Acta Biomedica Scientia
e - ISSN - 2348 - 2168
Print ISSN - 2348 - 215X
www.mcmed.us/journal/abs
Research Article

INVESTIGATING THE CORTICAL RESPONSE TO TYMPANIC MEMBRANE STIMULATION VIA FMRI

Dr. Jakkala, Suresh Babu*

Assistant Professor, Deportment of ENT, Narayana Medical College and hospitals, Nellore, Andhra Pradesh, India

ABSTRACT

This study aimed to investigate the somatosensory representations of the middle ear within the human cortex. Thirty subjects with normal hearing participated in a 3T-fMRI experiment, during which minor changes in tympanic membrane pressure were induced. Activation of the audiological association area 22 was observed bilaterally in response to stimulation of the postcentral gyrus (area 40) and Brodmann area 43. Additionally, Brodmann area 43 was activated during oropharyngeal pressure activities associated with oral intake, a process facilitated by the Eustachian tubes that connect the tympanic membranes to the pharynx. Notably, both BA 42 and BA 22 showed bilateral activation during changes in oropharyngeal air pressure, indicating cortical involvement in the acoustic reflex. These findings underscore the participation of cortical regions (areas 43, 42, and 22) in processing somatosensory information related to middle ear function, especially in response to pressure-induced movements of the tympanic membrane.

Keywords :- Somatosensory, Middle ear, Tympanic membrane, Auditory cortex, fMRI.

Access this article online		
Home Page: **www.mcmed.us/journal/abs**		**Quick Response code**
Received:**25.06.2024**	**Revised**:12.07.2024	**Accepted**:15.07.2024

INTRODUCTION

The functional organization of the primary somatosensory areas in the cerebral cortex is vital for understanding how somatosensory input is processed [1]. While the somatosensory homunculus extensively represents regions such as the hands and the orofacial area, the representation of the ear remains largely unexplored [2]. To assess the superficial sensitivity of the pinna, electrical stimulation of the primary somatosensory cortex can be used. Studies have shown that stimulation of the pinna's surface activates somatosensory regions associated with the face and neck [3]. However, there has been limited progress in measuring tympanic membrane pressure, which serves as an indicator of middle ear sensitivity, through neuroimaging techniques [4]. Clinical audiologists may be able to identify subclinical dysfunctions by assessing somatosensory cortex activity, potentially preventing irreversible hearing loss. Conditions such as idiopathic mild otitis media, which affect the tensor tympani muscle, can impair middle ear function [5]. While muscles in the middle ear, such as the tensor tympani and stapedius, are difficult to access, stretching these muscles may enhance their multisensory sensitivity, particularly proprioception. Additionally, research has identified the presence of Pacinian corpuscles in the tympanic membrane and described spindles and intrafusal fibers in both the stapedius and tensor tympani muscles [6]. Proprioceptive signals are generated when the tympano-ossicular chain moves, especially during mild stretches. Functional MRI has also been used to visualize tympanic membrane movements induced by changes in air pressure [7].

Corresponding Author: **Dr Jakkala, Suresh Babu**

MATERIALS AND METHODS

The study, conducted at Narayana Medical College and Hospital, Nellore, Andhra Pradesh, India, from 2012 to 2017, involved thirty healthy, right-handed volunteers (mean age 36; 16 males, 14 females). All participants provided written consent after undergoing audiometry and otoscopy, which confirmed the absence of ear, nose, or throat issues, as well as middle ear pressure abnormalities. The volunteers wore soundproof headsets equipped with an otoscope and tympanometric probe to measure ear canal pressure. Air pressure in the ear canal was manipulated using syringes, with variations of up to +40 mm H2O monitored by a manometer. Tympanometry with stimulation (200 daPa) was performed, involving 12-15 cycles of pressure changes randomly administered for 24 seconds each, with a 24-second interstimulus interval. The timing of the procedure was controlled by Pre-SENTATIONVR software in MR scanners [8]. Participants were instructed to maintain focus during the fMRI tests by keeping their eyes closed and their abdomen held, while the tympanic membrane was gently moved before entering the 3T tunnel to minimize the detection of stimulation. Only one ear was stimulated to prevent bidirectional cortex stimulation, following previous studies that reported intermittent effects when both vision and hearing were alternately stimulated.

fMRI Protocol

The study employed the Bruker Medspec S300 scanner, equipped with a birdcage head coil, to acquire 3T whole-body MR images. Automatic second-order shimming was performed to minimize distortion and reduce inhomogeneities in the B0 field. Functional BOLD contrast images were obtained using a gradient echo planar imaging (EPI) sequence. The slice thicknesses, aligned parallel to the AC-PC commissures, were set at 38.3 mm. Three EPI sequences, with spectral bandwidths of 2,400 Hz and echo times of 30 ms, provided isotropic voxel sizes of $3 \times 3 \times 3$ mm³. Each participant underwent six dummy scans before achieving equilibrium. The stimulus paradigm involved alternating 24-second pressure variations with rest intervals. Brain imaging was conducted with a repetition time (TR) of 11.99995 milliseconds and a resolution of 457 milliseconds, utilizing a matrix of 256x256x176 with two segments. The acquisition time for each image was 2.5 seconds.

