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Music Training Improves Verbal but Not Visual Memory: Cross-Sectional and Longitudinal Explorations in Children

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The hypothesis that music training can improve verbal memory was tested in children. The results showed that children with music training demonstrated better verbal but not visual memory than did their counterparts without such training. When these children were followed up after a year, those who had begun or continued music training demonstrated significant verbal memory improvement. Students who discontinued the training did not show any improvement. Contrary to the differences in verbal memory between the groups, their changes in visual memory were not significantly different. Consistent with previous findings for adults (A. S. Chan, Y. Ho, & M. Cheung, 1998), the results suggest that music training systematically affects memory processing in accordance with possible neuroanatomical modifications in the left temporal lobe.

Decades of study have demonstrated that early experience in life affects brain structures and cognitive functions in both animals (e.g., Hebb, 1947; Wiesel & Hubel, 1963; for a detailed review, see Greenough & Black, 1992) and humans (e.g., Bremner & Narayan, 1998; Dawson, Ashman, & Carver, 2000; Kaufman & Charney, 2001; Lenneberg, 1967; Roeder et al., 1999). Recently, researchers have begun to investigate the intrinsic connections between the changes of the neuroanatomical structures that relate to experience and the consequential development of associated cognitive functions (e.g., Bremner & Narayan, 1998; Chan, Ho, & Cheung, 1998; Kolb, 1996). Chan et al. proposed that the impact of early life experience on the development of cognitive functions is predictable when an association with the effect of experience on neuroanatomy is established. They theorized that because cognitive functions are highly localized in the brain, and different parts of the brain mediate specific cognitive functions, the degree of an individual's cognitive function should be associated with changes in neuroanatomical systems.

To examine the specificity of the effect of experience on cognitive functions with the neuroanatomical model, Chan et al. (1998) studied the memory of individuals who have undertaken music training. They studied this group because a previous study compared the brain structures of a group of musicians and nonmusicians and demonstrated that individuals with music training tended to have an enlarged left planum temporale when compared with individuals without music training (Schlaug, Jancke, Huang, & Steinmetz, 1995). This finding suggests that different experience (e.g., music training) affects the development of the cortical system in a specific pattern (enlarged left but not right planum temporale).

If the development of cognitive function is associated with brain development, then the memory function of individuals with music training should demonstrate a predictable pattern that follows the localization of cognitive functions. Specifically, studies of patients with brain damage have shown that the left temporal lobe primarily mediates verbal memory (e.g., Frisk & Milner, 1990; Milner, 1954, 1972, 1975) and that visual memory is mainly processed by the right temporal region (e.g., Jones-Gotman, 1986; Kimura, 1963; Milner, 1954, 1968, 1972, 1975; Saykin et al., 1992; Smith & Milner, 1981). Thus, if the neuroanatomical change is associated with the localization of cognitive function, then individuals with music training should demonstrate better verbal but not visual memory, given that their left but not right temporal lobe is assumed to be better developed. Indeed, our results support the finding that young adults with at least 6 years of music training demonstrate better verbal but not visual memory than those without such training (Chan et al., 1998). Although individuals with music training perform significantly better on the Hong Kong List Learning Test (HKLLT; Chan & Kwok, 1999), which is a verbal learning test similar to other widely used tests such as the California Verbal Learning Test (Delis, Kramer, Kaplan, & Ober, 1987) and Rey Auditory Verbal Learning Test (Rey, 1964; E. M. Taylor, 1959), their performances on the Benton Visual Retention Test (Sivan, 1992) and the Rey–Osterrieth Complex Figure Test (ROCF;

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Rey, 1941; Osterrieth, 1944) are not significantly different from those of their counterparts.

Although some studies have reported that musicians have better developed cognitive functions than do nonmusicians (e.g., Gardiner, Fox, Knowles, & Jeffrey, 1996; Rauscher et al., 1997), Chan et al. (1998) added to our understanding of the specific nature of this development. That is, they showed that whereas individuals with music training have better verbal memory than their age- and education-matched counterparts, there is no difference in other domains of functioning, such as academic performance (in terms of grade point average) and visual memory. Thus, depending on type of early life experience, the development of neuroanatomical systems and their associated cognitive functions seems to be shaped in a systematic fashion.

Although there is encouraging evidence to support the hypothesis that the development of cognitive function can be systematically shaped by early life experiences, that evidence is preliminary. To further test the hypothesis, the study that is described herein examined samples from cohorts other than those of young adults, but with expectations of similar results. Because only individuals with long durations of music training (i.e., more than 5 years) were studied previously (Chan et al., 1998), it was important to establish the temporal relation between the duration of music training and the improvement of memory. To address the above issues, in the first experiment in the present study we compared the verbal and visual memory of children with various durations of music training (0–5 years). It was anticipated that, consistent with our previous results for adults, children with music training would demonstrate better verbal but not visual memory than those without such training. It was also anticipated that there would be a significant correlation between the duration of music training and the proficiency of verbal memory.

The cross-sectional design mentioned above addressed two important issues that were related to the hypothesis. However, the causal relationship could not be drawn unless longitudinal data were available. Therefore, the second experiment of the present study followed up a group of participants in a school orchestra after 1 year. Some of the students terminated their training within 3 months of the baseline assessment, some joined the orchestra after the assessment, and others continued their training for an additional year. It was hypothesized that only children who had received music training, with the exception of those who terminated their training, would demonstrate improved verbal memory.

