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Intention is central to the concept of voluntary action. Using functional magnetic resonance imaging, we compared conditions in which participants made self-paced actions and attended either to their intention to move or to the actual movement. When they attended to their intention rather than their movement, there was an enhancement of activity in the pre-supplementary motor area (pre-SMA). We also found activations in the right dorsal prefrontal cortex and left intraparietal cortex. Prefrontal activity, but not parietal activity, was more strongly coupled with activity in the pre-SMA. We conclude that activity in the pre-SMA reflects the representation of intention.

A motor action is voluntary if and only if it is intended. William James (*1*) put forward the ideomotor theory of action, which states that any intention or idea of an action has the tendency to cause the relevant movements. To prevent ourselves from committing action errors, it is frequently important that we attend to our intentions before executing an action (*2*).

We have studied the neural mechanisms underlying intention by using functional magnetic resonance imaging (fMRI) to investigate the modulation of those mechanisms by attention. The neural representation of intention has been studied in previous imaging experiments by comparing task conditions in which participants made finger movements that were self-paced or triggered by an external cue (*3–5*). However, these two conditions differ in other respects. In particular, when participants generate self-paced movements, they hold in mind the previous intervals at which they have paced their recent movements so as to generate a pseudorandom series of responses (*6*).

We therefore set up two conditions, in both of which the participants made the same finger movements at their own pace (*7*). The conditions were equated for working memory load, action generation, and preparation. The only difference between the two conditions was the focus of attention. This was manipulated by requiring them to report either the time at which they felt the intention to move or the time at which they actually made the movement.

We used the temporal judgment task developed by Benjamin Libet (*8*). In his paradigm, participants made spontaneous finger movements while watching a spot moving round a clock face. They then reported the time at which they first felt the urge to move. He compared the reported times with the earliest time at which slow potentials could be recorded from the scalp. The purpose of these studies was to investigate the causal relationship between brain activity, intention, and action. In contrast, our interest focused on identifying the brain mechanisms involved in attention to intention.

Thus, we used fMRI not to measure the relative timings of brain activity but to study the enhancement of activity when participants attend to their intentions. We reasoned that attention to intention should enhance the blood oxygenation level–dependent (BOLD) signal in the brain areas that represent intention. The assumption is that attention to a mental representation enhances the activity in the relevant brain area. Such attentional modulation has been demonstrated in sensory processes such as visual perception (*9*) as well as in action generation (*10*, *11*).

In all trials, the participants spontaneously pressed a button at their own pace while watching a moving red dot revolving around a clock face at a speed of 2560 ms per cycle. In half of the trials (the intention condition), they were asked to pay attention to their intention before the movement. After a variable delay period, they were required to report the timing of their intentions by moving a cursor to where the red dot was when they first "felt the urge" to move. In the control condition (the movement condition), they were not required to attend to their intention and were asked instead to report when they had actually pressed the button.

We specifically predicted that activity in the pre–supplementary motor area (pre-SMA) or the underlying rostral cingulate motor area (CMAr) would be more salient when we attended to intention. There were three reasons. First, it has been reported that electrical stimulation of the medial frontal cortex elicits the feeling of an urge to move (*12*). Second, lesions of the medial frontal cortex abolish self-initiated movements in macaque monkeys (*13*). Finally, we have previously reported activity in the pre-SMA when participants generate actions of their own free choice (*6*). We further hypothesized that areas involved in attention to action, namely the dorsal prefrontal cortex (DPFC, also known as Brodmann's area 46) and intraparietal sulcus (IPS) (*14*), would also show higher activation when we attend to intentions. So as to investigate their relationship with the pre-SMA, we specifically tested whether the coupling was stronger when participants attended to their intentions.

We replicated the main behavioral findings for the Libet temporal judgment task (*8*). The participants on average reported their intention to move as being 228 ms earlier than the recorded button press (153 ms SD). The average reported timing for when they pressed the button was 29 ms earlier than the recorded button press (70 ms SD). The two temporal judgments differed significantly: $P < 0.001$ (one-tailed paired t test).

