by color during the pre-switch and sort by shape during the post-switch, while in the border phase they had to sort by shape or color based on the presence or absence of the border in the stimulus card, respectively. There are six trials in the pre-switch and post-switch phases, while the border phase has 12 trials. The score was calculated separately as the number of correct cards from the post-switch and border phase (0 = wrong, 1 = correct).

Cat-mouse task

The cat-mouse task is a children's version of the go/no-go task for measuring attention (go condition) and inhibition (no-go condition) in young children (Simpson & Riggs, 2006). The task has two conditions: the go condition and the no-go condition. Pictures of mice and cats are shown on a 13-inch notebook screen. There were a total of 24 trials consisting of 18 trials of go stimuli (mice) and 6 trials of no-go stimuli (cat). Each picture was randomly displayed on the screen for 2,000 msec, followed by 1,500 msec of fixation sign (+) in the go condition, the child should press the space bar as soon as possible after seeing the mice, but should not press any buttons when seeing the cat (no-go condition). The percentage of accuracy in the go and no-go conditions as well as the reaction times for the go condition was collected for data analysis.

Bird and dragon task

The bird and dragon task is a behavioral task for the assessment of children's inhibitory control (Kochanska & Knaack, 2003; Kochanska et al., 1996; Petersen et al., 2015). The task is composed of the activation stimuli (bird's command, 6 trials) randomly presented with the inhibitory stimuli (dragon's command, 6 trials). For the activation task, children should follow what a nice bird asks them to do (e.g., "Touch your nose"), while in the inhibitory task, children should ignore the dragon's command. The experimenter observed children's movements in response to the command of the bird or dragon, and the scores were coded on a rubric scale from 1 to 4. For the activation score, rubric scales were coded as 1 = no movement, 2 = wrong movement, 3 = partial movement, and 4 = full, correct movement. The inhibitory scores were coded in the opposite directions (reverse scores). Therefore, a higher score indicated that children had better performance on the bird and dragon task. The composite scores were computed by multiplying with the mean scores from the bird and the dragon trials and converting them to the percent correct for data analysis.

Tapping task

The tapping task (also known as pencil tapping or peg tapping task) is a behavioral task for assessing inhibitory control (Bierman et al., 2008; Kochanska et al., 1996; Willoughby et al., 2012). In the task, the child was asked to use a stick to tap on the table with the opposite movement from the experimenter using three rules. First, when the experimenter tapped twice on the table, the child was instructed to tap once. Second, when the experimenter tapped one time on the table, the child was instructed to tap twice. Third, when the experimenter tapped three times on the table, the child was instructed to do nothing. The experimenter explained to the child how to play the game and made sure that the child understood all the rules before beginning the trial. The child's performance was coded to the score for each trial (18 trails; 0 = fails to tap, 1 = incorrect and never self-corrects, 2 = self-corrects, and 3 = correct on the first attempt and does not change mind). The percentage of correct responses was calculated by dividing the actual score.

Procedure

A quasi-experimental, pretest-posttest control group design was used to investigate the impact of the music-movement training (MMT) program on EF skills, especially inhibitory control among pre-schoolers. Participants were divided by classrooms into two groups: the MMT group ($n = 39$; 21 boys, mean age 4.36 ± 0.42 years), and the active control group ($n = 40$; 17 boys, mean age 4.49 ± 0.29 years) (see Table 1). There were no significant differences between groups based on age, ethnicity, and gender ($p > .05$). Before the training session, all participants were assessed with various cognitive tasks related to EF skills (pre-training session) for 15–20 minutes. The tasks are delivered continuously in the same sequence: DCCS; MST; cat-mouse; bird and dragon; and tapping task. Then, the training session was conducted. The experimental group received a 45-minute MMT program, 3 times/week, for 8 weeks after school. The control group received regular classroom activities, such as storytelling and free play. The duration of activities in the control group followed the same as in the MMT group. Finally, when

Table 1. Descriptive characteristic of the participants.

		Gender		Ages	
	n	Female	Male	*Mean*	*SD*
Music-movement group	39	18	21	4.36	0.42
Control group	40	23	17	4.49	0.29

the training session ended, children from both groups were assessed again with the same cognitive performance tasks related to EF skills in the same sequence (post-training session). Measurement of cognitive tasks at both the pre-training and the post-training sessions was done by the researcher team, who have experience in developmental psychology.

Data analyses

To investigate the effectiveness of the MMT program on EF development between groups, we conducted independent sample t-tests for all cognitive performance tasks, with difference scores (post-training minus pre-training) as the dependent variable and group conditions as the independent variable. Bonferroni correction is conducted to restricted type-I error, in which the resulting significance level is .006 (.05/8). The data were analyzed using SPSS software, version 18. Consequently, independent sample t-test analysis revealed that there were no significant differences between gender on any subscales of the performance task ($p > .05$; see Appendix C). Additionally, the correlation between EF variable tasks during the pre-training period was investigated (see Appendix D).

