Movement Intention After Parietal Cortex Stimulation in Humans

Michel Desmurget,[1,2] Karen T. Reilly,[1,2] Nathalie Richard,[1,2] Alexandru Szathmari,[3] Carmine Mottolese,[3] Angela Sirigu[1,2]*

Parietal and premotor cortex regions are serious contenders for bringing motor intentions and motor responses into awareness. We used electrical stimulation in seven patients undergoing awake brain surgery. Stimulating the right inferior parietal regions triggered a strong intention and desire to move the contralateral hand, arm, or foot, whereas stimulating the left inferior parietal region provoked the intention to move the lips and to talk. When stimulation intensity was increased in parietal areas, participants believed they had really performed these movements, although no electromyographic activity was detected. Stimulation of the premotor region triggered overt mouth and contralateral limb movements. Yet, patients firmly denied that they had moved. Conscious intention and motor awareness thus arise from increased parietal activity before movement execution.

A central question in the study of human behavior concerns the origin of willed actions. Where in the brain are intentions formed? How do we become aware of these intentions? According to the dualist philosophy (*1*), our encephalon is just the recipient of conscious intentions formed elsewhere in a nonphysical realm. This implies that conscious intention comes first, as the leading cause of our actions. Although appealing from a spiritual point of view, this hypothesis was progressively challenged by a large set of studies (*2*–*4*). Results showing that the decision to move did not precede, but instead lagged, the onset of brain activity signaling motor preparedness were especially convincing (*5*–*7*). Thus, researchers suggested that conscious intention of a movement emerged as a consequence of increased neural activity in a premotor-parietal circuit, which elaborates motor plans before action (*2*). This cortical circuit has also been involved in motor awareness, that is, the awareness that we are actually executing the intended action (*7*–*10*).

However, the specific contribution of premotor and parietal regions to conscious intention and motor awareness remains unclear. We reasoned that, by directly stimulating parietal and premotor cortex regions, we should be able to evoke motor responses in specific body parts and that, in areas involved in carrying out advance computations related to conscious intention and motor awareness, these movements should be accompanied or preceded by the subjective experience of willed actions. We used direct electrical stimulation (DES) in seven individuals with brain tumors located anteriorly ($N = 4$, PM1 to PM4) or posteriorly ($N = 3$, PP1 to PP3) to the central sulcus. Patients were operated under local anesthesia by using DES as a functional mapping technique in order to minimize the risk of postoperative sequelae (*11*). DES was delivered with a bipolar electrode using standard increasing intensities (2, 5, and 8 mA) and durations (1, 2, and 4 s). Up to four replications were performed for each stimulation site. Replications were delivered nonconsecutively to avoid provoking seizures. Throughout the experiment, electromyographic (EMG) signals were collected in the contralesional hemibody in 12 muscles covering the face, hand, wrist, elbow, knee, and foot. Stimulation sites were localized with high resolution on individual magnetic resonance (MR) images by using a peri-operative neuronavigation system and reconstructed offline.

Fifty-seven sites were stimulated in the frontal, parietal, and temporal regions (fig. S2A). Posterior parietal stimulations were performed in Brodmann areas (BAs) 7, 39, and 40. Premotor stimulations were performed in the dorsal sector of BA 6, excluding the convexity and mesial structures involving the supplementary motor area (SMA). Of the stimulated sites, 46% were silent, meaning that DES did not produce any sensations or overt motor responses, and 20% were associated with somatic sensations such as tingling or itching. One participant (PP1) reported a robust visual illusion of background displacement when stimulated in the superior temporal gyrus (BA 22). Of the remaining sites (34%), 16% evoked responses related to motor awareness or movement intention, whereas 18% triggered actual movements. We will focus on these remaining sites, designated as responsive. The distribution of DES effects across brain areas is summarized in fig. S2B.

For the three patients with postcentral tumors, nine responsive sites were found in BAs 39 and 40 (Fig. 1). Stimulation of all these sites produced a pure intention, that is, a felt desire to move without any overt movement being produced or EMG activity recorded in the concerned muscles. In two of the patients (PP1 and PP2), the same sites were stimulated again later but at a higher intensity. Conscious motor intentions were replaced by a sensation that a movement had been accomplished, and yet, just as during the first stimulation trial, no actual movement or EMG activity was observed. Thus, these patients experienced awareness of an illusory movement (Fig. 2). For example, patient PP3 reported after low-intensity stimulation of one site (5 mA, 4 s;

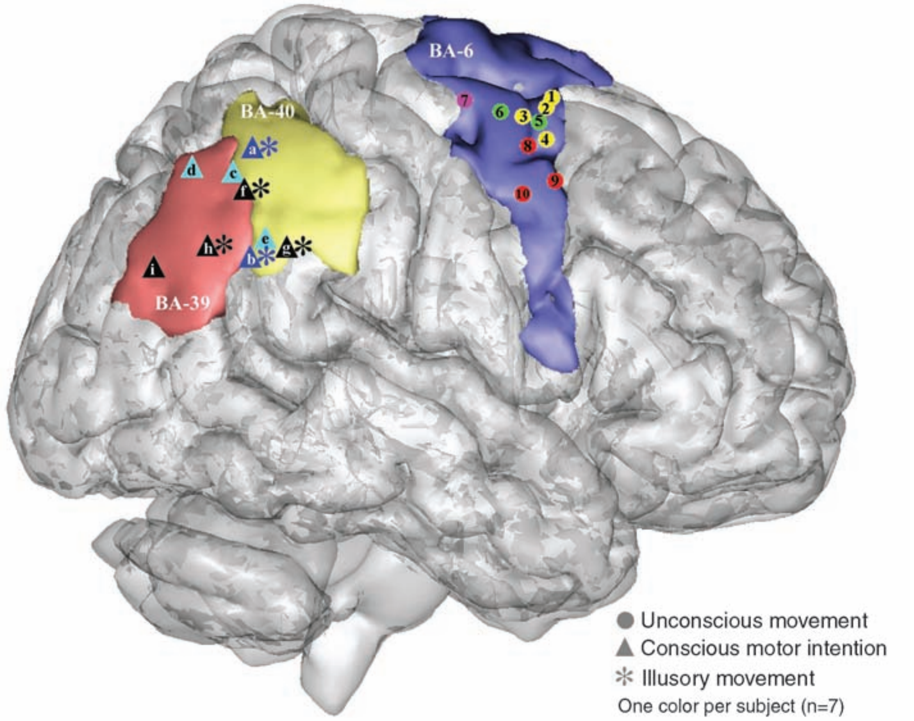

Fig. 1. Premotor and parietal responsive sites shown after registration of the individual MR image to the MNI template. Left stimulations have been reported on the right hemisphere. Colored areas define the anatomical boundaries of BA 40 (yellow), BA 39 (orange), and BA 6 (blue).

