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Effects of Short Term Music and Second Language Training on Executive Control

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Abstract

Separate lines of research have identified enhanced performance on non-verbal executive control (EC) tasks for bilinguals (Bialystok, Craik, Green, & Gollan, 2009) and those with music training (Moreno et al., 2011), but little is known about the relation between them in terms of the specificity of the effects of each experience or the degree of exposure necessary to induce these changes. Using an intervention design, the present study pseudo-randomly assigned 57 4- to 6-year-old children (matched on age, maternal education, and cognitive scores) to a 20-day training program offering instruction in either music or conversational French. The test battery consisted of verbal and non-verbal tasks requiring EC. All children improved on these tasks following training with some training-specific differences. No changes were observed on background or working memory measures after either training, ruling out simple practice effects. Children in both groups had better scores on the most challenging condition of a grammaticality sentence judgment task in which it was necessary to ignore conflict introduced through misleading semantic content. Children in both training groups also showed better accuracy on the easier condition of a non-verbal visual search task at post-test, but children in the French training group also showed significant improvement on the more challenging condition of this task. These results are discussed in terms of emergent EC benefits of language and music training.

Keywords

Second-Language Training; Bilingualism; Music Training; Executive Control; Verbal Ability

Even brief learning experiences can have lasting effects on performance and on the underlying neural mechanisms that support that performance in both humans and other species (Kolb et al., 2012; Kramer, Bherer, Colcombe, Dong, & Greenough, 2004; Reuter-Lorenz, 2002; Steven & Blakemore, 2004). This research has led to growing interest in the potential for training to improve cognitive function and brain development across the lifespan (Green & Bavelier, 2008; Kelly & Garavan, 2005). Evidence for such training-

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related plasticity in children would be particularly important as it may potentially form the basis for developmental interventions. Two experiences that have received attention in this regard are bilingualism and musical training; children with bilingual experience generally show improved executive control (EC; for meta-analysis see Adesope, Lavin, Thompson, & Ungerleider, 2010; for review see Barac, Bialystok, Castro, & Sanchez, 2014) and children with musical training often demonstrate better verbal and spatial abilities (for meta-analysis see Hetland, 2000) than their respective counterparts. However, there are two outstanding questions in this research. The first is the problem of selection and direction: Did children become bilingual or study music because these abilities were already advanced, or was the experience in fact responsible for the advantageous outcomes? The second is the issue of specificity: Although there is some similarity in the outcomes reported for bilingualism and musical training, no research has determined the extent to which the outcomes of these experiences are unique to each experience. In the present study, young children with no experience in either learning another language or studying music were given brief intense training in one of them to determine whether significant early-stage, training-specific cognitive changes could be detected and whether the outcomes for each were common or distinct.

There is little consensus on the mechanism responsible for the effects of bilingualism on EC, especially in children (see Bialystok, 2015 for discussion) but one view explains those effects in terms of the well-documented co-activation of languages in the bilingual mind, even when only one language is required (for review see Kroll, Bobb & Hoshino, 2014). This joint activation requires a control mechanism to select the target and avoid interference from the other language, and this practice with language selection may underlie the more general bilingual advantage in EC. Consistent with this view, most studies show that bilingual children outperform comparable monolinguals on a range of tasks that require attention and control (e.g., Adi-Japha, Berberich- Artzi, & Libnawi, 2010; Carlson & Meltzoff, 2008; Filippi et al., 2015; Kapa & Colombo, 2013), although some studies have not found these effects (Anton et al., 2014; Dunabeitia et al., 2014; but see Kroll & Bialystok, 2013, for a discussion). At the same time, bilingual children on average have a smaller vocabulary in each language than monolingual speakers of that language (Bialystok, Luk, Peets & Yang, 2010) and often show no advantage or perform more poorly than monolinguals on EC tasks based on linguistic processing (e.g., Foy & Mann, 2013), leading to interactions between the development of linguistic and non-verbal EC in bilingual children. Moreover, joint activation of languages cannot be the full explanation since attentional differences have been found between 7-month old infants who were being raised in monolingual or bilingual homes (Kovacs & Mehler, 2009; Singh et al., 2015). Thus, more research is needed on the emergence of these bilingual effects on EC.

Research is also needed to clarify the types of EC outcomes that may follow from bilingualism. Executive control has been measured in numerous ways, and the outcomes of bilingualism depend on the task. The first evidence for cognitive advantages of bilingualism came from tests of metalinguistic awareness. In a set of studies performed by Bialystok (1986, 1988), children were asked to focus attention on the grammar of sentences and ignore their salient meaning. Bilingual children were more accurate than monolingual children in judging the grammaticality of anomalous sentences with intact grammar but misleading

information (“Apples grow on noses”), a decision that requires EC to ignore the meaning. Thus, in spite of being a linguistic task, the control demands for that condition were substantial.

