Effects of musical training on speech-induced modulation in corticospinal excitability

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We investigated the effect of previous musical training on lateralization of language as indexed by the effects of reading aloud on the modulation of motor evoked potentials (MEPs) induced in the first dorsal interosseus muscles (FDI) by transcranial magnetic stimulation (TMS) of the primary motor cortex. We studied 13 right-handed subjects, seven musicians who had been playing a musical instrument for >10 years and six controls who had never studied a musical instrument. In all subjects, the amplitude of MEPs in the right FDI was facilitated by reading aloud. However, the musicians also showed significant facilitation in the left FDI, while controls did not. These results illustrate striking effects of musical training on lateralization of motor and language functions. *NeuroReport* 13:899–902 © 2002 Lippincott Williams & Wilkins.

Key words: Cortical excitability; Language; Motor cortex; Musical training; Transcranial magnetic stimulation

INTRODUCTION

In 1988, Schaaftsma [1] reported that MEPs induced by cortical stimulation were facilitated while the subject was reading out loud. Tokimura *et al.* [2] followed up these findings and showed that the effect of reading on corticospinal excitability is lateralized. This novel finding provided a non-invasive method for identification of the language dominant hemisphere using TMS. It remains unclear whether this method might have clinical applications, for example in the presurgical evaluation of patients by eventually replacing invasive techniques such as the Wada test [3]. While the findings of Tokimura *et al.* do suggest a close connection between language and hand motor areas, the physiological basis for which is uncertain. It is possible that changes in motor cortical excitability are non-specific and simply related to the penumbra of the blood flow and excitability changes in frontal and prefrontal, language-related structures. On the other hand, the modulation of cortico-spinal excitability in the dominant hemisphere can be caused by the activation of specific intrahemispheric cortico-cortical connections. If so, inter-individual differences in hemispheric specialization might influence such modulatory effects of language on motor cortical excitability.

Musicians are thought to have different hemispheric specialization patterns and greater interhemispheric connectivity than non-musicians. For example, the anterior half of the corpus callosum is larger in musicians trained intensively from an early age than in untrained subjects [4], and musicians have a less interhemispheric inhibition between bilateral hand motor areas [5]. These features presumably assist in the required execution of finely coordinated bimanual movements to play musical instruments proficiently. Changes in the motor system and its bihemispheric representation might influence the modulatory effects of language tasks on cortico-spinal outputs. In this study, we used single pulse TMS to examine the effects of musical training on the functional connectivity between language and bilateral hand motor areas.

MATERIALS AND METHODS

Subjects: Thirteen healthy subjects (seven male and six female), aged 19–39 years (25.6 ± 6.0, mean $\pm$ s.d.) were studied. They were all from Asian countries (nine Chinese and four Japanese). Hand preference was assessed with the 12-item Annett questionnaire [6]. All participants were classified as consistent right handers using the criteria suggested by a previous report [7]. Seven subjects were proficient instrumentalists having started learning a musical instrument ≥ 10 years prior to the study and continuing playing for ≥ 2 h/day. They were all enrolled in formal music instruction at Boston area music schools. In our study, they were defined as the musician group. The table (see Table 1) shows the details of their musical training. The other six subjects had never learnt to play a musical instrument, but were matched in handedness, average age, and gender distribution with the group of musicians. All

Table 1. Demographic characteristics of the subjects in the musician group.

Sex	Age	Handedness	Instrument	Training period (years)	Weekly practice (h)	Sight reading
M	37	R	Guitar	23	14	Possible
F	21	R	Tuba	10	21	Possible
M	25	R	Tuba	12	40	Possible
M	23	R	Oboe	10	21	Possible
M	19	R	Violin	16	14	Possible
F	25	R	Violin	16	28	Possible
F	25	R	Piano	23	40	Possible

subjects had normal neurological and general physical examinations. All gave written informed consent prior to entering the study that had been approved by the local Institutional Review Board.