[1]Centre de Neuroscience Cognitive, CNRS, UMR 5229, 69500 Bron, France. [2]Université Lyon 1, 69100 Villeurbanne, France. [3]Neurosurgery Unit 500, Hôpital Pierre Wertheimer, Hospices Civils de Lyon, 69003 Lyon, France.

*To whom correspondence should be addressed. E-mail: sirigu@isc.cnrs.fr

site a in Fig. 1), "I felt a desire to lick my lips" and at a higher intensity (8 mA, 4 s), "I moved my mouth, I talked, what did I say?" Similar results were found in patient PP1 for hand (two sites, g and h, in Fig. 1) and foot (one site, f, in Fig. 1) movements. Patient PP2 reported, after stimulation in BA 40 (8 mA, 4 s; site e in Fig. 1), that she felt "like a will to move" her chest (*12*). The same words were later used for another site with respect to the arm (8 mA, 4 s; site c in Fig. 1). Without prompting by the examiner, all three patients spontaneously used terms such as "will," "desire," and "wanting to," which convey the voluntary character of the movement intention and its attribution to an internal source, that is, located within the self (movies S2 and S3).

Electrical stimulation in the frontal cortex contrasted sharply with the above descriptions (Fig. 3). For the four precentral patients, 10 responsive sites were found in the dorsal part of the premotor cortex (BA 6; Fig. 1). These sites triggered movements of various limb segments and the mouth (fig. S2C) (*13*) devoid of conscious intention and awareness. Patients never expressed the desire to move and never became aware that they produced a motor response. For example, during stimulation patient PM1 exhibited a large multijoint movement involving flexion of the left wrist, fingers, and elbow, as well as a rotation of the forearm (8 mA, 4 s; site 7 in Fig. 1). He did not spontaneously comment on this, and when asked whether he had felt a movement he responded negatively. The ability of patients to detect electrically evoked movements did not change with the intensity of the stimulation. Higher currents evoked larger movements and

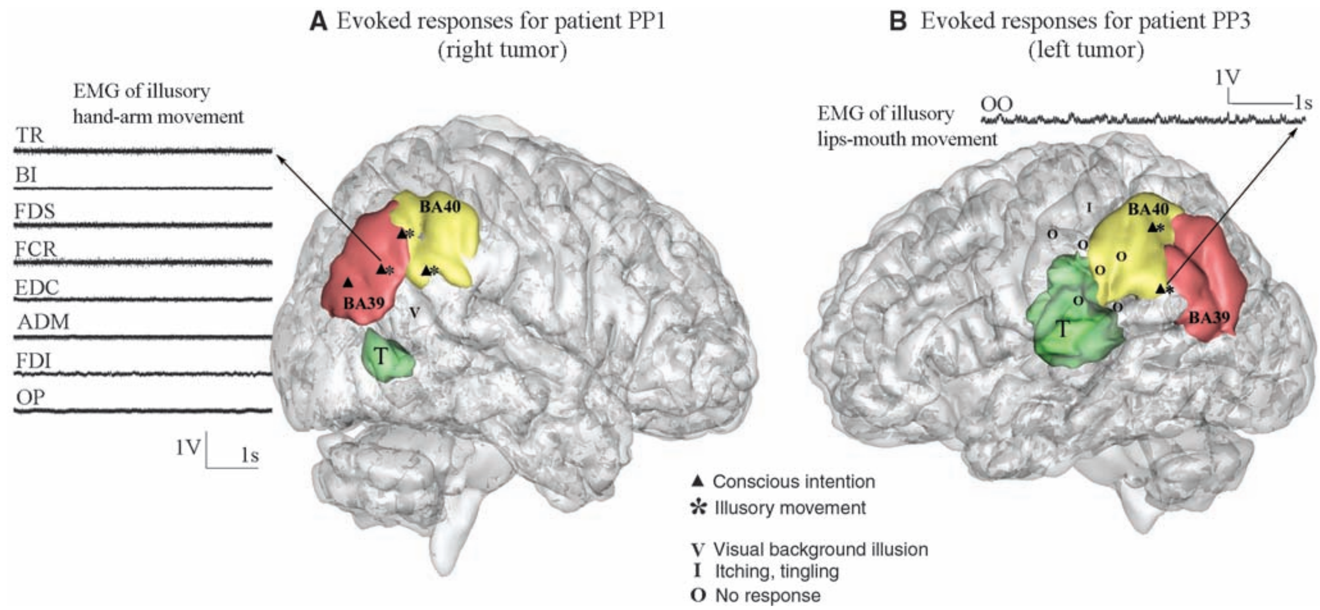

Fig. 2. (**A** and **B**) Individual brains and stimulation sites reconstructed for two patients harboring postcentral tumors. EMG signals are shown for the stimulation sites identified by arrows. T indicates tumor; TR, triceps; BI, biceps; FDS, flexor digitorium superficialis; FCR, flexor carpi radialis; EDC, extensor digitorium communis; ADM, abductor digiti minimi; FDI, first dorsal interosseous; OP, opponens pollicis; and OO, orbicularis oris. Colored areas define the anatomical boundaries of the tumor (green), BA 40 (yellow), and BA 39 (orange).

