The effect of musicianship on pitch memory in performance matched groups

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We compared brain activation patterns between musicians and non-musicians (matched in performance score) while they performed a pitch memory task (using a sparse temporal sampling fMRI method). Both groups showed bilateral activation of the superior temporal, supramarginal, posterior middle and inferior frontal gyrus, and superior parietal lobe. Musicians showed more right temporal and supramarginal gyrus activation while non-musicians had more right primary and left secondary auditory cortex activation. Since both groups' performance were matched, these results probably indicate processing differences between groups that are possibly related to musical training. Non-musicians rely more on brain regions important for pitch discrimination while musicians prefer to use brain regions specialized in short-term memory and recall to perform well in this pitch memory task. *NeuroReport* 14:2291–2295 © 2003 Lippincott Williams & Wilkins.

Key words: Auditory cortex; fMRI; Music; Pitch memory; Supramarginal gyrus

INTRODUCTION

Pronounced functional differences have been found between musicians and non-musicians in perisylvian brain regions using various brain mapping techniques [1–7]. Increased musical sophistication was typically associated with more lateralized (mostly left) activation. However, it is unclear whether the between-group differences are due to differences in performance of experimental tasks (e.g. percentage correct answers), cognitive strategies, or even anatomical structures. Since the effect of performance differences between musicians and non-musicians can be controlled for by carefully matching the performance scores of both groups, we designed a study to examine whether between-group differences in perceptual and/or cognitive strategies alone can explain functional brain differences between musicians and non-musicians. In addition, the influence of between-group structural brain differences on functional differences was assessed by measuring size and asymmetry of the planum temporale, a marker of hemispheric laterality.

The existing literature does not show a consistent pattern of brain activation in pitch memory or pitch discrimination experiments. When subjects listened to melodies, Zatorre *et al.* [8] showed that blood flow increases bilaterally in the superior temporal cortex (right more than left). A right inferior frontal region became activated when subjects were asked to perform a pitch memory task in contrast to a passive listening task. Griffiths *et al.* [9] found a more extensive right lateralized network including cerebellum, posterior temporal and inferior frontal regions when subjects were asked to make a same/different judgment while comparing pitch sequences of six tones. However, Platel *et al.* [10] revealed more left hemisphere activations involving the precuneus, superior temporal and superior frontal gyrus when subjects were asked to detect pitch changes in familiar tunes. When subjects were presented with deviances in tonal sequences, *Celsis et al.* [11] showed rightward asymmetry of the primary and secondary auditory cortex for tones, but left more than right posterior temporal lobe activation.

Our aim was to investigate the effect of musicianship on the neural activation pattern of a pitch memory experiment by selecting the high performing non-musicians from a larger group of subjects in order to achieve precisely matched groups of musician and non-musician. A pitch memory experiment was chosen since this is a challenging task for both groups and does not require any special musical knowledge. Since musicians with absolute pitch might use a different strategy in performing this task, only musicians who did not have absolute pitch were included.

MATERIALS AND METHODS

Subjects: Twenty normal right-handed volunteers (age range 18–40 years; 10 female and 10 male) without any neurological or hearing impairments, participated in this

study after giving written informed consent. For this experiment, we defined musicians as those who had formal music training and regularly played a musical instrument. None of the musicians had absolute pitch. A non-musician was defined as someone who had never played a musical instrument and who had no formal musical training.