Experiment 1: A Cross-Sectional Study

The first objective of the experiment was to explore the effect of music training on the memory of children. Particularly, the experiment aimed to investigate whether the dissociations in behavioral patterns (i.e., better verbal but not visual memory performances) that had been observed in young adults with music training could also be found in children. Children were chosen as the target not only because they were from a different cohort but also because their brains are generally more plastic (e.g., Bates et al., 2001; Kolb, 1999) and their cognitive functions are more readily modified by environment and experience (e.g., Dawson et al., 2000; J. S. Johnson & Newport, 1989; H. G. Taylor & Alden, 1997).

The second objective of the present experiment was to further refine the theory in terms of the temporal relationship between the duration of music training and the development of verbal memory. Thus, children with various durations of music training (i.e., 0–5 years) were recruited. Such an investigation promised to provide evidence against attributions of the observed better verbal memory to factors other than music training. Moreover, to validate the specificity of the effect of music training on the development of verbal memory, the temporal relationship between the duration of training and visual memory had to be examined. If music training selectively improved verbal but not visual memory, then no correlation between the training duration and visual memory performance would be found.

Method

Participants

Ninety male right-handed participants ages 6 to 15 ($M = 10.66$, $SD = 2.39$) were recruited on a voluntary basis from Raimondi College, which is an elementary and high school for boys in Hong Kong. Forty-five of the participants had musical training (MT); they were members of the Band and Orchestra Program of the school, and they had traditional (i.e., classical) lessons in playing classical music with Western instruments (e.g., violin or flute) for at least 1 hr per week provided by professional instructors from the Hong Kong Academy for Performing Arts. At the time of assessment, they had already participated in the program for 1 to 5 years ($M = 2.6$ years, $SD = 1.48$ years). The rest of the participants had no such musical training (NMT) and were the schoolmates of the MT group. Their demographic information is shown in Table 1. Two-tailed t tests demonstrated that the two groups were matched ($p > .05$) in terms of age, education level, and socioeconomic characteristics, including parental education levels and family income. All of the participants reported a negative history of head injury and neurological or psychiatric problems. Written informed consent was obtained from all of the participants and their parents prior to the experiment.

Materials

Verbal memory measures. The HKLLT–Form One, which is a sensitive verbal memory test (Chan et al., 1998; Chan, Kwok, et al., 2000; Cheung, Chan, Law, Chan, & Tse, 2000; Chan, Ho, & Poon, 2002), was chosen to assess the verbal learning and memory abilities of the participants. The test is a 16 two-character Chinese word list, and it was presented orally to each participant three times. The participants were asked to recall as many words as possible in the three learning trials and after 10-min and 30-min delayed recall trials. The total learning score, with a maximum of 48 points, was obtained by summing the number of words that were recalled during the first three learning trials. Verbal retention ability was evaluated—(number of words recalled in the delayed trials/number of words learned in Learning Trial 3) $\times$ 100%—and then analyzed.

Visual memory measures. The Brief Visuospatial Memory Test—Revised (BVMT–R; Benedict, 1997) was used to assess the

Table 1
Demographic Characteristics of the Music Training (MT) and No Music Training (NMT) Groups

Variable	MT (n = 45) *M*	MT (n = 45) *SD*	NMT (n = 45) *M*	NMT (n = 45) *SD*	*t*	*df*	*p*
Age (years)	10.99	2.20	10.32	2.55	−1.33	88	.19
Education level (years)	5.44	2.04	4.69	2.47	−1.58	88	.12
Father's education level (years)[a]	11.78	2.99	12.09	2.77	0.51	87	.61
Mother's education level (years)[a]	11.13	1.77	11.25	2.14	0.28	87	.78
Family income (thousands of HK$)[a]	41.41	25.21	49.84	35.85	1.28	86	.21

Note. HK$ = Hong Kong dollars.
[a] Response rates ranged from 98% to 99%.

visual learning and memory abilities of the participants. This test was chosen for its brevity and procedural similarity to the HKLLT to allow a clearer comparison between verbal and visual learning and memory abilities. The total learning score, with a maximum of 36 points, was obtained by summing the scores across the three learning trials. Retention scores in the 10-min and 30-min delayed recall trials were calculated as follows: (number of designs recalled in the delayed trials/number of designs learned in Learning Trial 3) × 100%.

To rule out the effect of test specificity, the ROCF was also used to assess visuospatial constructional and visual memory ability. This is often perceived as a test of visual memory (Lezak, 1995; Spreen & Strauss, 1998), and as it is relatively more difficult than the BVMT–R, it promised to be more sensitive to the differences in visual ability between groups. The immediate recall trial was followed by a 30-min delayed recall trial. The figure was scored according to Taylor scoring criteria based on the accuracy and position of the details that were drawn, with a maximum of 36 points (E. M. Taylor, 1959).

Measure of general intelligence. To investigate any possible confounding effect of differences in general intelligence among the participants on the results, the Hong Kong Weschler Intelligence Scale for Children (HK WISC; Psychological Corporation, 1981) was also administered. A short form, which consisted of two Verbal and two Performance subtests, was chosen for the general representation of the participants' verbal and performance skills. Their Verbal IQ was prorated from the Vocabulary and Digit Span subtests, and their Performance IQ was prorated from the Picture Completion and Block Design subtests. These subtests were chosen for their excellent reliability and high correlation with Full Scale IQ (Sattler, 1992).

The battery of tests was administered to each participant by well-trained research assistants. The research assistants were blind to the music training background of the participants.

Results

General Intelligence

Two-tailed *t* tests of participants' scores on the HK WISC indicated that the MT and the NMT groups were matched in terms of their prorated Full Scale IQ, $t(88) = -1.70$; Verbal IQ, $t(88) = -1.56$; and Performance IQ, $t(88) = -1.50$ (all *p*s *ns*; see Table 2).