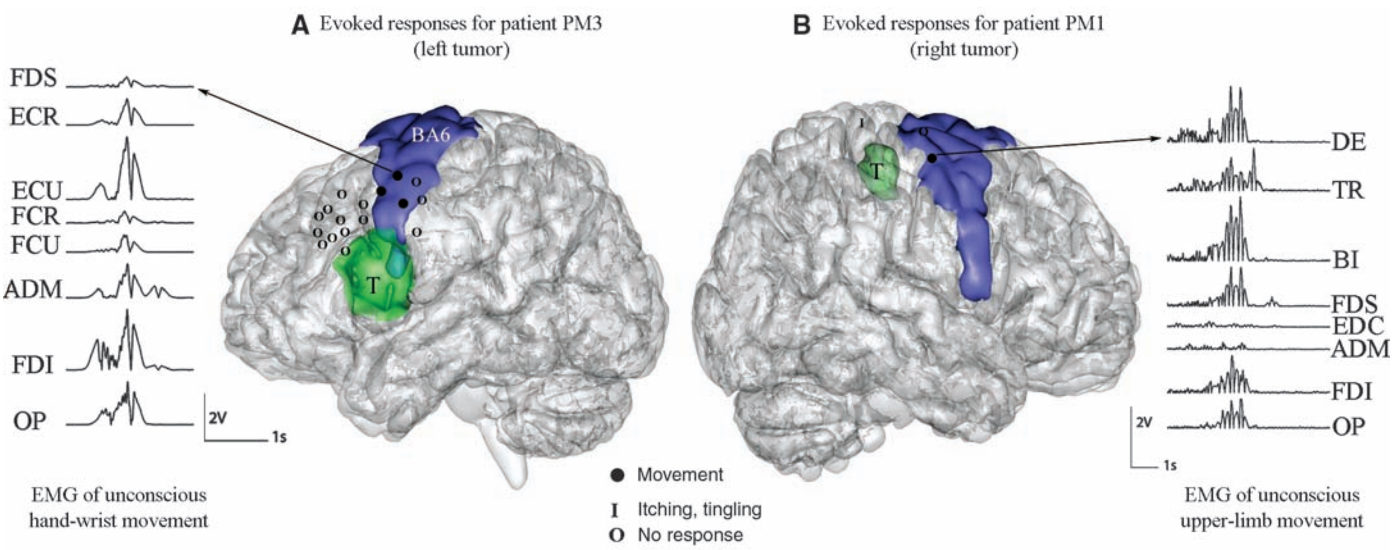

Fig. 3. (**A** and **B**) Individual brains and stimulation sites reconstructed for two patients harboring precentral tumors. EMG signals are shown for the stimulation sites identified by arrows. DE, deltoid; ECR, extensor carpi radialis; ECU, extensor carpi ulnaris; and FCU, flexor carpi ulnaris. Colored areas define the anatomical boundaries of the tumor (green) and BA 6 (blue).

recruited more muscles as compared with movements triggered by lower currents. Despite increasing stimulation intensity, patients remained completely unaware that a movement occurred (movies S1 and S4) (*14*).

We report two main contrasting findings: (i) Stimulation of the posterior parietal cortex caused human participants to intend to move and to report having moved, even in the absence of actual motor responses. (ii) Stimulation of the premotor cortex triggered limb and mouth movements that were not consciously detected by the patients.

Clinical observations of high-level movement deficits in patients with apraxia after parietal damage have led to the hypothesis that the posterior parietal cortex contains stored movement representations (*15*, *16*). It can be proposed that direct stimulation of the parietal cortex activates such representations. However, the fact that patients experienced a conscious desire to move indicates that stimulation did not merely evoke a mental image of a movement but also the intention to produce a movement, an internal state that resembles what Searle called "intention in action" (*17*). This finding is consistent with nonhuman primate results suggesting that the posterior parietal cortex harbors a "map of intentions," with different subregions dedicated to the planning of eye, reaching, and grasping movements (*18*), and that activity of parietal neurons is highly correlated to processes of motor planning and decision-making (*19*, *20*). It is tempting to propose that electrically induced intentions arise, in our study, from the activation of some nodes within this intentional map. Interestingly, when the stimulation intensity was increased, motor intentions were replaced by a form of illusory movement awareness. In the absence of any muscle contraction, the patients reported that they had actually performed the movement they previously intended to do. Although the nature of this phenomenon cannot be formally elucidated here, it may be hypothesized that motor intention arises from the activation of a limited subregion within the cortical network activated during movement execution. According to this view, higher intensities of stimulation would not simply prime a motor representation to consciousness (giving rise to intention) but also recruit the executive network responsible for movement monitoring through forward modeling. This process of forward modeling has been shown to rely on posterior parietal computations (*21*–*23*). It could form the basis of the illusory movement awareness experienced by our patients, assuming that the signal we are aware of when making a movement does not emerge from the movement itself but rather from the predictions we make about the movement in advance of action (*3*, *4*, *7*, *24*, *25*).

It has been reported that stimulation of the SMA triggers an urge to move that resembles an irrepressible desire to move going beyond patients' will (*26*). This suggests a potential role of SMA in generating motor intentions (*2*, *27*). However, intentions evoked by stimulation of SMA stand in contrast with what was described by our patients, who reported experiencing an endogenously generated wish to move. The imperative character of the motor intention with SMA stimulation is demonstrated by the fact that higher currents triggered movements (*26*), whereas none of the stimulated parietal sites ever evoked actual muscle contractions. It is possible that both the parietal cortex and the SMA are linked to motor intentions but that intentions processed in these two regions correspond to different stages of movement planning: Intentions in the parietal lobe may be processed in relation to sensory predictions, whereas in the SMA intentions may be more closely related to motor commands.

Regarding the dorsal premotor cortex, stimulations triggered complex multijoint movements, as already reported in awake monkeys (*28*). Stimulation intensities were comparable to those performed in the parietal cortex. Yet, patients remained unable to detect the limb and mouth movements evoked by electrical stimulations. This suggests that the proprioceptive volleys associated with the movement were disregarded or not decodable by the brain areas which normally receive these feedback signals. This finding strengthens the conclusion that awareness of initiating and executing a movement is not derived from afferent inputs but rather from the internal computations carried out in the posterior parietal cortex before action (*2*–*4*, *7*). Our data are compatible with behavioral studies showing that we are largely unaware of sensory feedback about the ongoing state of our motor system, as long as our intentions are achieved (*4*). Peripheral inputs probably intervene at a further stage for comparing expected and actual movements, that is, when we need to construct a veridical motor awareness (*2*, *24*, *25*). Recently, Berti *et al*. (*9*) have linked the comparative process leading to veridical awareness to the functioning of the dorsal premotor cortex (BA 6). As shown by the authors, this structure is the most commonly lesioned in hemiplegic patients who obstinately claim that they can move their paralyzed limbs. In our study, premotor stimulations did not evoke any form of conscious intention. As a consequence, the proprioceptive inputs could not be compared to any expected input to estimate movement state to construct a veridical motor awareness.

Our study suggests that motor intention and awareness are emerging consequences of increased parietal activity before movement execution. The subjective (and potentially illusory) feeling that we are executing a movement does not arise from movement itself, but it is generated by prior conscious intention and its predicted consequences.

References and Notes

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11. Materials and methods including stimulation protocol, EMG recording procedure, and reconstruction of stimulation sites are available as supporting material on *Science* Online.
12. This result is consistent with monkey studies showing that protrusion movements of the chest are represented in the posterior parietal cortex (*29*).
13. The movements observed in our premotor patients were similar to the movements reported in monkeys after long train stimulations (*28*). It is thought that these electrically induced movements are functionally meaningful (*30*, *31*).
14. The possibility can be ruled out that the absence of motor awareness in our patients was due to a low level of vigilance. The anesthetic and stimulation protocols were identical in premotor and in parietal patients who did report illusory movements. During peri-operative functional evaluation, premotor patients appeared well awake (see movies S1 to S4) and otherwise behaved as the parietal patients: They could talk, count, or move in response to verbal commands. Some of them reported sensory feelings of tingling or itching, indicating that they could introspect on stimulation-induced experiences. In one patient (PM4), we examined whether unseen passive movements of the forearm were perceived and reported. Indeed, this was the case.
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Supporting Online Material
www.sciencemag.org/cgi/content/full/324/5928/811/DC1
Materials and Methods
Figs. S1 and S2
References
Movies S1 to S4

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Michel Desmurget, Karen T. Reilly, Nathalie Richard, Alexandre Szathmari, Carmine Mottolese, Angela Sirigu*

*To whom correspondence should be addressed. E-mail: sirigu@isc.cnrs.fr

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This PDF file includes:

Materials and Methods
Figs. S1 and S2
References

SUPPORTING ONLINE MATERIAL

MATERIALS AND METHODS

The protocol was approved by the local ethics committee (CPP, Lyon Sud-Est IV, Centre Léon Berard, Lyon) and sponsored by CNRS (CNRS n° 07011). Before surgery patients were informed about the surgical procedure and gave a formal consent.