Experimental paradigm: Subjects listened to a sequence of 6–7 tones with a total duration of 4.6 s for each sequence, and were asked to make a decision whether or not the last or second to last tone (as indicated by a visual prompt) was the same or different from the first tone, indicating their answer with a button press response. All tones were taken from a frequency range of 330 Hz (D#4) to 622 Hz (D#5). The difference in frequency between the first, and the last or second to last tone was 41.17–64.23 Hz and the frequency range from the lowest to the highest tone in all tone sequences was not more than 108 Hz. We chose to vary the total number of tones (6 or 7 per sequence) and the comparison to be made (second to last tone with first tone or last tone with first tone) across sequences to decrease the possibility that subjects would choose to dismiss the intervening tones. The sequence length was kept constant for the 6 and 7 tone sequences by introducing a short pause prior to the first tone for the 6 tone sequences. This task was contrasted with a motor control condition in which subjects pressed a right or left button as indicated by a visual prompt. The non-musicians used in this study were selected from a larger sample of non-musicians in order to precisely match their performance scores in the pitch memory task with those of the subjects in the musician group. All subjects were familiarized with the pitch memory task using samples of the stimulation material for $\sim$10 min prior to the actual MR session. The behavioral performance during the fMRI session was calculated as a percentage of correct responses.

fMRI scanning: fMRI was performed on a Siemens Vision 1.5 T whole-body MR scanner. To avoid interference with the MR scanner noise as well as auditory masking effects, a sparse temporal sampling fMRI method with an effective repetition time (TR) of 17 s was used. This ensured that the clustered volume MR acquisition time (TA = 2.75 s) was always separated from the actual auditory task. In addition, the stimulus-to-imaging delay time was varied between 0 and 6 s in a jitter-like fashion to explore the time course of brain activation in response to the perceptual and cognitive demands of this pitch memory task. Initiation of the first set of 24 slices was triggered by a TTL pulse from a PC and all subsequent MR acquisitions were synchronized with stimulus presentation. A high resolution T1 weighted scan (1 mm^3 voxel size) was acquired for each subject for anatomical co-registration. fMRI data were analyzed using the SPM99 software package (Institute of Neurology, London, UK). After realignment, co-registration, normalization and smoothing (8 mm full-width-at-half-maximum), we estimated condition and subjects effects using a general linear model [12]. The effects of global differences in scan intensity were removed by scaling each scan in proportion to its global intensity. We contrasted the pitch memory task with the motor control task and applied a threshold of $p < 0.05$, corrected for multiple comparisons. Low frequency drifts were removed using a temporal high-pass filter with a cutoff of 200 s. We did not convolve our data with the hemodynamic response function (HRF) and we did not apply a low-pass filter.

We combined the imaging time points (ITPs) 0–3 (0–3 s after the end of the auditory stimulation) and ITPs 4–6 (4–6 s after the end of the auditory stimulation) into two blocks. This was done in order to achieve a higher number of events or acquisitions per block for statistical reasons, and to reflect the main change over time in the activation pattern, since the initial imaging time points reflected more of a perception network while the later time points reflected more of a memory network. In the fMRI analysis we contrasted the pitch memory task with the motor control task for these two combined clusters of imaging time points.

Morphometric assessment of brain laterality: One possible explanation for functional differences in perisylvian brain regions between musicians and non-musicians is a difference in brain anatomy. The planum temporale (PT) and the PT asymmetry can be used as a gross anatomical marker of perisylvian brain differences between the two groups. Our previous studies revealed anatomical PT differences between musicians with and without absolute pitch (AP) [13,14], although we found no differences in PT asymmetry between non-AP musicians and non-musicians in two separate studies. The surface area of the right and left PT and its asymmetry score was determined for all subjects who participated in this study. The PT was defined according to previously published criteria [13,15] and the surface area was calculated as described in detail elsewhere [14].

