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Instrument specific brain activation in sensorimotor and auditory representation in musicians

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ABSTRACT

Musicians show a remarkable ability to interconnect motor patterns and sensory processing in the somatosensory and auditory domains. Many of these processes are specific for the instrument used. We were interested in the cerebral and cerebellar representations of these instrument-specific changes and therefore applied functional magnetic resonance imaging (fMRI) in two groups of instrumentalists with different instrumental training for comparable periods (approximately 15 years). The first group (trumpet players) uses tight finger and lip interaction; the second (pianists as control group) uses only the extremities for performance. fMRI tasks were balanced for instructions (piano and trumpet notes), sensory feedback (keypad and trumpet), and hand–lip interaction on the trumpet. During fMRI, both groups switched between different devices (trumpet or keypad) and performance was combined with or without auditory feedback. Playing the trumpet without any tone emission or using the mouthpiece showed an instrument training-specific activation increase in trumpet players. This was evident for the posterior–superior cerebellar hemisphere, the dominant primary sensorimotor cortex, and the left Heschl's gyrus. Additionally, trumpet players showed increased activity in the bilateral Heschl's gyrus during actual trumpet playing, although they showed significantly decreased loudness while playing with the mouthpiece in the scanner compared to pianists.

Introduction

Playing an instrument requires neural integration of multiple sensory inputs, including auditory and somatosensory feedback, and fine-motor adjustment within split seconds. Therefore, musicians are perfectly suited for studying training-dependent neural plasticity effects. Combined sensorimotor training for years with high attention focused on the sensorimotor interaction, as in professional musicians, induces increased receptive fields in the primary somatosensory cortex (S1) (Elbert et al., 1995), increased primary motor cortex (M1) representation magnitude (Lotze et al., 2003), and alterations in the primary auditory cortex (A1) (Schneider et al., 2002). These changes include timbre specificity for certain instruments (Pantev et al., 2001). Moreover, Bangert et al. (2001) demonstrated jointly activated sensorimotor hand and auditory representations for isolated listening or finger moving after only a short time of piano training. This multisensory integration is observed when different feedback (e.g., somatosensory or auditory) is temporally tightly associated. Simultaneous tactile stimulation of the lip and auditory stimulation of the ear (using a trumpet tone) result in different activation patterns compared to the sum of isolated stimuli in trumpet players as well as in non-musicians. However, these activation patterns show significant differences between both groups, which highlight not only input-dependent alterations but also training-dependent effects (Schulz et al., 2003). The studies of Schulz et al. (2003) demonstrated that long-term synergistic training of sensorimotor interaction results in specific changes in the contextual representation.

A number of studies demonstrated the existence of a cerebral “music” network with context specific components (e.g., subject to perception, performance, imagery) (e.g., Bangert et al., 2006; Baumann et al., 2005; Lahav et al., 2007; Meister et al., 2004; Parsons et al., 2005). Most of these effects were ruled out either by comparing musicians with non-musicians or investigating homogenous groups of musicians or non-musicians. To understand these more general effects of musical training, on cerebral processing *per se*, it might be necessary to differentiate instrument-specific training effects. The interaction of the motor, auditory, and somatosensory systems is different with respect to the instrument used. However, only a few studies have investigated these effects. Overall, instrument-specific changes in brain structure (Bangert and Schlaug, 2006) as well as in behavior (Drost et al., 2007) have been shown, but there is a lack of studies investigating specific functional changes in primary cortical areas (except for A1).

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In the present study, we were interested in task-specific alterations of cortical representation sites subject to instrument-specific training. This task specificity can be nicely demonstrated in groups of musicians with comparable training time but different interaction with the instrument during training. Therefore we chose a group of instrumentalists who use a hand-lip-sound interaction during training (trumpet players). A control group providing comparable musical skills (i.e. reading notation, experience in complex finger movements, musical ear-training) was required. Piano players use hand-foot-sound interaction when playing their instrument and served as appropriate control group in this study. We varied different aspects of the interaction with a scanner-suited instrument in both groups of instrumentalists, and investigated interaction-associated changes in cerebral representation with functional magnetic resonance imaging (fMRI). We expected associated hand-lip representations in the trumpet players even when musicians were not allowed to interact on the instrument with both body parts. Moreover, we assumed a characteristic increase in auditory coactivation when using the instrument adapted to during long-term training. We were aware that these instrument-specific changes are not restricted to the cerebral cortex and extended our regions of interest to the cerebellar hemisphere. Furthermore, we tried to control associated movements with considerable technical effort (MRI-compatible model of a trumpet, orbicularis oris electromyogram (EMG), and fiber-glove for the hand). Additionally, in subgroups of subjects, we controlled the produced loudness with the scanner trumpet by using a microphone adapted for the MRI environment.

