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Specialization of the specialized in features of external human brain morphology

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Abstract

Recent studies have shown brain differences between professional musicians and non-musicians with respect to size, asymmetry or gray matter density of specific cerebral regions. Here we demonstrate: (1) that anatomical differences in the motor cortex can already be detected by coarse visual inspection; and (2) that within musicians, even a discrimination of instruments with different manual dominance is possible on a gross anatomical scale. Multiple raters, blinded for subject identity and hemisphere, investigated within-musician differences in the Omega Sign (OS), an anatomical landmark of the precentral gyrus associated with hand movement representation. The sample of 64 brains comprised matched groups of 16 expert string-players, 16 expert pianists and 32 non-musicians. Ratings were analysed by means of kappa statistics. Intra- and interobserver reliabilities were high. Musicians had a more pronounced OS expression than non-musicians, with keyboard-players showing a left and string-players a right hemisphere advantage. This suggests a differential brain adaptation depending on instrument played.

Introduction

Musicians typically initiate their training at an early age and continuously practice their highly specialized sensorimotor skills, often for many hours per day, throughout their entire professional careers. Several studies have explored the functional and structural brain basis of these skills, typically by comparing musicians with non-musicians (Elbert *et al*., 1995; Amunts *et al*., 1997; Schlaug, 2001; Schneider *et al*., 2002; Gaser & Schlaug, 2003; Bangert *et al*., 2006). One study reported a functional specialization within the musician group itself, demonstrating that functional brain differences in the auditory system are associated with listening to tones from the particular musical instrument played (Pantev *et al*., 2001).

Musician–non-musician comparisons have found evidence for structural differences in brain regions that may be directly involved in the perception, multimodal integration, motor control and execution of musical skills (Schlaug *et al*., 1995; Amunts *et al*., 1997; Gaser & Schlaug, 2003; Bangert *et al*., 2006). These structural differences in musicians' brains have been found to be related to early initiation and intensity of long-term instrumental training (Schlaug, 2001). In the absence of longitudinal data to examine causal relationships, the search for structural brain differences within musicians is a valuable alternative to support the notion of structural brain adaptation. For example, string-players strongly differ from keyboard-players by the requirement to develop fine hand/finger motor skills of their left hand, while keyboard-players may need to develop fine hand/finger motor skills in both hands or more in their right hand, as the left hand may have more an accompaniment function.

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Materials and methods

The precentral gyrus is particularly suited for examining within-musician differences in anatomy–behavior relationships. Previous studies have found enhanced gray matter density (Gaser & Schlaug, 2003) and an increased intrasulcal length of the precentral gyrus (ILPG) in musicians (Amunts *et al*., 1997), and a recent study found differences in the main output fiber tract of the precentral gyrus (Bengtsson *et al*., 2005). Furthermore, studies have found correlations between hand/finger skills and contralateral gray matter density in a subregion of the precentral gyrus (Herve *et al*., 2005). This subregion of the precentral gyrus has a reliably identifiable gross-anatomical feature, an inverted 'Omega Sign' (OS) (Yousry *et al*., 1997; Boling *et al*., 1999), also known as 'hand knob' or 'genu', an elaborated configuration of the superior precentral gyrus (Fig. 1) that is associated with functional hand/finger movement representation (Yousry *et al*., 1997; Volkmann *et al*., 1998).

Five neuroanatomically experienced observers, blinded to subject identification and hemisphere, rated the expression of the OS in either hemisphere with respect to salience and shape (coding in three categories: 'OS0' = OS not clearly visible; 'OS1' = OS visible; 'OS2' = OS exceptionally pronounced or double expression of OS) using 64 3D-surface renderings of spatially normalized and segmented gray matter images obtained from high-resolution (1 mm^3 voxel size) T1-weighted MRI scans. This right-handed sample was carefully selected from a large database of high-resolution anatomical scans, and comprised 32 professional musicians (16 string- and 16 keyboard-players), all of whom were actively performing musicians who had either finished their education or were still students at a music school. No amateur musicians were included in the musician group. Cross-instrumental musicians (i.e. string instrument players playing a keyboard instrument as a secondary instrument) were excluded. The comparison group consisted of 32 age- and gender-matched non-musicians (16 male). For complete group demographics, refer to

