

A Multi-modal Mental Imagery System: an fMRI Study of Visual and Mental Imagery

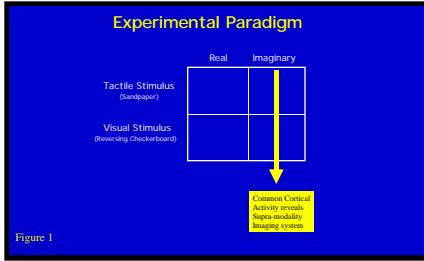
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ABSTRACT

It is well known that mental imagery, or the ability to conjure a sensory stimulus no longer present, is an important physiological function for a wide range of human cognitions. Various studies have demonstrated the interaction of mental imagery with other cognitive processes, including language, visual perception, and memory (Farah 1988; Mellet 1998; Fallgatter 1997; Kosslyn 1997; Kosslyn 1999), though the neural substrate associated with imagery remains unknown.

In this study, the cortical regions active while conjuring a sensation in both the tactile and visual modalities were studied using whole-brain functional magnetic resonance imaging (fMRI). A conjunction technique, which isolates task-specific cortical activity, identified a cross-modal imagery system. Three cortical areas were discovered: inferior parietal lobule (BA 40), left medial frontal gyrus (BA 6), and left middle frontal gyrus (BA 9), supporting a multi-modal mental imagery system consistent with connectionist models of sensory processing.



METHODS

Image Acquisition

A 1.5T MRI unit and a standard head coil (General Electric, Milwaukee, WI) were used to obtain T2*-weighted images with a gradient echo pulse sequence (TR, 4000; TE, 60; flip angle, 60degrees), which was sensitive to blood oxygenation level dependent signal changes caused by alterations in the ratio of deoxyhemoglobin in the local vasculature accompanying neuronal activation. The cubic size of each volume element, or voxel, was 10mm3, in which the in-plane resolution was approximately 1.5X1.5mm and the slice thickness was 4.5 mm. Twenty-one contiguous slices of brain were obtained parallel to a standard reference line that intersected the superior edge of the anterior commissure and the inferior edge of the posterior commissure.

Experimental Design

This study used a conventional block design paradigm, using a baseline brain activity to compare brain activity during the activity, or stimulation period. One image of the whole brain is acquired every four seconds. Therefore, the entire two minute and twenty-four second run yields a total of thirty-six whole brain images.

Six healthy (4 female, 2 male) subjects participated in the fMRI studies during the performance of two tasks (Table 1). Each task was done in two modalities; visual and tactile (Figure 1).

During the first forty seconds, baseline brain activity was recorded. A crosshair fixation point was presented during the baseline periods of the visual perception task and the visual imagery task (Figure 2). The stimulus in the visual perceptual activation period was a reversing checkerboard shown on a screen. During the visual imagery activation period, the subject was instructed to imagine the reversing checkerboard seen in the previous run. The eyes remained closed throughout the tactile perception run and the tactile imagery run, thus no crosshair was needed during baseline. Two pieces of smooth paper held in motionless hands, were used as a control during the tactile baseline period. The stimulus in the tactile perceptual activation period was sandpaper. The subjects were instructed to palpate, using both hands equally, the pieces of sandpaper. A forty-second recovery baseline period followed the activity period. The paradigm was then repeated, yielding a total of eight runs.

Our experimental design makes use of a conjunction and conservation technique (Hirsch, 2001) the conjunction technique conjoints activity in an identical task, common to multiple modalities. Thus, one may assume that the activity associated with this task is beyond the input and sensory related activity. The conservation technique isolates the activity conserved across multiple subjects, thus only leaving active cortical regions that are above individual differences (Figure 3 and Figure 4).

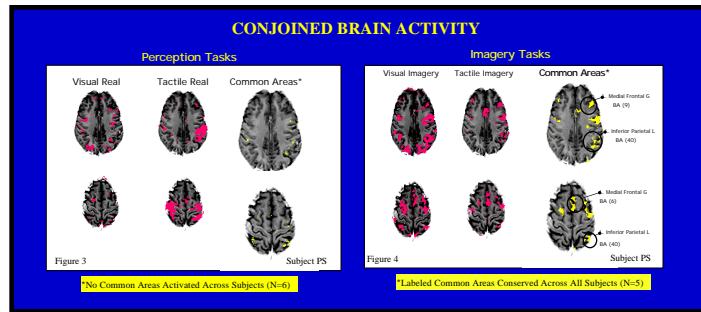
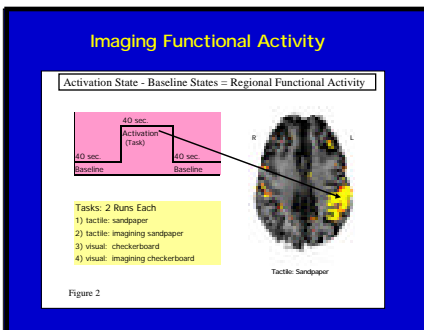
Activity observed in all subjects during the visual and tactile imagery tasks is presented in Figure 4. No activity was conserved across all subjects in the visual and tactile perception tasks. The left-hand column lists active anatomical areas. The cortical activity conserved across all subjects was then further assigned left or right hemisphere activation. Only activity conserved throughout anatomical area, Brodmann's Area, and hemisphere is considered conserved.

