

Activity in motor areas while remembering action events

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Episodic memory for simple commands is better following enacted than verbal encoding. This has been proposed to be due to the possibility to base retrieval on motor information. Here we used PET to test the hypothesis that motor brain areas show increased retrieval-related activity following enacted compared to verbal encoding. Brain activity was also monitored during retrieval after imaginary enactment during encoding. It was found that activity in the right motor cortex

was maximal following encoding enactment, intermediate following imaginary encoding enactment, and lowest following verbal encoding. These findings provide support that one basis for the facilitating effect on memory performance of overt, and to a lesser degree covert, encoding enactment is the possibility to base retrieval on motor information. *NeuroReport* 11:2199–2201 © 2000 Lippincott Williams & Wilkins.

Key words: Enactment; Episodic memory; Motor cortex; PET

INTRODUCTION

Cognitive studies show that overt and covert enactment during encoding of simple commands (e.g. roll the ball) improves subsequent verbal retrieval of the commands [1]. This is true for several different populations, including elderly [2] and demented [3] patients and patients with frontal lobe dysfunction [4,5]. It has been proposed that encoding enactment allows retrieval to be based on motor information [6]. Verbal retrieval following encoding enactment should, therefore, involve motor brain areas [7]. Here we used PET to monitor brain activity during retrieval following real encoding enactment, imagined encoding enactment, and verbal encoding (maintenance rehearsal).

MATERIALS AND METHODS

Six male subjects, aged 24–38 years all gave written informed consent to participation in the experiment. They were all right handed as assessed by the Swedish version of the Edinburgh handedness inventory.

The experiment involved three conditions. In all conditions, subjects encoded verbal commands and were then tested for memory of these by a cued-recall test (the verbs served as cues for remembering the nouns). Differences at encoding determined the differences between conditions. In the enactment condition, subjects overtly performed the activities described by the commands. In the imagery condition, subjects covertly performed the activities described by each command. In the verbal condition, subjects silently rehearsed the commands (maintenance rehearsal).

PET was used to measure whole brain activity during

the retrieval phase. Each subject was given 12 PET scans (4/condition). Within each condition, retrieval followed immediately after encoding for two scans whereas the study–test interval was about 10 min for the other two scans. The length of the retention interval did not affect the main results, so here data were collapsed across this variable. The first four scans involved the verbal condition. In the remaining eight scans, the enactment and imagery conditions were presented in a counterbalanced order. The reason for not counterbalancing all scans was that we tried to minimize the use of motor imagery in the verbal condition.

During encoding, the commands were read aloud by a female experimenter at the rate of 6.5s/item. During retrieval, the experimenter read the verbs at the rate of 5s/item. Subjects responded by saying aloud the target noun. In cases when a target noun could not be remembered, the subjects said 'no' (in Swedish). A total of 192 unique verb-noun combinations were used (12 lists with 16 items each). The items were constructed such that the action associated with each command was possible to perform with one hand (the right) when lying down on the scanner bed. For items involving objects (e.g. roll the ball), subjects were instructed to imagine the objects. The experimenter monitored that only the right arm was moved during the experiment. The i.v. cannula was located in the left arm.

PET data were acquired as previously described [8] and pre-processed and analyzed using SPM-96 (Wellcome Dept. of Cognitive Neurology, London, UK). The PET scans from each subject were realigned to the first scan,

transformed into a standard space [9] and smoothed to 10 mm. We only considered activations within motor areas. This was done by constructing a motor mask, which included cortical motor areas, basal ganglia, and cerebellum. Voxels that fell within this space were set to 1, and the remaining voxels were set to 0. All scans, for each subject, were multiplied by the motor mask before they were submitted to the statistical analysis. A multi-subject with replications approach to data analysis was used. Due to technical problems, data from three scans were missing. Missing scans occurred in all three conditions. For all subjects and all conditions, there was repetition of conditions.