Data acquisition: Subjects were seated in a comfortable chair and MEPs were recorded from bilateral FDI muscles using tin-plated electrodes with HUSH shielded cables (Dantec, Skovlunde, Denmark) with the active electrode placed over the muscle belly and the reference electrode on the interphalangeal joint. The skin under the electrode was vigorously cleaned and electrode resistance was kept $< 0.5\,\Omega$ during the experiment. Subjects were instructed to keep their hands relaxed. Responses were amplified and filtered using a Dantec Counterpoint electromyography (Dantec, Skovlunde, Denmark) with a band pass of 20–2000 Hz. Signals were digitized (digitization rate 10 kHz) using a Powerlab/8sp interface (ADInstruments, Mountain View, USA) and fed to a personal computer for off-line analysis. The peak-to-peak amplitude of the MEPs was measured and used for further analysis.

Transcranial magnetic stimulation: TMS was delivered using a Magstim model 200 (Magstim, Whitland, UK) and a figure-of-eight coil with each wing measuring 4.3 cm in diameter and a peak magnetic field of 2.2 T. The coil was positioned tangentially to the scalp, pointing anteriorly, 135° from the sagittal axis, over the optimal site on each hemisphere to elicit responses in the target muscles (right or left FDI).

Motor threshold was defined as the lowest TMS intensity to elicit MEPs of 50 μV peak-to-peak amplitude, in five of 10 successive trials in relaxed muscles. The stimulating intensity was set at about 120% of motor threshold, which could elicit MEPs with peak-to-peak amplitudes of about 500 μV.

Procedure: In front of the subjects, a computer monitor (Apple multiple screen 720 Display, 16 inch) was set at eye level to display short texts in each subject's maternal language (Chinese or Japanese) or a blank screen. The subjects were instructed to read aloud the texts on the screen or watch the center of the blank screen. The texts were scientific reports, long enough to keep subjects reading for > 2 min, without inducing emotional changes. Single pulse TMS was delivered approximately every 5 s and each hemisphere was tested for the two conditions, reading aloud and watching blank screen. The order of these conditions was randomized within and counterbalanced among subjects. The duration of each condition was 120 s and the first magnetic stimulus came at 15 s from the beginning. A total of 20 MEPs were acquired in each condition for each hemisphere.

Statistical analysis: Average MEP sizes for each condition and each subject were calculated. The difference of motor threshold was examined applying the paired *t*-test. The change of MEP size during reading aloud was expressed as percentage of the MEP size during silent watching of the blank computer screen for each subject and hemisphere. The effect of the musical background was analyzed by ANOVA with repeated measures, followed by the paired *t*-test with Bonferroni correction as a *post-hoc* test. The level of significance was set to $p < 0.05$.

RESULTS

Motor thresholds and musical background: The average motor threshold of the right and left hemisphere for musicians was 44.0 ± 5.9 and 45.9 ± 5.9, respectively. Motor thresholds in non-musician control subjects were 43.2 ± 13.3 and 45.8 ± 14.9, respectively for right and left hemispheres. There was no significant statistical difference in motor threshold according to hemispheres between musicians and non-musicians.

Facilitatory effect of reading in each hemisphere and each subject: Figure 1 demonstrates examples of the MEPs of representative subjects from the musician and control groups for the silent screen watching and the reading aloud conditions. Figure 2 shows the average MEP sizes during silent watching of the blank computer screen or during reading aloud for the two groups of subjects.

The MEPs recorded from the left FDI showed a significant interaction of subject group (musicians *vs* controls) and condition (reading aloud *vs* silent screen watching) on MEP amplitude ($F(1,11) = 7.06$, $p < 0.05$, Fig. 2a). In addition there were significant main effects of both group ($F(1,11) = 9.85$, $p < 0.01$) and condition ($F(1,11) = 19.84$, $p < 0.005$). *Post hoc* test using paired *t*-tests detected a significant increase of the MEP amplitude of left FDI induced by reading only in the subjects with musical background ($p < 0.05$).