Verbal Memory Abilities

Figure 1a presents the mean percentage of the number of words that were recalled in the three learning trials and the two delayed recall trials of the HKLLT. A Group (MT, NMT) × Trial (Learning Trials 1 to 3) repeated measures analysis of variance (ANOVA) was conducted to investigate the possible effect of music training on the verbal learning ability of the children. The main group effect was significant, $F(1, 88) = 25.93$, $p < .001$, which suggests that participants in the MT group generally recalled more words than did those in the NMT group. The total learning scores across the three trials showed that the MT group ($M = 32.31$, $SD = 5.07$) learned approximately 20% more words than did the NMT group ($M = 27.00$, $SD = 4.82$). The main trial effect was also significant, $F(2, 176) = 332.73$, $p < .001$. Post hoc *t* tests showed that participants generally learned more words in the second trial than they did in the first, and they learned more words in the third trial than they did in the second. The Group × Trial interaction effect was not significant, $F(2, 176) = 0.10$, which indicated a similar verbal learning pattern in the two groups.

Table 2
General Intelligence of the Music Training (MT) and No Music Training (NMT) Groups

Variable	MT (n = 45) *M*	MT (n = 45) *SD*	NMT (n = 45) *M*	NMT (n = 45) *SD*	*t*(88)	*p*
HK WISC Full IQ[a]	121.40	10.20	117.29	12.62	−1.70	.09
HK WISC Verbal IQ[a]	117.49	11.42	113.64	11.95	−1.56	.12
HK WISC Performance IQ[a]	121.07	12.47	116.51	16.07	−1.50	.14

Note. HK WISC = Hong Kong Weschler Intelligence Scale for Children.
[a] Prorated.

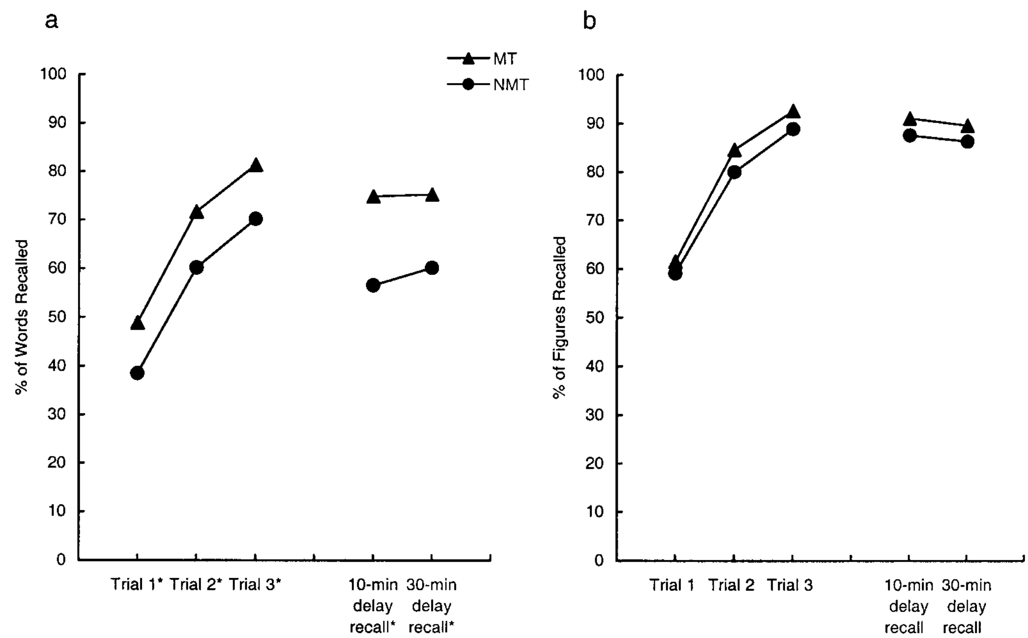

Figure 1. a: Percentage of words recalled in Learning Trials 1–3 and under 10-min and 30-min delayed conditions for the music training (MT) and the no music training (NMT) groups on the Hong Kong List Learning Test. b: Percentage of figures recalled in Learning Trials 1–3 and under 10-min and 30-min delayed conditions for the MT and the NMT groups on the Brief Visuospatial Memory Test—Revised. * $p < .05$.

A Group (MT, NMT) × Recall Condition (10-min delayed, 30-min delayed) repeated measures ANOVA was used to analyze the percentages of words that were retained in the 10-min and 30-min delayed recall trials to examine the effect of music training on verbal retention ability. The main group effect was significant, $F(1, 88) = 10.69$, $p < .01$, which demonstrated that participants in the MT group generally had better verbal retention ability than those in the NMT group. The main recall condition effect was also significant, $F(1, 88) = 4.41$, $p < .05$. A post hoc *t* test revealed that the participants generally recalled more words in the 30-min delayed recall trial than they did in the 10-min trial. However, inspection of the retention scores revealed only a very small difference between the two trials (10-min, $M = 10.51$, $SD = 2.91$; 30-min, $M = 10.83$, $SD = 2.76$).

Visual Memory Abilities

Figure 1b displays the mean percentage of scores of the MT and the NMT groups that were obtained in the three learning trials and the two delayed-recall trials of the BVMT–R. A Group (MT, NMT) × Trial (Learning Trials 1 to 3) repeated measures ANOVA was used to investigate the effect of music training on the visual learning ability of the children. The main group effect was not significant, $F(1, 88) = 1.38$, which suggested that the participants in both groups had similar visual learning abilities (MT, $M = 28.64$, $SD = 4.40$; NMT, $M = 27.36$, $SD = 5.90$). The main trial effect was significant, $F(2, 176) = 196.99$, $p < .001$, although the Group × Trial interaction effect was not, $F(2, 176) = 0.25$. Post hoc *t* tests showed that the children generally learned more figures in the second trial than they did in the first and learned more figures in the third trial than they did in the second.