RESULTS

Analyses of cued-recall data (based on conditions with complete data) revealed that the proportion of correctly recalled nouns was significantly higher ($t(22)=2.05$, $p < 0.05$) for the enactment condition (mean \pm s.d. 0.49 ± 0.15) than for the verbal condition (0.36 ± 0.14). Performance for the imagery condition was intermediate (0.41 ± 0.17), and not significantly different from that of the enactment condition ($p < 0.10$) or the verbal condition ($p < 0.20$). This ordering of performance levels across conditions is in agreement with that from previous studies using the same [10] or different [1] study items.

Analyses of the PET data revealed significantly increased activity ($p < 0.05$ after correction for multiple comparisons) in right motor cortex when the enactment and verbal conditions were contrasted (Fig. 1a). The activation mainly involved primary motor cortex. Figure 1b shows mean activity at the peak voxel as a function of conditions. It can be seen that whereas the motor cortex activation was maximal in the enactment condition, activity was also increased relative to the verbal condition in the imagery condition. A direct contrast between the imagery and verbal conditions revealed right motor cortex activation ($x,y,z = 10, -32, 58$; $Z = 3.11$, $p = 0.001$ uncorrected). When the enactment and imagery conditions were directly contrasted, increased activity was also observed in right motor cortex activation ($x,y,z = 14, -38, 76$; $Z = 3.80$, $p < 0.001$ uncorrected). This activation overlapped with the superior portion of the motor activation revealed in the enactment-verbal contrast (Fig. 1a). No regional activations were significant after correction for multiple comparisons in the imagery-verbal and enactment-imagery contrasts.

DISCUSSION

This PET study shows that retrieval of verbal events, after overt or covert motor activity at encoding, engages motor brain areas, specifically right motor cortex. Activity in right motor cortex was weakest in the verbal condition, intermediate in the imagery condition, and strongest in the enactment condition. This response mimics the degree to which precentral gyrus was activated in a recent fMRI study of executed and imagined hand movements [11], although the effect was seen on the contralateral side in the previous study and was maximal ipsilaterally in the present study. Activation of primary and secondary motor areas during conditions with no demand for overt motor execution seems to be a robust phenomenon [12-14].