For the MEPs of the right FDI, ANOVA showed no significant effect of the group and no significant interaction between group and condition ($F(1,11) = 0.56$, $p = 0.47$; $F(1,11) = 0.27$, $p = 0.60$, respectively), but there was a main effect of condition ($F(1,11) = 10.13$, $p < 0.01$), indicating that reading aloud facilitates the MEP size on the right hand in both groups of subjects equally (Fig. 2b).

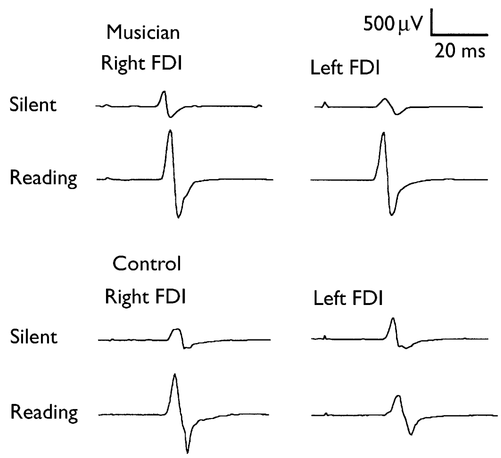

Fig. 1. Showing examples of the MEPs of one subject with musical background, elicited by TMS on the hand areas of both sides. The change of MEP size of left hand of subject with musical background during reading is larger than that of right hand.

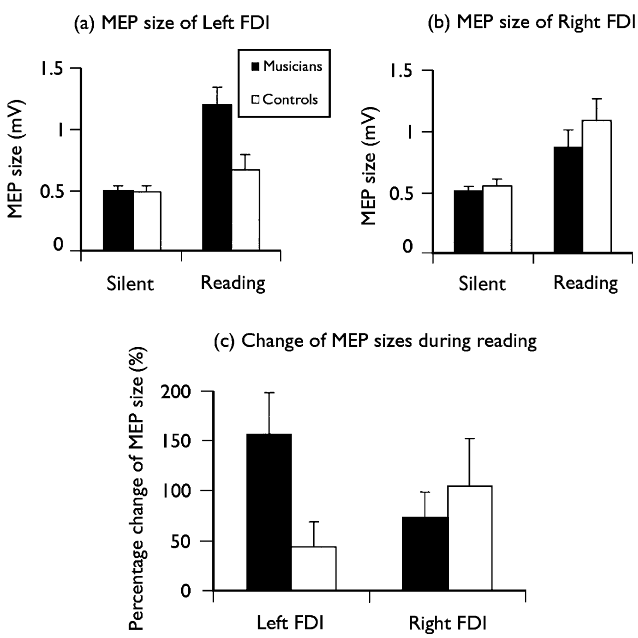

Fig. 2. Charts show the sizes of MEPs of the FDI during keeping silent or reading aloud in left (**a**) and right (**b**) hemispheres. (a) ANOVA with repeated measures showed the significant interaction between the change of MEP sizes of left FDI and the musical background ($p < 0.05$) as well as significant difference between subjects' backgrounds ($p < 0.001$) and significant changes due to reading aloud ($p < 0.005$). *Post hoc* test detected a significant increase of MEP sizes of left FDI in the subjects with musical background ($p < 0.05$), but not in those without background. (b) In the MEPs of the right FDI there was significant changes due to reading aloud ($p < 0.01$), but no significant difference and interaction due to subjects' musical backgrounds. (**c**) This chart shows the difference in facilitating effects of reading aloud on the MEPs according to tested sides and subjects' musical backgrounds. The chart demonstrates the changes, as percentages divided by MEPs recorded while keeping silent. ANOVA detected the significant interaction between musical backgrounds and sides of the MEPs ($F(1,11) = 7.92$, $p < 0.05$). The facilitation in left hands due to reading was significantly larger in subjects with musical background than those without ($p < 0.05$).

