Tina Memo No. 2004-014

Internal.

Funtional Contribution of Medial Pre-Cortex to Visuo-Spatial Transformation.

S.J.Johnston, E.C.Leek, N. A. Thacker, and A.Jackson.

Last updated
11 /4 / 2005

Imaging Science and Biomedical Engineering Division,
Medical School, University of Manchester,
Stopford Building, Oxford Road,
Manchester, M13 9PT.

Functional contribution of medial pre-motor cortex to visuo-spatial transformation

Stephen Johnston*, E. Charles Leek*, Neil Thacker**, Alan Jackson**

* School of Psychology, University of Wales, Penrallt Road, Bangor, Gwynedd, UK.
** Department of Biomedical Engineering, University of Manchester, Oxford Road, Manchester, UK.

Address for correspondence: Stephen Johnston,
Psychology Department,
University of Wales,
Penrallt Road,
Bangor,
Gwynedd, LL57 2AS, UK.

Email: s.johnston@bangor.ac.uk
Tel: +44 (0) 01248 388173
Fax: +44 (0) 1248 382599

Length : 3.95 pages.

This paper examines the functional contribution of medial premotor cortex – the supplementary motor area (SMA), to visuo-spatial transformation. Previous studies have found evidence of activation in SMA using 'mental rotation' tasks in which subjects make mirror image judgements about simultaneously presented depth rotated novel forms. This manipulation induces potential confounds in the cognitive demands of the task in addition to spatial normalisation processes. We clarify the role of SMA in visuo-spatial normalisation using functional magnetic resonance imaging (fMRI) with a sequential mirror-image judgement task involving 2D image-plane rotated forms. The results show preferential activation of SMA, as well as the ventrolateral prefrontal and parietal cortex during the visuo-spatial transformation of mirror image stimuli.

KEYWORDS: SMA, medial premotor cortex, visuo-spatial transformation, mental rotation, fMRI, spatial normalisation.

There is considerable evidence that the premotor cortex (BA6) plays an important role in preparation for movements (e.g. [8,18]), but also for functional sub-divisions within the premotor area. The medial premotor cortex, or supplementary motor area (SMA), has been shown to be involved in both the selection, and preparation, of internally generated movement [2,3,5,7,11], that is, movements that are made in the absence of an external prompt or stimulus. In contrast, lateral premotor areas appear to be involved in preparation for movements made in response to external cues [5, 11, 17]. Other data suggest functional specialisation within the anterior ('pre-SMA') and posterior (SMA) premotor cortex [2,3,13], as well as the dorsal and ventro- lateral premotor areas [6,18,19].

One potentially relevant observation to understanding functional specialisation in premotor cortex has come from studies of the 'mental rotation' of 3D novel objects using the Shepard and Metzler mirror image judgement task [20]. Mental rotation is frequently associated with superior, and inferior, parietal cortex, as well as prefrontal areas (e.g. [1,15,16]), but some studies have also reported activation in premotor areas during mental rotation[1,8,15,16,18]. These data suggest that the functions of premotor cortex are not restricted to movement planning, but may also play a more general computational role in visuo-spatial transformation. Interestingly, there is evidence from some behavioural studies, based on dual-task interference effects, supporting a functional link between visuo-spatial transformation in mental rotation, and motor planning [22]. Despite this, the functional significance of some previous reports of premotor area activation during mental rotation remains unclear. One issue is a potential confound, in some previous imaging studies using mental rotation tasks, that arise from requiring mirror-image judgements for depth rotation 3D object stimuli [1,8,15,16,18]. Under these conditions, observations of neural activation may reflect the operation of cognitive processes, and additional task demands, associated with the perspective deformation of 3D rotated objects (e.g., foreshortening and occlusion of features).

The aim of the current study was to address this issue. Subjects performed a mirror-image judgement task, using sequentially presented 2D novel forms, whilst undergoing fMRI. Critically, angular misorientation of stimuli was restricted to rotations within the fronto-parallel (image) plane precluding perspective deformation by depth rotation. This design eliminates this potential confound of previous studies and provides an opportunity to clarify the involvement of premotor cortex in visuo-spatial transformation.

Nine healthy right handed volunteers took part in the study, all of whom gave written informed consent. Scans were performed on a 1.5T Philips MR scanner. For each subject a total of 196 volumes consisting of 40 slices using a single shot EPI gradient sequence were collected (TR=3.15s, TE=40ms, 224mm FOV, 64 x 64 matrix, 3.5mm slice thickness). Reaction time data (RT) was collected using fibre-optic response boxes (www.curdes.com)

The experiment used a delayed-matching task in which subjects were required to make mirror-image judgements about 2D novel object shapes. The procedure is illustrated in Figure 1. On each trial two stimuli were presented sequentially. The task was to determine whether the two stimuli were mirror images of each other. ‘Yes’ responses were made with the right hand, ‘no’ responses with the left. There were two conditions: In the ‘mental rotation’ (MR) condition the stimuli were presented with either a 60^o or 120^o angular difference in the fronto-parallel plane between the principle axes of the stimuli. In the baseline condition the two stimuli were presented at the same orientation. In both conditions the first stimulus could appear with its principal axis aligned at any one of three orientations, 0^o, 60^o or 120^o, where the 0^o condition involved the alignment of the principal axis of the stimulus with the vertical (see Figure 2).

