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Chapter

Musical Training Enhances Inhibitory Control in Adolescence

Claudia L.R. Gonzalez, Frank Robertson and Robbin L. Gibb

Abstract

Music production is a complex activity that involves nearly every function in the brain. Whether skills transfer from musical training to other cognitive abilities is a growing area of research. There is evidence to suggest that musical training in children and adult musicians is associated with an improvement in a variety of executive functions (EFs). This study examined whether those associations are also present during adolescence, and whether there is a relationship between the time spent in musical training and EF. Adolescents between the ages of 14 and 18 completed three tests of EF: Tower of Hanoi to assess working memory, Wisconsin Card Sort Test to assess cognitive flexibility, and Stroop Color Word Task to assess inhibition. They also completed a musical experience questionnaire, including their lifetime musical practice hours. Adolescent musicians were found to have improved inhibitory control (as measured by the Stroop Task) relative to nonmusicians and inhibition correlated with musical practice time. No other elements of EF were found to be associated with musical training. These findings suggest that the impact of musical training may not be the same for all EFs, and that there may be unique associations between this type of training and inhibitory control.

Keywords: executive function, inhibition, music, adolescent, cognitive function

1. Introduction

From lullabies to symphonies, campfires to clubs, birthdays to funerals, music is woven throughout everyday life. Children respond to music starting in their very earliest moments and music is thought to predate speech evolutionarily [1]. Music is a powerful driver of cognitive and neurological development involving the use of nearly every cognitive faculty. Furthermore, it is well known that music engages the appetitive/rewarding neurochemical systems of the brain [2]. The impact of music throughout development is an area of interest across multiple disciplines. Both music and language allow us to communicate through sound, and both require the ability to process and produce precise sounds. The same abilities that allow us to sing and discern emotion from a melody, allows us to discern meaning from words [1]. Music is a highly complex cognitive activity. A musician must coordinate fine motor movements in order to reproduce a memorized series of sounds while receiving auditory, somatosensory, and visual feedback. Becoming an expert musician requires years of dedicated practice. Music has been proposed as an intervention for cognitive and neurological development because of the breadth and depth of the faculties exercised in this activity [3, 4]. It is not just those functions directly recruited to produce music that are impacted by it. Executive functions (EFs) are cognitive abilities that organize and direct the deployment of other cognitive processes and they also benefit from musical training.

EF includes abilities such as working memory, cognitive flexibility, and behavioral inhibition. Working memory is task-oriented memory that allows people to remember what they are doing and to recall relevant information that allows for task completion. Working memory is involved in accomplishing most tests of EF, as participants must at a minimum remember the rules of the task. One task that measures working memory ability is the *Tower of Hanoi* (*ToH*). ToH requires participants to move pieces of a tower across a set of three spaces. The rules of the game are such that this manoeuver takes a minimum of fifteen moves to complete. In order to avoid errors and complete the task in as few moves as possible, participants must keep the rules in mind and think through multiple moves ahead [5]. Working memory is a fundamental EF that allows for the planning and execution of this goal-oriented task. Cognitive flexibility or task switching is an element of EF that requires a person to move back and forth between several tasks successfully. These are the abilities that allow for multitasking. Cognitive flexibility can be measured using a tool like the *Wisconsin Card Sorting Task* (*WCST*) wherein participants complete multiple similar tasks back to back. Researchers measure how seamlessly participants transition to the new task by tracking the errors they make which would have been correct in the previous task [6]. This ability to rapidly switch between tasks is required for successful navigation of a world where many complicated jobs and separate priorities are competing for attention. Inhibition is the ability to resist doing something natural or instinctual and instead engage in some effortful activity. Being able to inhibit a behavior successfully allows one to sort out irrelevant information and remain focused on a given task. Inhibition also allows people to pause and consider other skills that can be used to solve the problems that are important to them. It is no surprise then, that inhibition is critical for academic success. Bull and Scerif [7] studied seven to nine-year olds and discovered that inhibition predicted a child's mathematical ability independent of their intelligence and reading ability. Objective tests of inhibition often ask participants to respond to one type of stimulus while introducing some other competing stimulus that the participant must ignore. A popular test of inhibition is the *Stroop Colour Word Task* (*SCWT*). Here stimuli are presented in pairs and participants are asked to respond to the less salient stimulus. In the classic SCWT, participants are presented with words that denote a color that are printed in different colors (i.e. "green" printed in green ink) and asked to respond to the color of the ink rather than reading the word. When these stimuli are congruent the task is simple, but when they do not match (i.e. "green" printed in red ink) inhibition is required, leading to increased response time and a higher error rate [8].