As with metalinguistic awareness, verbal fluency tasks incorporate both vocabulary knowledge and EC. For adults, category fluency is considered to be a vocabulary measure and letter fluency to involve EC (Grogan, Green, Ali, Crinion, & Price, 2009), but for children, even category fluency involves controlled attention (Friesen, Luo, Luk, & Bialystok, 2015). Thus, bilingual adults outperform monolingual adults on letter fluency, but bilingual children outperform monolingual children on category fluency.

Tasks requiring controlled attention to ignore interference from distracting stimuli are the main forum for investigating bilingual effects on EC. For example, several studies have shown bilingual children perform a flanker task more accurately than monolinguals (Yang, Yang & Lust, 2011; Yoshida, Tran, Benitez, & Kuwabara, 2011). In general, however, any task in which attention to a non-verbal perceptual stimulus is required in the context of distracting stimuli should be performed better by bilingual than monolingual children.

Finally, some recent work has shown evidence of more advanced performance on tasks of WM in bilingual than in monolingual children (e.g., Blom, Kuntay, Messer, Verhagen, & Leseman, 2014). In one study, Morales, Calvo and Bialystok (2013) tested 5- to 7-year-old children who were monolingual or bilingual on the Frog Matrices task, a visuospatial span task where the position of frogs within a 3 x 3 grid had to be recalled under conditions of increasing difficulty. Bilingual children outperformed monolingual children on the most challenging condition, although research with simpler tasks has shown no differences in WM abilities between these groups (Bialystok & Feng, 2009; Bonifacci, Giombini, Bellocchi, & Contento, 2011; Engel de Abreu, 2011).

Little research has investigated the degree of bilingualism needed for such changes to occur, but some studies with adults have detected brain-related modifications after brief exposure to a second language. McLaughlin, Osterhout, and Kim (2004) used event-related potentials (ERPs) and showed that after only 14 hours of French instruction, participants had enhanced processing of semantic anomalies on a lexical decision task, as indexed by increased amplitude of the N400 component. Similarly, Sullivan, Janus, Moreno, Astheimer, and Bialystok (2014) demonstrated that students who completed an 8-month university-level Spanish course (3 hours of instruction per week) had larger P3 amplitudes than controls on a Go/Nogo task, indicating strengthened response inhibition. Although few studies have examined the emergence of cognitive changes in such “bilinguals in training” (Sullivan et al., 2014), the ERP data demonstrate that such training effects may occur even after brief exposure. If so, then even minimal L2 experience may lead to measurable outcomes in young children. Establishing cognitive changes at the earliest stages of second language training would contribute to a clearer understanding of the relation between this experience and its cognitive outcomes.

The research on the effect of music training on cognition in children is parallel to that conducted for bilingualism, but the outcome measures are usually different. Similar to the

same-domain effect in which bilingualism impacts metalinguistic ability, musical training improves auditory processing (Kraus, Hornickel, Strait, Salter, & Thompson, 2014). Music training has also been shown to enhance inhibitory control (Moreno et al., 2011), focused attention (Neville et al., 2008), and intelligence (Schellenberg, 2004), intersecting to some extent with the EC skills promoted by bilingualism. More surprisingly, and counter to research with bilingualism, some studies have reported a boost to verbal domains such as reading (Anvari, Trainor, Woodside, & Levy, 2002; Moreno, Marques, Santos, Santos, Castro, & Besson, 2009) and language skills (Francois, Chobert, Besson, & Schön, 2013; review in Moreno, 2009). These benefits have been attributed to the practice of intensive memorization, visual-motor skills, and focused attention required for learning music (Chaffin, 2007; Ginsborg, Chaffin, & Nicholson, 2006; Orsmond & Miller, 1999). Also parallel to the research with bilingualism, some studies have failed to find these training effects (see Moreno & Bidelman, 2014, for a review).

For verbal abilities, the advantage of musicianship has been described at several linguistic levels, including early auditory processing (Kraus et al., 2014), verbal memory (Ho, Cheung, & Chan, 2003; Moreno et al., 2009), and vocabulary knowledge (Moreno et al., 2011). Kraus and colleagues (2014) studied children from low socioeconomic neighborhoods and showed stronger brain encoding of speech and increased reading scores after two years of music classes compared to their less-engaged peers in the program. These findings validate results claiming benefits of music classes on language development.

Evidence for benefits of music training on non-verbal abilities has been shown for visual-spatial and spatial-temporal domains (Bilhartz, Bruhn, & Olson, 1999; for reviews see rne, Wilson, & Prior, 2006). Some authors have attributed these non-verbal advantages to better processing of local details (Stoesz, Jakobson, Kilgour & Lewycky, 2007; Jakobson, Lewycky, Kilgour, & Stoesz, 2008) that are required by music performance. Hetland (2000) performed a meta-analysis of 15 studies investigating the effects of musical training on spatial abilities in children from 3 to 12 years of age, with musical training ranging from 4 weeks to 2 years, and reported a medium effect size of $r = .39$. Building on these findings, Bilhartz and colleagues (1999) studied the impact of early music instruction in the form of a 30-week, 75-minute weekly, parent-involved music program including vocal and instrumental training and exploration of pitch, notation, rhythms and composition. Children between the ages of 4 and 6 years old were tested with Stanford-Binet Intelligence Scale before and after the program. Musically-trained children outperformed the control group on the Bead Memory subtest that assesses visual imagery and sequencing strategies requiring attention and temporal-spatial abilities (Thorndike, Hagen, & Sattler, 1986) but there were no effects of training on any of the verbal measures.