Results

An independent samples t-test indicated group differences on cognitive flexibility as measured by the DCCS task. There was no significant change between groups on the post-switch ($t\ (77) = -0.46$, $p = .65$, $d = .1$) and border ($t\ (77) = -0.46$, $p = .65$, $d = .1$). Similarly, there was no significant change between groups on working memory as measured by the MST task ($t\ (77) = 1.38$, $p = .172$, $d = .31$). However, an independent sample t-test indicated group difference on inhibitory control as measured by the cat-mouse task. The MMT group showed a slight change on the go condition ($t\ (77) = 2.34$, $p = .02$, $d = .53$) and significant difference on the reaction time ($t\ (77) = -3.03$, $p = .003$, $d = .68$) when compared with the active control group. The descriptive analysis demonstrated that the MMT group ($M = 15.67$, $SD = 19.69$) had significantly higher different mean scores on the go condition than the control group ($M = 5.00$, $SD = 20.82$; Figure 2a), and the MMT group ($M = -181.99$, $SD = 253.21$) also had significantly higher different mean scores on the reaction time than the active control group ($M = -18.83$, $SD = 224.81$; Figure 2b). There was no significant change between groups on the no-go condition ($t\ (77) = 0.29$, $p = .77$, $d = .07$). Moreover, the MMT group ($M = 15.60$, $SD = 23.10$) showed significantly higher different mean scores on the percent correct of the bird and dragon task, another measure of inhibitory control, than the control group ($M = 2.64$, $SD = 15.51$; $t\ (77) = 2.92$, $p = .005$, $d = .66$; Figure 2c). Similarly, a difference between groups was found on the tapping task, another measure of inhibitory control. The children who received the MMT program ($M = 14.87$, $SD = 12.26$) showed significantly higher different mean scores on the percent correct for the tapping task when compared with the active control group ($M = 3.83$, $SD = 10.47$; $t\ (77) = 4.31$, $p < .001$, $d = .97$; Figure 2d). The pre-training score, post-training score, difference score, and standard deviations (*SD*) for all measures are reported in Tables 2 and 3.

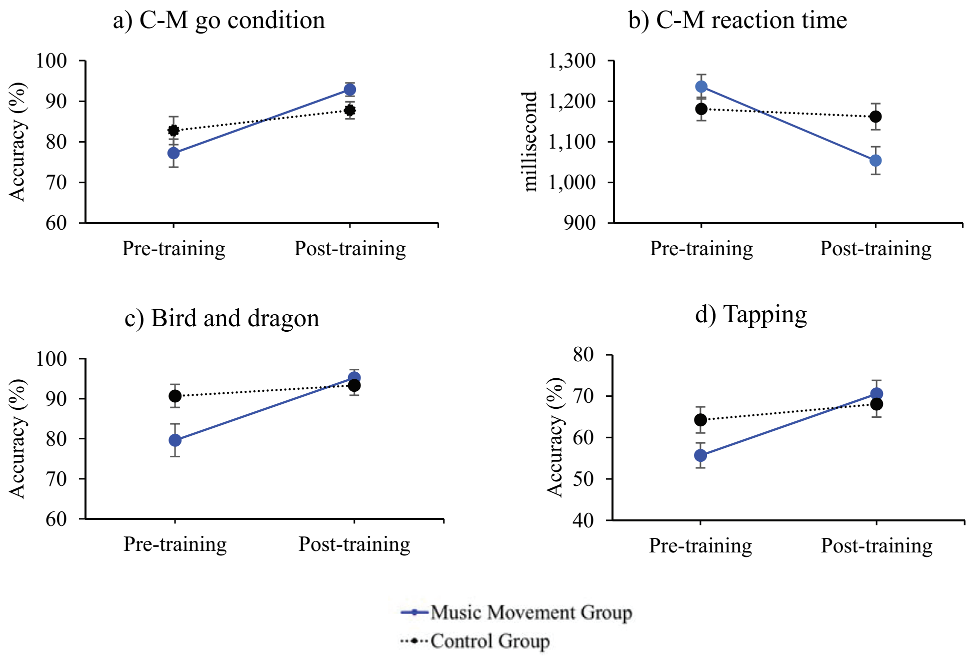

Figure 2. Graph demonstrated the mean scores for children's performance on the cat-mouse task on go condition (a) and reaction time (b), bird and dragon task (c), and tapping task (d), at pre and post-training sessions, compared between the MMT group (straight lines) and the control group (dash lines). Error bars indicate the standard error of the mean.

Table 2. Pre-training and post-training descriptive analysis in MMT and control groups: mean and standard deviation.

	MMT Group (n = 39)				Control Group (n = 40)			
	Pre-training		Post-training		Pre-training		Post-training	
Variables	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
DCCS: post-switch	1.08	2.33	2.18	2.86	2.38	2.95	3.43	2.95
DCCS: border	1.10	2.51	2.1	3.05	2.38	2.95	3.83	3.80
MST	3.85	1.91	4.49	2.01	4.30	2.48	4.18	1.74
C-M: go con. (%)	77.21	21.58	92.88	10.19	82.78	21.89	87.78	13.15
C-M: no-go con. (%)	86.75	19.93	89.32	16.88	82.92	24.31	83.75	24.60
C-M: RT (msec)	1,235.92	187.41	1,053.93	212.39	1,180.93	180.65	1,162.09	203.96
Bird and Dragon (%)	79.63	25.46	95.23	12.78	90.69	18.27	93.33	15.65
Tapping (%)	55.70	18.92	70.57	20.31	64.25	19.90	68.08	19.93

DCCS = Dimensional Change Card Sort; MST = Missing Scan Task; C-M = Cat-Mouse task; RT = Reaction Time

Table 3. Different mean scores (post-training minus pre-training score; Δ) descriptive analysis in MMT and control groups: mean and standard deviation.