Stimulation: Methods for direct electrical stimulation (DES) under local anesthesia have been described in details elsewhere (S*1*-*S3*). In brief, following opening of a large bone flap, a bipolar electrode with 5 mm spaced tips delivering a biphasic current was placed on the brain of awake patients (pulse frequency 60 Hz, pulse phase 1 ms, amplitude from 2 to 8 mA; duration 1 to 4 s). Up to four replications were performed for each stimulation site. Replications were delivered non-consecutively to avoid provoking seizures. Duration of the stimulation was controlled visually by the surgeon via a digital clock placed in front of him. Functionally, DES has been shown to propagate only along the stimulated white matter pathways (S*4, S5*) and to induce a marginal amount of cortical spreading (S*6*). Note that current propagation along white matter pathways is inevitable, even for single pulse stimulations (S*7*). However, it does not occur randomly. It follows physiologically meaningful pathways (S*8*-*S10*). The normal function of the stimulated region depends on these pathways. Based on these observations, it has been suggested that the spread of signal through the network should be seen "as a necessary part of the technique rather than as something to control or avoid" (S*11*).

For the present study, stimulations were performed in the following way: (i) the surgeon informed the patient that a stimulation was about to start ("we are going to stimulate"); (ii) the surgeon counted aloud to provide the patient and the experimenter standing next to the patient, with a feedback about the onset and the end of the stimulation (e.g. for a 4 s stimulation: "One, two, three, four"); (iii) at the end of the stimulation, the experimenter asked the patient whether he/she felt something and whether he/she moved, except when the patient commented spontaneously on his/her feelings.

As part of a clinical testing other stimulations were made to uncover: (*i*) areas potentially eloquent for movement, while the subjects were performing simple limb movements (e.g. touch each individual finger successively, with the thumb); (*ii*) areas potentially eloquent for language, while subjects were performing naming and counting tasks (only for patients with left hemisphere lesion). These stimulations are not considered in the present paper. Finally, a number of sham stimulations, i.e., the surgeon made *as if* he was going to stimulate but no stimulation actually occurred, were intermingled with the real stimulations, in order to test patients' behavior for false positives responses. No responses were found for these fake stimulations.

Localizing stimulation sites: A neuronavigation system was used for all patients. During surgery, coordinates of the stimulation sites were recorded on individual high resolution MR images, via the neuronavigation system (Fig. S1 below). Spatial normalisation of preoperative MR images into the standard MNI space was performed using the dedicated non-linear registration procedures provided by SPM5 (Wellcome Department of Cognitive Neurology, London, UK; http://www.fil.ion.ucl.ac.uk/spm/). Lesion areas were manually defined from preoperative MR images and masked to be excluded from the normalization transformation (S*12*). Transformation from MNI to Talairach coordinates was performed using the icbm2tal procedure (S*13*). Assignment of Brodmann area labels from Talairach coordinates was then performed using the *Talairach Client* tool (http://www.talairach.org/) (S*14*). 3D surface rendering images were generated from MR images using the Brainvisa software (http://www.brainvisa.info/).

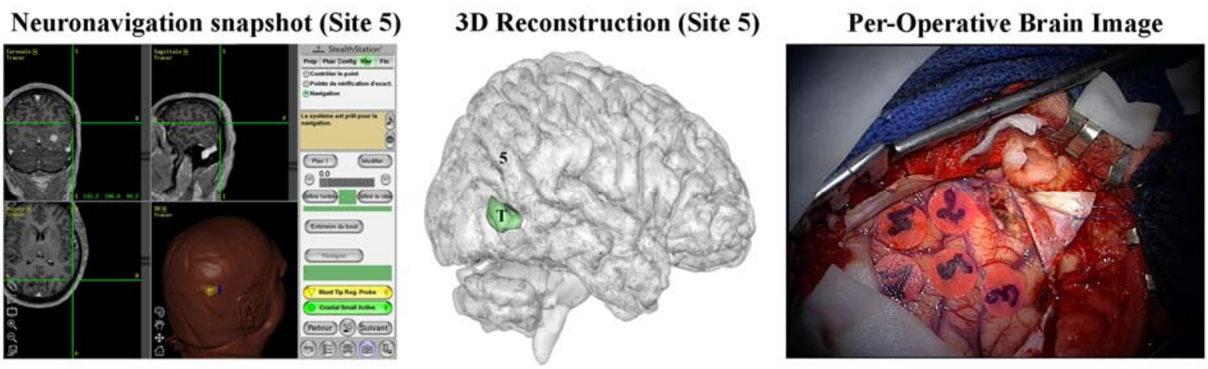


Fig. S1: Illustration of the site localization procedure. Each stimulation site was localized on a preoperative high resolution MR image of the subject, using the neuronavigation tool (snapshot, left panel). 3D rendering images of the brain surface and stimulation sites were then generated from MR images (middle panel). Neuronavigation coordinates were afterwards confronted with number-tags positioned during surgery on the cortical surface (right panel).

Electromyography (EMG): The method for EMG recording has been described in details in previous publications (S*15, S16*). In brief, disposable surface Ag/AgCl electrodes were used to record EMG continuously at a 1,000 Hz frequency, in the contralesional hemibody in 12 muscles covering the face, hand, wrist, elbow, ankle and knee. EMG signals were differentially amplified (gain = 1,000 to 10,000), band pass filtered (30–1000 Hz) and full wave rectified.

PATIENTS

Patients with postcentral lesions (N = 3), who were stimulated in the posterior parietal (PP) areas, are designated PP1 to PP3 hereafter. Patients with precentral lesions (N = 4), who were stimulated in the premotor (PM) areas, are designated PM1 to PM4 hereafter.