A Group (MT, NMT) × Recall Condition (10-min delayed, 30-min delayed) repeated measures ANOVA was used to analyze the retention scores in the 10-min and 30-min delayed recall trials to examine the effect of music training on visual retention ability. The main group effect, $F(1, 88) = 0.11$; the main recall condition effect, $F(1, 88) = 1.68$; and the Group × Recall Condition interaction, $F(1, 88) = 0.01$, were not significant. The results suggested that there was no difference in visual retention ability and pattern across recall conditions between the two groups and that the participants performed similarly in the 10-min and 30-min delayed recall trials.

Comparisons of the copy trial scores of the two groups on the ROCF (raw scores: MT, $M = 26.60$, $SD = 4.15$, and NMT, $M = 26.88$, $SD = 4.17$, $t(88) = 0.32$; age-scaled *z* scores: MT, $M = -0.47$, $SD = 0.94$, and NMT, $M = -0.25$, $SD = 0.89$, $t(88) = 0.25$) showed no difference in visuospatial constructional ability. Analyses of the scores that were obtained in the immediate (MT, $M = 18.63$, $SD = 5.89$, and NMT, $M = 16.60$, $SD = 6.78$, $t(88) = -1.52$) and the 30-min delayed (MT, $M = 17.72$, $SD = 5.69$, and NMT, $M = 16.30$, $SD = 6.63$, $t(88) = -1.09$) recall trials on the ROCF again yielded no difference in visual memory abilities, and these results were consistent with the findings that were obtained from the

BVMT–R. In general, the results were consistent with our previous study (Chan et al., 1998) and supported our hypothesis that music training selectively affected verbal but not visual memory.

Duration of Music Training and Verbal Memory

As a relatively large number of correlation analyses (number of individual analyses = 16) were conducted, Bonferroni's correction procedure was used to adjust the alpha value to minimize the problem of inflated Type I error, and this resulted in an adjusted significance level of .003.

The Pearson product–moment correlation ($n = 90$) on the total verbal learning score and the duration of music training yielded a significant result ($r = .59$, $p < .001$). To explore whether this relation was confounded by nonmusical factors, the correlations between the two variables and four demographic characteristics (age, education level, family income, and parental education levels), as well as the general intelligence scores of the participants, were examined (see Table 3). The results showed that the total verbal learning score was significantly correlated with age ($r = .50$, $p < .001$) and education level ($r = .51$, $p < .001$), but not with other demographic characteristics and the intelligence score. The duration of music training was not correlated with all demographic characteristics and the general intelligence score at the adjusted alpha level.

To further evaluate whether or not the positive relationship between the duration of music training and verbal learning performance still holds after ruling out possible confounding factors, including the age and education level of the participants, we computed a partial correlation. The results showed that the correlation between the duration of such training and the verbal learning score ($r = .54$, $p < .001$) remained significant even after controlling the effects of age and education level.

Duration of Music Training and Visual Memory

To evaluate the specificity of the effect of music training on verbal memory, we also explored the relationship between the duration of music training and visual memory performance. Correlational analyses showed no significant relationships between the duration of music training and visual learning ($r = .22$) and visual memory ($r = .21$) abilities as measured by the BVMT–R and the ROCF, respectively.

Discussion

Children with music training demonstrated better verbal but not visual memory than those without such training. Given that the two groups of participants were matched in terms of their intelligence scores, the differences in their verbal memory could not be attributed to variations of their general intelligence. In addition, the compatible performance in both the BVMT–R and the more difficult ROCF between the MT group and the NMT group suggests that the absence of differences in visual memory abilities could not be attributed to test sensitivity. Therefore, the results were consistent with our previous findings (Chan et al., 1998) and suggested that both adults and children with music training demonstrate better verbal but not visual memory than do their counterparts without this training background. These findings do not seem to be specific to the Chinese population because a similar verbal memory advantage has been demonstrated in groups of young adults with music training in Canada (Kilgour, Jakobson, & Cuddy, 2000). In the Canadian study, young adults with music training performed significantly better in recalling verbal materials than did the control participants across all conditions, including immediate and 15-min delayed recall trials in three experiments, and the results were consistent after controlling for the effects of general intelligence. Hence, it seems that the effect of music training on verbal memory can be observed in different cohorts and countries.

The results of the present study suggest that the beneficial effect of music training on verbal memory can be demonstrated in individuals with shorter durations of such training, that is, less than 6 years of music training. A positive correlation between the duration of music training and verbal memory was found, even after controlling for the effects of age and education level. That is, the more music training

Table 3
Correlations Between the Total Verbal Learning Score and the Duration of Music Training and the Demographic Characteristics as Well as the General Intelligence Scores of the Participants (N = 90)

Variable	Total verbal learning		Duration of music training	
	r	*p*	*r*	*p*
Age (years)	.499	.000	.282	.007
Education level (years)	.509	.000	.297	.004
Father's education level (years)[a]	−.069	.523	.016	.880
Mother's education level (years)[a]	−.084	.431	.021	.842
Family income (thousands of HK$)[a]	−.196	.068	−.146	.175
HK WISC Full Scale IQ[b]	.292	.005	.183	.084

Note. HK$ = Hong Kong dollars; HK WISC = Hong Kong Weschler Intelligence Scale for Children. Adjusted alpha level = .003.
[a] Response rates ranged from 98% to 99%. [b] Prorated.

during childhood, the better the verbal memory. This strongly implies that the better verbal memory in children with music training is not simply a matter of differences in age, education level, or their family's socioeconomic characteristics. The finding is also consistent with our speculation that an increase in the duration of music training might lead to a greater extent of cortical reorganization in the left temporal region and thus yield increasingly better verbal learning ability. This argument is in parallel with neuroimaging evidence that shows that taxi drivers with extensive navigation experience have a larger right posterior hippocampus, which is thought to be responsible for their better spatial processing (Maguire et al., 2000).

