Test-Retest Precision of Functional MR in Sensory and Motor Task Activation

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PURPOSE: To determine the test-retest precision of functional MR maps of regions in the brain "activated" by sensory, motor, and cognitive tasks. **METHODS:** Echo-planar images were acquired at 1.5 T in four subjects during voluntary motor activity involving the thumb and fingers and during tactile stimulation of the palm. Each subject performed the two tasks twice. Functional images of each task were generated at three thresholds. Test-retest precision was calculated in terms of two ratios: 1) the pixels activated in both iterations of the tasks in proportion to the pixels activated by either iteration of the task, and 2) the ratio modified to include first-order neighboring pixels. The first is referred to as *pixel precision*, and the latter as *first-order-neighbor pixel precision*. **RESULTS:** In each subject, activation from the first and second iteration of each task was located in the same region of the same gyrus. Pixel precision was .57 for the two tasks (at a threshold of 0.50). First-order-neighbor precision was greater than .80 for the two tasks at the same threshold. **CONCLUSION:** High test-retest precision can be obtained in functional MR.

Index terms: Magnetic resonance, functional; Efficacy studies

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Functional MR imaging, a noninvasive method of demonstrating changes in regional cerebral blood flow produced by sensory, motor, and cognitive tasks, can be used clinically to map eloquent regions of the brain before surgery and to study experimentally the organization of brain functions (1–10). Before functional MR can be evaluated extensively for clinical applications, its accuracy and precision in regard to paradigms that are used in patients must be studied. The purpose of this study was to measure the test-retest precision of the functional maps of two paradigms used in clinical functional MR imaging: a voluntary motor activity involving the thumb and fingers, and tactile stimulation of the palm.

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Methods

Functional imaging was performed with a 1.5-T commercial imager equipped with an end-capped bird-cage transmit-receive coil and a three-axis gradient coil (11). Four volunteers were recruited and consent was obtained. Functional MR studies in volunteers have been approved by our institution's review board. After ear plugs were inserted, the subject was positioned in the head coil and in the bore of the imager. The magnet was reshimmed and the transmit and receive attenuations were adjusted. Anatomic locater images were obtained in axial and sagittal projections with a spin-echo sequence of 300/20/1 (repetition time/echo time/excitations), a 24-cm field of view, a 1-cm section thickness, and a 256 × 256 matrix. Six contiguous 1-cm-thick parasagittal planes of section were chosen to encompass the left cerebral hemisphere. A series of anatomic reference images was obtained in this plane with a fast spin-echo sequence of 4000/102/2, a 24-cm field of view, and a 1-cm section thickness. A sequence of 140 images was acquired with a blipped single-shot, gradient-echo echo-planar imaging sequence at a rate of 1/s with parameters of 1000/40, 24-cm field of view, 64 × 64 matrix, and 1-cm section thickness (40-millisecond acquisition time) in each selected plane during four 20-second periods of rest alternating with three 20-second periods of task. During each acquisition, one task was performed three times. One task (referred to as the "motor task") consisted of the subject's apposing the