Better EF is associated with improved outcomes in school and life, and so has been a focus of research in the last decade [9]. Researchers have looked into training EF, particularly inhibition, to improve school performance in children. For example, kindergarten children trained for a month on tasks that promote inhibitory control such as a modified SCWT, achieved a grade one performance level after the training [10]. Another way to enhance inhibitory control and thus academic achievement is through musical training. Short-term musical interventions of a few months to a year have been found to be effective in raising children's EF and verbal intelligence [11, 12, 14]. Children engaged with music have higher intelligence and better inhibitory control than age-matched children without musical training [13–15]. Therefore, inhibitory control interventions are important means to enhance academic performance.

A great deal of research has focused on adult musicians and demonstrates a variety of behavioral and neurological benefits associated with this long-term musical training. Adult musicians show improved EFs compared with nonmusicians in working memory and particularly in inhibitory control [16, 17]. Beyond behavioral research, the brains of long-time musicians have been found to be structurally and functionally distinct from the brains of nonmusicians [18, 19]. These changes are thought to underlie the cognitive benefits found to be associated with musical training.

A gap in the literature is the understanding of how musical training affects cognitive function in adolescence. Adolescence is the period between childhood and adulthood, beginning at the onset of puberty around 11 years of age, and continuing until adulthood [20]. Adolescence is an important period of development; physically, socially, and cognitively. Adolescence and early childhood are both periods of high neuroplasticity and rapid cognitive development. These two windows of elevated neuroplasticity provide opportunities to help youth cultivate the faculties which they will carry with them into adulthood. Because musical training has been so thoroughly demonstrated to enhance cognitive development in early childhood it is worth asking whether musical training in adolescence is also effective in increasing EF skills. Weintraub et al. [21] found evidence for two developmental windows in childhood and adolescence while assessing the cognitive battery included in the NIH Toolbox for the assessment of Neurological and Cognitive Function. They found that in measures of memory, and general EF there was a sharp increase in proficiency between the ages of 3 and 6. A second smaller spike in executive function development occurs starting at 12 years old and continuing until early adulthood at age 25.

The current study investigates the association between musical training and EF in adolescence. Given the previously discussed benefits of musical training on cognitive function in children and adults, we wondered if musical training has the same positive associations with EF development in adolescents? We know that even short musical interventions can have significant impacts on a child's EF, and that child musicians engaged in extracurricular musical training show improved EF across a variety of domains [11, 12]. It is possible that these benefits wash out by the adolescent years, as children without musical training may catch up through other activities. However, if music does have a uniquely strong ability to train EFs as indicated by the existing literature, adolescent musicians will continue to exhibit improved cognitive abilities.

2. Methods

2.1 Participants

Forty adolescents (21 females, 19 males) between the ages of 14–18 were recruited from local middle- and high-schools in Lethbridge Alberta. Participants self-identified as right-handed, and were healthy, with no history of neurological impairment. Participants were not told the purpose of the study, but were told about each of the tasks they would complete before giving consent. Parental consent was obtained for participants younger than 18 before they arrived for testing.

3. Procedure

Each participant completed a music self-report questionnaire, and three tests of EF: the ToH (working memory), WCST (cognitive flexibility), and SCWT (inhibition). The entire experiment took between 35 and 45 min to complete.

3.1 Tower of Hanoi

Four square blocks were stacked on each other, on the first of three marked spaces (see **Figure 1**). Participants began the task centered on the second space, with both hands on the table. They were asked to move the tower of blocks to the third space, stacked in the same order that they began. Participants were only allowed to move one block at a time, and could only stack blocks on top of larger blocks. Participants' hands were filmed while completing this task. Total moves to complete the task were recorded. Completing the task requires a minimum of fifteen moves, and anything lower than twenty is consider good performance.