As with bilingualism, some studies have found no benefit from music training on verbal skills (Moreno & Bidelman, 2014), but positive outcomes may require a longer or more intensive training period. Nutley, Darki, and Klingberg (2014) conducted a longitudinal assessment of the effects of musical training on verbal and spatial WM with 352 participants between 6 and 25 years of age, at 2 or 3 time points, 2 years apart. Mixed model regression analyses revealed an overall positive association between practicing music and WM,

processing speed, and reasoning, showing that music training taps into higher-order cognitive abilities.

Some neurophysiological work has investigated temporally-specific markers of cognitive activity in children with and without music training. Moreno and colleagues (2009) assigned 32 non-musician, 8-year-old children to either music or painting lessons for a period of 6 months. In line with previous behavioral correlational findings (Anvari et al., 2002), only children who received music lessons improved on reading and pitch discrimination abilities in speech. ERP data recorded during testing showed an increase in late positivity amplitude in response to weak incongruities on their speech task for the musically trained children only. Moreno et al. (2011) later demonstrated that after just 20 days of intensive music or visual art training using an interactive computer-based training program, only musically-trained children revealed a larger P2 component for nogo trials in a visual Go/Nogo task, a change believed to be associated with enhanced activation of stimulus-response pairing. The change in P2 amplitude on nogo trials was positively correlated with improved verbal scores (Moreno et al., 2011). Thus, the advantages of musical training appeared in both verbal and non-verbal domains.

These experience-dependent cognitive changes display features of “dose-dependent response” in which longer periods of training are associated with larger outcomes. Bialystok and Barac (2012) showed that the length of time children spent in a bilingual educational environment was related to the degree of increase in EC, and Nutley and colleagues (2014) showed that improvements on WM measures were significantly correlated with the number of hours spent practicing music. Furthermore, Rodrigues, Laureiro, and Caramelli (2013) observed significant correlations between the age of starting orchestral studies and reaction time on three visual attention tests. Therefore, for both bilingualism and music training, very early stages of learning appear to show evidence of training-related plasticity.

Both bilingualism and music training have been shown to affect crucial aspects of children’s cognitive development. Although there is evidence that music and language skills share some overlapping processes (Koelsch, Gunter, Wittfoth, & Sammler, 2005) and cortical structures (Jentschke & Koelsch, 2009; Wong, Skoe, Russo, Dees, & Kraus, 2007), training-specific advantages and the time course for the emergence of these effects remain unknown. There is some evidence for unique and shared outcomes for bilingualism and music training on EC tasks in adults (Bialystok & DePape, 2009), but no study to date has examined the early emergence of these differences in young children. Such evidence is important to more precisely determine the effect of each experience on children’s development. Furthermore, few studies have assessed how much experience in either mode of training is sufficient to elicit these changes.

The present study compared the effect of intense short-term music and L2 training on EC abilities. Monolingual children with no previous musical training were randomly assigned to music or French training that was given over a period of 20 days. Children were tested before and after training using tasks that have been previously shown to reflect training-specific abilities. The purpose was to determine the extent to which changes could be observed after very brief training and the specificity of the two types of training on the

different outcome measures. Such information will contribute to our understanding of experience-dependent plasticity and suggest avenues for intervention to improve the cognitive functioning of all children.

The main prediction was that children would profit from the training experiences and that post-test scores on the outcome tasks would improve over pre-test scores with no change in background tasks. The second set of predictions addressed differential effects of the two training protocols, but these predictions were speculative. Outcome tasks were selected to capture abilities affected by either bilingualism or music training. Essentially, bilingualism enhances non-verbal EC and metalinguistic ability but limits language performance whereas musical training enhances both EC and language processing with unknown effects on metalinguistic ability. The set of tasks and the hypotheses for the expected effect of each training protocol are presented in Table 1. Thus, music training should lead to greater improvement than bilingualism on verbal WM (e.g., Ho et al., 2003) but bilingualism should lead to greater improvement than music training on non-verbal WM (Morales, Calvo, & Bialystok, 2013). Similarly, in line with previous research, bilingualism should lead to greater improvement than music training in metalinguistic performance (Bialystok, 1986). Although studies have found advantages for language tasks from music training, no studies have investigated its effect on metalinguistic performance, so there is no basis for predicting a positive outcome. For verbal fluency, both groups should improve equally but for different reasons – bilinguals because of enhancement of the EC component and musicians because of enhancement of the vocabulary component. Finally, it was expected that the French training group would show greater improvement than musicians on a non-verbal visual-spatial search task in which selective attention to relevant cues was critical, an ability identified as a core feature of the bilingual cognitive advantage. To summarize, the purpose was to determine whether (a) brief training in either of these experiences improved cognitive performance and (b) the extent to which the outcomes of the two experiences were similar or different.

