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Short-Term Music Training Enhances Verbal Intelligence and Executive Function

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Abstract

Researchers have designed training methods that can be used to improve mental health and to test the efficacy of education programs. However, few studies have demonstrated broad transfer from such training to performance on untrained cognitive activities. Here we report the effects of two interactive computerized training programs developed for preschool children: one for music and one for visual art. After only 20 days of training, only children in the music group exhibited enhanced performance on a measure of verbal intelligence, with 90% of the sample showing this improvement. These improvements in verbal intelligence were positively correlated with changes in functional brain plasticity during an executive-function task. Our findings demonstrate that transfer of a high-level cognitive skill is possible in early childhood.

Keywords

childhood development, evoked potentials, language development, learning, music

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Using neuroscientific methods to evaluate the outcomes of education or rehabilitation programs is an emerging field in cognitive science, in which transfer of skills is a central inquiry. Researchers who create such training programs have reported mixed results (Detterman & Sternberg, 1982). Some studies have found an improvement in performance on untrained transfer tasks (e.g., problem-solving tasks; Lovett & Anderson, 1994), although the magnitude of the improvement tends to be small, whereas other studies have found no transfer to untrained tasks (Olesen, Westerberg, & Klingberg, 2004). Unfortunately, the training paradigms in many of these previous studies lacked a pedagogical foundation and would be difficult to apply in nonlaboratory settings or toward long-term behavioral change, and having such a foundation and being applicable outside the laboratory are two issues that are crucial in the fields of education and rehabilitation.

Nonetheless, successful skill transfer has been observed for music training (Schellenberg, 2004). Broad transfer occurs when the novel and trained tasks recruit overlapping processing components and engage shared brain regions (Jonides, 2004). Recently, Dahlin, Neely, Larsson, Bäckman, and Nyberg (2008) showed that a training task that stimulates and influences the functioning of specific brain areas (or processes) results in improvement in the related cognitive activities. Music and language both involve analytic listening and also share mechanisms and underlying brain structures (for a review, see Jäncke, 2009). Research has demonstrated an association between music training and specific brain structures, especially in regions that are also involved in language processing, such as Heschl's gyrus and Broca's and Wernicke's areas (for a review, see Moreno, 2009). Evidence for a link between music and language has been reported at both subcortical (auditory processing: Wong, Skoe, Russon, Dees, & Kraus, 2007) and cortical (implicit processing: Jentschke & Koelsch, 2009) brain levels. This association is also evident at the functional level, having been reported for both lower-level (i.e., pitch discrimination: Moreno & Besson, 2006) and higher-level (i.e., semantic processing: Koelsch et al., 2004; syntax: Patel, 2009) aspects of cognition. However, specific mechanisms underlying the link between music and language remain underspecified.

Several studies have revealed associations between traditional music lessons and improvement in higher-level cognitive functions (Schellenberg, 2006). For example, Schellenberg (2004) demonstrated an improvement in general IQ for

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6-year-olds after 1 year of conservatory-based music training. When training involved 6 months of specialized listening-intensive music activities, improvements were evident in children's language comprehension and in corresponding brain-activation patterns (Moreno et al., 2009). These findings can be explained by a shared-resources interpretation. Notably, a recent model of intelligence—parieto-frontal integration theory (P-FIT; Jung & Haier, 2007)—highlights structural links common to music, language, and intelligence, specifically in shared brain structures such as prefrontal cortex (Brodmann's areas 9, 10, 45, 46, and 47), the anterior cingulate (Brodmann's area 32), and a region within the temporal lobes (Brodmann's area 21).

Influences of visual-art training on cognitive functions have not been studied as extensively as those of music training, but there is some evidence that training has an effect on perceptual learning, vision processing, and motor skills. Several studies have shown that both visual activities (Op de Beeck & Baker, 2010) and hand-related motor activities (Draganski et al., 2004) induce brain changes, and that these activities share brain resources with spatial-reasoning skills. There is also evidence that training in visual discrimination induces changes in the visual cortex (Op de Beeck, Baker, DiCarlo, & Kanwisher, 2006). In addition, Pollmann and von Cramon (2000) reported that working memory processes overlap with the processes underlying visuospatial skills. Hand-related motor training can also lead to changes related to visuospatial skills; Draganski et al. (2004) demonstrated that training in juggling induced modification in brain areas involved in visuospatial skills, including the midtemporal area and the left posterior intraparietal sulcus. In another study, the spatial skills of preschoolers were improved by executive-function training over a short period of time (Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2009).