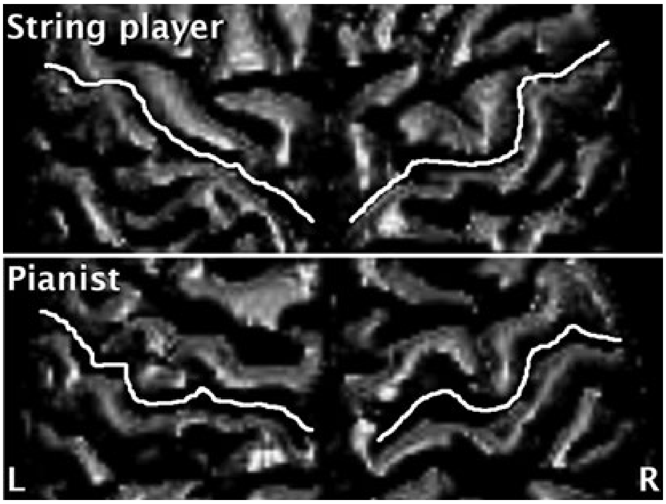

FIG. 1. 3D-surface renderings of the perirolandic region in a string-player (top) and a keyboard-player (bottom). A white line marked the location of the central sulcus, which was meant to serve as an orientation help for the blinded raters. While the string-player displays a prominent OS on the right hemisphere only, the keyboard-player shows a left more than right prominence of the OS.

Supplementary material, Table S1. The 3D-surface renderings were pseudo-randomized and presented in original and mirror configurations by flipping images in the midsagittal plane to assess a possible laterality bias of the blinded raters. Intra- (> 80% agreement between original and mirror versions within raters) and interobserver reliabilities (> 65% agreement across all raters) were determined by means of kappa statistics. Results are expressed as average incidence of the three categories (0–2, see above) across all raters (Bonferroni-corrected χ^2-tests on the subject groups; α-level = 0.01; all χ^2- and exact *P*-values are listed in Supplementary Table S3). All subjects from the database had participated in studies that were approved by the Institutional Review Board of the Beth Israel Deaconess Medical Center. All subjects had signed informed consent forms.

Results

In non-musicians (Fig. 2A and Supplementary Table S2), the incidence of a clearly visible OS (combined OS1 and OS2 ratings) was equally high in both hemispheres (34.9% of the left and 33.9% of the right hemispheres). String-players had a clearly visible OS (OS1 and OS2) in 55.2% in the right ($P < 0.001$) and in 39.7% in the left hemisphere. A reversed pattern was seen in the keyboard-players with an OS in 76.4% in the left ($P < 0.001$) and in 35.4% in the right hemisphere. The incidence of an OS in the right hemisphere of pianists and left hemisphere of string-players, respectively, did not differ significantly from non-musicians. Similar group and hemispheric differences were seen when the analysis included exceptionally pronounced OS ratings only ('OS2'); with 14.5% in the right hemisphere in string-players and 16.6% in the left hemisphere in keyboard-players (Fig. 2B and Supplementary Table S2).

We calculated an Asymmetry Index (AI; individual right minus left mean rater score per subject) to indicate the differential hemispheric expression of the OS within and between the different subject groups (Fig. 3). In the string-players, an AI ≥ 1 (right > left) appeared more frequently than in the controls ($P < 0.01$). The opposite effect was seen in the keyboard-players ($P < 0.01$; Fig. 3).

This asymmetry could be viewed as conflicting with the findings of Amunts *et al*. (1997), who used the ILPG to demonstrate a strongly asymmetric distribution in non-musicians with respect to this quantifier, whereas keyboarders showed a symmetric distribution. The overall precentral gyrus length, however, does not necessarily signify the same underlying anatomical process, as the comparison of the respective non-musician population samples in both studies indicates (asymmetric ILPG but symmetric OS expression). Moreover, nearly half of the musician group in the Amunts *et al*. (1997) study (nine out of 21) have been keyboard-players who additionally played a string instrument; possibly reflecting an effect where both left and right precentral gyrus are enhanced, independently, thus introducing apparent symmetry through a slight sample inhomogeneity.