We make no interpretation about the exact magnitude of the relative timings other than to confirm that the participants were genuinely attending to different events. The fact that the participants judged the urge to move as occurring roughly 200 ms before the movement itself replicates the results of previous experiments (*15*, *16*). However, the interpretation and validity of these subjective estimates has also been controversial (*17*, *18*). Because most factors affecting the accuracy of timing with the clock during the tasks in this experiment are likely to have been the same for both conditions, the statistical comparison between the two conditions should reflect a genuine difference in what the participants were attending to in the two conditions.

We also analyzed the latencies at which the participants pressed the button in the two conditions, so as to check whether the participants were generating similar actions in each condition. On average, the participants pressed the button 5747 ms after the red dot started revolving around the clock in the intention condition (1921 ms SD). They pressed the button 5562 ms after the red dot started moving in the movement condition (1628 ms SD). The values did not differ significantly: $P = 0.381$ (two-tailed paired t test). This suggests that pacing of the actions and the amount of time for preparation were similar in the two conditions. The variability of each participant's action onsets was measured by the standard deviation of the latencies across the whole experiment. The group averages of the variability were 1553 ms and 1609 ms for the intention and movement conditions, respectively. The averages of the variability did not differ significantly: $P = 0.611$ (two-

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tailed paired *t* test). Further details about the behavioral data and their relationships with the individual brain activities are available as supporting materials (figs. S1 and S2).

The fMRI results showed specific activations associated with attention to intention. We used an event-related approach to analyze activity during the 1-s period before the recorded button press in each trial. When the intention condition was compared with the movement condition, we found activations in the pre-SMA (coordinates 2, 4, 54; $P = 0.040$), right DPFC (coordinates 36, 36, 28; $P = 0.006$), and left IPS (coordinates –22, –54, 60; $P = 0.041$), but not in the CMAr. (These *P* values were corrected for multiple comparison within search volumes defined a priori.) These activations reflect differences in the intensity of activity in the two conditions. They cannot be due to the temporal judgment process itself or to the memory demand for remembering that position of the dot, because these were common to both conditions. Similarly, they cannot be due to preparing for or initiating a self-paced action, because this was also the same for both conditions. We also tested whether the latency of BOLD responses in these areas differed across the two conditions. No significant difference in latency was found in these areas at a lenient threshold of $P < 0.001$ (uncorrected for multiple comparisons). This suggests that temporal differences between the events were not a contributing factor to our fMRI results.

Within the motor and premotor regions, the pre-SMA was the only area in which there was a significant activation for intention versus movement at a lenient threshold of $P < 0.001$ (uncorrected for multiple comparisons). The activation is shown in Fig. 1 together with the time course of the hemodynamic responses. Previous studies of the effects of attention to action on activity in motor areas have not been specific about what the participants actually attended to; for example, whether they attended to the preparation of the action or to the somatic feedback from the action (*10*, *11*, *19*). By contrast, we specifically manipulated the focus of attention, either to the intention or to the action itself. This may be one reason why our results were more specific.

It could be argued that the activation in the pre-SMA might not be genuinely due to attentional modulation. As in any other study on this topic, attention is not directly observable, and thus we have to rely on indirect measures, in this case the reported onset of the attended event. It might be thought that such reports are not necessarily veridical. One possibility would be that after the movement the participants artificially worked out the time of their intentions by simply reporting a time that was earlier than the time of the movements. However, inspection of the time

course of the hemodynamic responses suggests that this is not the case. Because hemodynamic responses typically peak at about 5 to 6 s after the neuronal firings, the fact that responses at the pre-SMA peak at ~3 s after the movement suggests that the activity clearly began before the movement at an early stage of the preparation period. If the participants had worked out the onset of their intentions based on the perceived time of the action execution, the activity due to that procedure would have occured much later, presumably after the action or even during the report of the onset.

Alternatively, it could be argued that the activation in the pre-SMA reflects the difficulty of making judgments about the timing of intention. Indeed, eight participants reported that the intention condition was more difficult. However, inspection of the individual adjusted raw data for the time course of hemodynamic responses at the peak coordinates of the activation suggests that this is not the explanation for the result. We found that the recorded maximum of BOLD signal during the 18-s period after the onset of action was consistently higher for the intention condition than for the movement condition across all participants. This also suggests that this result was robust.