	MMT Group (N = 39)		Control Group (N = 40)				
Variables	*ΔM*	*SD*	*ΔM*	*SD*	*t*	*p*	*d*
DCCS: post-switch	1.00	3.62	1.33	2.61	−0.46	.65	0.10
DCCS: border	1.00	3.62	1.33	2.61	−0.46	.65	0.10
MST	0.64	2.49	−0.13	2.45	1.38	.17	0.31
C-M: go con. (%)	15.67	19.69	5.00	20.82	2.34	.02	0.53
C-M: no-go con. (%)	2.57	21.13	0.83	30.18	0.29	.77	0.07
C-M: RT (msec)	−181.99	253.21	−18.83	224.81	−3.03	.003**	0.68
Bird and dragon (%)	15.60	23.10	2.64	15.51	2.92	.005**	0.66
Tapping (%)	14.87	12.26	3.83	10.47	4.31	< .001**	0.97

DCCS = Dimensional Change Card Sort; MST = Missing Scan Task; C-M = Cat-Mouse task; RT = Reaction Time; Significant at the .006 level, corrected for repeated comparisons.

Discussion

The potential of music training to enhance executive function in young children is still a debated issue in terms of the types of music activities, the frequency and duration of the training, and the appropriate age to start the music intervention. Although music lessons and music instrumental training improve executive function in school-age children (Hennessy et al., 2019; Moreno et al., 2014), there are some limitations when applied to preschool children. For example, young children at this age still have a short attention span which interferes with deliberate practice. In addition, their gross and fine motor skills are not fully developed to perform complex movements when practicing music. Another important limitation is the small number of specialist music teachers who teach at the preschool level.

To overcome these limitations, the music-movement training (MMT) program was designed to promote EF in preschool children by making it simple for teachers to implement in the kindergarten classroom. The MMT program was specifically designed for training EF in preschool children. The program increased the complexity over time to challenging the EF of young children. The MMT program is different from other music training programs in several ways: 1) The program mainly focused on multisensory integration and sensorimotor synchronization without focusing on playing musical instruments. 2) The program is simple and can be taught by preschool teachers regardless of their previous music experience. 3) The program is low-cost because it used basic equipment found in the ordinary classroom and did not require special or expensive musical instruments. All of these characteristics make the MMT program practical for implementation in all kindergarten classrooms. The goal of this study is to test the hypothesis that music-movement training as classroom activities can enhance EF in preschool children.

The present study investigated the effect of the MMT program on children's EF. Our findings demonstrated that children in the MMT group had better performance on the inhibitory tasks as compared to the active control group. Our finding corresponds to a previous report that different types of classroom music activities benefit EF in young children (Bolduc et al., 2020; Bowmer et al., 2018; Shen et al., 2019). During the music-movement training, children create free body movements corresponding to the rhythm of the music. This type of music-movement activity allows children to control their thoughts and focus attention on creating body movements following a variety of musical rhythms. Also, children need to monitor their actions in more challenging activities. All of these processes required higher cognitive brain function to think before acting to complete the complex tasks (D'Souza et al., 2018; Habibi et al., 2018). The repetitive practice of focused attention and monitoring for inhibition might be the key mechanism of the MMT program to enhance inhibitory control after training (Strait et al., 2012).

Inhibitory control plays a central role in fostering effortful control and self-regulation, which are important skills associated with positive emotional, social, and cognitive development in young children (Spinrad & Eisenberg, 2015). Therefore, the MMT program might have the potential benefit of not only enhancing cognitive control but also might improve social-emotional control in preschoolers. Besides, the program is specifically designed to improve inhibitory control in young children; therefore, it might have potential benefit for young children with inhibitory control issues (i.e., ADHD children).

The MMT program has unique characteristics that are different from the common games for training inhibitory control in young children (e.g., Simon Says, Red Light/Green Light, etc). For example, the MMT program applies pieces of music and rhythms to guide movement via multisensory integration (i.e., visual, auditory, somatosensory, proprioceptive senses, and balance). While the children listen to the song and control their movements, they also observe others and prepare themselves to switch between acting as followers and the leader. Therefore, when young children focus attention to integrate multisensory information and create purposive movements, they also practice sensorimotor synchronization. Through these processes, the children always think before acting in a joyful environment and gradually become better at controlling their actions. These unique characteristics of the MMT program might have benefits for brain and behavioral development in young children and further support higher cognitive functions such as inhibitory control.

The effect of music training on working memory and cognitive flexibility in young children is still under debate. In the present study, the MMT program did not show a significant effect on working memory and cognitive flexibility in preschool children. Our finding is consistent with the previous reports that music training had no significant effect on preschoolers' working memory and cognitive flexibility (Frischen et al., 2019; Janus et al., 2016). In contrast, some studies reported that music instrumental training has benefits on the working memory and cognitive flexibility in school-age children and adult musicians (Moradzadeh et al., 2015). For example, school-age children who received music instrumental training for 1–6 years (e.g., guitar, violin, cello, flute, trumpet, keyboard, and drums), had higher scores on working memory performance than the control group (Lee et al., 2007; Roden et al., 2012). Also, children and adolescents who practice musical instruments for an average of 5.2 years perform better on shifting tasks than the untrained group (Moradzadeh et al., 2015; Zuk et al., 2014). Various factors might have influenced the outcome of music training on EF, for example, the types of musical instruments, the duration of the training, the intensity of practice, the age of children, and the teaching methods (i.e., private training, group training, computerized music training program, musical playschool, etc.). All of these factors can influence the outcome of music training on children's EF as well (D'Souza et al., 2018; Guo et al., 2017; Habibi et al., 2018; Janus et al., 2016; Jaschke et al., 2018; Putkinen et al., 2015; Sachs et al., 2017).