Despite this evidence that training can lead to changes in visuospatial performance, only one study to date has tested whether art skills can transfer to visuospatial performance. Although Gardiner, Fox, Knowles, and Jeffrey (1996) reported enhancement of reading and mathematical abilities following a specialized 7-month training program, the training included both music and visual-art components, which made it impossible to attribute the results unequivocally to either program. In the study reported here, we investigated transfer from music and visual-art training to children's performance on specific subtests of verbal and spatial intelligence and executive function. We tested several hypotheses using a short, intense series of training sessions.

Individual differences in verbal and spatial intelligence are strong predictors of achievement in school, the ability to learn in nonschool settings, and a variety of other outcomes, including productivity at work and health-related behavior (Gottfredson & Deary, 2004). Although what intelligence tests measure is the subject of active and engaged debate (Pinker, 2002), their predictive value has secured them a central role in educational systems. We measured verbal and spatial intelligence with two subtests from the Wechsler Preschool and Primary Scale of Intelligence–Third Edition (WPPSI-III; Wechsler, 2002). Our primary hypothesis was that music training would improve verbal intelligence independently of spatial intelligence, and that visual-art training would improve spatial intelligence independently of verbal intelligence. Our rationale was that music processing shares mechanisms and brain structures with language processing but not spatial processing, whereas visual-art processing shares mechanisms and brain structures with spatial processing but not language processing. Our secondary hypothesis was that music and visual-art training can lead to rapid transfer. Finding such transfer in just 4 weeks would replicate and extend previous findings showing rapid influences of training on cognitive performance and brain structure (for a review, see Kelly & Garavan, 2005).

We also investigated whether our training programs would influence executive function. To measure executive function, we used a go/no-go task in which we recorded behavioral performance (i.e., accuracy and reaction time) and event-related potentials (ERPs). According to the work done by Green and Bavelier (2008), computerized training (like the training programs we used in this study) should improve executive-function skills independently of training content (in the present case, music and visual art). We hypothesized that both of our computerized training programs would improve participants' executive control, as indexed by accuracy and reaction time. We expected that our training would induce functional plasticity reflected in the N2/P3 complex (ERP components thought to be involved in inhibitory processing; Green & Bavelier, 2008); specifically, we expected training to enhance N2 amplitudes (Fujioka, Ross, Kakigi, Pantev, & Trainor, 2006) and decrease P3 amplitudes (Moreno et al., 2009), as found in previous research. We also hypothesized that music training would increase the amplitude of the P2; this hypothesis was based on previous studies showing increased amplitude of the P2 after music training (Tremblay, Kraus, McGee, Ponton, & Otis, 2001) and auditory training (Reinke, He, Wang, & Alain, 2003).

Finally, we examined whether links between our training programs and changes in verbal or spatial intelligence might be mediated by changes in executive function; we explored this possibility because a link between executive function and intelligence has been reported (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008).

Method

Participants

Seventy-one children between 4 and 6 years old were recruited from various neighborhoods in a large city. Data from 7 participants were discarded (3 dropped out, 2 felt ill, and 2 did not speak English fluently). WPPSI-III data were available for 64 children, 32 (18 girls and 14 boys) who received visual-art training and 32 (20 girls and 12 boys) who received music training. The children in the two groups did not differ in age ($p > .8$; visual-art group: $M = 63.8$ months; music group: $M = 63.7$ months) or mother's education ($p > .6$; average education was a bachelor's degree). Nine children were not comfortable with the procedure for measuring ERPs in the go/no-go task and did not complete this task. Finally, 7 participants were excluded because of noise in the ERP signal. The final sample consisted of 48 participants, 24 in each training group.

The study received approval from the York University Research Ethics Committee, and all parents provided written informed consent. The children's assent was obtained prior to each testing session.