Figure 2c shows the difference of the facilitatory effects of reading aloud on the MEPs according to hemisphere and subject group. There was a significant interaction ($F(1,11) = 7.92$, $p < 0.05$) between group and hemisphere on MEP modulation (amplitude during reading aloud as a percentage change from amplitude during silent screen watching). The facilitation of MEPs induced in left hands during reading aloud was significantly larger in musicians than in controls ($p < 0.05$). Within controls, the facilitation of right FDI was significantly larger than that of left FDI. Within musicians, there was a non-significant trend for a greater facilitation of the left FDI than the right FDI. The facilitation of MEPs induced in right hands during reading loud was not different between the two groups.

DISCUSSION

Our results confirm the speech-related facilitation of the cortico-spinal projection of the dominant hemisphere to the hand, and additionally demonstrate an equally strong facilitation of the cortico-spinal projection of the non-dominant hemisphere to the hand in proficient musicians. These findings suggest that the speech related modulation of motor cortical outputs is not as lateralized in subjects with extensive musical training as in controls. Presumably, changes in the cortical organization of the motor system related to the training of musical instruments result in decreased hemispheric specialization. Several hypothesis can be considered to account for these findings.

Most important is the consideration of changes in motor system organization within and across hemispheres of musicians, which may influence the interaction between the motor and language systems. Remarkable anatomical and neurophysiological modifications have been found in musicians. Anatomically, the anterior half of the corpus callosum is larger in professional musicians especially with early commencement of their musical training [4] and the hand motor cortices were more symmetrical in key-board playing musicians than in controls [8]. Neurophysiologically, the interhemispheric inhibition is suppressed significantly in musicians, presumably for the required independent performance of each hand [5]. The musical training also modifies cerebral activity pattern associated with motor performance and musical perception [9,10]. These findings support the assumption that motor functions are less lateralized and interhemispheric interactions are enhanced in musicians, resulting in substantially improved motor skills of their non-dominant hand. It is certainly quite plausible that the intense training of a musical instrument enhances interhemispheric interaction and cortical organization of motor outputs on the non-dominant side. This change in motor representation could be reason for the bilateral speech-induced enhancement of cortico-spinal excitability observed in the present study.

The change in hemispheric lateralization of the motor representation in musicians could also involve the mirror cell system in the ventral premotor cortex. A close link between ventral premotor cortical activity and language has been proposed [11,12]. Therefore, another possible hypothesis to account for our results is the notion of increased bi-hemispheric motor-language interactions in musicians.

Musicians might also have congenitally decreased lateralization of language functions than non-musically inclined subjects. The correlation between musical talent and left-handedness is suggested, indicating less lateralized brain function in musicians [13,14]. Indeed, it could be argued that decreased lateralization of function might be a predisposing factor for musical inclination. Our subjects had started playing an instrument in their childhood, but had continued it so well enough as to make music their careers. Subjects that started to play an instrument equally early but either did not enjoy it or were not gifted enough and stopped playing would be a critical additional control group.

Alternatively, it is possible that musical training might induce changes in cortical, bihemispheric organization of language. Musical training, especially with early commencement, is suggested to produce the functional reorganization and enhance language skills [15,16]. Bilateral hemispheres including language areas are responsible for musical perception and processing [17]. Repeated bilateral recruitment during intensive and continuous training could result in bi-hemispheric localization of language function in our subjects.

Finally, our findings could be related to the effects of daily manual movements [18] and independent of musical training. However, this seems unlikely because some control subjects also performed bimanual movements such as keyboard typing everyday. Nevertheless, the best way to answer this would be to study subjects extensively trained in some manual task of a similar complexity to playing a musical instruments, but this was beyond the scope of the present study.

CONCLUSION

Our study has shown bilateral speech-induced enhancement of motor cortical excitability in subjects with musical training, who may have different intrahemispheric specialization patterns and greater interhemispheric connectivity. Although further studies are required, the findings suggest enhanced bi-hemispheric interactions and/or less lateralization of language functions between language and motor systems in musicians.

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