

Case Report

Direct evidence for the causal role of the left supplementary motor area in working memory: A preliminary study



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1. Introduction

Working memory is defined as active short-term memory involved in purpose-oriented tasks [1]. It plays an essential role in activities of daily living and social life, such as conversation, reading, and calculation. Previous functional magnetic resonance imaging (MRI) studies have reported activation in some brain regions during a language-related N-back task that evaluated working memory; these regions include the dorsolateral prefrontal cortex, anterior cingulate cortex, Broca's area, supramarginal gyrus, superior parietal lobule, and supplementary motor area (SMA) [2]. Although several studies involving human brain mapping have indicated that short-term memory could be subserved by several brain regions, including the perisylvian cortex, superior frontal gyrus, and fornix, there is no direct evidence that the SMA plays a role in working memory in the human brain [3–6]. Here, we report that the left SMA plays a role in verbal working memory and the usefulness of the intraoperative 2-back task for evaluating working memory during awake surgery.

2. Case reports

We encountered 2 patients with low-grade glioma localized solely in the left SMA who underwent tumor resection during an awake craniotomy. Their cognitive functions, which included working memory, were evaluated before and after surgery. The 2-back task was used to directly evaluate working memory during awake surgery. In addition, language functions were evaluated pre- and postoperatively with the Western Aphasia Battery. Cortical mapping was performed in SMA, whereas subcortical mapping was performed in the white matter region anterior to the pyramidal tract, which was the posterior border of the resection.

Case 1 was a 34-year-old right-handed woman with a 100% dominant right hand (Edinburgh Handedness Inventory). She was a homemaker and had received 14 years of schooling. She presented with headache and dizziness, and MRI revealed a lesion in the left SMA (Fig. 1). No defects in both language and motor function were observed in her initial evaluation. The following cognitive function tests were conducted: the *Wechsler Adult Intelligence Scale – Third Edition, Japanese Edition* (WAIS-III), letter cancellation test (LCT), and the verbal 2-back task. As the patient performed the verbal 2-back task, an occupational therapist read *Kana* (Japanese syllabogram) at a speed of 1 sound per second. The patient then repeated the *Kana* that she had heard 2 sounds before (2-back, Fig. 2). These tests revealed mild impairments in selective attention (Table 1). The patient underwent surgical resection of the SMA

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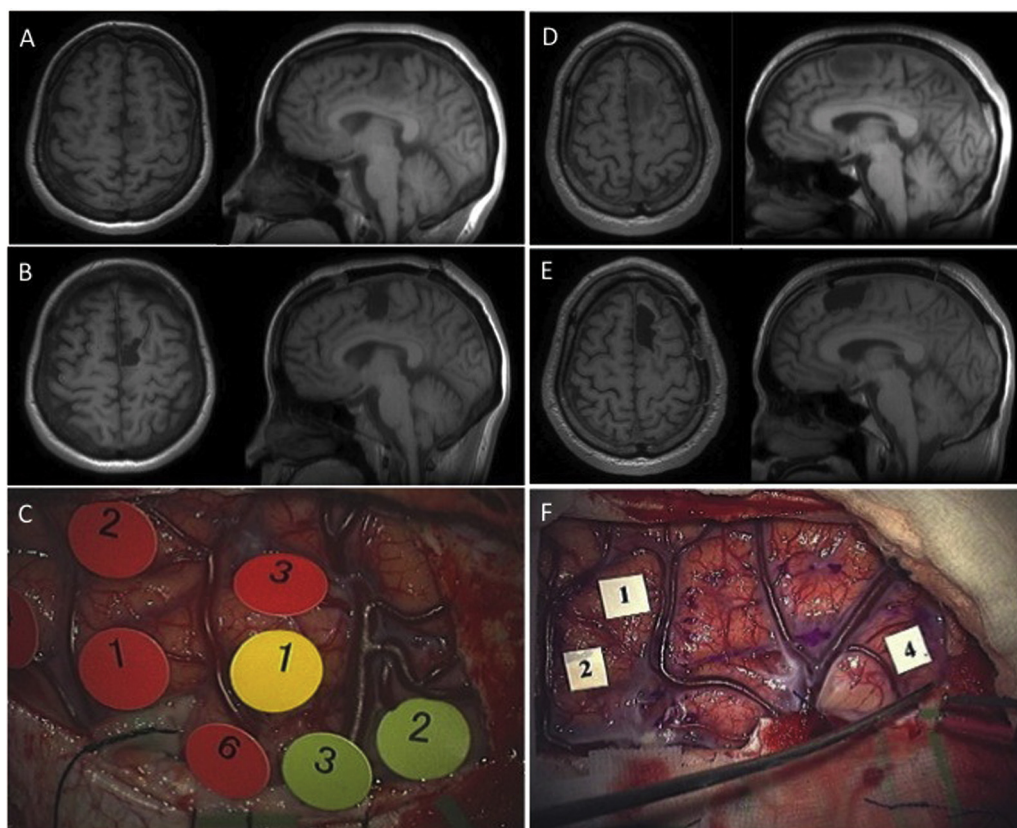