Training curricula

Two computerized training programs (both created by Sylvain Moreno) were administered. The training programs had the same learning goals, graphics and design, duration, number of breaks, and number of teaching staff; the only difference between them was the content of the training. The music curriculum (U.S. Patent App. No. 61/325,918; 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. This training relied primarily on listening activities and was not an instrumental training. The curriculum in visual art emphasized the development of visuospatial skills relating to concepts such as shape, color, line, dimension, and perspective. The children engaged in the training programs in two daily sessions of 1 hr each (15 min for organization and 45 min of training), 5 days a week, for 4 weeks. The training programs were projected onto a classroom wall and conducted in groups led by a teacher (for more details, see the section on training in Supplemental Methods and Analysis, as well as the supplemental videos, in the Supplemental Material available online).

Intelligence measures and background questionnaire

The WPPSI-III (Wechsler, 2002) is an intelligence test designed for children ages 2 years 6 months to 7 years 3 months. It provides subtest and composite scores that represent intellectual functioning in verbal and spatial domains. In this study, we administered the Vocabulary subtest to test verbal ability and the Block Design subtest to test spatial ability. The Vocabulary subtest comprises 25 words arranged in order of increasing difficulty. The child is asked to explain the meaning of each word (e.g., "What is a ___?" or "What does ___ mean?"). The Block Design subtest has 20 items, each consisting of a two-dimensional, red-and-white abstract design. The child uses blocks to assemble designs identical to the ones in the pictures. Each block has two red sides, two white sides, and two sides that are red and white (split along the diagonal). The designs are arranged in order of increasing difficulty. The WPPSI-III manual provides standardized instructions for the administration of both subtests.

Parents completed a background questionnaire asking about their children's previous music and visual-art training and the mothers' education (the latter variable served as a proxy for socioeconomic status).

Procedure

This study had a longitudinal design with three phases: pretest, training, and posttest. The WPPSI-III and go/no-go task were completed at pretest and posttest, with the order of the WPPSI-III subtests and the go/no-go task randomized across children. Testing took place in the laboratory and lasted 60 min. The use of the same tests before and after training reduced the likelihood of a novelty effect on performance, but increased the likelihood of a repetition effect on performance. However, because all children received the same tests on two occasions, it is possible to distinguish between practice and training effects. We return to this point in the Discussion.

At pretest and posttest, the children were tested individually by a research assistant who was blind to the type of training each child would receive or had received. After the pretest, children were assigned to music or visual-art training in a pseudorandom manner to ensure that there were no pretraining differences between groups on intelligence scores or answers on the background questionnaire. Between 5 and 20 days after the end of training, children returned to our laboratory to be reassessed on the WPPSI-III and go/no-go task. The posttest intelligence scores were reviewed by three research assistants.

In our go/no-go paradigm, geometric shapes were presented on a computer screen in randomized order while an electroencephalogram with 64 electrodes was recorded. There were four different stimuli: a white triangle, a purple triangle, a white square, and a purple square. All white stimuli indicated *go* trials, and all purple stimuli indicated *no-go* trials. Shape was not relevant to the required response; we used two shapes to avoid the possible repetition effects of always having the same color-shape pairing. At the beginning of the test block, a prompt appeared with the instructions. Each trial consisted of the following events: A white cross on a black background appeared for a duration that varied across trials (from 500 to 1,000 ms) and then a shape appeared in the center of the screen for a maximum of 500 ms. Participants had to press a key on go trials and not press a key on no-go trials. A blank-screen interval of 500 ms (the poststimulus interval) separated trials. The task lasted 15 min and consisted of 200 trials (80% go trials and 20% no-go trials; for details, see the section on the ERP procedure in Supplemental Methods and Analysis in the Supplemental Material). ERPs were recorded for go and no-go trials; accuracy rates and reaction time was recorded for go trials only. The order of trials was randomized for each participant. During the task, participants did not receive feedback about their performance.

Data analysis

Interrater reliability on the WPPSI-III. Three individuals who were blind to experimental group rated responses on the Vocabulary and Block Design subtests at both pretest and posttest. Although the WPPSI-III manual provides detailed instructions about scoring, scoring each response still requires interpretation on the part of the tester (see the section on data analysis in Supplemental Methods and Analysis in the Supplemental Material).

