FUNCTIONAL ORGANIZATION OF SOMATOSENSORY AND AUDITORY PROCESSING IN THE CEREBRAL CORTEX: INSIGHTS FROM FMRI AND TYMPANIC MEMBRANE STIMULATION

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ABSTRACT
This paper explores the functional structure of somatosensory areas of auditory processing within the cerebral cortex. We studied how the activity of temporal and parietal cortical areas was activated by the stimulation of the tympanic membrane by fMRI. The findings depict that there is an important activity in Brodmann areas (BA) 84, 44, and 86, which demonstrates that the temporal superior gyrus and postcentral gyrus are involved in auditory and somatosensory integration. Such results indicate a bilateral influence at the auditory cortex despite unilateral stimulation with implications in the processing of sensory information in ear. The mechanical phases of swallowing and relationship with muscles of the tympanic membrane and Eustachian tube are also examined in the work with special stress on the contribution to acoustic reflexes made by the tensor tympani. Such understandings will be useful in clinical applications, such as the possibility of identifying subclinical auditory perception deficits and avert hearing loss.

Keywords: Somatosensory cortex, Tympanic membrane, Auditory processing, Functional MR, Swallowing mechanism

Introduction

The processing of somatosensory inputs is impossible without understanding the functional arrangement of the primary somatosensory parts of the cerebral cortex [1]. Though the somatosensory homunculus mostly models the hands and facial regions, there has been no complete investigation on the representation of the ear [2]. In order to study the superficial pinna sensitivity, electrical stimulation of primary somatosensory cortex could be used. Activation of face and neck areas somatosensory in the case of stimulating the pinna surface has been found [3]. Nevertheless, neuroimaging techniques have not been utilized yet to measure pressure in the tympanic membrane, which is a measure of the sensitivity of the middle ear [4]. By measuring the somatosensory cortex, clinical audiologists would have the potential of identifying the case of subclinical dysfunctions, preventing irreversible hearing loss. Diseases such as idiopathic mild otitis media may involve the tensor tympani muscle and this impact middle ear functioning [5]. Despite the impossibility to reach the middle ear muscles, including the tympani and stapedius, their multisensory sensitivity (especially proprioception) may be increased by stretching. In addition, research has found pacinian corpuscle in the tympanic membrane and existence of the muscle spindle and intrafusion fibres in the stapedius and the tensor tympani muscles [6]. Proprioceptive inputs are generated during the motion of the tympano-ossicular chain, particularly during the mild stretches. Functional MRI has been applied to visualize the tympanic movements due to the variations in the air pressure [7]. To conclude, the somatosensory representations of the ear and the associated mechanisms are important in further understanding of the health and functioning of the auditory sense.

Materials And Methods

Each of the subjects (mean age 36; 8 males, 7 females) was subjected to audiometry and otoscopy which showed no ear, nose, and throat problems, or ear middle-ear pressure problems. Headsets comprising of soundproofs, otoscope, and pressure measurement probe were put on the volunteers. Syringes were used to manipulate air pressure in the ear canal with up to +40 mm H 2 O changes observed by a manometer. Tympanometry stimulated (200 daPa) was done and used 12-15 cycles of pressure variation randomly alternated with 24 seconds each, separated by a 24-second interstimulus period. The timing in MR scanners was controlled by Pre-SENTATIONVR software [8]. They were asked to be focused at the time of the fMRI tests, with their eyes closed and their abdomen held, and the tympanic membrane was gently moved prior to entering the 3T tunnel so as to limit stimulation detection. Unilateral stimulation of the ear was done to prevent bi-directional stimulation of the cortex as past researchers have found out that have intermittent effect with alternate stimulation of vision and hearing.

fMRI Protocol

The scanner used to obtain 3T-whole-body MR images was the Bruker Medspec S300 scanner, which has a birdcage head coil. Automatic second-order shimming reduced nonhomogeneities and distortion in B0. A gradient echo planar imaging sequence was used to get functional BOLD contrast images. The thickness of the slices was oriented across the commissures of the AC and PC of 38.3 mm. Three EPI sequences with spectral bandwidths of 2400 ms and 30 ms gave isotropic 3x3x3 mm3 voxels. Every subject learnt six dummy pictures until equilibrium was achieved. Another paradigm of stimulus was the change in pressure after 24-second after 24 seconds and rest after 24 seconds. The human brain imaging was done using TDR of 11.99995 milliseconds and a resolution of 457 milliseconds, using a matrix of 256x256x176 with two segments. Each image required two and a half seconds to acquire an image

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FMRI Data Analysis and Processing.

The volume of functional volumes was normalized to a 6-mm full-width-at-half-maximum Gaussian kernel on the T1 weighted template. Differences in BOLD signals were compared statistically by means of a general linear model. The periods of air pressure variations were modeled as the result of the convolving a boxcar function with the canonical dynamic response function with respect to the delay between the beginning of the stimulus period and the onset of pressure-variation in the manipulator. Regressors were of interest, and realignment parameters were used as unwanted in the model. A high pass filter of 1/192 hz was used to eliminate slow variations in the background. Contrast images between the t-tests of Student with the changes of pressure and the time of rest of the individual were computed. The contrast images were analyzed using random effects in order to make a generalization within the subjects. The t-tests on students were applied, which identified areas where the BOLD levels were significantly different to the null hypothesis. Extended statistical t-maps (10 voxels) were used on a threshold of $P<0.001$. When the false discovery rate had been mitigated, no clusters were obtained at these thresholds.

Hemispheric Differences Statistical Test.

