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Localized brain activation by selective tasks improves specific cognitive functions in humans

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Abstract

Neuroimaging studies have identified cognitive tasks that can selectively activate specific parts of the brains. However, the subsequent effect of localized brain activation on the cognitive functioning remains unclear. We discovered that after being engaged in the novel picture encoding task to activate hippocampus for 2 min, individuals demonstrated better memory, but not motor function. Similarly, after performing the finger sequencing task to activate the primary motor cortex, individuals showed improvement in motor function, but not in memory. These double dissociation results suggest that when we selectively activate specific part of the brain, the cognitive function mediated by that particular region but not the others can consequently be improved.

Keywords: Brain activation; Hippocampus; Motor cortex; Picture encoding; Finger sequencing; Double dissociation

Functional imaging techniques can detect signal changes of the brain when individuals undergo some cognitive tasks. Scientists suggest that these signal changes represent an increase of biochemical activity of the synapses and neurons in this particular region associated with the cognitive tasks [11]. Intense activation of the synapses, as demonstrated by some neurophysiological studies, induces potentiation making the neurons highly responsive to the upcoming inputs [1,20]. In the light of such findings, we hypothesized that if a specific region of the brain was activated for doing a particular cognitive task, this part of the brain would be more sensitive and active, and thus more ready for later cognitive functioning. The subsequent cognitive processing mediated by that brain region would be facilitated.

To test the effect of the brain activation, triggered by cognitive tasks, on subsequent cognitive processing, we incorporated the findings of neuroscience to localize the brain functions and those of neuroimaging to identify the tasks that serve to selectively activate different brain regions. The critical role of the primary motor cortex for voluntary body movement has been recognized since 1950's when electrical stimulation on particular parts of the motor cortex causes movement of their corresponding body parts [7]. Regarding memory, evidences from studies of neurological patients [16,18] and animals [16] with medial temporal lesions suggest that the hippocampus and its surrounding areas are crucial for the short-term 'declarative memory'. In specific, these areas are responsible for consolidating newly learned facts and events into the long-term storage.

With recent advances in using functional magnetic resonance imaging technique to investigate cognitive processing, certain cognitive tasks that can selectively activate specific parts of the brain have been identified [12]. After many attempts to explore and identify tasks associated with activation in the hippocampus [14,17], Stern and his colleagues reported that robust signal changes were detected in bilateral posterior hippocampal formation and parahippocampal gyrus when subjects were performing the novel picture encoding task (NPET) [19]. Tasks associated with the activation of primary motor cortex have also been documented. Among them [1,5,8], the finger sequencing task (FST) [5,8] has been more extensively studied and is found to be associated with bilateral motor cortex activation. Accordingly, we utilized the NPET and FST as the cognitive tasks to activate the hippocampus and primary motor cortex, respectively.

The present study included 170 students from the Chinese University of Hong Kong. They were randomly assigned to five groups ($n = 34$) and matched in terms of their age ($F_{(4,169)} = 0.39$, n.s.), education ($F_{(4,169)} = 0.81$, n.s.) and grade point average ($F_{(4,169)} = 0.59$, n.s.). Their memory as determined by the Hong Kong List Learning Test [3]

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Table 1
Demographic characteristics and baseline measurement[a]

	Group 1	Group 2	Group 3	Group 4	Group 5
Age (years)	20.41 ± 1.18	20.74 ± 1.58	20.62 ± 1.72	20.94 ± 2.64	20.59 ± 1.67
Gender (M/F)	18/16	18/16	18/16	18/16	18/16
Education (years)	17.29 ± 1.19	17.58 ± 1.25	17.09 ± 1.16	17.18 ± 1.17	17.32 ± 1.15
GPA (points)	2.98 ± 0.48	2.99 ± 0.42	3.06 ± 0.36	2.91 ± 0.49	3.04 ± 0.42
HKLLT (words)	34.32 ± 5.44	32.68 ± 4.97	32.03 ± 4.21	32.35 ± 6.35	31.82 ± 6.43
GPT (s)	132.03 ± 18.39	127.94 ± 15.55	126.91 ± 14.49	125.79 ± 14.11	125.32 ± 15.68

[a] All values, except the variable gender, are reported as mean ± SD. No significant different between groups ($n = 34$) for all variables, (ANOVA, n.s.). GPA, grade point average; GPT, grooved pegboard test; HKLLT, Hong Kong list learning test.

($F_{(4,169)} = 1.09$, n.s.), and their motor function as measured by the Grooved Pegboard Test [6] ($F_{(4,169)} = 0.99$, n.s.) were matched at the baseline level (Table 1). In the 2-min brain activation paradigms, subjects in group 1 performed the NPET while those in group 2 carried out the FST. Then their motor speed was assessed by the Finger Tapping Test [10]. Subjects in group 3, like group 1, did the NPET while those in group 4, as group 2, did the FST. After finishing the brain activation paradigms, memory of the subjects in these two groups was evaluated by means of a verbal learning task consisting of 20 two-character Chinese words selected from a set of normative data for bilingual students in Taiwan [4]. The fifth group, the control group, sat quietly for 2 min. Their memory and motor speed were assessed by the same verbal learning test and Finger Tapping Test.