ERP analysis. Mean ERP amplitudes were measured in latency windows selected according to prior research and determined from visual inspection of the waveforms. Analyses of variance (ANOVAs) were computed on peak and mean amplitude using group as a between-subjects factor and session (pretest or posttest), condition (go trial or no-go trial), and electrode (i.e., F1, Fz, F2, Fc1, Fcz, Fc2, C1, Cz, or C2) as within-subject factors. Go and no-go trials generated a P2 that peaked between 100 and 300 ms, an N2 that peaked between 250 and 450 ms, and a P3 that peaked between 400 and 1,000 ms after stimulus onset. The amplitude and latency effects of group and condition on these waves were quantified at the nine electrode sites just listed because the effects we found at those sites were larger than the effects we found at the other scalp sites.

Results

In the pretest session, there was no difference between groups on intelligence measures (verbal: $p > .3$; spatial: $p > .2$) or the go/no-go task (accuracy on go trials: $p > .9$; reaction time on go trials: $p > .3$; ERP peak analysis: $p > .2$).

Scores on the intelligence tests were analyzed with a three-way mixed-design ANOVA with factors of group, session, and test (verbal vs. spatial). There was a three-way interaction, $F(1, 62) = 11.37$, $p = .001$, $\eta_p^2 = .15$: Only the music group showed significant improvement in intelligence scores after training, and this improvement was evident only on the verbal test ($p < .001$, $\eta_p^2 = .33$; see Fig. 1 and Fig. S1 in Supplemental Methods and Analysis in the Supplemental Material). The strength of this effect and its consistency were striking: More than 90% of the children in our music program improved their verbal score from pretest to posttest; a sign test (with normal approximation to the binomial to calculate p) was significant, $p < .001$.

Accuracy on the go/no-go task was examined with a two-way mixed-design ANOVA with factors of group and session. The results revealed a significant interaction, $F(1, 46) = 6.42$, $p < .05$, $\eta_p^2 = .12$. The music group outperformed the visual-art group at posttest ($p < .05$), but not at pretest ($p > .9$; Fig. 2). A further analysis was conducted using d' scores: $d' = z(\text{hit rate}) - z(\text{false alarm rate})$. There was no main effect of group on performance, $p > .7$, but the analysis revealed a significant effect of session, $F(1, 46) = 4.58$, $p < .05$, $\eta_p^2 = .09$, and a significant interaction between group and session, $F(1, 46) = 6.94$, $p = .01$, $\eta_p^2 = .13$. Again, performance improved only in the music group (Fig. 3).

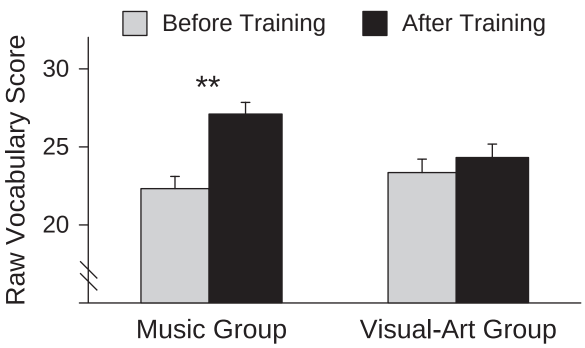

Fig. 1. Mean verbal intelligence scores before and after training as a function of training group. Vocabulary scores from the Wechsler Preschool and Primary Scale of Intelligence–Third Edition (Wechsler, 2002) were the measure of verbal intelligence. Error bars denote standard errors of the mean. Asterisks denote significant improvement (**$p < .001$).

Analysis of reaction times on go trials indicated no reliable differences between groups, $p > .2$, but a main effect of session, $F(1, 46) = 4.82$, $p < .05$, $\eta_p^2 = .09$: After training, response times were quicker for both groups (pretest: $M = 662$ ms; posttest: $M = 645$ ms).

ERP analyses revealed no significant differences between groups for the N2/P3 complex (all ps $> .2$), but a significant difference between groups for the P2 component. We conducted a three-way mixed-design ANOVA with factors of group, session, and condition. There was a significant three-way interaction, $F(1, 46) = 4.64$, $p = .05$, $\eta_p^2 = .21$: The music group showed significantly larger peak amplitudes in the no-go trials after training (pretest: mean peak amplitude = 6.8 μV; posttest: mean peak amplitude = 9.7 μV), whereas the visual-art group did not (pretest: mean peak amplitude = 6.7 μV; posttest: mean peak amplitude = 6.3 μV; see Fig. 4).