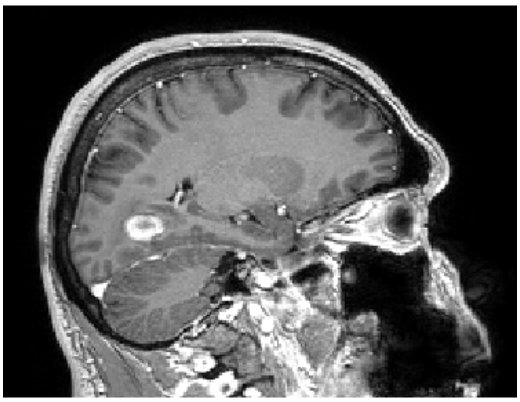
Some patients exhibited motor and speech deficits immediately after surgery. These deficits disappeared within weeks. After six months, all patients had resumed a normal social life, as is the case in most individuals with slow growing lesions (S*17*). At this time, they had no debilitating deficits when evaluated with classical clinical procedures.

Patient PP1

Male, 42 years old.

Cavernoma in the right temporo-parietal region.

5 sites stimulated.



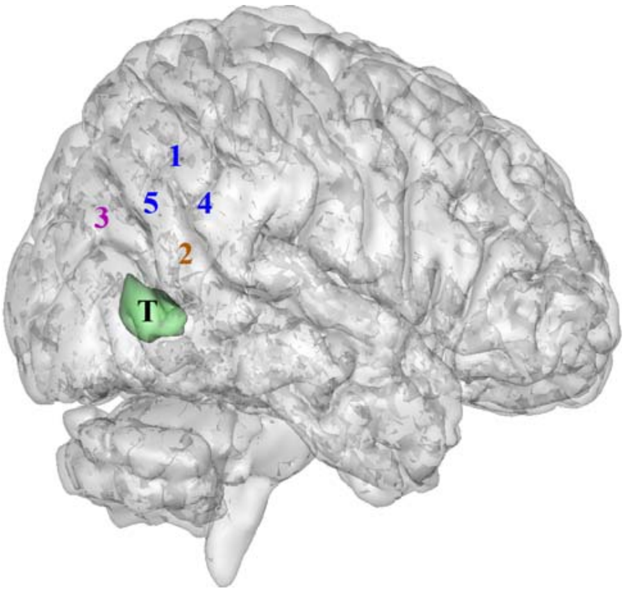


Fig. PP1. MRI and 3D image of the patient brain and stimulations sites (sites were stimulated from 1 to 5). Color code: ● Conscious Intention; ● Conscious Intention + Illusory Movement; ● Visual Illusion (background movement). T: Tumor.

Evoked movements.

Body Part	Stimulation Sites
Foot	1
Arm / Hand	3
Hand	4 ; 5

Verbatim samples of patient's report. Experimenter (E), Patient (P).

Site 1:

5 mA / 4s
E: Did you feel something?
P: Yes… It felt like I wanted to move my foot. Not sure how to explain
E: Which foot?
P [showing the left leg]: This one.
E: How did you want to move it?
P: I don't know, I just wanted to move it.

8 mA / 4s
E: Did you feel something?
P: A movement of the foot
E: You moved your foot?
P: Yes.
E: Are you sure?
P: Yes.

Site 3:

8 mA / 4s
P [spontaneously at the end of the stimulation]: My arm, maybe my hand
E: Did you move them?
P: No, I wanted to.

Site 4:

5 mA / 4s
E: Did you feel something?
P: Yes, yes, in my hand, like I wanted to close it
E: Which hand?
P: This one [closing and opening the left hand].

8 mA / 4s
P [spontaneously at the end of the stimulation]: My hand moved
E: Are you sure?
P: Yes, sure.

Site 5:

<u>2 mA / 4s</u>
P [spontaneously at the end of the stimulation]: Same, a desire to move my hand
E: Did you move it?
P: No

<u>8 mA / 4s</u>
P [spontaneously at the end of the stimulation]: My hand, my hand moved.
E: Your hand?
P: Yes, the fingers
E: Are you sure?
P: Yes, I think. Did it not move?

<u>Patient PP2</u>

Female, 41 years old.

Oligodendroglioma in the right posterior parietal region.

11 sites stimulated.

Note that positive functional responses were found in the tumoral region for this patient. This is a common observation which can be explained by the nature of the tumor (S*17*). Indeed, oligodendrogliomas are primary glial brain tumors that do not prevent the neurons from functioning.

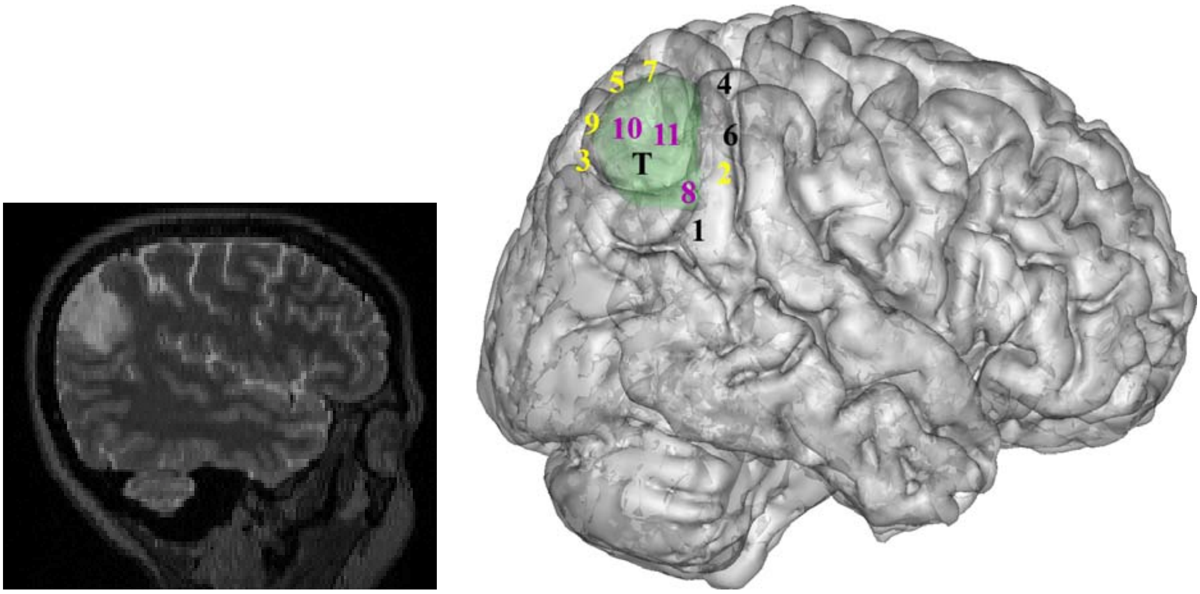


Fig. PP2. MRI and 3D image of the patient brain and stimulations sites (sites were stimulated from 1 to 11). Color code: ● Conscious Intention ; ● Itching and tingling sensations ; ● No response. T: Tumor.

Evoked movements.