RESULTS

Imaging results: After individually matching non-musicians with musicians using task performance as the criteria, the musician group had a mean ($\pm$ s.d.) correct response rate of 78 $\pm$ 6% while the mean of the non-musician group was 76 $\pm$ 6% ($p > 0.05$). In the pitch memory task, group mean activation images for both groups showed bilateral involvement of the superior temporal gyrus, supramarginal gyrus, posterior middle and inferior frontal gyrus, and superior parietal lobe (Fig. 1a,b). For scans acquired 0–3 s after the end of the auditory stimulation), contrasting the two groups (Fig. 2a, $p < 0.05$, FDR corrected) revealed more activation of the posterior PT and the supramarginal gyrus on the right and the superior parietal regions bilaterally in the musician group. For the later imaging time points (4–6 s after the end of the auditory stimulation), musicians showed more activation of right superior parietal region ($p < 0.05$, FDR corrected; Fig. 2b). Lowering the statistical threshold ($p < 0.01$, uncorrected), revealed additional activation of the left supramarginal gyrus and the right inferior frontal gyrus in the musician group (Fig. 2c) for the earlier imaging time points. For imaging time points 0–3 s, non-musicians differed from musicians by activating more Heschl's gyrus (HG) on the right and a small region in the anterior part of the left planum temporale (immediately posterior to HG) when contrasts were corrected for multiple comparisons (Fig. 3a). Lowering the statistical threshold ($p < 0.001$, uncorrected) revealed additional activation of the right

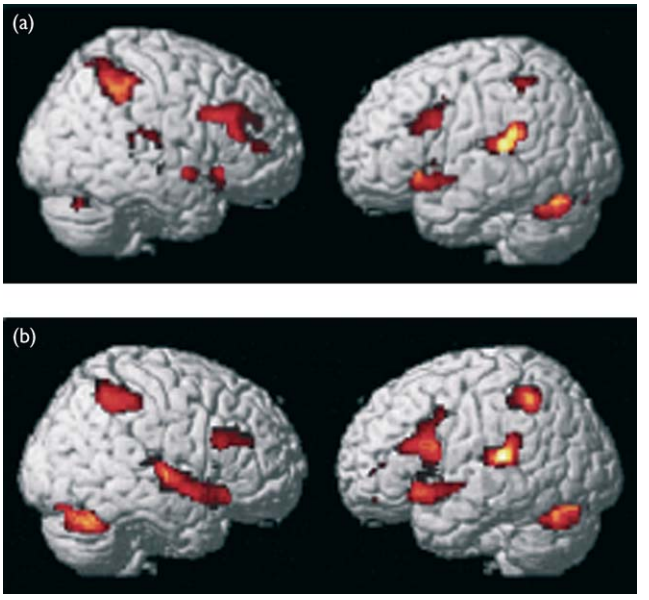

Fig. 1. (**a**) Mean image for musicians (pitch memory > motor control) for imaging time point (ITP) 0–6 ($p < 0.05$, FDR corrected). (**b**) Mean image for non-musicians (pitch memory > motor control) for ITP 0–6 ($p < 0.05$, FDR corrected).