It should be noted that activities in the MMT program specifically improve children's inhibitory control, without significant effects on working memory and cognitive flexibility. In the future, it is possible to add more music-movement activities specifically designed to enhance working memory and shift/cognitive flexibility in young children. For example, to promote working memory, the teacher may add music-movement activities that allow children to hold, update, and actively manipulate information in their minds. Also, to promote cognitive flexibility, the teacher may change the rule a children was already familiar with to a new, unfamiliar rule. The changing rule allows children to flexibly shift between ideas. Further research needs to investigate the effectiveness of the advanced music movement program that can improve various domains of EF in young children.

In conclusion, our findings provide additional evidence that music movement activities specially designed to challenge children's EF might be helpful for preschool teachers seeking to resolve inhibitory issues in young children. In addition, the program is cost-effective since it does not require expensive musical instruments and can be delivered by preschool teachers without previous knowledge of music.

Limitations and future directions of research

This study was investigated with a small sample, and the group differences are tested on many outcome variables, which might increase the Type I error rate. Therefore, further studies should examine a larger sample and should examine the long-term effects of music-movement training on children's EF. In addition, further study about the neural mechanisms that might explain the underlying effects of the MMT on children's EF is needed.

Implications for practice

The present study provides empirical evidence that a music-movement training program has the potential to promote inhibitory control in preschoolers. Teachers can integrate music-movement training programs into classroom activities in a simple way, without prior music knowledge. There are some principles of the training approach that teachers should understand when applying the MMT program to enhance inhibitory control in young children (Diamond, 2012; Strait et al., 2012). First, it is important to start with simple and enjoyable activities in which the children can easily succeed (i.e., moving and freezing activities). A good start will motivate children to collaborate in the training activities. Second, the key to the success of the MMT is repetitive practice to improve their confidence that they are getting better at controlling themself. Third, when children do well in one activity, teachers should challenge them, step by step, with more difficult activities (i.e., leader-follower activities and singing-playing-moving activities, etc.). These three principles are key to promoting behavioral inhibition and effortful control in young children through the MMT program.

Conclusion

Early childhood is a critical period of rapid EF development, which is vital to school learning outcomes and academic success. Results from this study provide empirical evidence that classroom activities could improve inhibitory control in preschool children. Teachers and educators can easily apply the MMT to regular classroom practices. The MMT program is simple, cost-effective, and does not require previous music knowledge of the teacher, thus making it easy to implement in all kindergartens or child development centers. Such activities not only challenge EF skills but also improve physical fitness and enjoyment. All of these are common characteristics of a successful program to enhance EF in young children (Diamond, 2012; Linnavalli et al., 2018). In conclusion, music-movement activities may be helpful for teachers seeking to enhance inhibitory control in preschool children. We suggest that the preschool curriculum should emphasize music movement training by integrating the MMT into everyday learning activities.

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Ethical statement

All parents were provided written legal guardian informed consent. The study protocol was approved by the University Central Institutional Review Board (MU-CIRB COA No. 2017/004.1801) and was in accordance with the 1964 Helsinki declaration and its later amendments.

References

Ackerman, D. J., & Friedman-Krauss, A. H. (2017). Preschoolers' executive function: Importance, contributors, research needs and assessment options. *ETS Research Report Series*, *2017*(1), 1–24. https://doi.org/10.1002/ets2.12148

Anderson, V., Jacos, R., & Anderson, P. J. (2008). *EFs and the frontal lobes: A lifespan perspective*. Taylor & Francis.

Bierman, K. L., Domitrovich, C. E., Nix, R. L., Gest, S. D., Welsh, J. A., Greenberg, M. T., Blair, C., Nelson, K. E., & Gill, S. (2008). Promoting academic and social-emotional school readiness: The head start REDI program. *Child Development*, *79*(6), 1802–1817. https://doi.org/10.1111/j.1467-8624.2008.01227.x

Bolduc, J., Gosselin, N., Chevrette, T., & Peretz, I. (2020). The impact of music training on inhibition control, phonological processing, and motor skills in kindergarteners: A randomized control trial. *Early Child Development and Care*, *191*(12), 1–10. https://doi.org/10.1080/03004430.2020.1781841

Bowmer, A., Mason, K., Knight, J., & Welch, G. (2018). Investigating the impact of a musical intervention on preschool children's executive function. *Frontiers in Psychology*, *9*, 2389. https://doi.org/10.3389/fpsyg.2018.02389

Bridgett, D. J., Oddi, K. B., Laake, L. M., Murdock, K. W., & Bachmann, M. N. (2013). Integrating and differentiating aspects of self-regulation: Effortful control, executive functioning, and links to negative affectivity. *Emotion*, *13*(1), 47–63. https://doi.org/10.1037/a0029536

Carlson, S. M. (2005). Developmentally sensitive measures of executive function in preschool children. *Developmental Neuropsychology*, *28*(2), 595–616. https://doi.org/10.1207/s15326942dn2802_3

Chaddock, L., Pontifex, M. B., Hillman, C. H., & Kramer, A. F. (2011). A review of the relation of aerobic fitness and physical activity to brain structure and function in children. *Journal of the International Neuropsychological Society*, *17*(6), 975–985. https://doi.org/10.1017/S1355617711000567

Chmielewski, W. X., & Beste, C. (2016). Perceptual conflict during sensorimotor integration processes - a neurophysiological study in response inhibition. *Scientific Reports*, *6*(1), 26289. https://doi.org/10.1038/srep26289

Chobert, J., Francois, C., Velay, J. L., & Besson, M. (2014). Twelve months of active musical training in 8- to 10-year-old children enhances the preattentive processing of syllabic duration and voice onset time. *Cerebral Cortex*, *24*(4), 956–967. https://doi.org/10.1093/cercor/bhs377

Chutabhakdikul, N., Thanasetkorn, P., Lertawasdatrakul, O., & Ruksee, N. (2017). *Tool development and evaluation criteria for assessment of executive function in early childhood; research report*. Health System Research Institute and the Institute of Molecular Biosciences, Mahidol University.