Body Part	Stimulation Sites
Chest	8
Hand	10
Arm	11

Verbatim samples of patient's report. Experimenter (E), Patient (P).

Site 8:

8 mA / 4s
E: Did you feel something?
P: I had a desire to do something
P [showing her chest]: Here I have a desire to do…
E: In the chest?
P: Yes
E: And what did you feel?
P: Like a, like a will to move
E: What did you feel?... Tinglings?
[*in french "picotement"-tingling- can be mistaken with "mouvement" –movement-*]
P: I felt like a will to move.

Site 10:

8 mA / 4s
E: Did you feel something?
P: I had a desire to move my right hand
E: You wanted to move your right hand?
P: Yes
E: Do you know what kind of movement you wanted to do?
P: No, I don't know.

Site 11:

8 mA / 4s
E: Did you feel something?
P: Like a will to move
E: You had a desire to move?
P: Yes
E: And where, what kind of movement did you want to do?
P: I wanted to raise my arm.

Patient PP3

Male, 76 years old.

Glioblastoma in the left fronto-temporo-parietal region.

9 sites stimulated.

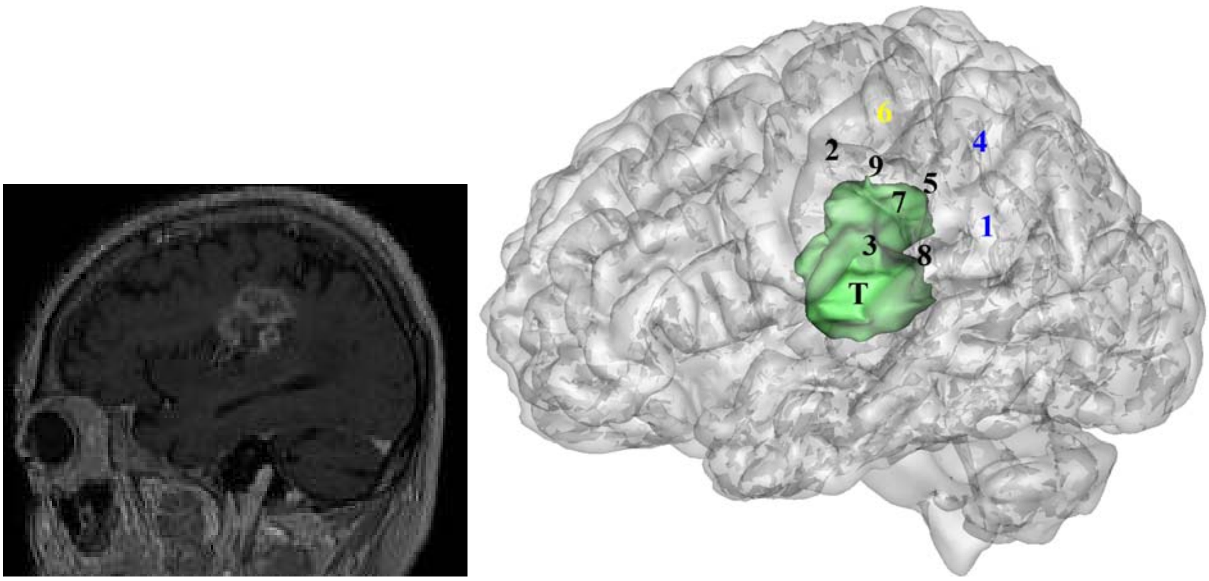


Fig. PP3. MRI and 3D image of the patient brain and stimulations sites (sites were stimulated from 1 to 9). Color code: ● Conscious Intention + Illusory Movement ; ● Itching and tingling sensations ; ● No response. T: Tumor.

Evoked movements.

Body Part	Stimulation Sites
Mouth / Lips	4
Mouth	1

Verbatim samples of patient's report. Experimenter (E), Patient (P).

Site 1:

5 mA / 4s
E: Did you move?
P: No… I had a desire to roll my tongue in my mouth
E: To roll what, your… ?
P: To roll my tongue in my mouth.

8 mA / 4s
E: Did you move?
P: Yes, yes, a corner of the mouth
E: You did move the mouth?
P: Yes

Site 4:

5 mA / 4s
E: Did you move?
P: No, I had something in my mouth
E: In your mouth?
P: Yes, in my mouth
E: What did you feel, tinglings?

P: No, it was something else
E: What was it? What did you feel in the mouth?
P: I felt a desire to lick my lips.
E: A desire to lick your lips?
P: Yes, yes that's it.

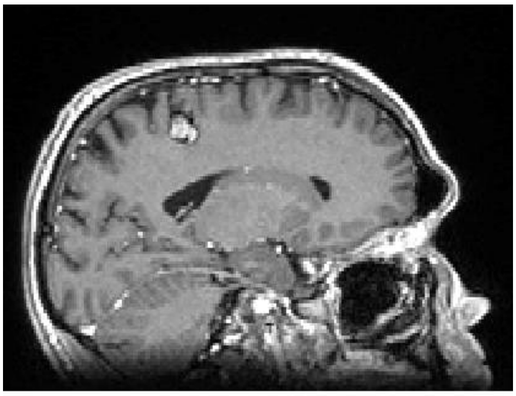
8 mA / 4s
E: Did you move?
P: Yes, Yes, I moved my mouth
E: You moved your mouth?
P: Yes, I moved my mouth, I talked, what did I say?

Patient PM1

Male, 31 years old.

Melanoma in the right central sulcus.

3 sites stimulated. Functional mapping was interrupted before its completion, due to the occurrence of a seizure after stimulation of M1 (BA 4).



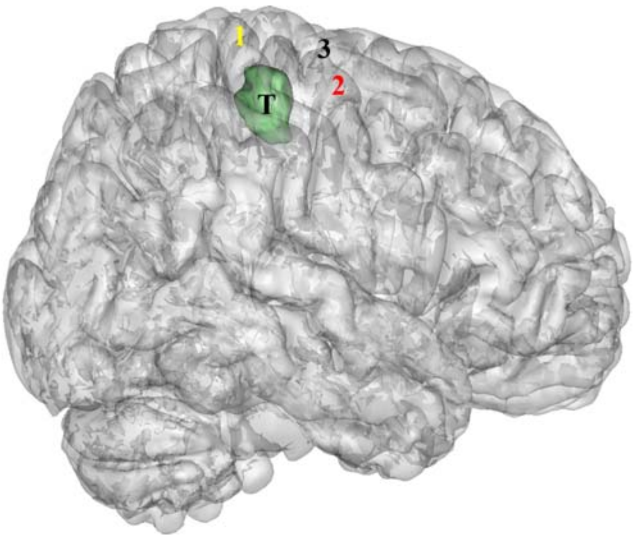


Fig. PM1. MRI and 3D image of the patient brain and stimulations sites (sites were stimulated from 1 to 3). Color code: ● Unconscious Movement ; ● Itching and tingling sensations ; ● No response. T: Tumor.