fMRI Data Processing and Statistical Analysis

Functional volumes were normalized using a 6-mm full-width-at-half-maximum Gaussian kernel, based on the T1-weighted template. Variations in BOLD signals were statistically analyzed using a general linear model (GLM). The periods of air pressure variation were modeled by convolving a boxcar function with the canonical hemodynamic response function, accounting for the delay between the onset of the stimulus and the manipulator's pressure variation. Realignment parameters were included as nuisance regressors in the model. A high-pass filter with a frequency cutoff of 1/192 Hz was applied to remove slow baseline drifts. Contrast images, derived from Student's t-tests comparing pressure variation and resting periods for each subject, were calculated. A random effects analysis was performed on these contrast images to draw generalizations across participants. Student's t-tests were also used to identify regions with significantly different BOLD signal levels compared to the null hypothesis. A threshold of $P<0.001$ was applied to the extended statistical t-maps, requiring a minimum of 10 voxels. After correcting for false discovery rate (FDR), no clusters remained significant at these thresholds.

Statistical Test for Hemispheric Differences

A separate analysis compared hemodynamic BOLD responses between the left and right hemispheres. A hemispherically symmetrical template was created using the standard MNI template. Functional images were spatially normalized and smoothed with the same Gaussian kernel as used in the main analysis. Student's t-tests were conducted to assess differences between stimulation and rest periods across subjects. Symmetric contrast images were generated by flipping the image along the antero-posterior y-axis to represent each subject's contrast between the two hemispheres. Individual contrast images were then created by subtracting the symmetric contrast images from the direct contrast images. A random effects analysis was performed on the differential images of each participant. Voxels showing significant differences, exceeding a threshold of 10 voxels, were considered, with the significance level set at $P<0.01$.

RESULTS

Out of the 30 subjects, six participants did not adhere to the instructions during the fMRI measurements, resulting in variations in right ear pressure. In three out of these six cases, participants reported feeling sensations in both ears. Despite this, no consistent patterns were observed in the participants' responses during the test. Analysis of the cortical activation revealed a need for further attention in Brodmann areas 42, 23, and 43, which are located in the postcentral gyrus and are part of the auditory associative cortex. These regions showed notable involvement during the task. Additionally, a statistically significant asymmetry between the right and left hemispheres was observed, suggesting lateralized processing of the auditory and somatosensory stimuli. Despite the variations in responses, the overall findings indicate that these cortical areas play a crucial role in processing stimuli from the ear, with specific involvement of the auditory and somatosensory networks.

Table 1: Identification of Activation Clusters in Temporal and Parietal Cortex Based on Maximal t-Values and MNI Coordinates.

Regions of interest	Side	Brodmann area (BA)	X	Y	Z	T
Temporal superior gyrus	L	BA 84	90	62	14	10.126
Temporal superior gyrus	L	BA 44	101	8	2	8.294
Temporal superior gyrus	R	BA 84	108	44	26	8.180
Temporal superior gyrus	R	BA 84	102	62	38	8.78
Parietal lobes Postcentral gyrus (caudal)	L	BA 86	114	8	14	10.98
Postcentral gyrus (caudal)	R	BA 86	108	20	32	8.68

DISCUSSION:

The findings of this study provide valuable insights into the neural processing of the tympanic membrane and the role of the primary somatosensory cortex in responding to pressure variations in the ear canal. Previous studies have demonstrated that the tympanic membrane projects to Brodmann area 43 (BA 43), a region traditionally associated with sensory processing of oral intake activities, such as gustation and swallowing [9]. In line with these studies, we expanded our investigation to explore the mechanical phases of swallowing, which involve complex interactions between the sensory and motor systems of the oropharynx, larynx, mandible, tongue, and face [10-12]. This interplay is crucial for efficient swallowing, which can be divided into three main phases: oral, pharyngeal, and esophageal. The perception of taste, the sensation of heat, and tactile input in the mouth, along with mastication aided by facial movements, are fundamental components of the oral phase of swallowing [13-15].

Interestingly, our study observed that air pulses applied to the ear canal activated nearby oropharyngeal regions, with a subsequent response in the postcentral gyrus, which corresponds to somatosensory processing [16]. The role of the tensor tympani and other middle ear muscles in the mechanical aspects of swallowing is well-documented. These muscles, including the tensor tympani, tensor veli palatini, and salpingopharyngeus, mediate pharyngeal swallowing, and their histochemical continuity has been noted in the long tendons of the tensor tympani and tensor veli palatini muscles [17]. The tensor veli palatini plays a significant role in sucking and other oro-pharyngeal motor functions. Furthermore, the presence of sensory receptors on the tympanic membrane and in the muscles of the Eustachian tube, which are interconnected during swallowing, suggests that somatosensory processing during swallowing could involve both the auditory and proprioceptive pathways [18].