Methods

Participants

We investigated 14 trumpet players (6 female; age 27.57 ± 5.21; Edinburgh handedness index 92.64 ± 18.29 (Oldfield, 1971); years of musical practice on the trumpet 17.00 ± 4.96) and 15 piano players (7 female; age 22.33 ± 2.92; Edinburgh handedness index 84.92 ± 47.52; years of musical practice on the piano 14.87 ± 3.31) who had no experience in playing a brass or wood wind instrument. Six out of 14 trumpet players had experience in playing a keyboard instrument (age of training onset on the keyboard instrument 8.67 ± 3.27). Four of them played a keyboard instrument in the last five years and only two in the last three months prior to the study (for further information see Supplementary Table 1). One trumpet player commenced training on the tenor horn before training on the trumpet. Since playing the tenor horn requires the same hand-lip interaction we included this period of time in our calculation of instrumental experience. We dealt in the same way with one pianist who started playing the accordion before the piano. The piano players were instructed in playing on a trumpet mouthpiece. The training period was shorter than 5 min to reduce possible changes in cortical plasticity due to training effects. The study was approved by the Ethics Committee of the Medical Faculty of the University of Greifswald and all subjects gave written informed consent.

To estimate the accumulated amount of instrumental training we calculated a practicing index multiplying the life practicing time by the weekly practicing time ([subjects' age − age when subjects commenced musical training on the particular instrument] × hours of weekly practicing considered for the last three months) as established by Kleber et al. (2010).

Somatosensory testing of the lip

To evaluate somatosensory responsiveness of the lip we tested 11 trumpet players (5 female) and 11 piano players (4 female) out of the group described above. Somatosensory testing was performed using Semmes-Weinstein monofilaments (Touch-Test™ Sensory Evaluators, North Coast Medical, Inc., Morgan Hill, CA, USA) that enable to apply forces by bending between 0.078 and 2941.176 mN within a 5% standard deviation. Four sites were tested (right upper lip, right lower lip, perilabial above the right upper lip, perilabial under the right lower lip) as described in the instruction manual. For that subjects had to close their eyes, filament was pressed against the skin at a 90° angle until it bowed and held in place for approximately 1.5 s. For filaments between 0.078 and 9.804 mN stimuli were applied up to three times in the same location. Subjects were instructed to say “now” when the stimulus was felt.

Experimental design

We created a MRI compatible model of a trumpet with the same proportions as an original small sized instrument. For that purpose we used a trumpet mouthpiece comparable to commercially available ones (e.g. KELLY Mouthpieces, Fond du Lac, WI, USA) attached to an acryl trumpet valve body providing a common somatosensory feedback during pressing the valves (see Fig. 1A). Such a mouthpiece is also used for training and even an amateur can produce sounds with it. For the tapping tasks we used commercially available four finger keypads fitting to the left and right hand (LUMItouch optical response keypad, Photon control, Burnaby, Canada) which did not provide any similarity in size, haptics or feedback features to a real piano keyboard.

Each subject executed six different tasks in a pseudorandomized order, each containing 10 activation blocks of 8 s duration alternating with resting blocks of 16 s duration showing a fixation cross to assess baseline activities. In each activation block pictures were used which encoded the finger movements in a different pseudorandomized order. The movements were indicated by either trumpet (for trumpet players) or piano (for piano players) notes encoding all possible pressing combinations of the digits II–IV or using pictures of stylized hands, where the fingers required to move were marked with red color.

Subjects were asked to perform the following tasks with the most comfortable velocity.

Task 1 (“hands only on the trumpet; presentation of notes”): Subjects had to execute isolated finger movements of the digits II–IV of the right hand on our trumpet model. The movements were indicated by either trumpet (trumpet players) or piano (piano players) notes. The lips were not involved during this task.

Task 2 (“hands only on the trumpet; presentation of finger symbols”): Similar to task 1, but the sequence was presented by pictures of stylized hands.

Task 3 (“hands only on the keypad; presentation of notes”): Similar to task 1, but movements were executed on a MRI compatible keypad.

Task 4 (“hands only on the keypad; presentation of finger symbols”): Similar to task 2, but movements were executed on a MRI compatible keypad.

Task 5 (“hands and lips on the trumpet; presentation of notes”): The subjects played on our trumpet model using both lips and fingers as during real trumpet playing.

Task 6 (“lips only on the trumpet; presentation of notes”): The subjects played on our trumpet model using the lips. The model was held with the left hand, the right arm was lying beneath the trunk. Since no finger movements had to be executed both groups saw trumpet notes while playing on the model. For an overview on the conditions see Fig. 1B.

We used a combination of a trumpet model and a keypad both combined with notes and finger symbols to differentiate possible differences in brain activation between conditions and musician groups and between an instrument specific context and the movement indicator (notes or finger symbols).