Method

Participants

Seventy-two English-speaking monolingual children between 4- and 6-years old who had no prior musical training or exposure to a second language were recruited either by responding to an advertisement in a local paper or contacted from a university database. General questions regarding the children's language background and musical experience were asked as a primary screening measure. In return for participation, children were enrolled in a free French or music summer camp for 20 days (see Training curricula, below, for details).

After the first phase of testing, children were pseudo-randomly assigned to either the French or music training program to assure that the average score on the background measures for each group were similar. Ten families withdrew their children prior to commencement of the training program and five children did not meet the required minimum attendance by the end of training (15/20 days) and were excluded from data analysis to ensure learning. By the end of the training, complete data were available for 57 children, 28 (16 boys and 12 girls) who received French training and 29 (14 boys and 15 girls) who received music training. The subgroups remained similar in age and SES, and had comparable scores on the PPVT and

Raven test background measures (Table 2) across testing sessions. Five tasks were used to assess various aspects of EC at both testing sessions (see Questionnaires and Tasks). The study received University Ethics Committee approval and parents provided written informed consent. The procedure was explained to each child and verbal assent was obtained prior to each testing session. Each child received small toys at the end of each session to thank them for their participation.

Training curricula

Children attended 20 days of training in either French or music, for 3 hours each day, with a one-hour break in the middle of each day. Two teachers specializing in French or music education carried out their respective curricula in a classroom setting, following the procedures used in our previous study (Moreno et al., 2011). The computerized instruction for French and music programs differed in content but used the same structure and shared the same learning goals, graphics/design, and duration. The music curriculum (Moreno, 2010) was based on a combination of motor, perceptual, and cognitive tasks and included training in rhythm, pitch, melody, voice, and basic musical concepts. The French training included vocabulary (e.g., days of the week, body parts, animals), communication schemes (e.g., interacting with a character in the projected game), and discussions with the teacher or other children in the class. At the end of the camp, children demonstrated their achievement through a performance for the families. To maintain the “camp-like” environment, no individual achievement measures were taken for children’s progress in the trained domain.

Questionnaires and Tasks

Language and Social Background Questionnaire (LSBQ)—The LSBQ was completed by parents/guardians during the first testing session and provided information about each child, including age and socioeconomic status (SES). SES was assessed using a 5-point scale for mother’s education with 1 indicating no high school diploma, 3 indicating some college or college diploma, and 5 indicating graduate or professional degree. Other questions pertained to the child’s sex, handedness, education, time spent using video or computer games, musical exposure, non-English language use and fluency, as well as specific vision or hearing problems.

Peabody Picture Vocabulary Test III, Forms A and B (PPVT A and B; Dunn & Dunn, 1997)—The PPVT is a standardized measure of receptive vocabulary. The experimenter presents a test plate with four pictures depicting objects, actions, or concepts, provides a word, and children point to the picture corresponding to that word. Testing proceeded through the plates until the participant made eight errors within a block of 12 words. The PPVT normally takes 15–20 minutes to complete with children and follows a standardized scoring system based on the participant’s age ($\mu = 100$, $SD = 15$). The test consists of parallel forms, A and B, and these were counterbalanced across the pre- and post-test sessions so children did not complete the identical test twice.

Raven Standard Progressive Matrices (Raven test; Raven, Court, & Raven, 1996)—This is a standardized, non-verbal test of fluid intelligence. Children viewed test figures and chose the item from a set of 6 options that provided the best completion. This

task normally takes children 10–15 minutes to complete. Results are converted to standardized scores based on participant's age ($\mu = 100$, $SD = 15$). Scores obtained on this task are not considered to be predictive of intellectual development for children under 6 years old but are psychologically valid as assessments of the child's present level of intellectual activity. Our purpose in using the test was only to assure that children in the two training groups were equivalent on a standard cognitive measure.

Verbal Fluency (adapted from Spreen & Strauss, 1998)—The category version of this task was used as a measure of word retrieval and EC (see Friesen et al., 2015). Children were given 60 seconds to produce as many words as they could that belonged to the category of “fruits and vegetables” or “clothing”. Both categories were tested at each session, with the order of administration counterbalanced across sessions. A trained research assistant processed and listened to the digital recordings of every participant's responses using Audacity® for Windows. The fluency score was calculated as the average number of words produced in the two categories.

