FUNCTIONAL ANATOMY OF PITCH MEMORY IN PERFORMANCE MATCHED GROUPS OF MUSICIANS AND NON-MUSICIANS

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ABSTRACT

Functional differences between musicians and non-musicians have been found mainly in perisylvian and sensorimotor brain regions. It is unclear whether differences in performance, cognitive strategies or brain structure account for these between-group functional differences. In this study, we wanted to determine whether functional brain differences in a pitch memory task still exist when a group of musicians and non-musicians were matched with regard to their performance score. Musicians, non-musicians, and a group of AP musicians underwent functional magnetic resonance imaging using a new variation of a sparse temporal sampling technique with clustered volume acquisition while performing a pitch memory task (comparing the first tone with the last or second last tone in a sequence of 6-7 tones). The pitch memory task was contrasted with a motor control condition. Non-musicians were selected from a larger group of subjects in order to match non-musicians with musicians with regard to their performance score. There was an overall similarity between groups in the activation pattern which involved the superior temporal gyrus and the supramarginal gyrus (left more than right). Group contrasts showed that musicians activated more the right planum temporale (PT) and supramarginal gyrus (SMG) while non-musicians activated more Heschl's gyrus (HG) on the right, right cerebellum and left anterior PT. These results indicate between-group processing differences since performance was similar between both groups. While musicians seemed to use more short-term auditory storage center (e.g., supramarginal gyrus), non-musicians seem to use more primary auditory cortex, most likely because of HG's importance in pitch discrimination. Contrasting AP musicians with non-AP musicians revealed activations in the left superior temporal sulcus (STS) for the AP group. The STS may play a role in the categorization of pitch information, typical for musicians with AP.

1. INTRODUCTION

Pronounced functional differences were found between musicians and non-musicians in peri-sylvian brain regions using various brain mapping techniques (Altenmueller, 1986; Besson et al., 1995; Pantev et al., 1998; Trainor et al., 1999; Ohnishi et al., 2001; Schlaug, 2001). It is unclear whether these between-group functional differences are due to differences in performance, cognitive strategies or brain structure.

The existing literature does not show a consistent pattern of brain activation comparing those studies that have examined pitch processing. Zatorre *et al.* (1994) showed blood flow increases bilaterally in the superior temporal cortex (right more than left) when subjects listened to melodies. 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.* (1999) found a more extensive right lateralized network including cerebellum, posterior temporal and inferior frontal regions when subjects were asked to make a same/different judgement while comparing pitch sequences of 6 tones. However, Platel *et al.* (1997) found more left hemisphere activations involving the precuneus, superior temporal and superior frontal gyrus when subjects were asked to detect pitch changes in familiar tunes. Celsis and colleagues (1999) found rightward asymmetry of the primary and secondary auditory cortex for tones, but left more than right posterior temporal lobe activation when subjects were presented with deviances in tonal sequences.

Our musician group consisted of musicians with and without absolute pitch (AP). The anatomical, perceptual and/or cognitive processes that underlie the AP ability are not fully known. There are several theories with regard to differences in the perceptual and/or cognitive strategies comparing AP with non-AP subjects that range from categorical perception, to verbal encoding, to the use of internal pitch templates, as well as to a better long-term pitch memory in AP musicians. Siegel (1974) showed that AP performed better when they were able to verbally encode tones and they were not better than non-AP musicians when they were forced to use their sensory encoding mode. Siegel (1974) concluded that AP musicians perceive and process tones categorically which has been supported by other researchers (Burns and Ward, 1978; Rakowski, 1993). In a later publication, Siegel (1977) made a comparison between the categories for pitch in musicians with AP and the categories for phonemes in speech.

An alternative hypothesis is that AP musicians have an internal (reference) template of tones of the musical scale. The conscious or unconscious comparison of every auditory stimulus with this internal template enables AP musicians to identify every tone. Some support for this theory comes from studies by Langner (1997) which suggest that brainstem cochlear neurons might show special oscillations that might provide an internal pitch reference. Further support comes from auditory memory experiments. Studies have reported a smaller or absent P300 component (Klein et al., 1984) indicating that the working memory of AP-musicians is – due to the already existing internal auditory template – not as much involved in a pitch memory task as compared to musicians without AP.

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In this study, we are contrasting non-musicians and musicians with and without absolute pitch with each other in order to examine whether between-group differences in perceptual or cognitive strategies can explain functional brain differences between musician and non-musician. The influence of between-group differences in performance was minimized by matching for performance. The influence of between-group brain structural differences on functional differences was assessed by measuring size and asymmetry of perisylvian brain regions.

2. MATERIALS AND METHODS

2.1. Subjects

30 normal right-handed volunteers (age range: 18-40) without any neurological or hearing impairments, participated in this study after giving written informed consent. We defined musicians as those who had a formal music education and played a musical instrument regularly. AP-musicians underwent established tests for AP and performed better than 90% correct on pitch identification tests. A non-musician was defined as someone who never played a musical instrument and did not have a formal musical education.

2.2. Experimental paradigm

Subjects had to listen to a sequence of tones (6-7 tones with a total duration of 4.5 seconds for each sequence) and were asked to make a decision whether or not the last or second to last tone (depending on a visual prompt) was "same" or "different" to the first tone indicating their answer with a button press response. All tones were taken from a frequency range of 330 (D#4) to 622 (D#5) Hz. The frequency difference between the first and the last or second to last tone was between 41.17 to 64.23 Hz. 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 tones 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 subject could become inattentive to 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 depending on a visual prompt. The non-musicians were selected from a larger sample of non-musicians in order to match them with the musician group in their performance score (% correct responses) in the pitch memory task.