When we compared intention with movement, there were also activations in the DPFC (area 46) and IPS (Fig. 2). Rowe *et al.* (*10*, *19*) have previously reported that there was activation in the DPFC and IPS when participants were instructed to attend to their actions as opposed to performing them without attention. These authors argue that these activations reflect attention to action (*14*), but as mentioned earlier, no distinction was made between attention to intention and attention to

the movements themselves. Activity has also been reported in the DPFC when participants directly compare time intervals in memory (*20*); in our experiment, however, although the participants made temporal judgments, these were about events rather than intervals. Furthermore, they made such judgments in both task conditions. Other authors have found activity in the DPFC (*21*) and IPS (*22*, *23*) during movement preparation. Thoenissen *et al.* (*23*) specifically relate the parietal activity to motor intention, by which the authors mean a preparatory process that is not correlated with the motor performance or the likelihood of producing a response.

To further investigate the mechanism for attention to intention, we performed a connectivity analysis to look for changes in the relationship between the activations of the DPFC, IPS, and pre-SMA across task conditions. We specifically tested whether the regression coefficients for activity between these areas and activity in the pre-SMA increased significantly from the movement condition to the intention condition. We found that this was true for the regression for the pre-SMA on the DPFC ($P < 0.020$), but not for the regression for the pre-SMA on the IPS ($P = 0.238$). The regression plots of one participant are shown in Fig. 2.

These results suggest that activity in the DPFC is closely associated with the trial-by-trial enhancement of the activity in the pre-SMA when participants attend to intention. This result strongly resembles that of a previous connectivity study of attention to action (*19*). Furthermore, there are direct anatomical connections between the DPFC and the pre-SMA (*24*–*26*). The fact that we did not find a change in connectivity between the IPS and the pre-SMA may be due to the paucity of
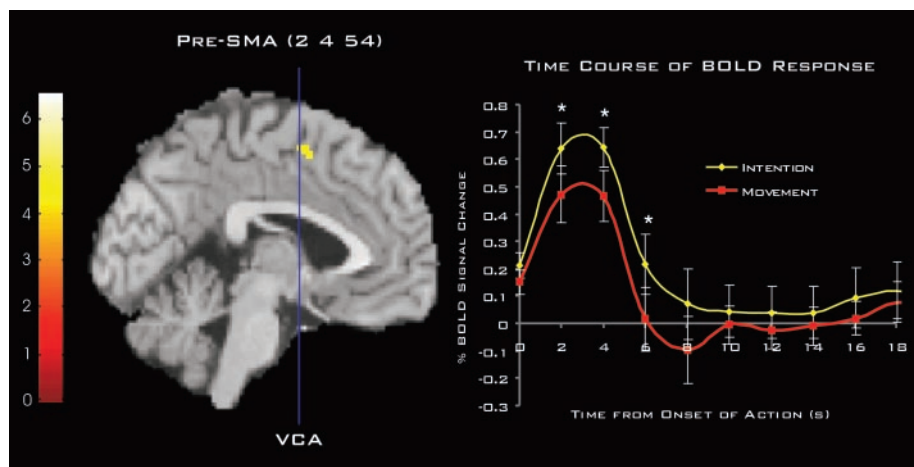