Evoked movements.

Body Part	Stimulation Sites
Hand / Arm	2

Verbatim sample of patient's report. Experimenter (E), Patient (P).

Site 2:

> 8 mA / 4s
> E: Did you feel that you moved?
> P: Here? No… No
> E: No?
> P: No.

Patient PM2

Female, 43 years old.

Nodular lesion consecutive to the treatment of a brain nocadia abscessus in the right prefrontal region.

3 sites stimulated. Functional mapping was interrupted before its completion, due to the occurrence of a seizure after stimulation of the premotor region (BA 6).

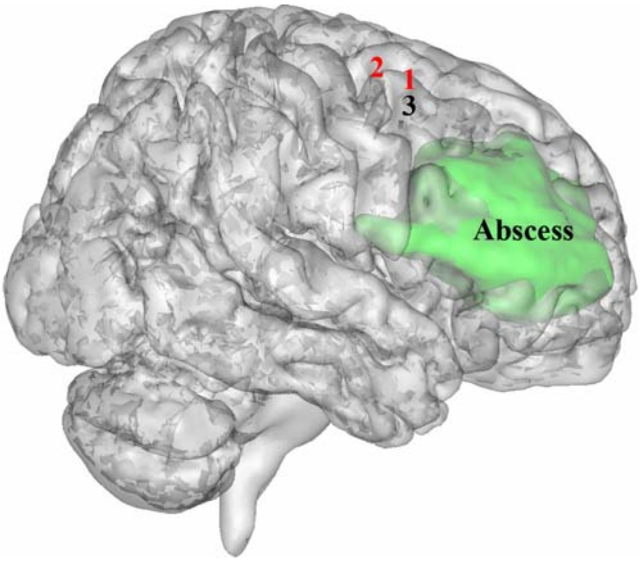


Fig. PM2. MRI and 3D image of the patient brain and stimulations sites (sites were stimulated from 1 to 3). Color code: ● Unconscious Movement ; ● No response.

Evoked movements.

Body Part	Stimulation Sites
Hand / Arm	1 ; 2

Verbatim sample of patient's report. Experimenter (E), Patient (P).

Site 2:

> 2 mA / 2s
> E: Did you feel something?
> P: No.
> E: Why did you move your hand?
> P: I did not move.

Patient PM3

Male, 52 years old.

Meningioma in the left lower frontal circonvolution.

17 sites stimulated.

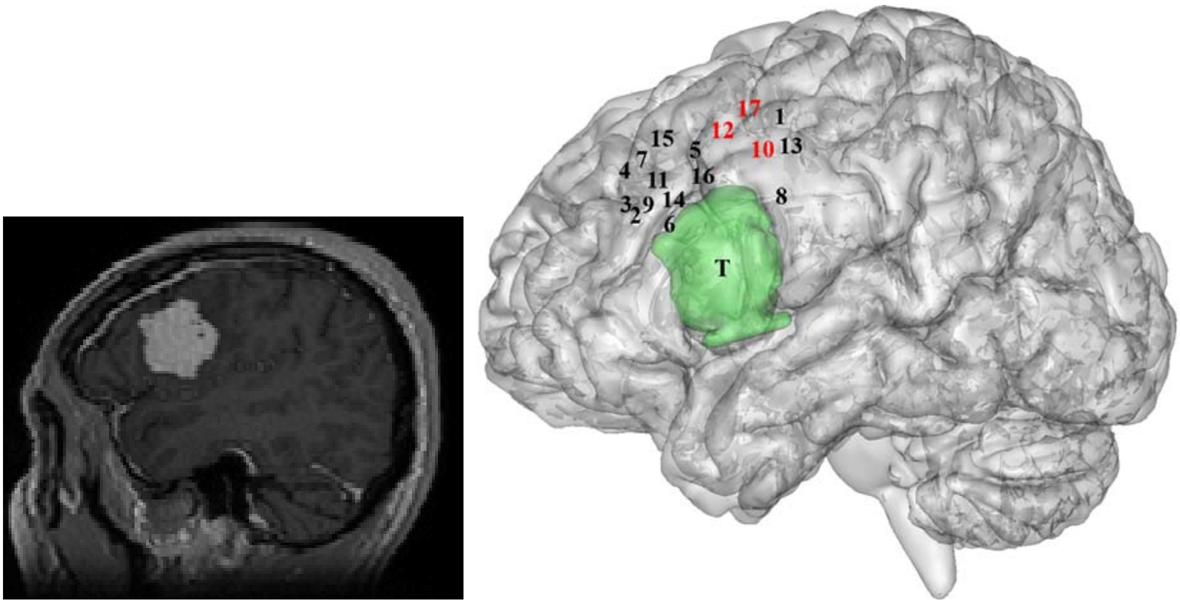


Fig. PM3. MRI and 3D image of the patient brain and stimulations sites (sites were stimulated from 1 to 17). Color code: ● Unconscious Movement ; ● No response.

Evoked movements.

Body Part	Stimulation Sites
Hand / Arm	17
Mouth	10 ; 12

Verbatim sample of patient's report. Experimenter (E), Patient (P).

Site 17:

> 5 mA / 2s
> E: Did you move?
> P: No, I don't think so.

Patient PM4
Female, 54 years old.

Oligodendroglioma in the right prefrontal region (tumoral recurrence).

9 sites stimulated.

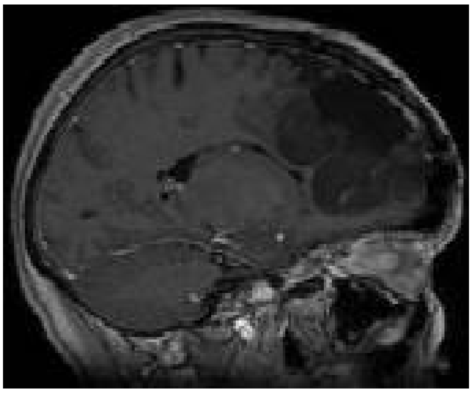
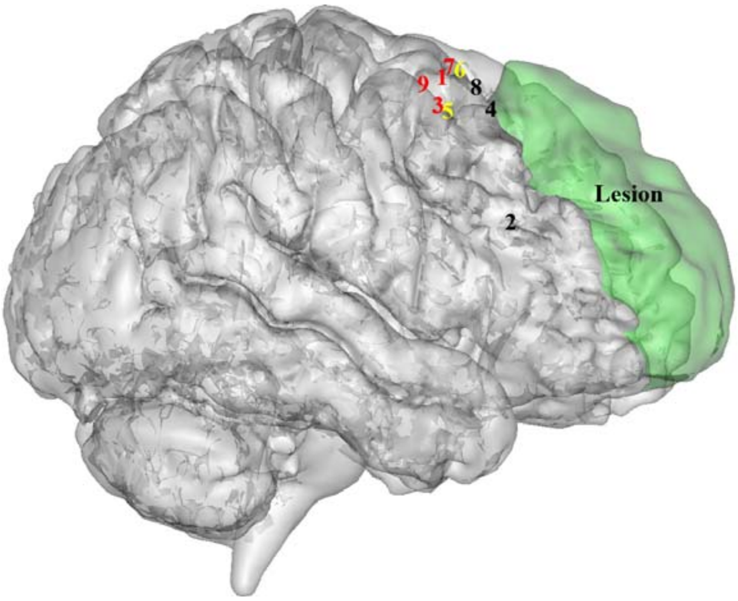