Subject Information

Subject	Age	Gender	Handedness	Laterality Quotient *
AA	27	M	Right	100
BM	19	F	Right	100
DM	16	F	Right	100
PS	18	F	Right	100
EM	18	F	Right	100
AP	19	M	Right	100

* Edinburgh handedness inventory (Oldfield, 1971)

Table 1



RESULTS

Conjunction activity was labeled according to Brodmann's area (BA), and stereotaxic coordinates based on the Human Brain Atlas (Talairach & Tournoux, 1988). Conserved activity for all subjects was isolated from the activity that was specific to individual subjects to produce a cortical substrate; was either a system of areas, or a single area.

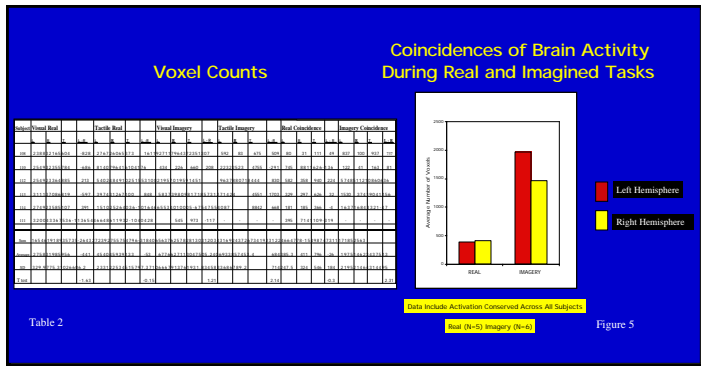
Conjunction:
The imagery task is isolated from the sensory aspects of input by finding the common activity across modalities. Figure 4 illustrates this technique by showing the areas in common to both visual and tactile imagery tasks. This common activity among the three modalities, produces aspects of the imagery task that are not sensory specific (shown in the right column by the yellow areas with assigned anatomical labels).

The same technique was used with the perception task. Conjoining the visual and tactile perception task produces little cortical activation within one subject, and no cortical activation across all subjects. The absence of conjoint activity suggests that the perception task is specific to sensory modality.

Isolation:
If an area is not present in all subjects, it is assumed that individual differences, rather than a common neural substrate produce the cortical activation. In contrast, if the same area is active in all subjects, it can be assumed that this area is part of a functional specialty typical of the population of normal subjects. This yields a false positive rate of p< .4X10⁻⁷. With the additional criteria that 100% of the subjects observe the same effects sets a high standard, consistent with population inferences.

Global Findings:
Voxel counts were performed to examine the laterality and intensity of activation during the imagery task (Table 2). With a significant t test value of 2.31 it was found that the imagery task caused greater left hemisphere activation (Figure 5).

Regional Findings:
When active areas in visual and tactile imagery tasks are conjoined, three areas are conserved across all subjects: inferior parietal lobule (BA 40), left medial frontal gyrus (BA 6), and left middle frontal gyrus (BA 9) (Table 3 and Figure 6). These results are consistent with our hypothesis; the existence of a multi-modal imagery neurocognitive system, and further evidence for a network model.



Visual and Tactile Imagery Tasks, Anatomical and Brodmann's Areas Per Subject

Anatomical Region	Subjects				
	AA	BM	DM	EM	AP
Middle frontal gyrus (Gfm)	10,46,9,8	9	9,6,5	9,6	9,46
Inferior parietal lobule (Lp)	40	40	40,50	40	40
Medial frontal gyrus (Gfd)	8,6	6	6,8	6	6,8

Table 3

The Imagery Substrate: Conserved Brodmann's Areas and Hemisphere in all Subjects:

- Inferior parietal lobule (Lp), Brodmann's Area 40, right & left hemisphere
- Medial frontal gyrus (Gfd), Brodmann's Area 6, left hemisphere
- Middle frontal gyrus (Gfm), Brodmann's Area 9, left hemisphere

CONCLUSIONS

We employ fMRI to determine the cortical areas that participate in mental imagery. Two types of imagery were studied: visual imagery and tactile imagery. The cortical regions found in this study were active during the imagery task in both sensory modalities for all subjects and include inferior parietal lobule (BA 40), left medial frontal gyrus (BA 6), and left middle frontal gyrus (BA 9). We conclude these areas are independent of sensory input. Further, there was a significantly (p < 0.05) larger volume of active regions in the left hemisphere than in the right hemisphere across all subjects, suggesting that the supra-modal imagery substrate lies predominantly in the left hemisphere.

Talairach Axial Slice + 50

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