Forward and Backward Corsi Blocks (adapted from Milner, 1971)—The Corsi Blocks task was included as a measure of non-verbal WM. The apparatus consisted of 10 blocks spread in a random array on a wooden base that was placed between the participant and the experimenter. The blocks were labeled from 1 to 10 on the back so the numbers could be seen only by the experimenter. The forward condition was always administered first; the experimenter followed a standardized list of number sequences which she tapped out at the rate of one block per second, and then the child was asked to tap the same blocks in the same order. The backward condition followed the same procedure except that block positions needed to be recalled in reverse order, providing a more challenging measure of non-verbal WM. There were two practice trials before each condition. For each direction the minimum span was 2 and the maximum span was 9. Each span was made up of two trials for each sequence length. Children had to correctly re-tap at least one of the two trials to successfully complete that span length. A score out of 88 was calculated for each condition as the number of blocks correctly recalled by the end of the last successfully completed span + 1. Testing continued until the end of the sequences with 9 blocks, although the score used the analyses was based only on performance up to the $n + 1$ list.

Forward and Backward Word Span—The Word Span task was included as a measure of verbal WM. Similar to Corsi Blocks, the Word Span task has a forward and a backward condition. The experimenter read sequences of words (at a presentation interval 1 second) belonging to one of two semantic categories, animals or food, with the number of words in each list increasing from 2 to 8. The word lists used for each of the forward and backward conditions were counterbalanced across testing sessions. As in Corsi Blocks, a score was calculated by counting the number of words correctly recalled throughout the test to span + 1 for a maximum in this case of 70. Testing continued until the end of the sequences with 8 words.

Sentence Judgment Task (Bialystok, 1986, 1988)—Children heard four types of sentences that were read aloud by the experimenter. The sentences were correct (e.g.,

“Apples grow on trees”), syntactically incorrect but semantically meaningful (e.g., “Apples growowed on trees”), syntactically correct but semantically anomalous (e.g., “Apples grow on noses”), or syntactically incorrect and semantically anomalous (e.g., “Apples growowed on noses”). Sentences containing both syntactic and semantic errors were used as fillers to create a balanced design in which there would be equal numbers of correct and incorrect responses, and were therefore not analyzed. Children were trained to identify correct sentences by giving them examples of sentences from the different categories and asking them whether or not they were “said the right way” even if they sounded “silly”. Thus the children were required to make judgments of sentence grammaticality and ignore semantic plausibility. Accuracy on the semantically anomalous sentence is associated with better executive control (Bialystok, 1988) and better attention to speech (Astheimer, Janus, Moreno, & Bialystok, 2014). The test included 24 sentences, with six exemplars of each type, counterbalanced so the child completed only one version of each sentence across testing sessions.

Visual Search Task—Children were required to scan a display to determine whether or not a target stimulus was present. There were two conditions corresponding to feature search (first 24 trials) and conjunction search (last 24 trials). In feature search, the child needed to attend to one feature of the target (green triangle) to identify it among distractors that differed only on that feature (yellow triangles). In conjunction search, two features were required to define the target (turquoise circle) among distractors that shared one of these two features (turquoise squares and pink circles). Conjunction search is considered to require more EC than feature search so better performance on that condition may reflect better EC (Hommel, Li, & Li, 2004). The distractor set size on each trial was small (0 or 5 distractors) or large (15 or 25 distractors). The task was administered on a computer, and children responded by pressing the number key “1” (target present) or “0” (target absent). Children were instructed to respond as quickly as possible without making errors. Performance was analyzed using measures of accuracy (percent correct) and speed of processing (reaction time).

Procedure

The study used a three-phase design: pre-test, training, and post-test. Children were tested individually by research assistants who were blind to the training group to which the child was assigned.

During the first testing session, parents or guardians completed the LSBQ while children were given the various tasks. Testing at both pre- and post-test sessions included the background measures for vocabulary (PPVT), general cognitive function (Raven test) and outcome measures for WM (Corsi Blocks, Word Span) word retrieval (Verbal Fluency), metalinguistic ability (Sentence Judgment), and attention (Visual Search).

Two research assistants who were blind to group assignment scored responses on all the measures at both pre-test and post-test. Each task was analyzed separately using a repeated measures ANOVA. The between-groups factors were training condition and language group, and within-groups factors were determined by the individual tasks.

Results

Background information for age and maternal education and mean scores for vocabulary knowledge (PPVT) and non-verbal cognitive functioning (Raven test) are reported in Table 2. There were no differences between children in the French and music groups for any of these measures at pre-test (all $ps > .15$) or post-test (all $ps > .41$).

Scores from all outcome measures are reported in Table 3. Because the Word Span and Corsi Block tasks were based on different maxima, they were analyzed separately, each using a three-way ANOVA for session (pre-test, post-test), group (French, music), and condition (forward, backward). For the Word Span task, there was a main effect of group, $F(1, 55) = 14.52, p < .001, \eta_p^2 = .21$, in which the French group (15.6) outperformed the music group (12.9), and condition, $F(1, 55) = 187.9, p < .001, \eta_p^2 = .80$, in which children performed better on the forward (18.9) than the backward (9.6) direction. There was no effect of session, $F = 1.12$, and no interaction effects, $F_s < 1.17$, so the group difference is a constant and pre-existing difference between children in the two training groups.

