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LETTER TO THE EDITOR

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Auditory motion processing in early blind subjects

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Although the neural substrates of visual motion processing have been extensively researched for several decades (for a review, see Culham et al. 2001), little is known about auditory motion processing. The few neuroimaging studies investigating auditory motion show the involvement of inferior and posterior parietal lobules, the dorsal and ventral pre-motor cortex (Bremmer et al. 2001; Griffiths et al. 1998, 2000; Lewis et al. 2000) and occasionally the additional involvement of the planum temporale (Baumgart et al. 1999; Bremmer et al. 2001; Lewis et al. 2000; Warren et al. 2002). These studies were conducted only on sighted subjects. In blind people, further functional neuroimaging has shown the involvement of striate and extra-striate cortices during Braille reading (Büchel 1998; Burton et al. 2002a; Sadato et al. 1996, 1998) and during language tasks (Burton et al. 2002b, 2003; Röder et al. 2002). However, fewer studies have investigated simpler auditory tasks (Alho et al. 1993; Kujala et al. 1995; Leclerc et al. 2000; Weeks et al. 2000). The present study investigated whether auditory motion perception could induce an occipital activation in early blind subjects (but not in sighted controls), indicating the developmental cross-modal reorganisation of their occipital cortex.

Six early blind subjects and six blindfolded sighted controls matched in gender and age and who gave their informed consent participated in the study. The fMRI data were acquired by a 2 Tesla Brucker Imager. The experimental protocol was divided into 40 blocks each lasting 24 s, which were distributed over two sessions. The repetition time was 4.8 s, which corresponded to five scans per block. Two active conditions (one condition per block) were recorded with a rest period in-between. The first condition was a fixed stimuli condition and the second one a motion stimuli condition. Auditory stimuli were composed of pure tones, or complex sounds, either fixed at various positions around the subject (fixed stimuli condition), or animated by a transverse movement in the horizontal plane (motion stimuli condition). In both conditions the auditory stimuli were composed of ~10% pure tones (one sine wave) and ~90% complex sounds (six sine waves).

The presence of two different kinds of sound (pure tones and complex sounds) within each block allowed auditory recognition by the subjects both in the fixed stimuli and in the motion stimuli conditions.

After having heard an individual stimulus, subjects were requested to determine the nature (i.e., ‘‘is it a pure tone or a complex sound ?‘‘) and detect any movement of the sound. If movement was detected, the subjects were asked to determine the direction of the movement (i.e. from right to left ear or the reverse). Their answer was given by pressing buttons held in each hand. When the stimulus was identified as a fixed pure tone or as a pure tone moving towards the right, subjects had to press the button in their right hand. When the stimulus was identified as a fixed complex sound or as a complex sound moving towards the left, subjects had to press the button in their left hand. In all other cases (i.e. pure tone moving towards the left or complex sound moving towards the right), subjects had to press both buttons simultaneously. All subjects underwent a training period to learn this system before taking part in the study. Within a block, the same stimulus was repeated until subjects gave an answer (with a maximum of three repetitions); thereafter the next stimulus was given.

Behavioural results showed no significant difference in the percentage of correct responses between early

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blind subjects and blindfolded sighted controls, in either motion stimuli or fixed stimuli. Pre-processing and statistical analysis of fMRI data were carried out using SPM99 (http://www.fil.ion.ucl.ac.uk/spm). The contrast (motion vs. fixed stimuli) was performed in order to show the specific activations related to auditory motion processing. This was tested in both groups of subjects at a *P*-value of 0.05, corrected for multiple comparisons. In blindfolded sighted controls, auditory motion processing recruited a large brain network encompassing left and right inferior parietal lobules (BA 40,) the left superior parietal lobule (BA 7), the left and right dorsal premotor cortex (BA 6) and left frontal areas (BA 9, 46). In early blind subjects, auditory motion processing also activated the left superior parietal lobule (BA 7) and the right dorsal pre-motor cortex (BA 6) but to a lesser extent as compared to sighted control subjects. In addition, auditory motion perception activated the left visual associative area BA 18 ($x=-2$, $y=-94$, $z=-14$) in the early blind subjects only.

In conclusion, a different, though overlapping, brain activation pattern was observed during auditory motion processing [via the contrast (motion vs. fixed stimuli)] between early blind and blindfolded sighted subjects. This result cannot be attributed to behavioural performance differences since both groups had a similar percentage of correct responses. In sighted subjects, this study confirms the implication of inferior and superior parietal lobules and of the dorsal premotor cortex in auditory motion processing (Bremmer et al. 2001; Griffiths et al., 1998; Griffiths et al. 2000; Lewis et al. 2000). In blind subjects, it shows for the first time that these same brain areas are activated to a lesser extent by this task. The activation pattern is close but slightly different in location to the one observed in blind people during an auditory localisation task (Weeks et al. 2000). Occipital activation was also found in our blind subjects as expected. This result shows that a "simple" auditory task, in comparison to linguistic operations (Burton et al. 2002b) and speech comprehension (Röder et al. 2002), recruits the occipital cortex in blind people. The fact that this activation was localised in BA 18 is consistent with other observations of the early blind's brain plasticity involving BA 19 and expanding to BA 18 (and maybe BA 17) in the absence of visual input (Büchel et al. 1998; Sadato et al. 2002). This involvement of the occipital cortex brings supplemental evidence that early visual deprivation leads to cross-modal reorganisation of the brain. The areas which are normally visually dominated are taken over by the non-impaired modalities in blind individuals. This cross-modal reorganisation, along with practice-induced reorganization of occipital cortex, might explain why blind subjects have better behavioural performances than sighted subjects during several auditory (Lessard et al. 1998; Röder et al. 1999) and tactile discrimination tasks (Van Boven et al. 2000). Future work will investigate if blind subjects are able to discriminate auditory motion better than blindfolded sighted controls.

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