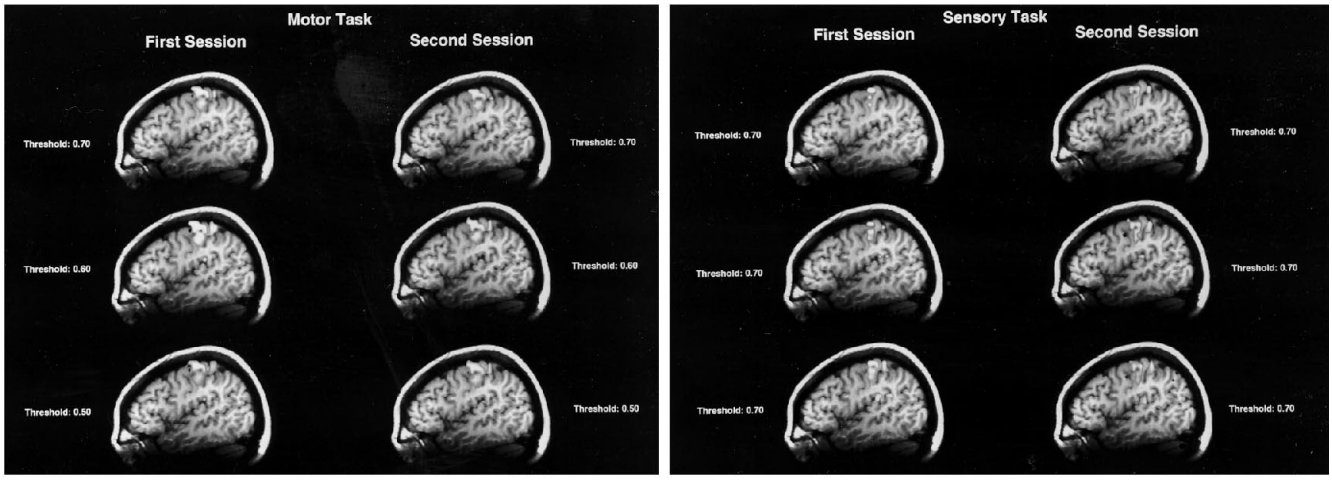

Fig 1. Functional images of the first and second iterations of the motor task (*A*) and the sensory task (*B*) in one volunteer at thresholds of 0.7, 0.6, and 0.5 correlation coefficient value. Note that the activation is in a similar location on the two sets of images and the number of activated pixels varies with threshold.

thumb with the index finger repetitively at a rate of about 2 Hz during the specified 20-second periods. The other task (referred to as the "sensory task") consisted of an investigator's scratching the subject's palm with the fingertips in a craniocaudal direction at a rate of 1 Hz during the specified 20-second periods. Each subject performed each task twice. For each set of 140 images in each plane, the signal intensity of each pixel was plotted as a function of time. The time course plots for each pixel in the sequence were compared with a square wave reference function with a period of 40 seconds, representing the off/on periods of the task. With the use of a cross-correlation method (11), pixels that had changes in signal intensity temporally correlated with the reference function were displayed as "activated" pixels. Images ("functional images") were created of the activated pixels and registered to the anatomic images. For this study, images were generated at three correlation coefficient values of .70, .60, and .50 (*P* values calculated per voxel were 1.2×10^{-5}, 5×10^{-8}, and 2×10^{-11} for thresholds of .50, .60, and .70, respectively).

The functional images of the first and second iteration of each task were compared to evaluate the location of the activation qualitatively. Then the number and location of pixels activated in each section were tabulated. Two ratios reflecting agreement with respect to the location of activity within a given section number were calculated to measure reproducibility at the pixel level and at the first-order-neighbor level. Reproducibility at the pixel level was calculated as the ratio of the number of pixels in which activation was demonstrated in each iteration of the task to the number of pixels in which activation was demonstrated in either iteration of the task. Reproducibility at the first-order-neighbor level was measured by including in the numeration any pixel that was activated in each iteration or bordered a pixel activated with another iteration.

Results

Four subjects performed each of the two tasks twice within a single experimental session. Erratically located activations suggestive of motion artifacts were rare. In each iteration of a task, activation was apparent in the same cerebral gyrus, but not with exactly the same coordinates (Fig 1). Most of the activity measured when either task was performed occurred within the second and third parasagittal sections and in a region of the image that corresponded to the frontal parietal junction. Of the total measured activity, 86%, 52%, and 45% occurred within these two sections at the .70, .60, and .50 thresholds, respectively, during the motor task; during the sensory task, 83%, 65%, and 57% of the total measured activity occurred under the three threshold criteria, respectively.