It is worth noting, however, that although in the present sample a linear positive relationship between the duration of music training and verbal memory was found, infinite enhancement of memory with increasing years of music training seems less probable. Although an optimal amount of music training that contributes to greatest benefit in verbal memory is expected, it is suggested that further studies continue the exploration of such a relationship in individuals with a wider range of music training.

Experiment 2: A Longitudinal Study

Although the findings of Experiment 1 suggest the possibility of a causal effect of music training on the improvement of verbal memory, the correlational nature of the study limited the drawing of further inferences. To isolate causal evidence for the theory, in Experiment 2 we traced and compared the changes in verbal memory among a subgroup of children who participated in Experiment 1. These were children who began or continued to receive music training from the Band and Orchestra Program of the school for 1 year and those who were members of the orchestra but had terminated their training within 3 months of the baseline measurement. It was anticipated that those who had received music training during the whole period would demonstrate more improvement in verbal memory than would those who had terminated their training. Moreover, to investigate the specific effect of music training on modifying the development of verbal memory, the change in visual memory among the groups was examined and compared. On the basis of the assumption that music training would affect only verbal and not visual memory development, it was predicted that the three groups of children would show no differences in their changes in visual memory.

Method

Participants

Members of the Band and Orchestra Program of Raimondi College who had participated in Experiment 1 were recruited voluntarily after 1 year. Thirty-three of the 45 members in the MT group participated in this follow-up experiment, which indicated a 26.7% dropout rate. Two-tailed *t* tests suggested that there was no difference between the participants and those who dropped out in their age, education level, family income, parental education levels, general intelligence, and verbal and visual memory abilities at an adjusted alpha level of .006. The participants were categorized into two groups according to their music training backgrounds. The continued training group ($n = 24$) were those who undertook music training ($M = 2.46$ years, $SD = 1.59$ years) at baseline (i.e., at Experiment 1) and who continued their training for an additional year until the second experiment. The discontinued training group ($n = 9$) were those who received music training at baseline ($M = 2.83$ years, $SD = 1.62$ years) but who had not attended lessons for at least 9 months before the second experiment. Among the NMT group in Experiment 1, 17 children started music training after the assessment. They were classified as the beginners group, which represented children who had no music training at baseline and had received such training for a year until the second experiment. The participation in or termination of music training was decided on a voluntary basis. The demographic information and intelligence scores of all participants are shown in Table 4. ANOVA results suggested that the three groups were generally matched in terms of their demographic characteristics and intelligence scores, although significant but small differences in age, $F(2, 47) = 4.85$, $p < .05$, and education level, $F(2, 47) = 6.34$, $p < .01$, were found. Post hoc comparisons using Tukey's honestly significant difference (HSD) test indicated that the beginners group was younger in age and lower in education level than the continued training group. No other group differences were found.

Table 4
Demographic Characteristics and General Intelligence of the Beginners, the Continued, and the Discontinued Training Groups

Variable	Beginners ($n = 17$)		Continued ($n = 24$)		Discontinued ($n = 9$)				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*df*	*p*
Age (years)	8.88	1.96	10.98	2.22	10.67	2.45	4.85	2, 47	.01
Education level (years)	3.24	1.99	5.54	2.04	5.11	2.37	6.34	2, 47	.00
Father's education level (years)[a]	13.44	2.48	12.83	2.93	11.33	1.94	1.86	2, 46	.17
Mother's education level (years)[a]	12.13	2.09	11.08	1.72	11.89	1.62	1.72	2, 46	.19
Family income (thousands of HK$)[a]	62.00	38.65	47.83	31.07	31.78	12.34	2.70	2, 45	.08
HK WISC Full Scale IQ[b]	115.69	11.38	121.75	11.36	122.75	8.68	1.78	2, 45	.18
HK WISC Verbal IQ[b]	113.04	12.22	117.14	11.06	120.67	12.25	1.34	2, 47	.27
HK WISC Performance IQ[b]	114.88	14.96	121.83	14.39	119.22	0.07	1.28	2, 47	.29

Note. HK$ = Hong Kong dollars; HK WISC = Hong Kong Weschler Intelligence Scale for Children.
[a] Response rates ranged from 96% to 98%. [b] Prorated.

Materials

The HKLLT–Form One and the BVMT–R, which were used in the Experiment 1, were chosen again to assess the verbal and visual memory abilities of the participants.

Results

Verbal Learning and Retention Ability

A Group (beginners, continued, discontinued) × Condition (baseline, follow-up) repeated measures ANOVA was conducted to compare the verbal total learning scores in the HKLLT among the three groups at both baseline, from the initial assessment completed at the beginning of Experiment 1, and the follow-up (see Figure 2a). The Group × Condition interaction, $F(2, 47) = 4.99$, $p < .05$, was significant, and therefore the simple group and condition effects were examined. One-way ANOVA results suggested a group difference in the verbal total learning score at the baseline measurement, $F(2, 47) = 9.11$, $p < .01$. Post hoc Tukey's HSD comparisons revealed that the verbal learning ability of the beginners group was significantly lower than those of the continued and discontinued training groups. The continued and discontinued training groups did not differ from each other in verbal learning scores. This is consistent with the cross-sectional data of both our previous study (Chan et al., 1998) and Experiment 1, which showed that individuals with music training demonstrated better verbal memory than those without such training.