The analysis of Corsi Block scores showed no difference between groups, $F(1, 55) = 2.72, p = .11$, and again a main effect of condition, $F(1, 55) = 92.39, p < .001, \eta_p^2 = .62$, with higher scores on forward (17.8) than backward (10.0) conditions. There was no effect of session, $F(1, 55) = 1.51, p = .23$, and no interaction effects, $F_s < 2.6$. Thus, span scores were stable across the two testing sessions, with significantly better performance on the forward task than the backward counterpart.

Verbal Fluency scores were analyzed by a two-way ANOVA for session and group and revealed a main effect of session, $F(1, 55) = 5.80, p = .02, \eta_p^2 = .10$, showing comparable improvement for both groups on the average number of words that children generated across the two categories from pre- (7.1) to post- (7.7). There was no main effect of group, $F < 1$, and no session by group interaction, $F(1, 55) = 1.97, p = .17$.

For the Sentence Judgment task, no analyses were conducted on the correct condition because children performed at ceiling, or on the incorrect condition because it was designed as a filler and performance cannot be interpreted. Therefore, the task was analyzed with a three-way ANOVA for group, session, and two sentence types (ungrammatical and anomalous). There was no effect of group, $F < 1$, but a significant main effect of session, $F(1, 55) = 16.19, p < .001, \eta_p^2 = .23$, with better performance at post-test (3.4) than at pre-test (2.7), and a main effect of sentence type, $F(1, 55) = 5.68, p = .02, \eta_p^2 = .09$, showing better performance overall on anomalous (3.4) than ungrammatical (2.7) sentences. An interaction of session and sentence type, $F(1, 55) = 16.21, p < .001, \eta_p^2 = .23$, was also found, indicating that improvement over the sessions occurred for semantically anomalous sentences, $p < .001$, but not for ungrammatical sentences, $F < 1$. Because the groups differed in word span ability and the sentence judgment task is a verbal task, a correlation was computed between overall performance on these two tasks to determine whether an analysis of covariance would be appropriate. However, there was no correlation between these measures, $r(57) = -0.05$.

Accuracy data for the Visual Search task were analyzed using a four-way ANOVA for session, group, search type (feature, conjunction) and distractor set size (small, large). There were main effects for session, $F(1, 55) = 14.08, p < .001, \eta_p^2 = .20$, search type, $F(1, 55) = 113.82, p < .001, \eta_p^2 = .68$, and distractor set size, $F(1, 55) = 130.70, p < .001, \eta_p^2 = .70$. These effects were qualified by a 2-way interaction between search type and distractor set size, $F(1, 55) = 88.04, p < .001, \eta_p^2 = .62$, indicating a significantly larger difference in accuracy between small and large distractor set sizes for the conjunction search (26.4%) than for the easier feature search (2.7%), $t(1, 56) = 9.5, p < .001$. Finally, there was a three-way interaction of session, group, and distractor set size, $F(1, 55) = 4.04, p = .05, \eta_p^2 = .07$.

To investigate this interaction, separate 2-way ANOVAs for session and set size were run for each training group. For French, there was a main effect of session, $F(1, 27) = 7.94, p < .01, \eta_p^2 = .23$, showing significant improvement in the post-test, and a main effect of distractor set size, $F(1, 27) = 76.63, p < .001, \eta_p^2 = .74$, showing better performance on small set sizes, with no interaction, $F < 1$. For music, there was again a main effect of session, $F(1, 28) = 6.40, p = .02, \eta_p^2 = .18$, showing improvement across sessions, a main effect of distractor set size, $F(1, 28) = 54.22, p < .001, \eta_p^2 = .66$, showing better performance on small sets, and an interaction of session by distractor set size, $F(1, 28) = 4.55, p = .04, \eta_p^2 = .14$. Children in the French group improved on both small, $p = .04$, and large set searches, $p = .05$, but children in the music group only improved on small set searches, $p < .01$, with no change in performance on large sets, $p = .47$. To confirm the role of training in these effects, independent samples t-tests indicated no significant training group difference at pre-test for either the small set searches, $t(55) = .53, p = .60$, or the large set searches, $t(55) = -1.73, p = .10$.

Reaction time (RT) data for the Visual Search task were analyzed the same way as accuracy data, using a four-way ANOVA for session, group, search type (feature, conjunction) and distractor set size (small, large). There were main effects for session, $F(1, 52) = 10.02, p < .01, \eta_p^2 = .16$, search type, $F(1, 52) = 121.45, p < .001, \eta_p^2 = .70$, and distractor set size, $F(1, 52) = 70.53, p < .001, \eta_p^2 = .58$. A 2-way interaction between search type and distractor set size, $F(1, 52) = 62.39, p < .001, \eta_p^2 = .55$, indicated a significantly larger difference in RT between small and large distractor set sizes for the conjunction search (332 ms) than for the easier feature search (39 ms), $t(1, 56) = 9.97, p < .001$. There were no other main or interaction effects, $F_s < 2.83, p_s > .10$.