D'Souza, A. A., Moradzadeh, L., & Wiseheart, M. (2018). Musical training, bilingualism, and executive function: Working memory and inhibitory control. *Cognitive Research: Principles and Implications*, *3*(1), 11. https://doi.org/10.1186/s41235-018-0095-6

Degé, F., Patscheke, H., & Schwarzer, G. (2022). The influence of music training on motoric inhibition in German preschool children. *Musicae Scientiae*, *26*(1), 172–184. https://doi.org/10.1177/1029864920938432

Diamond, A. (2012). Activities and programs that improve children's executive functions. *Current Directions in Psychological Science*, *21*(5), 335–341. https://doi.org/10.1177/0963721412453722

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Diamond, A., Barnett, S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*(5855), 1387–1388. https://doi.org/10.1126/science.1151148

Diamond, A., & Ling, D. S. (2016). Conclusions about interventions, programs, and approaches for improving executive functions that appear justified and those that, despite much hype, do not. *Developmental Cognitive Neuroscience*, *18*, 34–48. https://doi.org/10.1016/j.dcn.2015.11.005

Flook, L., Smalley, S. L., Kitil, M. J., Galla, B. M., Kaiser-Greenland, S., Locke, J., Ishijima, E., & Kasari, C. (2010). Effects of mindful awareness practices on executive functions in elementary school children. *Journal of Applied School Psychology*, *26*(1), 70–95. https://doi.org/10.1080/15377900903379125

Frischen, U., Schwarzer, G., & Degé, F. (2019). Comparing the effects of rhythm-based music training and pitch-based music training on executive functions in preschoolers. *Frontiers in Integrative Neuroscience*, *13*, 41. https://doi.org/10.3389/fnint.2019.00041

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*(1), 31–60. https://doi.org/10.1037/0033-2909.134.1.31

Gebel, B., Braun, C., Kaza, E., Altenmuller, E., & Lotze, M. (2013). Instrument specific brain activation in sensorimotor and auditory representation in musicians. *NeuroImage*, *74*, 37–44. https://doi.org/10.1016/j.neuroimage.2013.02.021

Gerry, D., Unrau, A., & Trainor, L. J. (2012). Active music classes in infancy enhance musical, communicative and social development. *Developmental Science*, *15*(3), 398–407. https://doi.org/10.1111/j.1467-7687.2012.01142.x

Guo, X., Ohsawa, C., Suzuki, A., & Sekiyama, K. (2017). Improved Digit Span in Children after a 6-Week Intervention of Playing a Musical Instrument: An Exploratory Randomized Controlled Trial. *Frontiers in Psychology*, *8*, 2303. https://doi.org/10.3389/fpsyg.2017.02303

Habibi, A., Damasio, A., Ilari, B., Elliott Sachs, M., & Damasio, H. (2018). Music training and child development: A review of recent findings from a longitudinal study. *Annals of the New York Academy of Sciences*, *1423*(1), 73–81. https://doi.org/10.1111/nyas.13606

Hannon, E. E., & Trainor, L. J. (2007). Music acquisition: Effects of enculturation and formal training on development. *Trends in Cognitive Sciences*, *11*(11), 466–472. https://doi.org/10.1016/j.tics.2007.08.008

Hennessy, S. L., Sachs, M. E., Ilari, B., & Habibi, A. (2019). Effects of music training on inhibitory control and associated neural networks in school-aged children: A longitudinal study. *Frontiers in Neuroscience*, *13*, 1080. https://doi.org/10.3389/fnins.2019.01080