Despite applying unilateral tympanic stimulation in our study, we observed bilateral activation in auditory associative areas, specifically BA 42 and BA 22, highlighting the bilateral nature of the auditory response. This is consistent with findings from other studies that demonstrated the ability of the middle ear to exhibit an acoustic reflex even in the case of unilateral stimulation. The tensor tympani, which is primarily involved in controlling vocalization reflexes, also contributes to the middle ear's acoustic reflex by modulating the impedance of the ear and reducing nasopharyngeal resonance by adjusting eardrum tension [19]. These mechanisms are thought to help in speech processing and the preservation of interaural level differences, contributing to the regulation of air pressure and impedance in both middle ears. The bilateral activation of the auditory reflex in our study suggests that the middle ear plays a more complex role in auditory perception than previously thought.

CONCLUSION:

Variations in tympanic membrane pressure can induce changes or expansions in associative auditory regions such as BA 42, BA 22, and BA 43. These changes are likely linked to involuntary reflexes that help regulate middle ear pressure during activities like swallowing or speech perception. One study suggests that BA 43 plays a role in modulating both involuntary reflexes and oropharyngeal pressure. While direct representation of tympanic membrane movement due to pressure was not observed in S1, the postcentral gyrus seems to process information closely related to somatosensory perception.

REFERENCES

1. Afifi AK, Bergmann RA (2005): Functional Neuroanatomy: Text and Atlas. New York: Mc Graw-Hill. 494 p.

2. Avan P, Loth D, Menguy C, Teyssou M (1992): Hypothetical roles of middle ear muscles in the guinea-pig. Hear Res 59:59–69.
3. Bluestone CD (1983): Pediatric Otolaryngology. Vol. 1. Philadel- phia: WB Saunders co. 1580 p.
4. Bluestone CD, Beery QC, Andrus WS (1974): Mechanics of the Eustachian tube as it influences susceptibility to and persistence of middle ear effusions in children. Ann Otol Rhinol Laryngol 83 (Suppl 11):27–34.
5. Borg E, Nilson R (1984): Acoustic Reflex in Industrial Noise. New York: Academic Press.
6. Borg E, Zakrisson JE (1975): The activity of the stapedius muscle in man during vocalization. Acta Otolaryngol 79:325–333.
7. Cerf-Ducastel B, Van de Moortele PF, MacLeod P, Le Bihan D, Faurion A (2001): Interaction of gustatory and lingual somatosensory perceptions at the cortical level in the human: A functional magnetic resonance imaging study. Chem Senses 26:371–383.
8. Ehrenstein WH (1994): Auditory aftereffects following simulated motion produced by varying interaural intensity or time. Perception 23:1249–1255.
9. Giraud AL, Truy E, Frackowiak RS, Gregoire MC, Pujol JF, Collet L (2000): Differential recruitment of the speech processing sys- tem in healthy subjects and rehabilitated cochlear implant patients. Brain 123:1391–1402.
10. Hage SR, Jurgens U, Ehret G (2006): Audio-vocal interaction in the pontine brainstem during self-initiated vocalization in the squirrel monkey. Eur J Neurosci 23:3297–3308.
11. Hamdy S, Mikulis DJ, Crawley A, Xue S, Lau H, Henry S, Diamant NE (1999): Cortical activation during human volitional swallowing: An event-related fMRI study. Am J Physiol 277:G219–G225.
12. Howell P, Marchbanks RJ, El-Yaniv N (1986): Middle ear muscle activity during vocalization in normal speakers and stutterers. Acta Otolaryngol 102:396–402.
13. Hugues GB, Pensak ML (2007): Clinical Otology. New York: Thieme. 528 p.
14. Job A, Nottet JB (2002): DPOAEs in young normal-hearing subjects with histories of otitis media: evidence of sub-clinical impairments. Hear Res 167:28–32.
15. Job A, Raynal M, Rondet P (1999): Hearing loss and use of personal stereos in young adults with antecedents of otitis media. Lancet 353:35.
16. Kierner AC, Zelenka I, Lukas JR, Aigner M, Mayr R (1999): Observations on the number, distribution and morphological peculiarities of muscle spindles in the tensor tympani and stapedius muscle of man. Hear Res 135:71–77.
17. Kierner AC, Mayer R, v Kirschhofer K (2002): Do the tensor tympani and tensor velipalatini muscles of man form a functional unit? A histochemical investigation of their putative connec- tions. Hear Res 165:48–52.
18. Leblanc A (1998): Atlas des organes de l’audition et de l’e´quilibra- tion. Guide pratique pour l’oto-rhino-laryngologiste. France: Springer-Verlag. XI, 58 p.
19. Leow LP, Huckabee ML, Sharma S, Tooley TP (2007): The influence of taste on swallowing apnea, oral preparation time, and duration and amplitude of submental muscle contraction. Chem Senses 32:119–128.

Cite this article:
Dr. Suresh Jakkula. (2024). Investigating The Cortical Response To Tympanic Membrane Stimulation Via Fmri.. *Acta Biomedica Scientia*, 11(2), 84-87.