However, at the 1-year follow-up measurement, no group difference was found, $F(2, 47) = 2.33$. Further investigations with paired *t* tests suggested that the nonsignificant group difference may have been due to the significant improvement in the verbal total learning score ($M = 15.63\%$, $SD = 18.88\%$) of the beginners group after 1 year of training, $t(16) = 3.47$, $p < .01$. The continued training group also demonstrated significant improvement ($M = 10.17\%$, $SD = 14.88\%$) in their verbal learning ability, $t(23) = 3.37$, $p < .01$. However, there was no significant change in the verbal learning score ($M = -3.94\%$, $SD = 9.05\%$) of the discontinued training group after 1 year, $t(8) = -1.35$. These findings support the hypothesis that those who received music training and did not terminate it would improve their verbal memory.

Table 5 shows the mean verbal retention scores of the three groups at baseline and at the 1-year follow-up and their respective percentage changes. Consistent with the results from the learning trials, an ANOVA of the two delayed recall trials revealed significant group differences in the retention scores at baseline: 10-min, $F(2, 47) = 7.68$, $p < .01$; 30-min, $F(2, 47) = 6.68$, $p < .01$. Similarly, at the follow-up testing no group difference was found—10-min, $F(2, 47) = 2.39$—with the exception in the 30-min delayed recall trials, $F(2, 47) = 4.90$, $p < .05$, that the continued training group still retained significantly more words than the beginners. Nevertheless, the difference between the retention scores of the beginners group and those of the

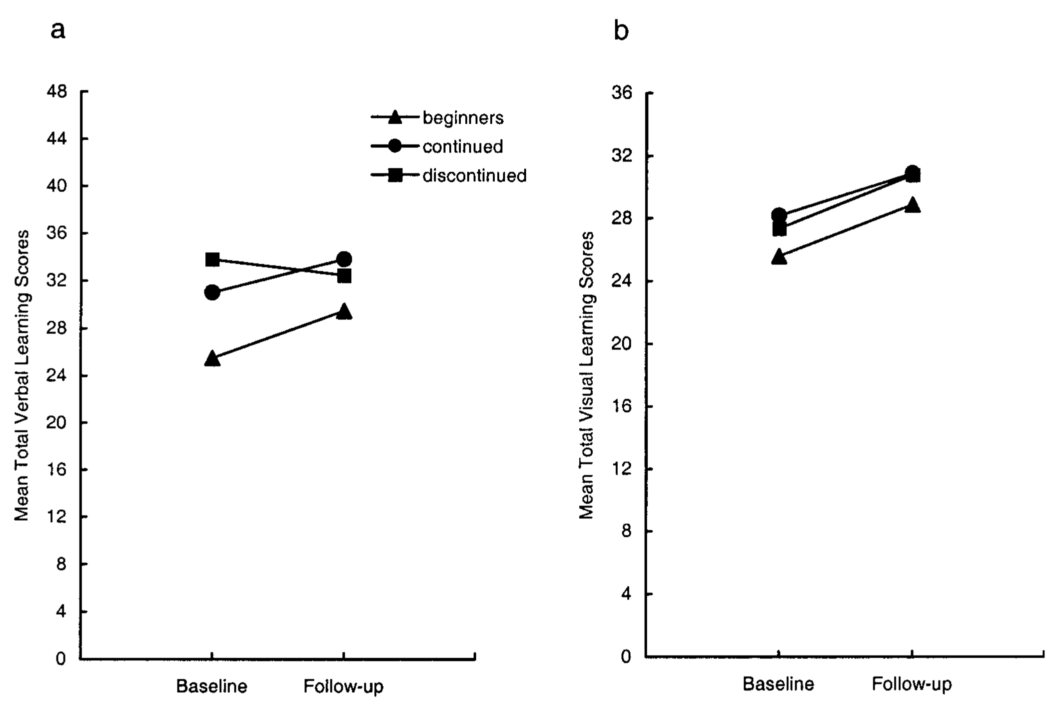

Figure 2. a: Mean total verbal learning scores for the beginners, the continued training, and the discontinued training groups on the Hong Kong List Learning Test. b: Mean total visual learning scores for the beginners, the continued training, and the discontinued training groups on the Brief Visuospatial Memory Test—Revised.

Table 5
Verbal Retention Scores of the Beginners, the Continued, and the Discontinued Training Groups at Baseline and at the 1-Year Follow-up, and Their Respective Percentage Changes

Test	Beginners ($n = 17$)		Continued ($n = 24$)		Discontinued ($n = 9$)			
	M	*SD*	*M*	*SD*	*M*	*SD*	$F(2, 47)$	*p*
10-min retention								
Baseline	8.71	2.39	11.33	3.00	12.67	2.35	7.68	.001
Follow-up	10.35	2.89	12.38	2.87	11.33	3.16	2.39	.103
% change	25.68*	45.48	12.65*	26.97	−9.97	19.31		
30-min retention								
Baseline	8.94	2.73	11.58	2.72	12.22	2.05	6.68	.003
Follow-up	10.12	2.69	12.79	2.70	12.56	3.24	4.90	.012
% change	21.99†	48.38	12.44**	20.04	1.32	14.33		

† $p < .10$ (marginally significant). * $p < .05$. ** $p < .01$.

discontinued training group diminished to a nonsignificant level after 1 year as suggested by post hoc Tukey's HSD tests.

Moreover, the beginners and the continued training groups improved or tended to improve significantly in their verbal retention scores: beginners, 10-min, $t(16) = 2.33$, $p < .05$, and 30-min, $t(16) = 1.87$, $p = .079$; continued, 10-min, $t(23) = 2.30$, $p < .05$, and 30-min, $t(23) = 3.04$, $p < .01$. However, the discontinued training group failed to show such improvement, or any trend to improve: 10-min, $t(8) = -1.55$, $p = .16$, and 30-min, $t(8) = 0.28$, $p = .79$ (see Table 5).