Fig. 1. Activation of the pre-SMA associated with attention to intention as compared to attention to movement only. The peak of activation is anterior to the vertical line passing through the anterior commissure (the VCA line). The figure on the right shows the adjusted data for the time course of the hemodynamic response for the group; these data were extracted from the peak of the activation. The error bars represent standard errors. The points at which the data differed significantly (one-tailed paired *t* test, $P < 0.005$) are marked with asterisks.
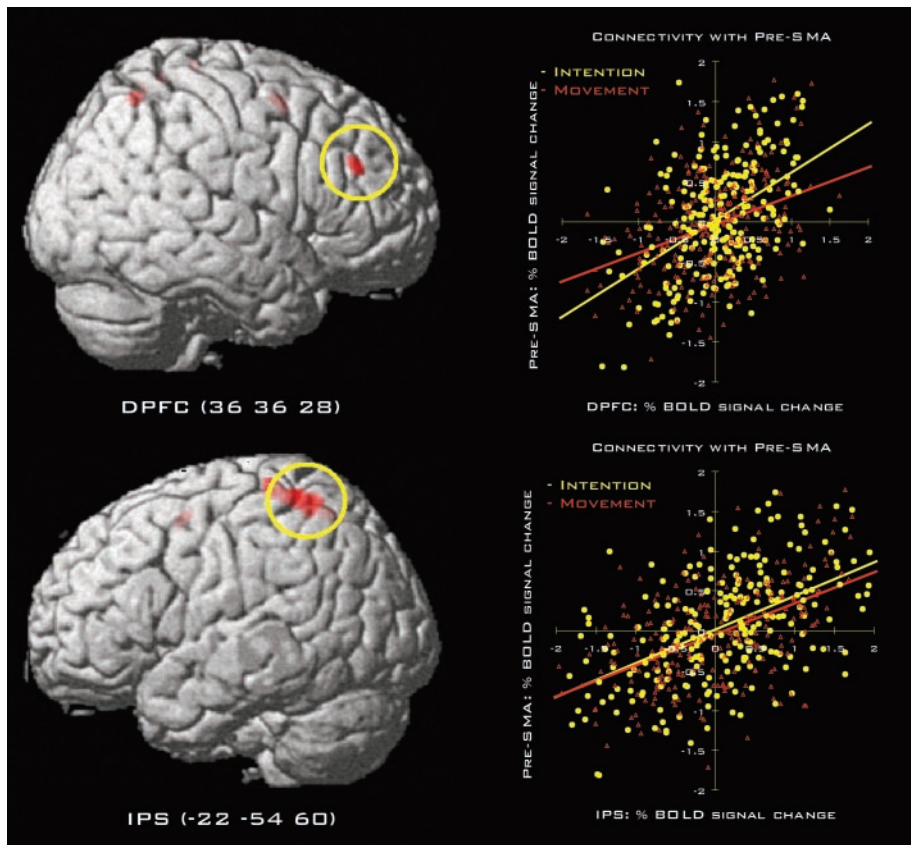
Fig. 2. Activation of the right DPFC and left IPS associated with attention to intention as compared to attention to movement only. The plots on the right show the regression slopes for activity in the pre-SMA and activity in the DPFC and IPS. The data shown are for an individual participant, but they reflect the trend for the group. For each condition, the plots include the mean corrected data for the five scans immediately after the onset of movements in each trial. The slopes for the regression of activity of the pre-SMA on the activity on the right DPFC are steeper for the intention condition than for the movement condition, but they are similar for the regression of activity of the pre-SMA on the activity on the left IPS.

direct connections between the parietal cortex and the pre-SMA (*25*, *26*). Alternatively, even where the connections are strong, as between the parietal and premotor cortex (*26*), the connection strength is not modulated by attention to action (*27*).

Our data demonstrate an association between enhancement in the pre-SMA and the activity of the DPFC. However, we cannot distinguish between two possible interpretations. The first is that the DPFC drives the enhancement of activity in the pre-SMA; the second is that the activity in the DPFC reflects the monitoring of the enhanced activity in the pre-SMA. Activity has been reported in the DPFC, as well as in the parietal cortex, when trials were compared in which participants either were or were not perceptually aware of stimuli (*28*). One interpretation is that these activations reflect the conscious monitoring of activity in the visual areas. However, in that study, as in ours, the data do

not distinguish between the possibilities that the DPFC is influencing activity elsewhere or is monitoring that activity.

Although the exact mechanism is unclear, our experiment demonstrates that when participants attend to intention, there is enhanced activity in the pre-SMA. It has been suggested that the effective editing and evaluation of intentions are only possible when we are conscious of the intentions (*29*). Conscious awareness of visual stimuli has been demonstrated to be associated with the intensified BOLD signal in the relevant sensory area in the brain (*30*). Within the context of voluntary actions, it has been reported that awareness of the production of spontaneous movements is associated with an enhancement of the pre-movement slow potentials recorded over the medial frontal region (*15*). Taken together, if the intensity of activity in the pre-SMA correlates with the awareness of

intention, our results suggest that attention to intention may be one mechanism by which effective conscious control of actions becomes possible.