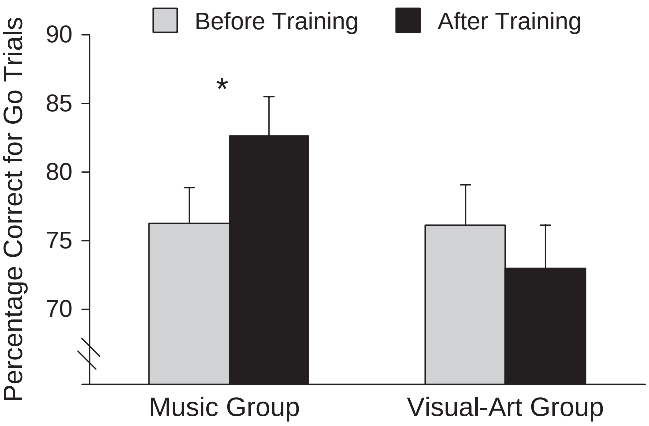

Fig. 2. Percentage correct on go trials for the music group and the visual-art group before and after training. Error bars denote standard errors of the mean. The asterisk denotes significant improvement (*$p < .05$).

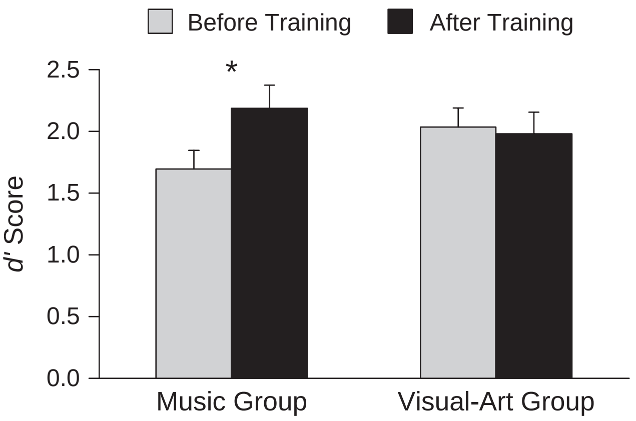

Fig. 3. The *d*' scores for the music group and the visual-art group before and after training. Error bars denote standard errors of the mean. The asterisk denotes significant improvement (**p* < .05).

To explore the relationship between executive function and improvement in intelligence scores, we calculated Pearson correlations between the change in verbal intelligence score (posttest minus pretest) and change in peak P2 amplitude (posttest minus pretest) and found a significant positive correlation in the music group only ($r = .5$, $p < .05$; visual-art group: $r = -.2$, $p > .3$; Fig. 5).

Discussion

Our findings represent the first demonstration of broad transfer of an educationally vital skill: Training in music-listening skills transfers to verbal ability. After a short music-training program, children exhibited enhanced performance on a measure of vocabulary knowledge reflecting verbal intelligence. Although there was no significant increase in verbal or spatial skills following visual-art training, there was a trend for an improvement in spatial skills (see Fig. S1 in the Supplemental Material), but this trend cannot be distinguished from a practice effect. It is possible that the time course for significant transfer is different for these two domains. Preschool children are auditory experts with well-developed language abilities, but visuo-motor skills are less developed at this stage of life. This "in development" status may necessitate a longer time course for the transfer of visuospatial skills than for the transfer of verbal skills. In other words, a longer or more intensive training period in visual art might significantly influence spatial intelligence. Nonetheless, our results demonstrate that verbal performance can be improved independently of spatial performance and suggest that music and language are closely linked in cognition. One possible explanation for our finding is that music processing overlaps with mechanisms used in other cognitive activities (Patel, 2009).

Only 20 days of music training also led to improved performance in an executive-function task (the go/no-go task) and induced brain modifications in a neurocorrelate of that performance (increased P2). An important aspect of our findings is that the brain plasticity observed in our executive-function task was related to improvements in behavioral measures of intelligence. The link between executive function and music is understandable if one considers that music training requires high levels of control, attention, and memorization. Therefore, the transfer effect may be due to these same executive functions being used to process different (i.e., nonmusic) stimuli.