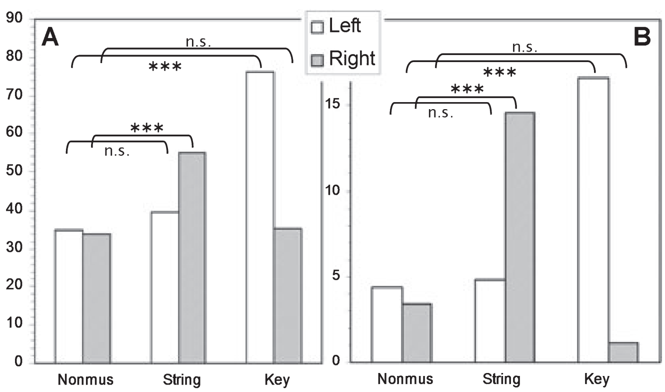

FIG. 2. Incidence of OS detections by the blinded raters in our sample of non-musicians (Nonmus), string-players (String) and keyboard-players (Key). (A) Percentage of OS 1 or 2 ratings (i.e. all visible OS). (B) Percentage of OS 2 ratings (i.e. exceptionally developed OS). White: left precentral gyrus, gray: right precentral gyrus [***$P < 0.001$ ($\chi^2 > 18$); n.s. not significant ($\chi^2 < 2$)].

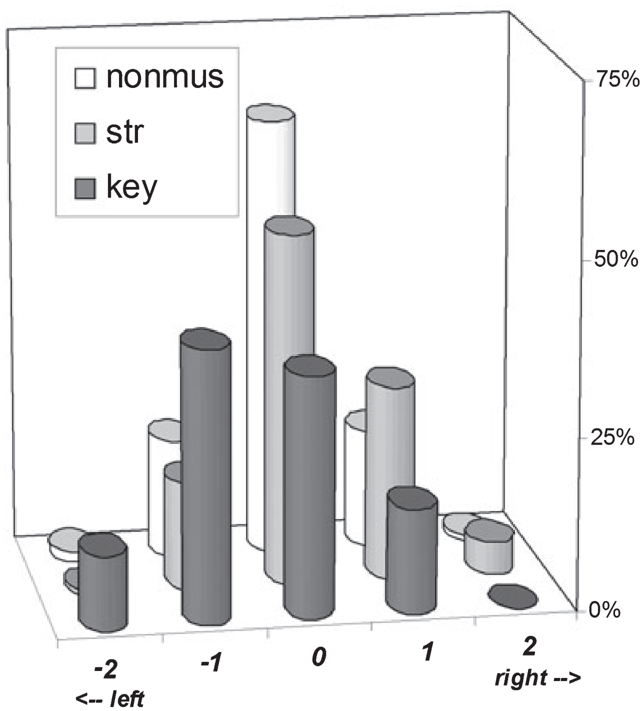

FIG. 3. OS AI. The distribution is centered in non-musicians (nonmus), and lateralized towards the right in string-players (str) and towards the left in keyboard-players (key). The AI was calculated using the class indices from the OS 0, 1, 2 ratings as a semiquantitative ordinal scale.

Discussion

Our results indicate considerable within-musician differences in the OS expression, suggesting an association between acquired sensorimotor skills and features of external brain anatomy. Although we cannot completely rule out a genetic cause for the OS expression, a differential hemispheric expression, depending on the instrument, in this strongly right-handed group of musicians may be rendered unlikely. Further studies aiming at the long-term dynamics of a putative structural plasticity mechanism involving the OS shape could employ longitudinal approaches, or comparisons with very young musicians at the very beginning of their musical training. Considering the wealth of animal (Kleim *et al*., 1996; Anderson *et al*., 2002) and human data (Bengtsson *et al*., 2005) showing structural changes in response to long-term motor training, our results are some of the first showing hemispheric differences depending on the instrument played.

Supplementary material

The following supplementary material may be found on http://www.blackwell-synergy.com

Table. S1. Subjects' biometrics and matching statistics for the three groups.

Table. S2. Incidence of visible OS and exceptionally developed OS in non-musicians, string players and keyboard players.

Table. S3. Results from all statistical tests performed on the rating data.

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Abbreviations

AI, asymmetry index; ILPG, intrasulcal, length of the precentral gyrus; OS, Omega Sign.

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