The important contribution by the present study is the

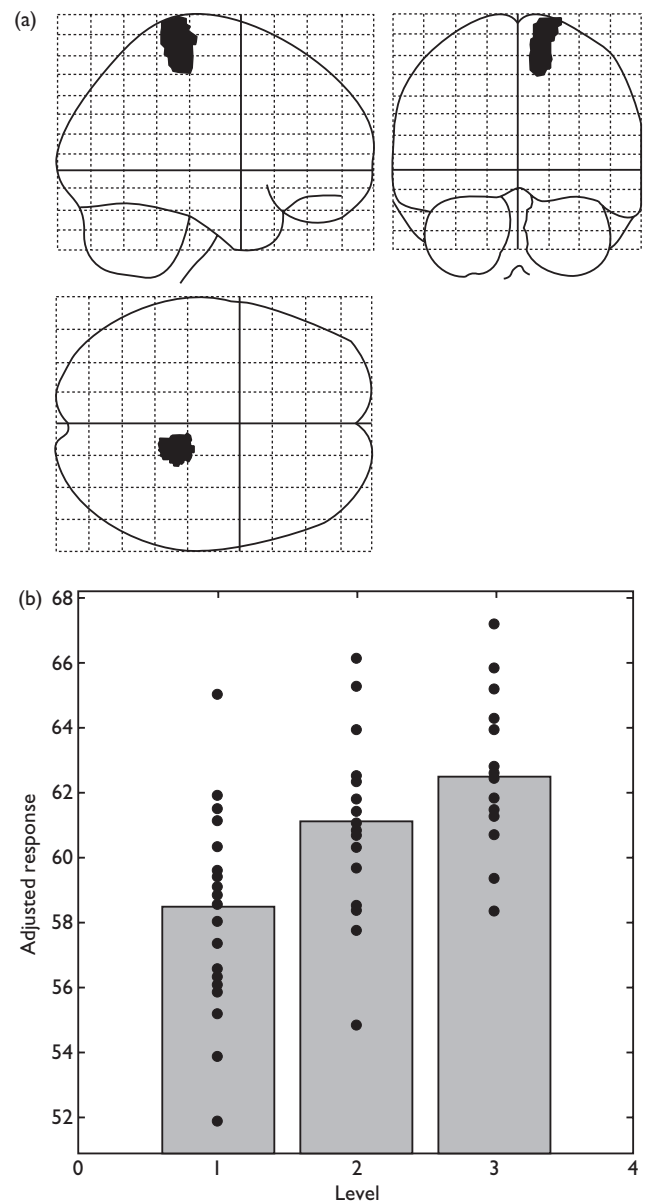


Fig. 1. (a) Sagittal (upper left), coronal (upper right), and horizontal (lower left) brain outlines showing results from the enactment-verbal contrast (maxima in right motor cortex: $x,y,z = 12, -32, 60$; $14, -38, 74$). (b) Plot of mean activity levels in verbal (left), imagery (middle), and enactment (right) conditions for the peak voxel in motor cortex ($x,y,z = 12, -32, 60$).

demonstration that motor activity can be associated with verbal episodic cued recall. This may indicate that motor information was part of the episodic memory trace, when motor activity had been part of the encoding phase (cf. [15]). It is also possible that retrieval of a noun triggered motor imagery processes, which in turn evoked motor brain activity.

Our findings confirm that one basis for the facilitating effect on memory performance of overt and (to a lesser degree) covert encoding enactment is the possibility to base retrieval on motor information [6]. As such these findings

predict that patients with different kinds of brain damage, but with an intact motor system, should benefit from encoding support in the form of enactment [5]. More generally, the demonstration of involvement of motor regions in non-motor cognitive operations, such as episodic memory retrieval, adds to demonstrations of motor neuronal involvement in a variety of complex non-motor processes [16].

CONCLUSION

This study has shown that remembering of action events engages motor brain areas. This may reflect reactivation of motor information acquired during the encoding phase, a possibility that points to the importance of the way information initially is experienced for subsequent retrieval-related brain activity patterns [15].

REFERENCES

1. Nyberg L and Nilsson L.-G. *Psychol Res* 57, 215–219 (1995).
2. Bäckman L and Nilsson L.-G. *Hum Learn* 3, 55–69 (1984).
3. Karlsson T, Bäckman L, Herlitz A *et al. Neuropsychologia* 27, 737–742 (1989).
4. McAndrews MP and Milner B. *Neuropsychologia* 29, 849–859 (1991).
5. Mimura M, Komatsu S, Kato M *et al. Cortex* 34, 297–303 (1998).
6. Engelkamp J. *Das Menschliche Gedächtnis*, 2nd edn. Göttingen: Hogrefe, 1991.
7. Heil M, Rolke B, Engelkamp J *et al. Eur J Cogn Psychol* 11, 261–280 (1999).
8. Hadjikhani N and Roland PE. *J Neurosci* 18, 1072–1084 (1998).
9. Talairach J and Tournoux P. *Co-Planar Stereotaxic Atlas of the Human Brain*. Stuttgart: Georg Thieme; 1988.
10. Persson J. Unpub Masters Thesis. Department of Psychol, Umeå University, 1997.
11. Lotze M, Montoya P, Erb M *et al. J Cogn Neurosci* 11, 491–501(1999).
12. Leonardo M, Fieldman J, Sadato N *et al. Human Brain Mapping* 3, 83–92 (1995).
13. Stephan KM, Fink GR, Passingham RE *et al. J. Neurophysiol* 73, 373–386 (1995).
14. Deiber MP, Ibanez V, Sadato N *et al. J. Neurophysiol* 75, 233–247, (1996).
15. Nyberg L, Tulving E, Habib R *et al. Neuroreport* 7, 249–252 (1995).
16. Carpenter AF, Georgopoulos AP and Pellizzer G. *Science* 283, 1752–1757 (1995).

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