3.2 Wisconsin Card Sorting Task

This study used a computerized version available on PsyToolkit (https://www.psytoolkit.org/experiment-library/stroop.html) [22]. Four square cards appeared at the top of the screen. Left to right they contained one red circle, two green triangles, three blue crosses, and four yellow stars (see **Figure 2**). A fifth card appeared at the bottom of the screen, containing a random combination of colored shapes. Participants were asked to click the card at the top of the game window that matched the card at the bottom of the game window according to shape, color, or number. Which rule to use was not disclosed to the participant, and changed several times throughout the session. When a participant clicked the correct card, a bell rang and the word "Good" in white flashed on the screen. In the case of an incorrect trial a white "No" flashed on the screen and was spoken by a robotic voice. Total errors were recorded as well as perseveration errors, wherein participants continued using a previous rule (which was formerly correct) in the next round of trials.

3.3 Stroop Color Word Task

This experiment utilized a computerized version of the Stroop available at expfactory.github.io [23]. Participants were instructed to identify the color of words printed on the screen as red, blue, or green, by pressing buttons on the keyboard (**Figure 3**). Each trial began after a 500 ms fixation and words were presented on

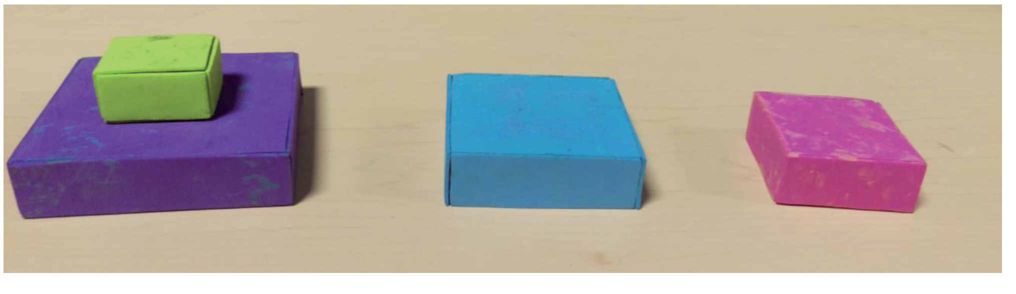

Figure 1.
Tower of Hanoi: this task measures planning and working memory. Participants moved blocks from the left space to the right, according to a set of specific rules. Completing the ToH requires a minimum of 15 moves. Move to complete is the measure of EF in this task.

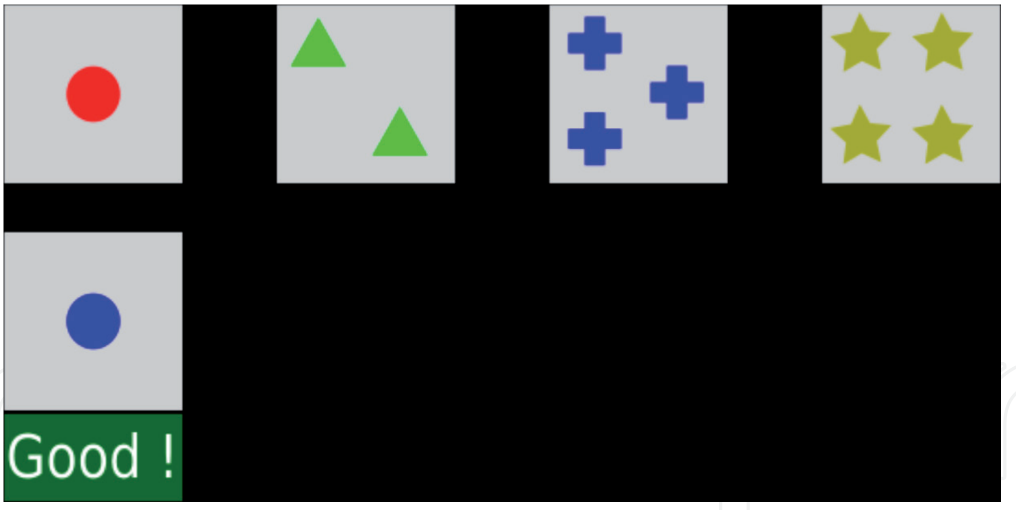

Figure 2.
Wisconsin Card Sort Task: participants clicked on the cards at the top in order to match with the card at the bottom. Cards could match based on the number, color, or type of shapes on the card, and this rule changed throughout the session.