Hoch, L., & Tillmann, B. (2012). Shared structural and temporal integration resources for music and arithmetic processing. *Acta Psychologica (Amst)*, *140*(3), 230–235. https://doi.org/10.1016/j.actpsy.2012.03.008
Janus, M., Lee, Y., Moreno, S., & Bialystok, E. (2016). Effects of short-term music and second-language training on executive control. *Journal of Experimental Child Psychology*, *144*, 84–97. https://doi.org/10.1016/j.jecp.2015.11.009
Jaschke, A. C., Honing, H., & Scherder, E. J. A. (2018). Longitudinal analysis of music education on executive functions in primary school children. *Frontiers in Neuroscience*, *12*, 103. https://doi.org/10.3389/fnins.2018.00103
Kochanska, G., & Knaack, A. (2003). Effortful control as a personality characteristic of young children: Antecedents, correlates, and consequences. *Journal of Personality*, *71*(6), 1087–1112. https://doi.org/10.1111/1467-6494.7106008
Kochanska, G., Murray, K., Jacques, T. Y., Koenig, A. L., & Vandegeest, K. A. (1996). Inhibitory control in young children and its role in emerging internalization. *Child Development*, *67*(2), 490–507. https://doi.org/10.2307/1131828
Kraus, N., Hornickel, J., Strait, D. L., Slater, J., & Thompson, E. (2014). Engagement in community music classes Sparks neuroplasticity and language development in children from disadvantaged backgrounds. *Frontiers in Psychology*, *5*, 1403. https://doi.org/10.3389/fpsyg.2014.01403
Lakes, K. D., & Hoyt, W. T. (2004). Promoting self-regulation through school-based martial arts training. *Journal of Applied Developmental Psychology*, *25*(3), 283–302. https://doi.org/10.1016/j.appdev.2004.04.002
Lamb, S. J., & Gregory, A. H. (1993). The relationship between music and reading in beginning readers. *Educational Psychology*, *13*(1), 19–27. https://doi.org/10.1080/0144341930130103
Lee, Y.-S., Lu, M.-J., & Ko, H.-P. (2007). Effects of skill training on working memory capacity. *Learning and Instruction*, *17*(3), 336–344. https://doi.org/10.1016/j.learninstruc.2007.02.010
Lertladaluck, K., Suppalarkbunlue, W., Moriguchi, Y., & Chutabhakdikul, N. (2021). School-based mindfulness intervention improves executive functions and self-regulation in preschoolers at risk. *The Journal of Behavioral Science*, *16*(2), 58–72. https://so06.tci-thaijo.org/index.php/IJBS/article/view/249238
Linnavalli, T., Putkinen, V., Lipsanen, J., Huotilainen, M., & Tervaniemi, M. (2018). Music playschool enhances children's linguistic skills. *Scientific Reports*, *8*(1), 8767. https://doi.org/10.1038/s41598-018-27126-5
Mahone, E. M., & Schneider, H. E. (2012). Assessment of attention in preschoolers. *Neuropsychology Review*, *22*(4), 361–383. https://doi.org/10.1007/s11065-012-9217-y
Miendlarzewska, E. A., & Trost, W. J. (2013). How musical training affects cognitive development: Rhythm, reward and other modulating variables. *Frontiers in Neuroscience*, *7*, 279. https://doi.org/10.3389/fnins.2013.00279
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734
Moradzadeh, L., Blumenthal, G., & Wiseheart, M. (2015). Musical training, bilingualism, and executive function: A closer look at task switching and dual-task performance. *Cognitive Science*, *39*(5), 992–1020. https://doi.org/10.1111/cogs.12183
Moreno, S., Bialystok, E., Barac, R., Schellenberg, E. G., Cepeda, N. J., & Chau, T. (2011). Short-term music training enhances verbal intelligence and executive function. *Psychological Science*, *22*(11), 1425–1433. https://doi.org/10.1177/0956797611416999
Moreno, S., Wodniecka, Z., Tays, W., Alain, C., & Bialystok, E. (2014). Inhibitory control in bilinguals and musicians: Event related potential (ERP) evidence for experience-specific effects. *PLoS One*, *9*(4), e94169. https://doi.org/10.1371/journal.pone.0094169
Moseley, R. L., & Pulvermuller, F. (2018). What can autism teach us about the role of sensorimotor systems in higher cognition? New clues from studies on language, action semantics, and abstract emotional concept processing. *Cortex*, *100*, 149–190. https://doi.org/10.1016/j.cortex.2017.11.019
Muckschel, M., Stock, A. K., Dippel, G., Chmielewski, W., & Beste, C. (2016). Interacting sources of interference during sensorimotor integration processes. *NeuroImage*, *125*, 342–349. https://doi.org/10.1016/j.neuroimage.2015.09.075
National Association for the Education of Young Children. (2005). *NAEYC early childhood program standards and accreditation criteria: The mark of quality in early childhood education*.
Nigg, J. T. (2017). Annual research review: On the relations among self-regulation, self-control, executive functioning, effortful control, cognitive control, impulsivity, risk-taking, and inhibition for developmental psychopathology. *Journal of Child Psychology and Psychiatry*, *58*(4), 361–383. https://doi.org/10.1111/jcpp.12675
Nozaradan, S., Zerouali, Y., Peretz, I., & Mouraux, A. (2015). Capturing with EEG the neural entrainment and coupling underlying sensorimotor synchronization to the beat. *Cerebral Cortex*, *25*(3), 736–747. https://doi.org/10.1093/cercor/bht261
Paraskevopoulos, E., Kuchenbuch, A., Herholz, S. C., & Pantev, C. (2014). Multisensory integration during short-term music reading training enhances both uni- and multisensory cortical processing. *Journal of Cognitive Neuroscience*, *26*(10), 2224–2238. https://doi.org/10.1162/jocn_a_00620
Patel, A. D. (2011). Why would musical training benefit the neural encoding of speech? The OPERA hypothesis. *Frontiers in Psychology*, *2*, 142. https://doi.org/10.3389/fpsyg.2011.00142
Patel, A. D. (2012). The OPERA hypothesis: Assumptions and clarifications. *Annals of New York Academy of Sciences*, *1252*(1), 124–128. https://doi.org/10.1111/j.1749-6632.2011.06426.x

Pecenka, N., Engel, A., & Keller, P. E. (2013). Neural correlates of auditory temporal predictions during sensorimotor synchronization. *Frontiers in Human Neuroscience*, *7*, 380. https://doi.org/10.3389/fnhum.2013.00380

Petersen, I. T., Bates, J. E., & Staples, A. D. (2015). The role of language ability and self-regulation in the development of inattentive-hyperactive behavior problems. *Development and Psychopathology*, *27*(1), 221–237. https://doi.org/10.1017/S0954579414000698

Putkinen, V., Tervaniemi, M., Saarikivi, K., & Huotilainen, M. (2015). Promises of formal and informal musical activities in advancing neurocognitive development throughout childhood. *Annals of New York Academy of Sciences*, *1337*(1), 153–162. https://doi.org/10.1111/nyas.12656

Roden, I., Kreutz, G., & Bongard, S. (2012). Effects of a school-based instrumental music program on verbal and visual memory in primary school children: A longitudinal study. *Frontiers in Psychology*, *3*, 572. https://doi.org/10.3389/fpsyg.2012.00572