As the sample sizes of the individual groups were relatively small and unequal, the above findings were reanalyzed with nonparametric tests, including the Kruskal–Wallis test, the Mann–Whitney test, and the Wilcoxon signed ranks test, and the results were consistent with the findings from ANOVA. Therefore, those who participated in, but not those who terminated, the music training program generally improved or tended to improve in their verbal learning and retention abilities.

One may argue that age and/or educational level might be a contributing factor for the above findings because the beginners were younger and attained a lower education level than the other two groups. To rule out the possible confounding effects of age and education level on the results, the correlation between the two variables and the total verbal learning and retention scores were computed. No correlation was found between the two variables and the percentage changes in the total verbal learning (age, $r = -.16$; education level, $r = -.13$), 10-min delayed (age, $r = .01$; education level, $r = .01$), and 30-min delayed (age, $r = -.04$; education level, $r = -.01$) retention scores of the participants. In addition, both the beginners and the relatively older continued training group showed significant improvement in their verbal memory ability, whereas the discontinued training group did not demonstrate any improvement even though they were similar in age and education level to the continued training group. Thus, it was unlikely that the observed improvement was attributable to age and education factors.

Visual Learning and Retention Ability

A Group (beginners, continued, discontinued) × Condition (baseline, follow-up) repeated measures ANOVA of the total learning scores of the BVMT–R showed no significant interaction effect, $F(2, 47) = 0.19$, or main group effect, $F(2, 47) = 2.07$ (see Figure 2b). Only the main condition effect was significant, $F(1, 47) = 30.09$, $p < .01$. Similar analyses of the 10-min and 30-min delayed recall scores of the BVMT–R showed findings that were consistent with those mentioned above. In both cases, the Group × Condition interaction—10-min, $F(2, 47) = 1.29$; 30-min, $F(2, 47) = 0.19$—and main group—10-min, $F(2, 47) = 0.88$; 30-min, $F(2, 47) = 2.56$—effects were not significant. Only the main condition effect—10-min, $F(1, 47) = 6.56$, $p < .05$; 30-min, $F(1, 47) = 13.40$, $p < .01$—was significant. The absence of group differences in the visual memory scores both at baseline and at the follow-up testing was reconfirmed with nonparametric Kruskal–Wallis tests. Therefore, the present findings were consistent with both our previous study (Chan et al., 1998) and Experiment 1, which demonstrated that individuals with music training did not differ from those without such training in their visual learning and retention abilities. The results also indicate that the changes in the total visual learning and visual retention scores among the participants were independent of their participation in the music training program. This supports the hypothesis that music training does not improve visual memory.

Discussion

In this experiment, children who had received 1 year of music training (the beginners and the continued training group), regardless of their music training background, demonstrated improvement in verbal learning and retention abilities. However, those who terminated their music training within 3 months of the baseline measurement (the discontinued training group) failed to show any improvement. These findings supported the hypothesis that music training might improve verbal memory. The difference in the changes in verbal memory among the three groups could not be attributed to demographic factors, as the three groups were matched in terms of their general intelligence and socioeconomic characteristics. Although the beginners were younger and had attained lower education levels than the other two groups, our analyses showed that the observed improvement could not be attributed to these two variables. In addition, it seems inconceivable that the group differences in the verbal memory change were due to the differences in the baseline verbal memory abilities among the groups. This is because at baseline, the continued and the discontinued training groups were matched in verbal memory. At the 1-year follow-up, however, the continued training group demonstrated positive changes in verbal memory scores, which could not be observed in the discontinued training group. Moreover, the performance of the discontinued training group was comparable to that of the other two groups in the visual memory test at the follow-up, which suggests that their performance in the verbal memory test did not seem to be related to noncognitive factors such as motivation or cooperation.

One interesting finding was that although the participants in the discontinued training group did not show any improvement in their verbal memory performance after terminating their training for at least 9 months, their verbal memory performance remained stable over time. That is, they did not lose their verbal memory advantage (in comparison with the NMT group in Experiment 1) that they had gained prior to their discontinuation. We speculated that this might be because this group of children had almost 3 years of music training ($M = 2.83$, $SD = 1.62$) before discontinuing, and that their music training may have a long-lasting effect. Thus, it would be important to explore the effect of the duration of music training on the stability of verbal memory performance, but the number of participants of the discontinued group ($n = 9$) was too small for meaningful analysis. Therefore, we computed the Pearson product–moment correlation between the duration of music training and the percentage change in the total verbal learning score for the children with music training ($n = 41$). Although nonsignificant, the results showed a negative correlation between the percentage increase in verbal memory performance and the duration of music training ($r = -.26$, $p = .11$). In other words, the longer the duration of music training, the less the improvement in verbal memory tends to be. This seems to suggest that the effect of music training on verbal memory may stabilize over time and that this trend suggests the possibility of a ceiling of verbal memory improvement. Although this is consistent with our proposal in Experiment 1 of the existence of an optimal duration of music training, a larger sample with a wider range of duration of music training is needed to confirm our hypothesis.

General Discussion

The behavioral data from the present study seem to mesh well with neuroimaging findings that demonstrated an enlargement in the left planum temporale in musicians (Schlaug, Jancke, Huang, & Steinmetz, 1995). We proposed that music training during childhood might serve as a kind of sensory stimulation that somehow contributes to the reorganization/better development of the left temporal lobe in musicians, which in turn facilitates cognitive processing mediated by that specific brain area, that is, verbal memory. This concept is parallel to the idea suggested by Rauscher et al. (1997), who proposed that music training modifies the brain area responsible for spatiotemporal reasoning and that piano lessons will improve tasks that use that reasoning. More important, the findings of the present study seem to suggest that specific experience (music training in this case) might affect the development of memory in a predictable way in accordance with the localization of brain functions—that is, modification of the left temporal lobe, thus facilitating verbal memory, but not the right and visual memory. This suggests that experience might affect the development of cognitive functions in a systematic fashion. Although this proposal looks promising, at this stage, it is more a speculation than a model. Further studies to compare the neuroanatomical structures, especially on the planum temporale, of children with and without music training will be necessary to test the hypothesis.