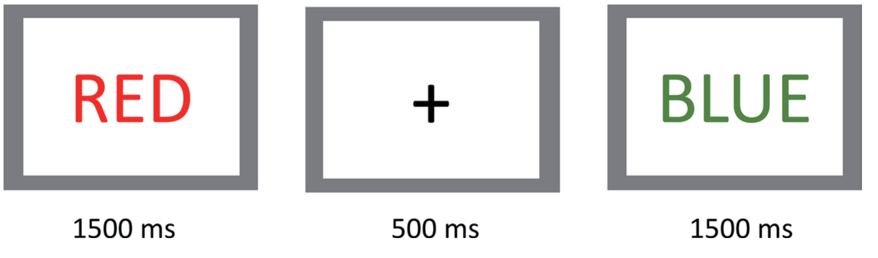

Figure 3.
Stroop Color Word Task: participants responded to a series of words by pressing a key corresponding to the color that the word was printed in. Each word appeared on the screen for 1500 ms. A fixation mark appeared on the screen for 500 ms before each trial. Trials were categorized as congruent and incongruent, and errors were recorded for each condition.

the screen for 1500 ms or until participants responded. Participants completed 23 practice trials, followed by 96 measured trials. Forty-eight of these trials were congruent, meaning the color of the word matched the printed meaning of the word, (e.g. "Red" in red ink). Forty-eight were incongruent, meaning the color of the word did not match its printed meaning, (e.g. "Green" in red ink). Errors were recorded for both the congruent and incongruent conditions (**Figure 3**).

3.4 Music self-report questionnaire

Participants completed a self-report questionnaire detailing their musical training. Each participant reported whether they were currently playing any instruments or singing a vocal part. They reported each of those instruments and gave the time spent practicing each week, and the years spent practicing that instrument. They then repeated the exercise for any musical experience they had in the past and subsequently abandoned. Finally, participants were asked to rank their knowledge of music theory, ability to read music, and general musical aptitude on a five-point Likert scale (1–5), where 1 was no ability and 5 was exceptional.

For the purposes of this study, we considered participants to be musicians if they had at least three years of musical training, and a minimum of five hundred reported lifetime hours engaged in musical training. This eliminated participants who had only just begun engaging with music, and allowed this study to focus on the long-term impacts of musical training.

4. Results

In order to test the hypothesis that teenagers with a history of musical training would have higher executive function than those without, a series of Welch nonparametric T-tests were conducted. This test was chosen because it does not assume normalcy, and is more robust to dependency between multiple comparisons. Musician status was used as the independent variable and number of moves to complete the ToH as well as errors in the WCST and the SCWT were dependent variables. In order to account for multiple comparisons Bonferroni correction was used. SCWT errors were found to be significantly different between musicians and nonmusicians (see **Table 1**). Musicians were found to commit significantly fewer errors than nonmusicians.

Variable	Orientation	Musician mean	Musician SE	Non-musician mean	Non-musician SE	t Statistic	*p*-Value
Tower of Hanoi (moves to complete)	Lower for better EF	32.889	3.53	26.684	3.47	−1.2717	0.5593
WCS errors (preservation errors)	Lower for better EF	7.750	0.770	9.500	1.09	1.2744	0.2124
Stroop errors (total errors)	Lower for better EF	4.389	0.759	9.737	1.40	3.3774	0.0022*

Musicians make significantly fewer errors in the Stroop Task than nonmusicians. Welch Pairwise two tailed T-tests.
Adjusted for Bonferroni correction.

Table 1.
Comparison between musicians and nonmusicians on tests of EF.

4.1 Correlation between musical practice time and executive function

In order to examine whether increased musical training time, or self-reported musical ability was associated with executive function, a Pearson's Product-Moment Correlation analysis was performed. This analysis allowed us to treat musicianship as a continuous variable, and to evaluate whether increased musical training time was associated with better EF in the absence of any categories. Musical training time correlated with SCWT Errors; the more musical experience a participant reported, the fewer errors on the SCWT, ($r_{(40)} = -.405; p = 0.01$).