To investigate the effect of activating the primary motor cortex on motor function, we compared the performances of subjects in group 1, 2 and 5 on the Finger Tapping Test [10]. The motor speed of individuals who had done the FST was approximately 20% higher than that of subjects who had performed the NPET and who had sat quietly ($F_{(2,99)} = 18.76$, $P < 0.01$). Similar result pattern was observed across ten trials ($F_{(9,891)} = 10.58$, $P < 0.01$; Fig. 1). The motor speed of subjects who had been engaged in

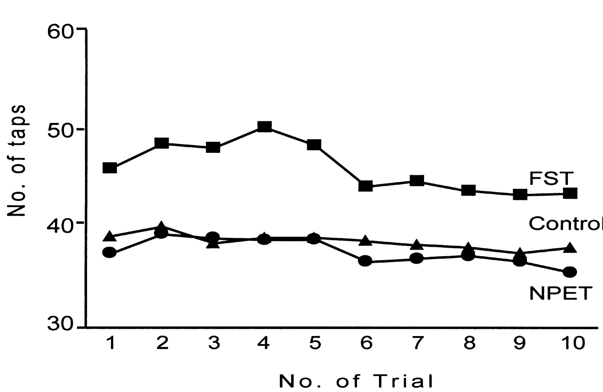

Fig. 1. Performance in the finger tapping test across ten trials. Subjects who had done the finger sequencing task (filled squares), when compared with those who had performed the novel picture encoding task (filled circles) or sat quietly (filled triangles), made significantly more taps across ten trials.

the NPET and had sat quietly was not significantly different (post hoc *t*-test at 0.05 level).

The present result may be explained as a practice effect in which practicing one motor task could improve the performance of another motor task because the earlier exercise may increase the flexibility of the fingers and thus improve the later motor performance. To rule out the practice effect and better understand the immediate effect of brain activation on cognitive functions, we utilized visual materials to activate the hippocampus and evaluated its function by verbal materials. Since visual and verbal processing tends to be modality specific [15], practice on the visual modality should not be associated with improvement on the verbal processing.

Our findings suggested that subjects who had engaged in the NPET learned approximately 22% more words in the verbal learning task than subjects who had done the FST or who had sat quietly, and the difference was significant ($F_{(2,99)} = 10.94$, $P < 0.01$); results were consistent across three trials ($F_{(2,198)} = 474.11$, $P < 0.01$; Fig. 2a). The performance of the latter two groups was not different significantly. In addition, we compared the subjects' rates of learning which was calculated as the difference between the number of words learned in the first and third trials in proportion to the number of words learned in the first one. As indicated in Fig. 2b, individuals who had performed the NPET demonstrated a significant higher rate of learning than those who had done the FST or had sit quietly ($F_{(2,99)} = 4.20$, $P = 0.02$).

It should be emphasized that the memory ability between groups was not significantly different before activation. Thus, subjects' improved performance on the verbal learning task cannot be simply attributed to a baseline difference. Moreover, these results are also unlikely to be explained by a practice effect, given that the activation and testing paradigms were across modalities.

While the present results are analogous to previous notion of brain plasticity in which the neural organization and processing is constantly altered in response to some external factors [2,9,13], it further demonstrated a double dissociation phenomenon to indicate that the effect is quite specific. That is, after performing a cognitive task that activates the hippocampus, subjects demonstrated improvement in

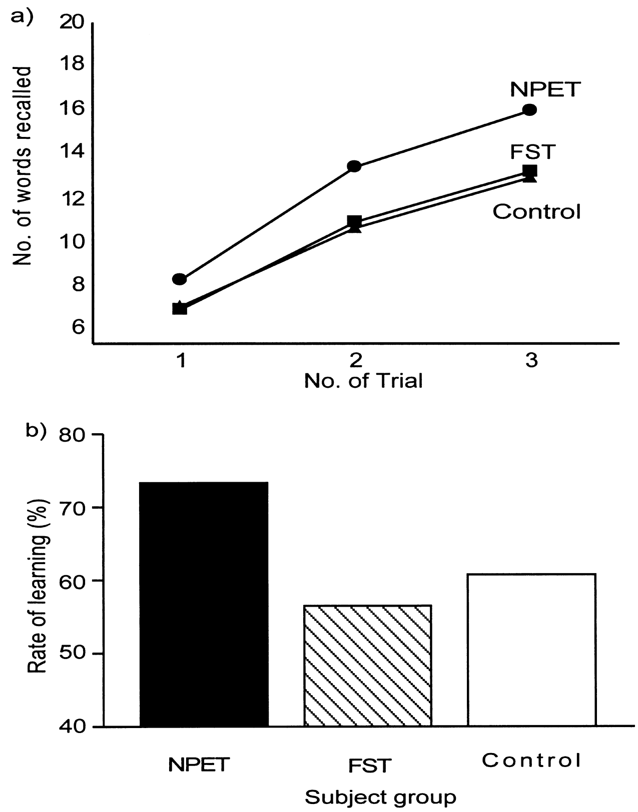

Fig. 2. Performance in the verbal learning test across three trials. (a) Subjects who had engaged in the novel picture encoding task (filled circles) recalled significantly more words than subjects who had done the finger sequencing task (filled squares) or sat quietly (filled triangles). (b) Subjects who had done the novel picture encoding task (solid) demonstrated a significant higher rate of learning than those who had performed the finger sequencing task (hatched) or sat quietly (open).

memory, but not in motor function. Similarly, after engaging themselves in a cognitive task that activates the primary motor cortex, subjects demonstrated better motor function, but not memory. It should be caution that although it may be a very attractive proposition that a 2-min stimulation of the brain with a specific cognitive task can improve learning and memory, the long-term effect of this type of stimulation is still unknown, and the optimal duration and interval of these brain stimulation exercises remain unclear.

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