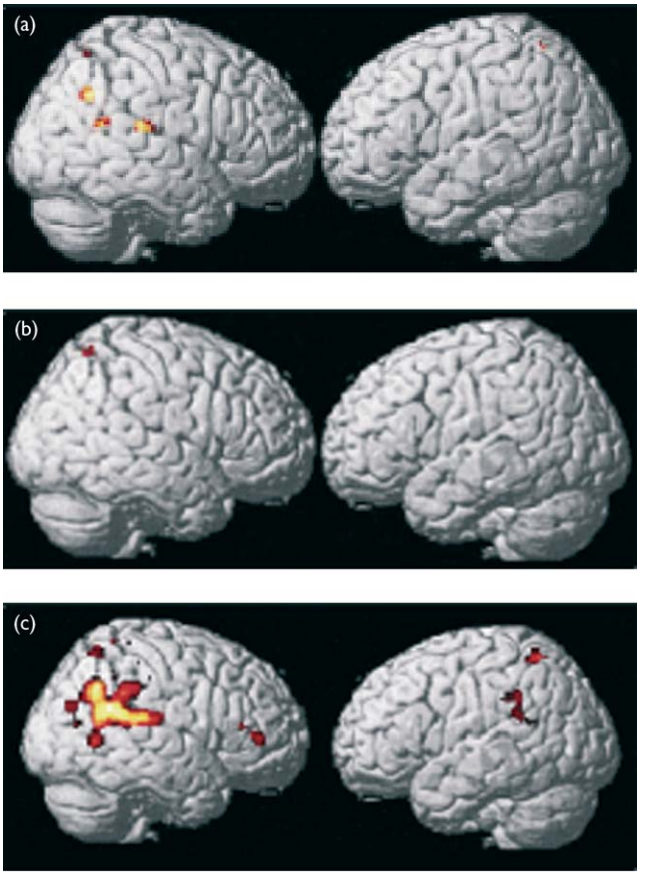

Fig. 2. (**a**) Contrast for musicians > non-musicians for ITP 0–3 ($p < 0.05$, FDR corrected). (**b**) Contrast for musicians > non-musicians for ITP 4–6 ($p < 0.05$, FDR corrected). (**c**) Contrast for musicians > non-musicians for ITP 0–3 ($p < 0.01$, uncorrected).

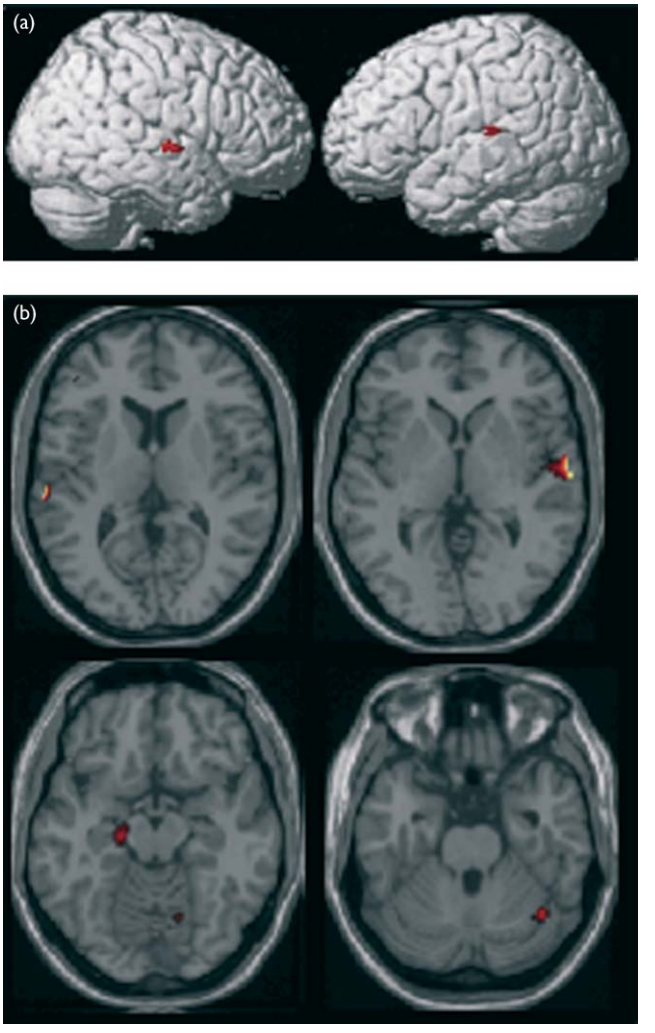

Fig. 3. (**a**) Contrast for non-musicians > musicians for ITP 0–3 ($p < 0.05$, FDR corrected). (**b**) Contrast for non-musicians > musicians for ITP 0–3 ($p < 0.001$, uncorrected).

lateral cerebellum (lobulus V and VI) and the left hippocampal gyrus in the non-musician group (Fig. 3b).

Planum temporale results: As shown previously [15], PT measurements showed no significant difference for the left ($t = 0.42$), the right PT ($t = -0.428$), or the laterality index ($t = -0.752$) between musicians and non-musicians.