5. Discussion

While music has been demonstrated to have positive associations with EF in childhood and adulthood, the impact that music has on EF throughout adolescence is less well understood. Two research questions were investigated: (1) Does musical training have the same positive associations with EF in adolescence as it does in young children? (2) Is there a relationship between time spent on musical training and adolescent EF? The results of this study showed a positive association of musical training with a key contributor to EF: inhibition. Inhibition, as measured by the SCWT, was the only domain of EF in which adolescents with musical training differed from nonmusicians. Furthermore, the results of the SCWT showed a positive correlation with lifetime musical training (i.e. total number of lifetime practice hours); the more hours engaged in practice, the better the behavioral inhibition in adolescence. Once again, the SCWT was the only measure of EF associated with musical training, indicating that spending more time engaged in musical training results in greater improvements to inhibition. Taken together, these results indicate a unique relationship between musical training and inhibitory control.

During the SCWT participants are asked to parse an incoming stream of information and control their responses in a nonintuitive fashion. This is a central skill set for a musician attempting to properly respond to input from the current sounds, the sheet music, their fellow bandmates, and the sensorimotor feedback that comes with performing a piece of music. Musicians must inhibit a large number of possible responses to these stimuli in order to select the actions that will create the music they wish to produce. Mastering behavioral inhibition to generate the perfect performance is one feature that makes music so rewarding. Imagine a saxophone player attempting to sight read a new melody. The musician reads each oncoming note moments before they have to play it, just like a participant reads the next word in the SCWT as it flashes on the screen. The musician's fingers move to carefully practiced positions, each one unique to the note, just like a participant during the SCWT taps the correct key, unique to the color.

The fact that adolescent musicians in this sample did not show any improvement in the areas of working memory and cognitive flexibility, was somewhat surprising given the results of other studies. A meta-analysis including 18 studies showed improved working memory in children with musical training [24]. Bhide et al. [25] showed that short-term musical training improved working memory in a population of 6 and 7-year-olds who were struggling with reading. The children were engaged in 19 sessions over two months, during which they were given rhythm training. At the end of the two months children were shown to perform significantly better on a digit span backwards test of working memory. Zuk et al. [15] found that working memory and cognitive flexibility was better in both preadolescent children and in adults with musical training. Puzzling, they report that musical training had no influence on inhibitory control in either group. This is in stark contrast to the finding of the present study in which inhibition was found to be most influenced by musical training. Our finding is consistent with other studies in children and adult musicians which have shown that improvement in inhibition is the most reliable effect that musical training has on EF across a variety of tasks, and throughout the lifespan. Children's inhibition improves in response to musical interventions and long-term private music education [3, 12, 14, 15]. Adult musicians have improved inhibition that persists into old age [17, 26, 27]. The current study demonstrates that the relationship between musical training and inhibitory control is not disrupted throughout the tumultuous developmental years of adolescence.

Inhibition may be improved by the dedication required for musical training and thereby lead children to be more effective in developing their cognitive abilities. There is evidence that musical training in children improves inhibition more than other equivalent forms of artistic training. Moreno and colleagues showed that twenty days of musical training was sufficient to improve performance of kindergarten children on a visual Go-No Go task. The children were trained on pitch, tempo, melody, voice, and other basic concepts, using a computer program that focused on listening tasks. These children outperformed an active control group receiving an equivalent fine arts training [3, 12]. This result suggests that there is something especially important about music in the development of inhibition. Furthermore, it appears that musical training is an effective intervention for training inhibitory control. In fact, musical interventions are commonly used to enhance behavior in children with developmental delays, ADHD, and even autism [28, 29].

This form of therapy is also used in people with brain injury and neurodegenerative disorders [30, 31]. Perhaps the common element here is that musical interventions improve inhibitory control which in turn improves behavioral outcomes.