Discussion

The present study investigated the effects of brief music or L2 training on the development of EC abilities in children. Children in the music and French groups were matched on age and SES and tested before and after training on a variety of background measures and tasks that involve EC. There were no differences between groups or changes in performance after training for measures of English receptive vocabulary (PPVT), cognitive level (Raven test), or spatial span (Corsi Blocks). However, even with the very short training used in the present study, reliable improvements in some crucial tasks were found for both groups. These findings confirm that training effects can be detected at early stages with as little as 20 days of experience.

For word span, children assigned to the French training group had higher initial scores than those in music, but this difference did not change over sessions. For both word and spatial span, scores were higher for forward measures than backwards measures, with no interaction with group or session. The lack of improvement in backward span is surprising because backward span is usually considered to involve EC. However, given the low levels of performance in all the conditions of these span tasks (see Table 3), it may be that the tasks were too difficult and the training was too brief for children to make measurable progress.

On the remaining three tasks, performance improved after training with few differences between groups in the extent of that improvement. Although category fluency in adults is considered to be a measure of vocabulary, in children it also involves EC because of the effortfulness associated with generating words by these young children for whom lexical access and generation procedures are not yet automatic (Friesen et al., 2015). Thus, category fluency for children involves similar control processes to retrieve words from semantic categories as those used by adults to retrieve words from phonemic categories. In both cases, these processes require EC. In the present study, both groups produced significantly more responses after training than they did before training, with no difference in the degree of improvement for the two training methods. Thus, both music training and French training led to better control over lexical access and word retrieval in response to a category cue.

In the sentence judgment task, the ungrammatical condition assesses grammatical knowledge and the anomalous condition reflects EC to avoid responding to the salient meaning (Bialystok, 1986). Following training, both groups showed improvement in the post-test session for the anomalous sentences with no change in scores for the ungrammatical sentences. In previous research, children's ability to perform the anomalous judgment was greater for bilingual children than monolinguals (e.g., Bialystok, 1986) and related to children's ability to selectively attend to speech for monolinguals (Astheimer et al., 2014). Previous research has shown no effects of bilingualism on performance on the ungrammatical sentences, and judgment of these sentences did not improve after either training condition. Thus, both French training and music training enhanced children's ability to selectively attend to linguistic information in a distracting context but not to their ability to simply judge grammaticality if no distraction was present.

The visual search task was generally performed better following training but with some differences between the two groups. Notably, children in both training groups improved on searches with smaller (easier) distractor set sizes, but only children who underwent French training also improved over time on the more difficult, larger distractor set size, condition. This difference between training groups is small and should not be over-interpreted, but the main effect in which training helped all the children to improve their control of visual search is substantial.

There were two main purposes for the present study. The first was to determine whether training on a skill previously shown to be associated with enhanced EC or cognitive outcomes could improve children's performance on these tasks in the earliest stages of training. The second was to determine whether the two training methods, L2 and music, promoted different aspects of EC in these early stages. In broad terms, the answer to the first

question is “yes” and the answer to the second question is “no”. We will discuss each of these results in turn.

For three of the tasks that involved EC, verbal fluency, grammaticality judgment, and visual search, all the children performed significantly better after training than in the pre-test session. It could be argued that in the absence of a passive control group, these improvements could be due to simple practice effects and not to the training. However, the main factor that rules out that possibility is the specificity of these effects. If the source of improvement were practice, then children should improve on *all* tasks in the second session, particularly those that were identical to those administered in the first session. Like the EC tasks, Raven matrices require complex problem solving that should increase with practice, yet no change in these scores was observed after training. Similarly there were no improvements on the PPVT test, although the exact words tested were different in the two sessions. Instead, improvement was found specifically for tasks that rely on EC for their performance. The point becomes clearer by examining conditions within the same task. In the grammaticality judgment task, children were asked to say if a sentence was grammatically correct or not in the context of four sentence types. Although the sentences were the same in the two sessions, improvement was found only when the judgment of grammaticality was made for the anomalous sentences that require EC and not on judgments of the ungrammatical sentences that do not.

The second purpose was to determine if early training in these two skills leads to different types of improvement. The brief computer-based intervention used in this study (2 hours per day, for 20 days) was previously effective in differentiating between performance outcomes for music and visual art training (Moreno et al., 2011). The one training-specific outcome found was that children in the French group showed broader improvement in visual search than did children in the music training. Although small, this difference is potentially important because visual search was one of the tasks for which it was predicted that there would be a greater impact of language training than music training.

No previous studies have examined such brief intervention in second language training on children, but evidence from adults learning French as a second language has shown detectable changes after just four weeks (McLaughlin et al., 2004). No comparable, controlled design has been used in the past to assess behavioral changes with French training in children. The present results support the prediction that such changes in children are detectable, but they seem not to be different from the early effects of other training interventions. It is possible that more expertise is required for the outcomes to differentiate. A dose-dependent relationship has also been found by several authors, whereby longer periods of both L2 experience (Bialystok & Barac, 2012) or greater L2 proficiency (Crivello et al., 2016) and longer experience with music training (Nutley et al., 2014) are associated with more pronounced improvement in EC.