Roman, A. S., Pisoni, D. B., & Kronenberger, W. G. (2014). Assessment of working memory capacity in preschool children using the missing scan task. *Infant and Child Development*, *23*(6), 575–587. https://doi.org/10.1002/icd.1849

Roskam, I., Stievenart, M., Meunier, J. C., & Noel, M. P. (2014). The development of children's inhibition: Does parenting matter? *Journal of Experimental Child Psychology*, *122*, 166–182. https://doi.org/10.1016/j.jecp.2014.01.003

Saarikivi, K. A., Huotilainen, M., Tervaniemi, M., & Putkinen, V. (2019). Selectively enhanced development of working memory in musically trained children and adolescents. *Frontiers in Integrative Neuroscience*, *13*, 62. https://doi.org/10.3389/fnint.2019.00062

Sachs, M., Kaplan, J., Der Sarkissian, A., & Habibi, A. (2017). Increased engagement of the cognitive control network associated with music training in children during an fMRI Stroop task. *PLoS One*, *12*(10), e0187254. https://doi.org/10.1371/journal.pone.0187254

Schellenberg, E. G. (2011). Examining the association between music lessons and intelligence. *British Journal of Psychology*, *102*(3), 283–302. https://doi.org/10.1111/j.2044-8295.2010.02000.x

Schellenberg, E. G. (2020). Music training, individual differences, and plasticity. In M. S. C. Thomas, D. Mareschal, & I. Dumontheil (Eds.), *Educational neuroscience: Development across the life span* (pp. 415–441). Routledge.

Schellenberg, E. G., Corrigall, K. A., Dys, S. P., & Malti, T. (2015). Group music training and children's prosocial skills. *PLoS One*, *10*(10), e0141449. https://doi.org/10.1371/journal.pone.0141449

Shamrock, M. (1997). Orff-Schulwerk: An integrated foundation: This article on the methodologies and practices of Orff-Schulwerk was first published in the Music Educators Journal in February 1986. *Music Educators Journal*, *83*(6), 41–44. https://doi.org/10.2307/3399024

Shen, Y., Lin, Y., Liu, S., Fang, L., & Liu, G. (2019). Sustained effect of music training on the enhancement of executive function in preschool children. *Frontiers in Psychology*, *10*, 1910. https://doi.org/10.3389/fpsyg.2019.01910

Simpson, A., & Riggs, K. J. (2006). Conditions under which children experience inhibitory difficulty with a "button-press" go/no-go task. *Journal of Experimental Child Psychology*, *94*(1), 18–26. https://doi.org/10.1016/j.jecp.2005.10.003

Slater, J., Strait, D. L., Skoe, E., O'Connell, S., Thompson, E., & Kraus, N. (2014). Longitudinal effects of group music instruction on literacy skills in low-income children. *PLoS One*, *9*(11), e113383. https://doi.org/10.1371/journal.pone.0113383

Slevc, L. R., & Okada, B. M. (2015). Processing structure in language and music: A case for shared reliance on cognitive control. *Psychonomic Bulletin and Review*, *22*(3), 637–652. https://doi.org/10.3758/s13423-014-0712-4

Spinrad, T. L., & Eisenberg, N. (2015). Effortful control. In R. Scott & S. Kosslyn (Eds.), *Emerging trends in the social and behavioral sciences* (pp. 2–11). John Wiley & Sons.

Strait, D. L., Parbery-Clark, A., Hittner, E., & Kraus, N. (2012). Musical training during early childhood enhances the neural encoding of speech in noise. *Brain and Language*, *123*(3), 191–201. https://doi.org/10.1016/j.bandl.2012.09.001

Thaut, M. H., Hodges, D. A., Loui, P., & Guetta, R. E. (2019). Music and attention, executive function, and creativity. In M. H. Thaut & D. A. Hodges (Eds.), *The Oxford handbook of music and the brain* (pp. 262–284). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780198804123.013.12

Tiberio, S. S., Capaldi, D. M., Kerr, D. C., Bertrand, M., Pears, K. C., & Owen, L. (2016). Parenting and the development of effortful control from early childhood to early adolescence: A transactional developmental model. *Development and Psychopathology*, *28*(3), 837–853. https://doi.org/10.1017/S0954579416000341

Willoughby, M. T., Kupersmidt, J. B., & Voegler-Lee, M. E. (2012). Is preschool executive function causally related to academic achievement? *Child Neuropsychology*, *18*(1), 79–91. https://doi.org/10.1080/09297049.2011.578572

Zatorre, R. J., Chen, J. L., & Penhune, V. B. (2007). When the brain plays music: Auditory-motor interactions in music perception and production. *Nature Reviews Neuroscience*, *8*(7), 547–558. https://doi.org/10.1038/nrn2152

Zelazo, P. D. (2006). The dimensional change card sort (DCCS): A method of assessing executive function in children. *Nature Protocols*, *1*(1), 297–301. https://doi.org/10.1038/nprot.2006.46

Zhou, Q., Chen, S. H., & Main, A. (2012). Commonalities and differences in the research on children's effortful control and executive function: A call for an integrated model of self-regulation. *Child Development Perspectives*, *6*(2), 112–121. https://doi.org/10.1111/j.1750-8606.2011.00176.x

Zuk, J., Benjamin, C., Kenyon, A., & Gaab, N. (2014). Behavioral and neural correlates of executive functioning in musicians and non-musicians. *PLoS One*, *9*(6), e99868. https://doi.org/10.1371/journal.pone.0099868

Appendix A. The information of each main activity that classifies into three-unit characters

