Functional Magnetic Resonance Imaging Correlates of Cognitive-Motor Learning: Preliminary Findings

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PURPOSE:

To use whole-brain, functional MRI (FMRI) to map the changes in brain activation patterns associated with the acquisition of cognitive-motor skills.

INTRODUCTION:

The study of motor learning in humans has a long tradition, but our knowledge of the supporting neural systems is incomplete. Recent PET studies in neurologically intact humans have produced conflicting findings. Seitz et al. [1] reported rCBF increases during the early stages of learning a complicated finger movement task in the left primary motor (M1) and premotor (PM) cortices, left sensory hand area (S1), right anterior lobe of the cerebellum, and bilateral parietal cortex. In later stages of learning, rCBF in the parietal cortex disappeared. Another study [2] demonstrated *increases* in rCBF in the primary motor cortex, SMA, and pulvinar thalamus over the course of learning.

Previous studies have defined motor learning by an increase in movement rate. Using FMRI, we have [3] previously shown that rate is positively correlated with percent signal change from the primary motor cortex. The present FMRI study avoids this confounding factor by defining learning as an improvement in reaction time (RT). This study was designed to investigate the role of cognitive-motor processing in sequential learning and to determine how the brain implements this key aspect of skill learning.

METHODS:

Six healthy right-handed subjects were imaged using a standard GE 1.5-T Signa scanner equipped with a 30.5 cm i.d. three-axis local gradient coil and an endcapped quadrature birdcage RF coil. A blipped gradient-echo echo-planar pulse sequence (TE = 40 ms; FOV = 24 cm; 64 x 64 matrix; 3.75 mm in-plane resolution) was used. Sixteen contiguous saggital slices (7 mm slice thickness) were obtained covering the entire brain.

During each series, 64 consecutive images (TR = 4 s) were obtained during 10 alternating baseline (rest) and activation periods of 12 s each. Motor learning was assessed with a four-choice serial RT task [4]. Subjects executed index finger keypresses as fast and as accurately as possible in response to a visual stimulus projected on a back-illuminated screen. The stimulus was a filled box that appeared within one of four open boxes, arranged in a diamond formation. The four boxes corresponded to the four keys on a keypad.

A block of trials (imaging series) began with eight seconds of rest to allow stabilization of the MR signal. The onset of the first stimulus signaled subjects to execute a particular keypress. After 900 ms, the stimulus disappeared and the onset of the next stimulus occurred 100 ms later. RT was measured from the onset of a stimulus until the subject pressed a key. A block consisted of 120 trials. Mean RT was computed across the 120 trials for each block. All subjects received one block of practice trials that consisted of random presentations of the stimulus. Practice trials were followed by 10 blocks of experimental trials.

Subjects participated in one of two conditions. In the *random* condition, subjects received pseudorandom presentations of stimuli. This condition allowed for examination of the neural systems that give rise to cognitive operations controlling learning of perceptual-motor translation processes. In the *repeat* condition, subjects received 5 blocks of trials that contained repetitions of a 12-element sequence. Designating the four stimulus locations as up (U), down (D), left (L), and right (R), the sequence was D-R-L-U-L-R-D-L-R-U-D-U. This was followed by one block of pseudorandom trials and then another 4 blocks of the same repeated sequence. This condition allowed for an examination of the neural systems that give rise to the cognitive-motor operations involved in serial event learning.

RESULTS:

Figure 1A present the RT results for the random and repeat conditions. The random condition produced no appreciable decline in RT over the 12 blocks, suggesting that the perceptual-motor learning contribution to this task is minimal. In contrast, a progressive drop in RT was observed in the repeat condition. In addition, the increase in RT when switching between repeated and random (Block 6) trial blocks also indicated sequence specific learning associated with the repeat condition.

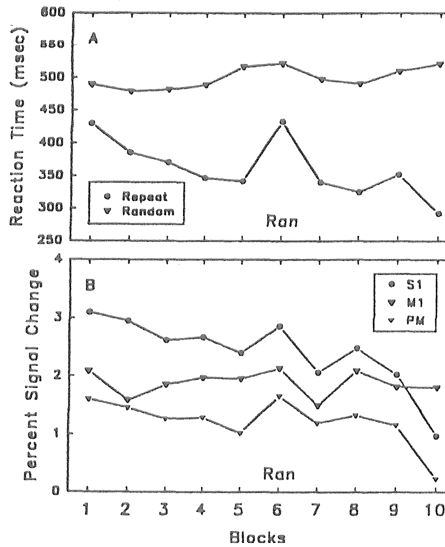

Figure 1

Three specific brain regions of interest were identified for examination of learning effects: left M1, S1, and the PM cortex. Figure 1B presents percent signal changes from a representative subject from the repeat condition. Decrements in motor learning were observed in S1 and PM cortex over the 10 blocks; no such changes were observed in M1. In addition, increases in signal change were observed in the transition between repeated and random trials for the S1 and PM cortices.

CONCLUSIONS:

These findings indicate that FMRI can provide important scientific data regarding the neural systems subserving the cognitive-motor systems involved in motor sequence learning.

REFERENCES:

1. R.J. SEITZ, E. ROLAND, C. BOHM, ET AL., *Neuroreport.* 1, 57 (1990).
2. S.T. GRAFTON, J.C. MAZZIOTTA, S. PRESTY, ET AL., *J. Neurosci.* 12, 2542 (1992).
3. S.M. RAO, J.R. BINDER, P.A. BANDETTINI, ET AL., *Neurology* 44 (in press).
4. M.J. NISSEN AND P. BULLEMER, *Cogn. Psychol.* 19, 1 (1987).