Fig. PM4. MRI and 3D image of the patient brain and stimulations sites (sites wre stimulated from 1 to 8). Color code: ● Unconscious Movement; ● Itching and tingling sensations ; ● No response.

Evoked movements.

Body Part	Stimulation Sites
Foot	1 ; 7 ; 9
Hand	3

Verbatim sample of patient's report. Experimenter (E), Patient (P).

Site 1:

8 mA / 1s
E: Did you move?
P: No

RESULTS

Distribution of the stimulation sites:

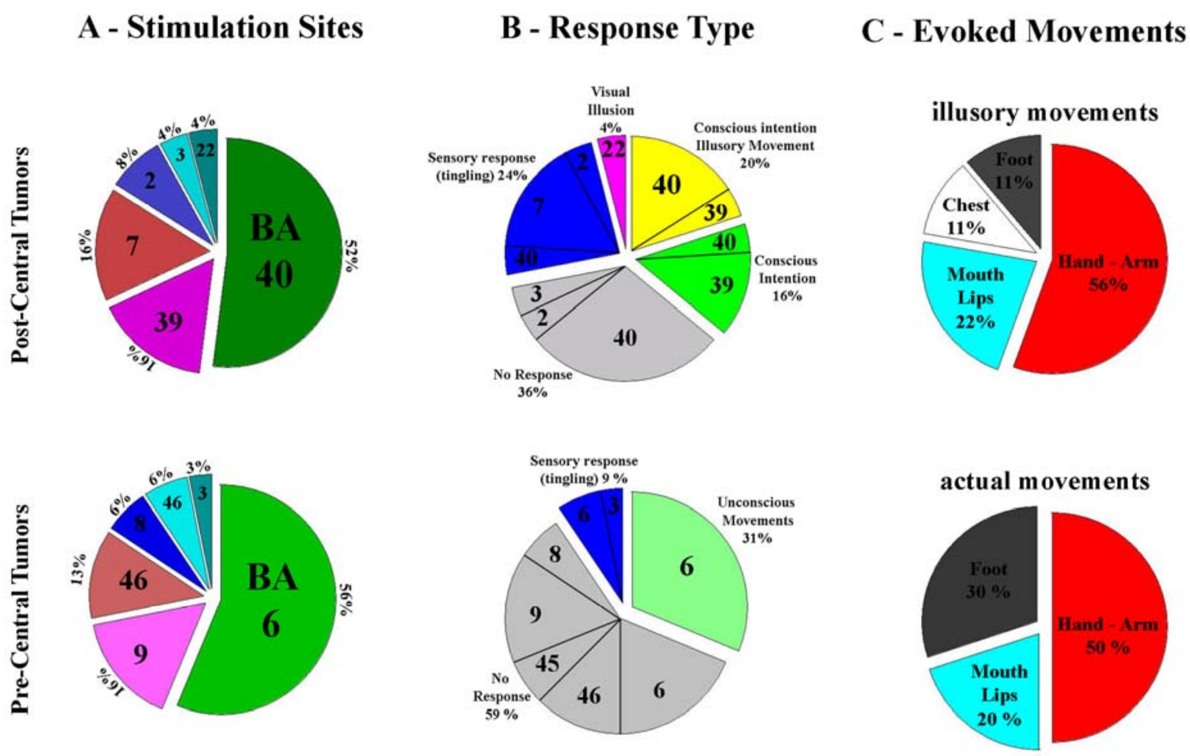


Fig. S2: Summary of the stimulation data: (A) anatomical distribution of the stimulation sites (numbers refer to Brodmann areas); (B) functional distribution of the DES-related responses (total is not exactly 100% for the bottom panel due to roundings); (C) type of movements evoked by the stimulation (bottom row: actual evoked movements, pre-central stimulation sites ; top row: illusory evoked movements, post-central stimulation sites). BA: Brodmann Area.

It may be worth noting that no stimulation was performed in M1. This raises the question whether movements evoked from M1 stimulation would be consciously perceived by the subjects, in contrast to the movements evoked from the preomtor cortex. We could not address this issue because no patients with lesions in the peri-central region could be recruited. This region is not a common location for most types of tumors in adults (S*18*-*S20*). In 3 of our 4 patients, the tumors were too anterior to allow access to M1 or to make stimulation of this region clinically relevant. In the fourth patient, the rolandic area was partially uncovered. However, the first stimulation of M1 at the lowest possible intensity produced a seizure, thus preventing further investigation.

LEGENDS FOR VIDEOS **(available for download at http://www.isc.cnrs.fr/sir/article/videos_desmurget.zip)**

PM1.avi: This video shows a large multijoint movement triggered by direct electrical stimulation of the premotor cortex (8 mA, 4s), in patient PM1. This movement was not consciously perceived by the patient. Stimulation was delivered over the site numbered 2 in the 3D figure of patient PM1 (see above).

PM4.avi: This video displays finger, hand and wrist movements triggered by direct electrical stimulations of the premotor cortex, in patient PM4. It is shown that higher currents recruit more muscles and trigger larger movements. Intensity of the stimulation had no effect on the ability of the subject to consciously perceive the evoked movements. Stimulations were delivered for 1 s at 2, 5 and 8 mA, over the site numbered 3 in the 3D figure for patient PM4 (see above).

PP2.avi: This video shows a "pure intention" following stimulation of the posterior parietal cortex. The patient reported that she felt "like a will to move" her chest. Stimulation (8 mA , 4s) was delivered over the site numbered 8 in the 3D figure for patient PP2 (see above).

PP3.avi: This video displays a "pure intention" after stimulation of the posterior parietal cortex at median intensity (5 mA, 4s), followed by an "illusory sensation of movement" when the intensity of the stimulation was raised (8 mA, 4s). The patient reported first that he "had a desire to roll his tongue in his mouth" and then that "he had moved the corner of his mouth". Stimulations were delivered over the site numbered 1 in the 3D figure for patient PP3 (see above).

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