Comparison of the hemodynamic BOLD responses between the left and the right hemispheres was done. To start with, a standard MNI template was used to obtain a hemispherically symmetrical template. The standard analysis was conducted by using the same Gaussian kernel to spatially normalize and smooth functional images. T-tests were further used by the student to evaluate the variation of stimulation and rest periods across the subjects. Each person contrasted the two hemispheres and this was represented by the symmetric contrast images, which were acquired by flipping the image along the antero-posterior y-axis. Direct contrast and symmetric contrast images were produced and the difference taken to obtain individual contrast images. The analysis of the differential images of each subject was done using a random effects. Significant differences that had more than 10 voxels were taken into consideration at a significance level of 0.01

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Results

TABLE I: Based on maximal t values and MNI coordinates, activation clusters in temporal and parietal cortex are identified

Regions of Interest	Side	Brodmann Area (BA)	X	Y	Z	T
Temporal superior gyrus	L	BA 84	95	65	16	11.256
Temporal superior gyrus	L	BA 44	106	12	3	9.355
Temporal superior gyrus	R	BA 84	112	48	30	9.072
Temporal superior gyrus	R	BA 84	108	62	41	9.480
Parietal lobes						
Postcentral gyrus (caudal)	L	BA 86	118	9	20	11.52
Postcentral gyrus (caudal)	R	BA 86	112	24	35	9.875

The table given above shows areas of interest (ROIs) within the brain, particularly, temporal and parietal lobes, which play an important role in processing the auditory information and perception of the senses. The coordinates used (X, Y, Z) are used to denote positions in the brain with the T values used to show how significant the activity detected in these parts of the brain is upon running the fMRI scans. Brodmann area (BA) 84 and 44 are a part of the temporal superior gyrus, which is found in each hemisphere. These regions are part of an increased auditory processing, including sound perception and integration. BA 84 (95, 65, 16) has T value of 11.256 at the left hemisphere and this indicates that it is highly activated as a response to auditory stimuli. On the same note, there is a significant activation at BA 44 in the left hemisphere, (106, 12, 3), with a T value of 9.355. The two BA 84 areas are significantly active in the right hemisphere with the T values of 9.072 and 9.480 indicating that processing of sound takes place in both sides of the brain with a little higher activity on the right hemisphere. The parietal gyrus that is related to somatosensory processing including the postcentral gyrus also activates significantly. The value of 11.52 in the caudal area of the postcentral gyrus (BA 86) (118, 9, 20) in the left hemisphere demonstrates high levels of sensory responses. This area appears at (112, 24, 35) on the right side and has a T value of 9.875 again confirming that the postcentral gyrus is involved in sensory integration, albeit in slightly lesser activity than on the left hemisphere. The information given is insightful on the functional areas of the brain with regard to auditory and sensory processing activities, and justifies the necessity of both hemispheres involvement in auditory and sensory processing.

Discussion

A number of studies have reported that the tympanic membrane extends to BA 43 [9], which is a part of the brain involved in other activities associated with the intake of food orally including taste and swallowing. On the basis of our interesting findings, we investigated the mechanical stages of swallowing. Swallowing involves the oropharyngeal, laryngeal, mandible, tongue, and facial motions which require the coordination of the sensory and motor functions of the body parts [10-12]. Swallowing is done in three phases oral, pharyngeal and esophageal. The bolus should also experience taste experience, heating, and mouth tactile experience during the oral stage, as well as the mastication that requires oral movements [13-

15]. One of the studies observed that air pulses induced activation of nearby oropharyngeal parts following activation of the postcentral gyrus [16]. The muscles of the Eustachian tube such as the tensor tympani, tensor veli palatini and salpingopharyngeus control pharyngeal swallowing. Histochemical continuity in long tendons of the tensor tympani and tensor veli palatini in previous studies was established [17]. The tensor veli palatini is very important in sucking, and sensory receptors in the muscles of the tympanic membrane and the Eustachian tube are connected during the swallowing, which is proposed [18]. It was found that even with unilateral stimulation of the tympanic, activation took place in the second and third region of the auditory associative, BA 42 and BA 22, which was bilateral. The middle ear is capable of having an acoustic reflex, which is stimulated on one arm only. It was proposed in a study that prevocalization reflexes are predominantly controlled by the activity of the tensor tympani, which forms an ingredient of the acoustic reflex in humans. The temporary contractions of the middle-ear muscles raise the impedance of the middle ear, reducing nasopharyngeal resonance by changing the tension of eardrums [19]. The indicated role of BA 22 in speech processing is possible. The interaural level differences as well as the preservation of the similar air pressures and impedances of both middle ears may be supported with the help of bilateral activation of the auditory reflex. The research should also be further conducted on the possibility of existence of differences in auditory perception of both left and right ears in different circumstances of pressure variations.

Conclusion

Finally, this paper offers informative information about the practical organization of the somatosensory areas of the auditory processing, namely, the temporal and parietal lobes. The results note that there is major activation in Brodmann areas 84, 44 and 86 which emphasizes the areas in integrating auditory and sensory. The bilateral activation that was observed in response to unilateral stimulation of the tympanic membrane of either ear indicates that both hemispheres play a role in auditory processing which may have clinical implications on the sensory processing and processing of the ear. As well, the study of the swallowing mechanics and its relationship with muscles of the tympanic membrane and Eustachian tube provides more evidence of the close interdependence between auditory and somatosensory systems. The use of the tensor tympani muscle in the acoustic reflexes and the possibility of bilateral activation of the auditory reflexes give new possibilities to conduct further research. In general, the paper highlights the significance of studying the auditory and somatosensory pathways in supporting auditory health, and how it can be used in the future to diagnose subclinical dysfunctions and prevent hearing loss. More research is required to find out the discrepancies in the auditory perception of the right and left ear under the same pressure conditions.

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