This is the first study to examine such early effects of L2 and music learning in children. Children in the French and musical training programs remained similar from pre- to post-test on a variety of background and task measures, but both training groups showed evidence of improvement on tasks of EC. Most research investigating the effects of L2 learning and

musical training describes group performance at only one time point (after training), leaving many unknowns regarding the predispositions, motivation, or skills of participants before they commence language or music lessons.

The longitudinal intervention design used in the present study provides a rigorous method for studying effects of training on the emergence of changes in EC. The results clearly support the role of plasticity in children's development and underscore the importance of stimulating activities as children establish their ability in fundamental aspects of EC.

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Highlights

- Brief training in music or French improved children's executive control performance
- Improvement only on tasks that involved executive control
- Few differences between effects of the two training programs
- Demonstrates power of short training to modify cognitive performance

Table 1

Main process involved in each task and hypothesized relative improvement in the two training groups at post-test for each task.

Task	Processes	Hypotheses
Word Span	Verbal WM, Inhibition	French < Music
Corsi Blocks	Spatial WM, Inhibition	French > Music
Verbal Fluency	Vocabulary, Word Retrieval, EC	French = Music
Sentence Judgment	Attention	French > Music
Visual Search	Attention	French > Music

Table 2

Mean score and standard deviation for background measures at pre- and post-test by group.

Task	French		Music	
	Pre-test <i>M (SD)</i>	Post-test <i>M (SD)</i>	Pre-test <i>M (SD)</i>	Post-test <i>M (SD)</i>
Age in months	66.2 (6.0)	68.8 (5.9)	65.93 (6.8)	66.3 (6.7)
Maternal Education	3.7 (.8)	---	3.4 (.9)	---
PPVT	112.9 (13.6)	110.4 (10.3)	112.3 (10.9)	112.8 (10.7)
Raven test	103.9 (15.2)	103.6 (15.1)	98.6 (12.4)	101.2 (12.7)

Table 3

Mean score and standard deviation for outcome measures at pre- and post-test by group

Task and Variable	French		Music	
	Pre-test <i>M (SD)</i>	Post-test <i>M (SD)</i>	Pre-test <i>M (SD)</i>	Post-test <i>M (SD)</i>
Word Span Task (out of 70)				
Forward Score	19.9 (5.9)	21.4 (4.7)	16.7 (4.5)	17.7 (5.0)
Backward Score	11.2 (3.3)	10.0 (3.8)	8.3 (3.8)	9.0 (4.0)
Corsi Blocks Task (out of 88)				
Forward Score	19.5 (9.1)	18.7 (7.8)	16.4 (6.8)	16.4 (6.1)
Backward Score	10.7 (7.3)	11.3 (7.3)	7.4 (5.2)	10.7 (6.2)
Verbal Fluency (in 60 sec)	6.6 (2.9)	7.6* (2.7)	7.5 (1.8)	7.8* (1.6)
Sentence Judgment (out of 6)				
Correct	5.5 (.7)	5.6 (.9)	5.4 (1.0)	5.8 (.5)
Ungrammatical	2.5 (2.0)	2.6 (1.6)	2.9 (2.0)	2.7 (2.0)
Anomalous	2.5 (2.5)	4.2* (2.0)	2.7 (2.2)	4.0* (1.8)
Incorrect	4.3 (1.7)	4.0 (1.9)	4.3 (1.7)	4.0 (1.8)
Visual Search Task (% correct)				
Small Set Feature	91.1 (.1)	93.5 (.1)	90.9 (.1)	95.8 (.1)
Small Set Conjunction	86.8 (.1)	91.2 (.1)	83.9 (.2)	95.0 (.1)
Combined	89.0 (.1)	92.3* (.1)	87.4 (.1)	95.3* (.1)
Large Set Feature	84.2 (.2)	91.7* (.1)	91.5 (.1)	92.9 (.1)
Large Set Conjunction	58.3 (.2)	63.1 (.2)	63.8 (.2)	65.9 (.2)
Combined	71.3 (.1)	77.4* (.1)	77.6 (.1)	79.3 (.1)
Visual Search Task (reaction time, in milliseconds)				
Small Set Feature	1271 (401)	1079* (206)	1203 (295)	1096 (172)
Small Set Conjunction	1419 (390)	1198* (240)	1398 (333)	1287 (217)
Combined	1345 (363)	1144* (191)	1300 (250)	1192* (167)
Large Set Feature	1258 (372)	1137 (225)	1252 (247)	1158 (194)
Large Set Conjunction	1640 (483)	1611 (373)	1704 (468)	1639 (243)
Combined	1446 (364)	1382 (260)	1478 (317)	1399 (155)

* Significant change from pre- to post-test for that group, $p < .05$.