It is possible that the effects of music training on verbal performance were mediated through enhanced attention and verbal memory rather than verbal ability. Other measures of executive function, such as span or task switching, may reveal indirect relationships between training and verbal outcomes. The study reported here cannot distinguish between these alternatives, so further studies using alternative behavioral tasks and structural neuroimaging are necessary to explore these possibilities.

Our findings highlight two phenomena that need to be explained in more detail: the speed of brain modification and far transfer effects. Some evidence suggests that training has a rapid effect on cognition and brain structures (for a review, see Kelly & Garavan, 2005). For example, Taubert et al. (2010) found significant increases in gray-matter volume in frontal and parietal areas after only two training sessions in a complex whole-body balancing task. Using a different technique, Scholz, Klein, Behrens, and Johansen-Berg (2009) observed fractional anisotropy increases (i.e., increases in water diffusion in several brain areas) after 6 weeks of training with 5 training days per week, and Takeuchi et al. (2010) found such increases after 2 months of daily practice.

Evidence also supports this impressive speed of transfer after music training. For example, Bangert, Haeusler, and Altenmüller (2001) showed that audio-motor coupling occurred following a 20-min piano lesson, as shown by topographic analysis of very slow ERPs. More recently, Lappe, Herholz, Trainor, and Pantev (2008) reported ERP changes in young adults after 2 weeks of music training, and Moreno and his colleagues (Moreno & Besson, 2006; Moreno et al., 2009) showed brain-plasticity effects in language after 8 weeks and 6 months of music training. These results confirm the powerful ability of music to induce brain plasticity and broad transfer effects.

In addition, the far transfer effect we found (i.e., functional brain plasticity) is consistent with previous reports of an influence of music training (Tremblay et al., 2001) and auditory training (Reinke et al., 2003) on the auditory P2. Increased P2 amplitude has been interpreted as reflecting an increased neuronal representation resulting from training (Recanzone, Schreiner, & Merzenich, 1993) or as an improvement in neural synchrony (Tremblay et al., 2001). However, these studies trained and tested performance in one modality, whereas our music training influenced a visual P2. Our explanation for this cross-modal effect is related to our interpretation of far transfer and the sharing of brain resources in cognitive processing: Music training stimulates cognitive processing related to