DISCUSSION

Comparing the performance-matched non-musicians to the musicians revealed more right-sided activation of the planum temporale and the supramarginal gyrus (SMG) as well as bilateral activation of superior parietal areas. Lowering the statistical threshold led to additional activation of right inferior frontal and left SMG. Thus, both SMGs, to different degrees, were more activated in musicians compared to non-musicians. We recently showed a positive correlation between the performance score in this particular pitch memory task and activation of the left SMG in a large

group of non-musicians [16]. It was argued that better performing subjects used a more efficient short-term auditory storage region. Our current study indicates that despite matching our two groups in their performance scores, the musicians still show more activation of the SMG than the non-musicians. Several neurophysiological and lesion studies have shown the importance of the SMG for short-term auditory-verbal memory processes and phonological storage [17,18]. Our studies and those of others [11] extend the role of the SMG to a memory and storage center for non-verbal, musical information.

Interestingly, the musician group showed stronger activation of posterior superior temporal regions on the right, and SMG activation (right more than left) compared to the non-musician group. One possible explanation for this is that both groups showed a very strong left-sided activation with this task (Fig. 1a,b) while the right hemisphere was activated to a lesser degree and showed more variability between the two groups. Thus, any voxel-by-voxel group differences would be more likely to show on the right hemisphere. Only by lowering the statistical threshold, did we see additional differences in the left hemisphere, mainly in the left SMG (Fig. 2c), which again was more activated by the musicians than the non-musicians. Since none of our musicians had absolute pitch, these predominant right hemisphere group differences do not conflict with reports that have shown strong left-sided PT activations when musicians with AP were compared with musicians without AP [5,6].

In addition to the activation of PT and the supramarginal gyri, musicians also showed more right inferior frontal activation in contrast to the non-musicians which appeared when the threshold was lowered. Zatorre *et al*. [8] found profound right-sided inferior frontal lobe activations when comparing a pitch memory task with a passive listening task. The extensive and reciprocal fronto-temporal connections [19,20] establish a fronto-temporal network that may be relevant for the temporal order or overall pattern of pitch-relevant information [9]. This confirms the findings of other studies showing activation of frontal brain regions when the analysis of higher order pitch patterns was required [21].

Musicians also showed more activation of the superior parietal lobe for the early time points as well as parts of the right superior parietal lobe for the later imaging time points. Several previous studies have shown the involvement of superior parietal areas in auditory tasks [22]. Some have argued that the parietal lobules are involved in auditory selective attention [22], but it is also possible that musicians use a visual-spatial strategy and imagine the tones on a virtual staff in order to perform well in this pitch memory task [10,23]. Comparing the non-musicians with the musicians revealed bilateral activation of primary and early secondary auditory areas including HG bilaterally and the anterior left PT. Several studies have shown the importance of primary auditory areas for pitch discrimination (for review see [24]). In order to perform well in this task, non-musicians seem to rely more on a network that enables them to discriminate pitches.

In addition to differences between the two groups in perisylvian regions, differences in the left hippocampal gyrus were revealed. An animal study showed that individual cells and cell assemblies in the hippocampus code memory processing of pitch and auditory temporal information in rats [25].

Non-musicians also showed more right hemispheric cerebellar activation. Several studies have now shown an involvement of the cerebellum in auditory tasks (for a short review see [16]), although the role of the cerebellum in pitch processing is not yet known. Possibilities range from facilitating pitch discrimination to sequential ordering of auditory information.

CONCLUSION

Considering that both groups were matched in performance and did not show any significant brain asymmetries, our results indicate perceptual and/or cognitive processing differences between musicians and non-musicians in this pitch memory task. Musicians activate a network that includes auditory short-term memory regions (e.g. SMG) and regions implicated in visual-spatial processing (e.g. superior parietal cortex). Non-musicians seem to rely more on a network that includes brain regions important for pitch discrimination (e.g. Heschl's gyrus) and traditional memory regions (e.g. hippocampal gyrus). Both processing strategies seem to lead to similar performance scores in this pitch memory task. Long-term musical training appears to influence the neural networks used for successful performance on this pitch memory task.

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