Although the neuroimaging data is not yet available to confirm the model, this model seems to be a better explanation of the observed verbal memory advantage in individuals with music training than other possible alternative explanations. For instance, it could be argued that the better verbal memory might be related to the memorization of many musical notes common to music training. Such memorization might result in a better general memory ability, which might in turn contribute to the observed verbal memory advantage. However, this explanation could not account for the modality specificity of the memory improvement (verbal but not visual) that we found in the music training group. Moreover, the reading and memorization of musical notes seems to be related more to visual rather than verbal ability.

In fact, the speculation that music training might cause neuroanatomical changes is not without grounds. Neuroimaging evidence has revealed structural (Amunts et al., 1997; Schlaug, Jaencke, Huang, Staiger, & Steinmetz, 1995; Schlaug, Jancke, Huang, & Steinmetz, 1995) and functional (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995; Pantev et al., 1998) differences between the brains of musicians and nonmusicians. For instance, Schlaug, Lee, Thangaraj, Edelman, and Warach (1998) reported that the cerebellums of musicians are 5% larger than those of nonmusicians. They reasoned that long periods of finger exercises stimulate extra neural growth in musicians. Similarly, evidence from functional magnetic resonance imaging demonstrates a 25% increase in the cortical representation of auditory processing in musicians (Pantev et al., 1998), and the process of acquiring musical skills may cause use-dependent functional reorganization of the brain. Such diverse evidence strongly implies that music training somehow brings about changes in the cortical organization/structures of the brain. Because it is commonly acknowledged that different brain areas are responsible for different major neuropsychological functions, the effect of music training on cognitive abilities should correspond to cortical areas that have been modified by such training. In line with this notion are the results of another study (Chan, Cheung, Ho, & He, 2000) that demonstrated that the engagement of participants in certain cognitive tasks selectively improves cognitive functions that are mediated by the regions that are supposed to be activated by the tasks. Specifically, participants who engage in tasks that activate the hippocampus perform better in memory tests than they do in motor tests, whereas those that activate the primary motor cortex show better motor but not memory function. This selective improvement suggests that the effect of experience or environmental stimulation on cognitive functions should be specific to the brain areas that are affected.

The literature on hemispheric specialization has suggested that the left hemisphere is mainly responsible for language processing, and the right hemisphere is mainly responsible for music and visual functioning. Hence, the present results, which show a relationship between music training and verbal but not visual ability, seem to be counterintuitive. However, neurophysiological data such as magnetoencephalographic responses (Hirata, Kuriki, & Pantev, 1999), electroencephalograph recordings (Davidson & Schwartz, 1977; Hirshkowitz, Earle, & Paley, 1978), and behavioral evidence (Bever & Chiarello, 1974; P. R. Johnson, 1977) suggest that a shift occurs from the right hemisphere (as in most musically naive individuals) to the left hemisphere in the processing of music as the music training experience increases. Some researchers (Bever & Chiarello, 1974; Davidson & Schwartz, 1977) have reasoned that musicians use an analytical instead of a holistic style of processing music. In view of the use-dependent plasticity of the mammalian brain, which suggests that behavioral activities guide/modify the development or the synaptic connections of neural structures (Nelson & Davenport, 1999), such increases in the use of the left hemisphere might underlie the improved functioning that is mediated by the left temporal area in musicians. However, such a mechanism has yet to be determined.

The absence of difference in visual memory between children with and without music training in the present study seems to contradict previous findings (Rauscher et al., 1997) that showed significant improvement in a spatiotemporal reasoning task in preschool children who received private piano keyboard lessons as compared with their counterparts who had training on computer. This discrepancy may be due to the difference in the cognitive domains that were measured in the two studies. Whereas the visual task that was used in the present study focused on testing visual memory with less emphasis on spatial reasoning, the task that was used by Rauscher et al. emphasized the processing sequence or the ordering of events and not memory. Although the two studies examined the effects of music on neurocognitive processes, the underlying constructs that were examined were different. Therefore, the discrepant results should not be considered as contradictory.

That experience can influence the development and organization of mammalian brain structures and functions is well supported by numerous animal (e.g., Greenough & Black, 1992; Hebb, 1947; Nakamura, Kobayashi, Ohashi, & Ando, 1999; Wiesel & Hubel, 1963) and human studies (e.g., Bremner & Narayan, 1998; Dawson et al., 2000; Kaufman & Charney, 2001; Lenneberg, 1967; Maguire et al., 2000; Pally, 1997; Roeder et al., 1999). Classical examples include the beneficial effects on the development of neuroanatomical structures and functions in animals that are reared in complex and stimulating environments (e.g., Hebb, 1949; Juraska, Henderson, & Muller, 1984; Rosenzweig & Bennett, 1996; Kolb, 1996) and the detrimental effects on the development of those in animals that are deprived of sensory experience (e.g., Gordon & Stryker, 1996; Wiesel, 1982; Wiesel & Hubel, 1963). The present findings suggest that the experience of music training might improve the memory functioning that corresponds to neuroanatomical structures that might be modified by such training. The theoretical implication of the systematic mechanism of experience-induced cognitive improvement has the potential to stimulate further investigation into possible ways in which to enhance human brain functioning and to develop a blueprint for cognitive rehabilitation, such as using music training to enhance verbal memory.

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