Unit	Week	Objective	Characteristic of Unit	Activity
Unit 1: moving and freezing activities	1–2	Promote inhibitory control	Children were asked to move their body parts faster or slower according to the rhythm of the music. In addition, children had to stop when the music suddenly stopped.	(1) Sculpture (2) Dancing rainbow (3) Let's take a photo (4) Rabbit and tortoise
Unit 2: a leader and follower activities	3–5	Promote inhibitory control and cognitive flexibility	Children work together in a small group (3–4 per group) by switching their roles between the leader and the follower. Children listen to the song and rhythm made by the teacher. The child who is the leader creates the body movement that corresponds to the song and rhythm, while children who are the followers follow the movement of the leader. After that, their roles were switched. One of the followers switches to become the leader and the child who is the leader becomes a follower, and so on.	(1) Pinon pinon (2) The king (3) Mother duck and her ducklings (4) The train
Unit 3: singing-playing-moving activities	6–8	Promote inhibitory control, working memory, and cognitive flexibility	This unit combined singing, playing simple musical instruments (i.e., body percussion, rhythms sticks, maracas, tambourine, drums, etc.), and moving body parts following the rhythm of a song.	(1) Rhythms sticks (2) Running horses

Appendix B. Information about the songs that were used in each main activity of the MMT program

Units	Activities	Songs
Unit 1: Moving and freezing activities	Sculpture	Name: Stop and Start Artist: Hap Palmer Album: Rhythms on Parade
	Dancing rainbow	Name: Boanopstekker Artist: Shenanigans Album: Children's Dances of Terra del Zur. Vol. 1
	Let's take a photo	Name: Game-Foto (Dance/ Stop with the Music, Pose, and Photo) Artist: Bruno Raco Album: Children's Ballet Music
	Rabbit and tortoise	Name: Slow and Fast Artist: Hap Palmer Album: Rhythms on Parade
Unit 2: Leader and follower activities	Pinon pinon	Name: Pinon Pinon Artist: Shenanigans Album: Children's Dances of Terra del Zur. Vol. 1
	The king	Name: Minoesjka Artist: Shenanigans Album: Children's Dances of Terra del Zur. Vol. 1
	A mother duck and her ducklings	Name: Seven Jumps Artist: Shenanigans Album: Children's Dances of Terra del Zur. Vol. 1
	The train	Name: The Goodbye Train (Reverence) Artist: Craig Wingrove Album: Musical Gems XVI Creative Movement for Pre-Ballet Class

(*Continued*)

Units	Activities	Songs
Unit 3: Singing-playing-moving activities	Rhythms sticks	Name: Pinon Pinon Artist: Shenanigans Album: Children's Dances of Terra del Zur. Vol. 1
	Running horses	Name: Running Horses (Thai song) Artist: No information Album: No information

Appendix C. Different mean scores (post-training minus pre-training score; Δ) and the independent sample t-test of gender differences on any subscales of the performance task of MMT and control group

	Boys		Girls				
Variables	*ΔM*	*SD*	*ΔM*	*SD*	*t*	*p*	*d*
MMT group (N = 39; 21 boys)							
DCCS: post-switch	0.71	3.35	1.33	3.99	−0.53	0.60	0.17
DCCS: border	0.71	3.35	1.33	3.99	−0.53	0.60	0.17
MST	0.24	2.49	1.11	2.47	−1.09	0.28	0.35
C-M: go con. (%)	14.82	19.27	16.67	20.70	−0.29	0.77	0.09
C-M: no-go con. (%)	0.79	27.12	4.63	11.15	−0.59	0.56	0.19
C-M: RT (msec)	−166.30	290.07	−200.29	208.98	0.41	0.68	0.13
Bird and dragon (%)	21.03	24.03	9.26	20.83	1.64	0.11	0.52
Tapping (%)	12.86	10.99	17.22	13.51	−1.11	0.27	0.35
Control group (N = 40; 17 boys)							
DCCS: post-switch	1.47	3.06	1.22	2.28	0.30	0.77	0.09
DCCS: border	1.47	3.06	1.22	2.28	0.30	0.77	0.09
MST	0.06	2.49	−0.26	2.47	0.40	0.69	0.13
C-M: go con. (%)	3.2	27.08	6.28	15.20	−0.41	0.68	0.14
C-M: no-go con. (%)	−2.94	39.63	3.62	21.29	−0.68	0.51	0.21
C-M: RT (msec)	−29.65	277.18	−10.84	183.20	−0.26	0.80	0.08
Bird and dragon (%)	0.65	19.03	4.11	12.56	−0.69	0.49	0.21
Tapping (%)	6.54	11.41	1.84	9.47	1.42	0.16	0.45

DCCS = Dimensional Change Card Sort; MST = Missing Scan Task; C-M = Cat-Mouse task; RT = Reaction Time; Significant at the .006 level, corrected for repeated comparisons.

Appendix D. The correlation between executive function variable tasks at the pre-training session. The results showed a significantly positive correlation among variables

Variables	1	2	3	4	5	6	7	8
DCCS: post-switch								
DCCS: border	.95**							
MST	.31**	.40**						
C-M: go con. (%)	.25*	.22	.23*					
C-M: no-go con. (%)	.04	.05	−.02	.26*				
6. C-M: RT (msec)	−.16	−.11	−.09	−.18	.28*			
Bird and dragon (%)	.28*	.26*	.06	.39**	.14	.09		
Tapping (%)	.29**	.29*	.09	.34**	.24*	.09	.37**	

DCCS = Dimensional Change Card Sort; MST = Missing Scan Task; C-M = Cat-Mouse task; RT = Reaction Time; Significant difference at * $p < .05$, ** $p < .01$, and *** $p < .001$.