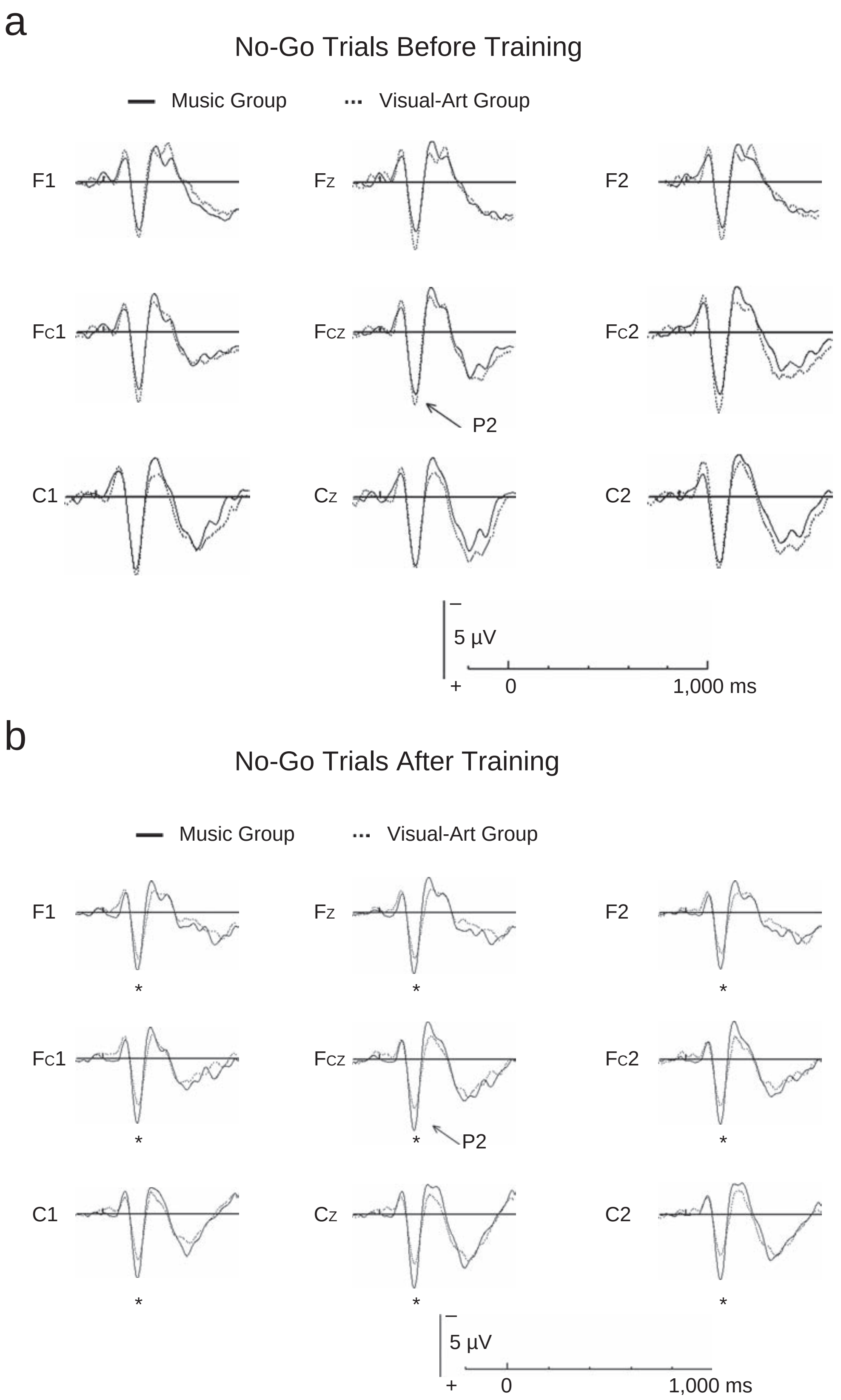

Fig. 4. Event-related potential (ERP) recordings during no-go trials (a) before and (b) after training in the music and visual-art groups. Separate graphs are shown for the nine recording sites (F1, Fz, F2, Fc1, Fcz, Fc2, C1, Cz, and C2). Asterisks denote significant between-group differences in the mean P2 ERP peak (*$p < .05$). The arrow illustrates the location of the P2 in all the waveforms.