Fig. 1. Results of imaging and functional mapping. Case 1 (left). Preoperative T1-weighted MRI sagittal image showing a hypointense lesion in the left SMA (A). Postoperative T1-weighted MRI sagittal image showing a resection cavity located in the SMA, which did not extend to the cingulate gyrus below (B). Intraoperative functional mapping results (C); Tags 1 (left) and 2 (upper left) indicate speech arrest and a negative motor response by stimulation during simultaneous movement and object-naming task. Tag 3 (lower) indicates an inability to answer with any *Kana* in the 2-back task. Tag 6 indicates incorrect responses with different *Kana* in the 2-back task. Case 2 (right). Preoperative T1-weighted MRI showing a hypointense lesion in the left SMA (D). Postoperative T1-weighted MRI showing a resection cavity located in the SMA, which did not extend to the cingulate gyrus below (E). Intraoperative functional mapping results (F); Tags 1 and 2 indicate speech arrest and a negative motor response by stimulation during simultaneous movement and object-naming task. Tag 4 indicates incorrect answers with different *Kana* in the 2-back task.

tumor with intraoperative functional mapping performed during awake craniotomy. During the procedure, the patient performed an object-naming task, coordinated movement of the upper and lower extremities, and the 2-back task. Movement and object-naming tasks were examined simultaneously when direct electrical stimulation was applied and further monitored continuously during tumor resection. The 2-back task was evaluated independently from the naming and movement tasks only when direct electrical stimulation was applied. The functional area was evaluated by applying direct electrical stimulation using a bipolar probe with a 5-mm tip that delivered a biphasic current (pulse frequency:

60 Hz, single-pulse phase duration: 1 ms, amplitude biphasic current: 1–4 mA). Each stimulation site was stimulated 3 times, and at least 2 positive responses indicated a positive mapping area. When the SMA proper was stimulated, the patient provided incorrect responses in the 2-back task or was unable to answer with any *Kana* reproducibly, and the stimulated site was evaluated as a positive mapping area (Fig. 1). Because the SMA region was a tumor itself (diffuse astrocytoma, WHO grade II), we decided to resect the SMA lesion with an expectation that the positive mapping lesion identified with the verbal 2-back task would be compensated postoperatively. Compared with preoperative WAIS-

Table 1
Results for cognitive brain functions.

Test name	Baseline (WAIS-III)/mean \pm SD (LCT, 2-back)	Case 1			Case 2			
		Preop	Postop 7 days	Postop 1 month	Preop	Postop 7 days	Postop 1 month	
WAIS-III	VIQ	90–109	83	91	NA	80	77	NA
	PIQ	90–109	95	98	NA	82	78	NA
	FIQ	90–109	87	93	NA	78	75	NA
	WM	90–109	100	92	102	67	65	65
	PS	90–109	89	66	75	72	63	81
LCT	(s)	89.8 \pm 14.0	101	149	136	134	148	106
	(% correct)	97.6 \pm 2.4	94	100	99	100	98	99
2-Back task	(% correct)	74.8 \pm 19.8 ^a	85	73	80	64	53	62

Baseline/mean, baseline quotient and mean value of coeval normal Japanese; SD, standard deviation; WAIS-III, Wechsler Adult Intelligence Scale – Third Edition; VIQ, verbal intelligence quotient; PIQ, performance intelligence quotient; FIQ, full-scale intelligence quotient; WM, working memory; PS, processing speed; LCT, letter cancellation test; NA, not available.

^a Mean and SD of the 2-back task using in the study are derived from the results of 35 normal volunteers.

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