

# The processing of internally-generated interoceptive sensation

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### INTRODUCTION

The capacity to engage in mental imagery is a powerful quality of human cognition. It enables an individual to consider information outside the scope of the current environment and is a critical component of both past recollection and future projection (Buckner & Wheeler, 2001). Many individual sensory modalities of mental imagery have been investigated, including visual, auditory, olfactory, somatosensory, and motor imagery (Kosslyn, Ganis, & Thompson, 2001). However, a prominent omission from previous research has been the visualization of internal state sensations, or interoceptive imagery. While an increasing amount of evidence points to the insula as the primary cortical representation of internal state (Craig, 2004; Critchley, Mathias, & Dolan 2001) there have been no studies investigating its function outside the current environmental context. The goal of this study was to examine the role of the insula during interoceptive imagery.

#### METHODS

<u>Subjects</u>. Nineteen adults (mean age = 28.1, 13 female) participated in the study. All subjects provided informed consent and were compensated for their time.

Task. Each participant was directed to visualize, as clearly as possible, either an everyday motor action or internal state sensation described by a text phrase. For each phrase they were encouraged to make the experience as 'real and vivid' as possible. If the phrase was for an everyday motor action they were instructed to visualize themselves doing the action from a first-person perspective. If the phrase was for an internal state sensation they were encouraged to literally 'feel' their body in that state. Examples of internal state phrases used in the study were 'freezing cold', 'upset stomach' and 'itchy skin'.

<u>Design</u>. Each subject completed two fMRI runs containing six blocks of each condition. Within each block the subject was presented with a cue to alert them to the visualization condition and then three words from either the internal or action visualization condition. Total scan time for this task was 10 minutes.

<u>Preprocessing</u>. Image processing was completed using SPM5. Preprocessing steps for the functional imaging data included a 6-parameter rigid-body affine realignment of the fMRI timeseries, unwarping to reduce the influence of movement-related variance, coregistration of the data to a  $T_1$ -weighted anatomical image, and 8 mm full-width at half-maximum (FWHM) Gaussian smoothing.

<u>Analysis.</u> A two-level mixed effects methodology was used. The first level was completed on each subject's data individually using restricted maximum likelihood estimation of the general linear model. Hemodynamic responses were modeled by a boxcar function convolved with a canonical hemodynamic response. A high pass filter with a frequency cutoff of 128 seconds was used to remove low frequency drift in the data. The resulting beta estimates from each subject were then entered into a second-level statistical test to compute the final 2x2 ANOVA.

#### DISCUSSION

The results of this experiment demonstrate that interoceptive imagery involves the use of cortical structures necessary for the processing of realtime internal state sensations. Differences in BOLD signal were observed in the modality-specific areas that give rise to the unique sensory qualities of each visualization condition. For the visualization of internal state sensations this meant increased activity in areas of interoceptive sensory processing, including the mid and anterior insula in the right hemisphere. This is a critical finding, as it suggests that primary interoceptive cortex, located in the posterior insula, was not significantly involved in the imagery of internal state sensations.

## REFERENCES

Craig AD. (2004). Human feelings: why are some more aware than others? *Trends in Cognitive Sciences*, 8(6):239-241.

Critchley HD. (2001). Neuroanatomical basis for first- and second-order representations of bodily states. Nature Neuroscience, 29(2):537-545.

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#### **GENERAL VISUALIZATION RESULTS**



A conjunction analysis was preformed to test for regions with a significant response to both internal state and action imagery conditions. The parameters for this comparison were  $t^2(60) > 3.23$ , p(FDR) < 0.05, 8 voxel extent threshold. Bilateral areas of inferior temporal cortex, polar visual cortex, frontal operculum/anterior insula, lateral frontal cortex, premotor cortex, and anterior cingulate were shown to be active within both imagery conditions.



A *t*-contrast was used to test for regions with preferential BOLD response in one imagery modality over the other. The parameters for this comparison were t(60) > 3.23, p(FDR) < 0.05, 8 voxel extent threshold. For the interoceptive imagery condition (see above) voxel clusters were found along the right insula, bilateral frontoparietal operculum, anterior cingulate, and substantia nigra. For the action imagery condition (see below) significant clusters were found in left premotor cortex, left primary somatosensory cortex, left intraparietal sulcus, and bilateral visual cortex.

