Cortical Activation During Swallowing Rehabilitation Maneuvers: A Functional MRI Study of Healthy Controls

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Introduction

Malignancy of the head and neck, as well as its treatment, often affects structures vital to speech and swallowing. Preservation of these functions has emerged as a critical component of treatment planning[1]. Given the relationship between quality of life and oral intake[2], maintenance of a functional swallow is essential. Dysphagic patients often undergo swallow therapy consisting of a combination of compensatory maneuvers such as postural adjustments and peripheral muscle strength exercises. Both the Effortful and Mendelsohn maneuver are currently used in the clinical setting as a component of a comprehensive rehabilitation. However, the brain responses to these tasks and how activation differs from dry swallowing has not been investigated. In this study, we seek to provide preliminary data regarding the neural networks associated with commonly-employed rehabilitation strategies. We hypothesize that with increased understanding of the neural bases behind these maneuvers, factors of peripheral injury as well as the central adaptor response can be considered in order to develop enhanced rehabilitation strategies for this challenging patient population.

Subjects and Functional Tasks

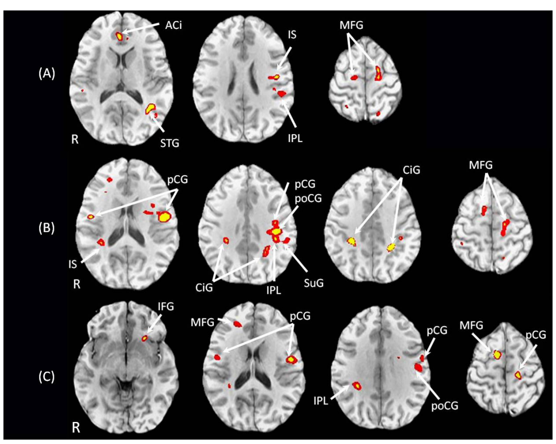
Ten healthy adults, ranging in age from 20 to 30 years were recruited for this prospective study. A single-trial paradigm was employed in which a swallowing task was performed once every 16 seconds. The tasks consisted of three voluntary swallow maneuvers (dry swallow, Effortful swallow, and the Mendelsohn maneuver). For the dry swallow, the subject swallowed own saliva once during the "on" period. For the Effortful swallow, subjects were instructed to swallow with effort squeezing their muscles of the back of the tongue and throat as hard as possible. For the Mendelsohn maneuver, subjects were instructed to swallow normally, but maintain laryngeal elevation for 3 seconds mid-swallow. Subjects performed 10 trials of each task for a maximum duration of 4 seconds per swallow. These productions were followed by a fixation point for a time interval of 16 seconds. Brain activity and head motion were monitored using software (Brainwave, Medical Numerics) that permits the observation in real time.

Method and Data Analysis

All images were acquired with a 3T GE Scanner. Twenty-six slices covering the whole brain was acquired using a gradient echo EPI (2sec TR; 30msec TE; 4.5mm thickness; 128×128 matrix). Anatomical images were obtained using T1-weighted spin-echo and 3D-spoiled GRASS sequences. Using AFNI software [3], a 3D rigid-body registration and spatial smoothing using a Gaussian filter (FWHM=4mm) were applied. Deconvolution analysis [4] was used to estimate the impulse response function (IRF) of the fMRI signal. The estimated IRF was subsequently convolved with the temporal sequence of swallow generation blocks. F-statistic for regression was obtained to assess the significance of activation. The anatomical data were spatially normalized and transformed to the Talairach and Tournoux space. For group analysis, the area under the curve was calculated based on individual subject's data using the IRF. Group activation maps were produced as t-scores of relative signal change between active and baseline tasks compared to a null hypothesis of no change. For the multiple comparison correction, AlphaSim using Monte-Carlo simulations indicated that clusters smaller than 150mm^3 should be rejected at a corrected p-value of $\alpha \leq 0.005$. ROI analysis was applied to measure the volume of activation within the areas. Contrasts showing Effortful vs. dry, Mendelsohn vs. dry, and Mendelsohn vs Effortful were obtained at voxel probability threshold $p<0.005$. Additionally, the averaged signal percentage change was calculated and compared for the swallow associated precentral gyrus in each task.

Results

The pattern of the IRF showed that the time to peak BOLD response in the swallowing-associated precentral gyrus was delayed approximately 2 seconds during the Effortful and Mendelsohn tasks, indicating a correlation between the delayed BOLD signal and prolonged the task performance.



Consistent activations in the angular gyrus, cerebellum, inferior frontal gyrus (IFG), insula, medial frontal gyrus (MFG), middle frontal gyrus (MiFG), middle temporal gyrus (MTG), postcentral gyrus (poCG), precentral gyrus (pCG), superior frontal gyrus (SFG), supramarginal gyrus, superior temporal gyrus (STG), and thalamus, were observed. Of interest, it was evident that, whereas activations were bilateral in the inferior parietal lobe (IPL), insula, MFG, poCG, pCG, supramarginal gyrus, and STG, the pCG and poCG showed strong right hemisphere dominant activation. Areas including angular gyrus, cingulate gyrus, IPL, MiFG, poCG, pCG, SFG, supramarginal gyrus show greater activations with Effortful and Mendelsohn tasks compared to the dry swallow task. Averaged signal percentage changes in the pCG were 1.35%, 1.44%, 1.43% for dry, Effortful, and Mendelsohn swallow, respectively. When comparing the Effortful to the dry swallow (A), increased activation was observed in the left STG, left insula, left IPL), bilateral MFG, and right anterior cingulate. Comparing the Mendelsohn maneuver to the dry swallow (B), increased activation was observed in the bilateral poCG, bilateral pCG, and bilateral cingulate gyrus, bilateral MFG, left IPL, left supramarginal gyrus, and right insula. Finally, when comparing the Mendelsohn maneuver to the Effortful swallow (C), significant activation was noted in the left IFG, poCG, pCG, right MFG, and IPL.

Discussion

Event-related fMRI designs have been successfully used to demonstrate cortical processing associated with swallowing without severe head motion artifacts which may occur during a block paradigm. We present the first data regarding the central, adaptive response elicited during swallowing rehabilitation tasks. These data, in healthy controls, now provide a foundation for further investigation regarding the neural correlates of swallowing impairment as well as the differential activation during rehabilitation in this population. Ultimately, we hypothesize that consideration of the neural activation associated with dysphagia rehabilitation should be not only considered, but included as a fundamental component of the development of novel rehabilitation strategies.

References

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