All subjects were made familiar with the pitch memory task for approximately 10 min prior to the actual MR session using samples of the stimulation material. The behavioral performance during the fMRI session was calculated as correct responses (in %).

2.4. FMRI scanning

Functional Magnetic Resonance Imaging (fMRI) was performed on a Siemens Vision 1.5 Tesla 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 a repetition time (TR) of 17 seconds was used. This ensured that the clustered volume MR acquisition (over 2.75 seconds) was always separated from the actual auditory task. In addition, the stimulus-to-imaging delay time was varied between 0 to 6 seconds 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 ($1mm^3$ 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).

FMRI data were analyzed using the SPM99 software package (Institute of Neurology, London, UK). After realignment, co-registration, normalization and smoothing (8mm full-width-at-half-maximum), we estimated condition and subjects effects using a general linear model (Friston *et al.*, 1995). 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 200s. We did not convolve our data with the hemodynamic response function (HRF) and we did not apply a low-pass filter.

Planum temporale and Heschl's gyrus measurements were done as previously described (Schlaug et al., 1995; Keenan et al., 2001). Investigators were blinded with regard to group identity of the subjects.

3. RESULTS

The non-AP musician group had a mean correct response rate of 78% (SD= 6) and the matched non-musician group had a mean response rate of 76% (SD=6) ($p>0.05$). The group of AP musicians had a mean correct response rate of 84.5% (SD=7.6)

Group mean activation images for the musicians and non-musicians showed involvement of the superior temporal gyrus, supramarginal gyrus, posterior middle and inferior frontal gyrus, and superior parietal lobe bilaterally in the pitch memory task. Contrasting the musician group with the non-musician group revealed more activation of the posterior planum temporale as well as of the supramarginal gyrus on the right and the precuneus region bilaterally in the non-musicians group for imaging time points 0-3s (MR scans acquired 0-3s after the end of the auditory stimulation). Non-musicians differed from musicians by activating more the right Heschl's gyrus (HG), right lateral cerebellum (lobulus V and VI), left hippocampus, and a small region in the anterior part of the left planum temporale (immediately posterior to HG). When performance was not matched between musicians and non-musicians, then musicians had significantly more bilateral supramarginal gyrus activation.

Both AP and non-AP musicians activated the superior parietal gyrus (L>R), including primary and secondary auditory areas (e.g., PT). Differences between AP and non-AP musicians were seen only for imaging time points 0-3s. AP musicians had significantly more activation in the left superior temporal sulcus, while non-AP musicians had more activation in the right superior parietal lobe (SPL).

Planum temporale measurements did not indicate any significant hemispheric asymmetry differences between non-AP musicians and non-musicians. AP musicians showed the previously observed increased leftsided PT asymmetry compared to the other groups. There were trends for group differences in Heschl's gyrus which is being further explored in larger samples for each group.

4. CONCLUSION

Our results may indicated perceptual and/or cognitive processing differences between musicians and non-musicians considering that both groups were performance matched and no significant anatomical brain asymmetries were detected. Our previous studies indicated a correlation between activation of the supramarginal gyrus and good performance in this pitch memory task (Gaab et al., 2003). The supramarginal gyrus has been implicated as a short-term auditory storage region for verbal and non-verbal material (Celsis et al., 1999). While musicians seemed to make use of this region bilaterally for short-term auditory storage, non-musicians showed a stronger activation of primary and early secondary auditory brain regions. This might indicate a strategy difference between both groups; musicians might try to memorize the first tone of the pitch sequence for a comparison with the last or second-to last tone while non-musicians might try to continuously discriminate between tones without effectively storing the target tones in memory. This interpretation is supported by several studies that have stressed the importance of primary auditory cortex for pitch discrimination (for review see Tramo et al., 2002) and the strong activation of Heschl's gyrus in the non-musician group.

AP musicians on the other hand showed an activation pattern that differed from non-musicians as well as non-AP musicians. Although there were common areas of activation between AP and non-AP musicians such as the superior temporal gyrus (left more than right) involving HG and extensively the planum temporale, AP-musicians had strong activation of the left STS that was not seen in non-AP musicians. It is likely that the STS plays a role in enabling AP musicians to categorize tones as belonging to certain pitch classes. This is supported by the strong activation of the STS for sound categorization (Belin et al., 2000) and the psychophysical evidence for the categorical nature of AP (Siegel, 1974, 1977; Burns and Ward, 1978; Rakowski, 1993).

We and others have previously shown stronger activation of the left planum temporale in auditory tasks comparing AP with non-AP musicians (Schlaug, 2001; Ohnishi et al., 2001). Similar group differences were found with MEG (Hirata et al., 1999). Ohnishi et al. (2001) describe significantly greater activation of the left PT when comparing musicians with non-musicians while they were listening to music. Within the musicians studied, there was a strong correlation between years of training and the involvement of the left PT, as well as a correlation between involvement of left PT and AP ability. A predominant role of the PT in absolute pitch musicians is also supported by increased anatomical left-sided asymmetry of the PT in AP musicians (Schlaug et al., 1995; Zatorre et al., 1998; Keenan et al., 2001). Thus, the left PT as well as the left STS could be part of a cortical network that underlies the absolute perception and identification of tones in AP possessors.

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