Note added in proof: It has also been reported that patients with a lesion in the angular gyrus of the parietal cortex cannot distinguish between the onsets of intentions and movements (*31*).

References and Notes

1. W. James, *The Principles of Psychology* (Holt, New York, 1890).
2. J. T. Reason, *Human Error* (Cambridge Univ. Press, Cambridge, 1990).
3. M. Jahanshahi *et al.*, *Brain* **118**, 913 (1995).
4. I. H. Jenkins, M. Jahanshahi, M. Jueptner, R. E. Passingham, D. J. Brooks, *Brain* **123**, 1216 (2000).
5. R. Cunnington, C. Windischberger, L. Deecke, E. Moser, *Neuroimage* **15**, 373 (2002).
6. H. C. Lau, R. D. Rogers, R. Ramnani, R. Passingham, *Neuroimage*, in press.
7. Materials and methods are available as supporting material on *Science* Online.
8. B. Libet, C. A. Gleason, E. W. Wright, D. K. Pearl, *Brain* **106**, 623 (1983).
9. M. Corbetta, F. M. Miezin, S. Dobmeyer, G. L. Shulman, S. E. Petersen, *Science* **248**, 1556 (1990).
10. J. Rowe, K. Friston, R. Frackowiak, R. Passingham, *Neuroimage* **17**, 988 (2002).
11. H. Johansen-Berg, P. M. Matthews, *Exp. Brain Res.* **142**, 13 (2002).
12. I. Fried *et al.*, *J. Neurosci.* **11**, 3656 (1991).
13. D. Thaler, Y. C. Chen, P. D. Nixon, C. E. Stern, R. E. Passingham, *Exp. Brain Res.* **102**, 445 (1995).
14. R. E. Passingham, J. B. Rowe, K. Sakai, in *Attention in Action*, G. W. Humphreys, Ed. (Taylor & Francis, in press).
15. I. Keller, H. Heckhausen, *Electroencephalogr. Clin. Neurophysiol.* **76**, 351 (1990).
16. P. Haggard, M. Eimer, *Exp. Brain Res.* **126**, 128 (1999).
17. S. Klein, *Conscious Cognit.* **11**, 273 (2002).
18. S. Joordens, M. van Duijn, T. M. Spalek, *Conscious Cognit.* **11**, 231 (2002).
19. J. Rowe *et al.*, *Brain* **125**, 276 (2002).
20. S. M. Rao, A. R. Mayer, D. L. Harrington, *Nature Neurosci.* **4**, 317 (2001).
21. J. B. Pochon *et al.*, *Cereb. Cortex* **11**, 260 (2001).
22. I. Toni *et al.*, *J. Cognit. Neurosci.* **14**, 769 (2002).
23. D. Thoenissen, K. Zilles, I. Toni, *J. Neurosci.* **22**, 9024 (2002).
24. M. T. Lu, J. B. Preston, P. L. Strick, *J. Comp. Neurol.* **341**, 375 (1994).
25. G. Luppino, M. Matelli, R. Camarda, G. Rizzolatti, *J. Comp. Neurol.* **338**, 114 (1993).
26. M. Matelli, G. Luppino, *Neuroimage* **14**, S27 (2001).
27. J. B. Rowe, R. E. Passingham, *Neuroimage* **14**, 77 (2001).
28. D. M. Beck, G. Rees, C. D. Frith, N. Lavie, *Nature Neurosci.* **4**, 645 (2001).
29. B. J. Baars, *A Cognitive Theory of Consciousness* (Cambridge Univ. Press, Cambridge, 1988).
30. K. Moutoussis, S. Zeki, *Proc. Natl. Acad. Sci. U.S.A.* **99**, 9527 (2002).
31. A. Sirigu *et al.*, *Nature Neurosci.* **7**, 80 (2004).
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