The benefits to inhibition have been shown to persist in adults with a history of musical training. Bialystok and Depage [32] showed that musicians performed better on an auditory Stroop test of inhibition than those with no musical training. This result was confirmed by D'Souza, et al. [27] using a full battery of inhibition tests, including the visual Stroop, a flanker task, and an auditory stop signal test. Musicians showed a significant advantage on each of these measurements compared with adult nonmusicians. These improvements continue even as people age. In a study of professional musicians older than age 50 [26], musicians were found to outperform nonmusicians in a full battery of inhibition tasks. This battery included an auditory Stroop task, a go-no-go task, a distracted reading task and a Simon task (in which a color appeared on one side of the screen, and participants had to hit a matching button which was on the same side as the color in congruent trials and on the opposite side in incongruent trials). Music practice can thus be beneficial throughout life.

It is possible that certain kinds of musical practice improve inhibition better than others. Bialystok and Depage [32] did not find any difference between vocalists and instrumentalists in their study, however recent findings have suggested that there may be differences between different kinds of musical training. For example, percussionists who must keep careful track of time may have better inhibition than other musicians. A study compared inhibition abilities between vocalists, percussionists, and nonmusicians between the ages of 18 and 35 [33]. The authors found that percussionists outperformed both vocalists and nonmusicians in inhibitory control. This finding further supports the notion that musical training which involves more inhibitory control improves this EF.

5.1 Limitations and future research

The current study has a number of limitations. A relatively small sample size meant that subdivisions between different types of musicians were inappropriate. This study only accepted participants in mid and late adolescence, making developmental inferences more difficult. The correlational nature of this study makes it impossible to make determinations about cause and effect. Finally, the uncertainty about the relationship between various EF's, and overlap in how these functions are measured is a general problem in this field which this study did not address. Future research could be designed in such a way that tackles these issues and allows for a more thorough understanding of adolescent EF.

Few studies have explicitly examined distinctions between forms of musical training, and this should be a priority for future research investigating relationships between musical training and cognitive abilities. A study directly examining the differences between vocalists and percussionists in EF found that percussionists out-performed vocalists, and nonmusicians in the area of inhibition [33]. Previous research has shown no difference in inhibition between vocalists and instrumentalists, which only serves to make the enhanced abilities of percussionists even more interesting [32]. The timing of musical training is another factor which might lead to distinct outcomes. Early musical training has been shown to increase the volume of the corpus callosum in the brain whereas later training does not [34]. An implication of this finding is that musical training will have a larger effect if it occurs within early development. These findings indicate that some subdivisions by age of musical training and by musical speciality may be important to the EF differences observed here. This study was unable to account for these potential distinctions due to the limited sample size.

Extra-curricular musical training means practicing for hours every week. While other children may take a break, or not have an opportunity to engage in a cognitive exercise after school, music students are translating dots on a page into music in the air. This extra period of instruction and practice may itself be the cause of the improved cognition observed across the board in musicians. It is also true that musical instruction costs money. This means that the average musician may be of higher socioeconomic status, which could be a potential confound when interpreting the current results. Intervention studies, where music lessons can be provided regardless of economic status, and musical training that can be compared against equally challenging programs are needed to address these issues.

While this study does establish a relationship between inhibition and musical training in adolescents, it is unclear whether musical involvement in the adolescent years is truly responsible for this improvement. It is possible that childhood musical training contributes in important ways to the effect observed here. Similarly, it is possible that adolescents with stronger inhibitory skills are more likely to continue engaging in musical training even as they gain more independence in the mid adolescent years. In order to address this issue, it would be necessary to give adolescents musical interventions in the style that has been used to improve childhood EF.

6. Conclusion

The current study examined the relationship between musical training and EF in mid to late adolescence. Musical training was found to be associated with better inhibition, as measured by the SCWT but not working memory or cognitive flexibility. Future research should focus on determining causality, and accessing whether it is feasible to use music to improve inhibitory control in adolescents.

Author details

Claudia L.R. Gonzalez[1,2*], Frank Robertson[1,2] and Robbin L. Gibb[1,2]

1 The Brain in Action Laboratory, Department of Kinesiology, University of Lethbridge, Canada

2 Department of Neuroscience, Canadian Centre for Behavioural Neuroscience, University of Lethbridge, Canada

*Address all correspondence to: claudia.gonzalez@uleth.ca

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