The Table lists the mean and standard deviation at the pixel level and the first-order-neighbor pixel level for four subjects. Reproducibility assessment was limited to parasagittal sections 2 and 3, owing to the sparseness of activity found in the remaining sections. Reproducibility was greater at the lower threshold levels of .50 and .60 than at the .70 level for the sensory task. For the motor task, the differences between thresholds were small. The mean reproducibility ratio at the same pixel level for the motor tasks was .54, .59, and .57 at the .70, .60, and .50 threshold level, respectively. The mean reproducibility ratio at the pixel level for

Proportion of pixels activated by both iterations of a sensory or motor task to the number activated by either

Pixel Precision with Functional MR	Threshold		
	.70	.60	.50
Same pixel precision			
Motor task	.54 (.16)	.59 (.15)	.57 (.09)
Sensory task	.39 (.39)	.45 (.15)	.57 (.11)
First-order-neighbor pixel precision			
Motor task	.74 (.24)	.84 (.14)	.81 (.09)
Sensory task	.59 (.46)	.76 (.06)	.82 (.09)

Note.—Numbers in parentheses are standard deviation.

the sensory tasks was .39, .45, and .57 at the .70, .60, and .50 threshold level, respectively.

Reproducibility at the first-order-neighbor pixel level was consistently greater than at the pixel level. The threshold level had less effect on the reproducibility at the first-order-neighbor level than found at the same pixel level. The mean reproducibility at the first-order-neighbor pixel level for the motor tasks was .74, .84, and .81 at the .70, .60, and .50 threshold level, respectively. The mean reproducibility ratio level at the first-order-neighbor pixel level for the sensory tasks was .59, .76, and .82 at the .70, .60, and .50 threshold level, respectively. The standard deviations of the reproducibility ratios were greater at the .70 threshold than at .60 or .50.

Discussion

A small group of healthy volunteers was studied to estimate the test-retest precision of clinically used paradigms. Poorer precision may be anticipated in patients who have neurologic impairment than in our cooperative, normally functioning subjects. Two tasks, one active (motor) and one passive (sensory), were selected from many used in functional MR studies. Precision from language or vision or cognitive tasks may not necessarily be equivalent to that of the tasks we selected. In this study, imprecision caused by patient positioning and machine drift was minimized by acquiring the data for both functional MR studies in the same session. Greater precision may be achieved if the rate and intensity of the tasks in each iteration are controlled. To determine the effect of varying performances on activations, additional studies are needed.

The average test-retest agreements increased and the standard deviations decreased as the threshold was changed from a correlation coefficient value of .70 to .60 or .50. The low level of agreement at the threshold of .70 is possibly attributable to a small number of pixels displayed at a very high threshold. The modest change in average agreement and variance between thresholds of .60 and .50 suggests that these thresholds are useful for calculating functional images given the number and type of images in our experiments. Nearest-neighbor precision was greater than same-pixel precision. Our nearest-neighbor pixel convention increased the effective pixel size by 400%. An alternative nearest-neighbor pixel convention, the eight pixels that border a single pixel, increases the effective pixel size by 800%. This convention produces an even greater test-retest congruence.

The motor and sensory tasks activated similar regions in the rolandic cortex. The motor task includes sensory input; therefore, some overlap is unavoidable. Furthermore, motor and sensory functions may not be uniquely located in the rolandic cortex, as some current thinking suggests (12).

The pixel precision for first and second iterations of a functional MR study indicates that the data are dominated by true-positive responses rather than by motion artifacts located erratically in the images. Artifacts caused by head motion synchronous with tasks (13) or motion of objects outside the field of view (F. Z. Yetkin, V. M. Haughton, R. W. Cox, et al, unpublished data) may produce artifacts. The variation of the test-retest precision with the threshold suggests that the threshold for a functional MR experiment can be optimized for precision.

Conclusion

A high level of precision is obtainable in functional MR studies, even without rigid controls on the subject's performance. With some techniques, only a small fraction of pixels activated in one iteration of a task will not be activated in another iteration. The activation in each iteration conforms to the same region of the brain. When functional MR is used to measure small differences in the location of cerebral activation for different tasks, a measure of precision should be supplied.

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