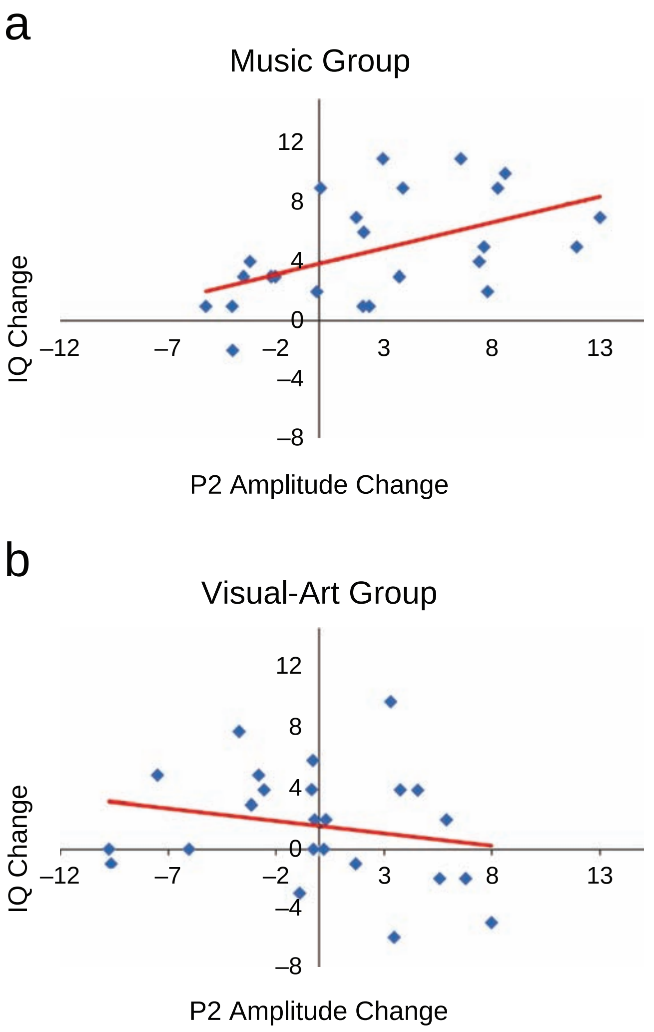

Fig. 5. Scatter plots (with best-fitting regression lines) showing the correlation between change in verbal intelligence score (i.e., posttest score − pretest score) and change in peak P2 signal amplitude (i.e., posttest P2 amplitude − pretest P2 amplitude) for the (a) music group and (b) visual-art group.

parieto-occipital brain regions (Schulze, Mueller, & Koelsch, 2011), and these same brain areas are also involved in the visual P2 (Omoto et al., 2010). Thus, music training influences the P2 through brain resources that are common across cognitive tasks.

We advance a shared-resources explanation for the correlation we found between brain plasticity and intelligence. Studies investigating a visual P2 component have found associations between the P2 and higher-level processes (memory: Dunn, Dunn, Languis, & Andrew, 1998, and Lefebvre, Marchand, Eskes, & Connolly, 2005; semantic processing: Federmeier & Kutas, 2002). Further, studies investigating the structural correlates of the P2 showed that this ERP component was evoked by parieto-occipital brain regions that are also involved in intelligence (P-FIT model: Jung & Haier, 2007). Therefore, our finding of a correlation between this functional plasticity and verbal intelligence is further evidence that increased P2 amplitude is not solely a perceptual-training effect. This correlation also reflects the influence of music training on higher cognitive processing (Bialystok & DePape, 2009) and highlights the possible identification of a brain mechanism that can be interpreted as a potentiator of a general processing network. In conclusion, these findings corroborate the shared-resources hypothesis and suggest that broad transfer is enabled by sharing of a brain network between higher-level cognitive activities.

Although the same tests were used in the pretest and posttest sessions, we do not believe that practice effects or item-specific memory can account for our results. Practice effects would be expected equally in the two training groups, especially because the children were pseudorandomly assigned to the groups. Although posttest improvements were found for both groups, the results showed improvements that were specific to the training (i.e., only verbal scores improved in the music group). Although a possible effect of item-specific memory may be of concern because there is some evidence for a correlation between verbal memory and musicianship (Ho, Cheung, & Chan, 2003), we do not believe there is any evidence that the music group simply remembered more of the words for the posttest than the visual-art group did. First, memory span in early childhood is small (i.e., 7 ± 2 items), so it would be challenging for a 4- to 6-year-old child to memorize 32 words in less than 10 min. Moreover, the children were never aware of the correct answer, so memorizing the words would not have improved their scores. Most important, the fact that only one of the groups showed a positive correlation between brain plasticity (P2) and verbal IQ changes suggests a link between the specific training and the verbal IQ outcome, rather than improvement due to repeated testing. For these reasons, we believe that the use of the same instruments for the pretest and posttest sessions in our particular experimental design is not problematic.

Our findings demonstrate a causal relationship between music training and improvements in language and executive functions, supporting the possibility of broad transfer between high-level cognitive activities. The strength of our results (i.e., over 90% of our music-group participants showed improvement in verbal intelligence) confirms that our multidimensional computerized training fully engaged children. These findings are relevant for education for two reasons. First, evidence has shown that WPPSI Verbal IQ (i.e., composite Verbal score) is highly predictive of academic achievement (Kaplan, 1996) and that there is a strong relationship between IQ evaluated at age 5 (using the WPPSI) and IQ evaluated later in life, with correlations ranging from .72 to .92 (Yule, Gold, & Busch, 1982). Second, computerized tutorials make it easier to implement training in educational environments such as classrooms and clinical settings. Therefore, the success of our computerized training is encouraging. Our findings open a new path for conceptualizing both education and rehabilitation, for improving them by using computerized technologies, and for developing viable programs in neuroeducation and neurorehabilitation.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

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