An interleaved block design was used consisting of four blocks of the MR condition, and four blocks of the baseline condition. The blocks were interleaved so that each subject received one block of the MR condition followed by one block of the baseline condition. The stimuli were an asymmetric set of 2D novel forms[21] – see Figure 2.

Co-registration and realignment of the MRI data were done using TINA software (www.tina-vision.net). The remaining analyses were conducted using SPM99 (http://www.fil.ion.ucl.ac.uk/spm). The data were normalised to the Montreal Neurological Institute (MNI) template and smoothed with a 10mm 3D Gaussian kernel. A random effects model was used to analyse the data. The inputs for this were the individual contrast images for the 'MR - baseline' contrast. A height threshold of $p < 0.001$ uncorrected, with a minimum of 15 adjacent suprathreshold voxels, was applied. For predicted areas of activation a small volume correction was applied to correct for multiple comparisons. Results are reported in the MNI coordinate system.

Since target stimuli were seen more frequently in the 0^o condition, RT data were analysed only across conditions with equal numbers of presentations (i.e. 60^o & 120^o). Figure 1 shows the mean RTs (and standard error of the mean) per condition. A paired t-test showed a significant difference between the RTs for the 60^o and 120^o conditions ($t(8)=-2.98$, $p < .01$). Subjects took longer to match stimuli as angular disparity increased. This replicates the basic mental rotation effect [20].

In the fMRI data, the contrast of MR – baseline resulted in three areas of activation. Clusters of activation were seen in the superior parietal lobe (SPL) (MNI

Coord: 6, -62, 58; $p < 0.002$ corrected), across the superior and medial frontal gyri (MNI Coord: 2, 14, 54; $p < 0.005$ corrected) and the ventrolateral prefrontal cortex (VLPFC) (MNI Coord: -42, 18, 2; $p < 0.002$ corrected). Data are shown in Figure 3, with an ROI time course for the medial premotor activation.

The aim of this study was to determine whether the visuo-spatial transformation of image plane rotated objects would lead to significant activations in (medial) premotor cortex under conditions which eliminate confounds associated with previous studies using depth rotated 3D object forms. The results are consistent with this hypothesis. Activation was found for 2D image rotation in the superior and medial frontal gyri encompassing the anterior part of medial premotor cortex (or pre-SMA [13]), including both BA6 and BA8. These results, and those of other studies reporting medial premotor area activation in mental rotation tasks [1,8,15,16,18], provide further evidence that medial premotor cortex is involved in the computation of visuo-spatial transformations. This finding is interesting in the context of other work demonstrating an association between medial premotor cortex and the planning of internally generated movements [2,3], and between 'pre-SMA' and the processing and maintenance of sensory information [13]. The functional link between effects of stimulus orientation in mental rotation tasks, and movement planning, may involve the computation of vector transformations required both for mapping visuo-spatial representations of object stimuli onto each other, and for calculating movement trajectories for visually guided actions. Supporting evidence has been found for mental transformation mechanisms of this type in the motor cortex for visually guided movement in monkeys [12].

Two other areas of cortical activation were also found in the current study. In agreement with previous studies of mental rotation effects (e.g. [16]), activations in

VLPFC (left) and right SPL (right) were found. One function that has been proposed for the SPL is as a mediator of spatial attention (e.g. [14]), although its contribution to visuo-spatial transformation is unclear. One possibility is that the SPL is involved in monitoring the location of object features during visuo-spatial transformation. Prefrontal cortex is often associated with executive function and working memory tasks (e.g. [4]). Thus, this activation may represent the operation of some components of working memory during visuo-spatial transformations [4, 5].

In conclusion, the current study shows that medial premotor cortex, in addition to VLPFC and SPL, is preferentially active during mirror-image judgements of image-plane rotated 2D novel objects. The results provide further evidence for a functional association between orientation effects in mental rotation , and the planning of internally-generated movements. It is suggested that this functional link involves the computation of vector transformations underlying visuo-spatial transformations and the planning of visually-guided movement.

The work reported in this paper was supported by project grant (5/S15963) from the Biotechnology and Biological Sciences Research Council, UK (BBSRC) awarded to ECL, NT & AJ.

References

[1] M.S. Cohen, S.M. Kosslyn, H.C. Breiter, G.J. DiGirolamo, W.L. Thompson, A.K. Anderson, S.Y. Bookheimer, B.R. Rosen, J.W. Belliveau, Changes in cortical activity during mental rotation. A mapping study using functional MRI, Brain 119 (1996) 89-100.

[2] M.-P. Deiber, V. Ibanez, N. Sadato, M. Hallett, Cerebral Structures Participating in Motor Preparation in Humans: A Positron Emission Topography Study, Journal of Neurophysiology 75(1) (1996) 233-247.

[3] M.-P. Deiber, M. Honda, V. Ibanez, N. Sadato, M. Hallett, Mesial Motor Areas in Self-Initiated Versus Externally Triggered Movemnets Examined With fMRI: Effect of Movement Type and Rate, Journal of Neurophysiology 81 (1999) 3065 – 3077.

[4] M. D'Esposito, G.K. Aguirre, E. Zarahn, D. Ballard, R.K. Shin, J. Lease, Functional MRI studies of spatial and nonspatial working memory, Brain Research: Cognitive Brain Research 7 (1998) 1-13.

[5] F. Hamzei, C. Dettmers, M. Rijntjes, V. Glauche, S. Kiebel, B. Weber, C. Weiller, Visuomotor control within a distributed parieto-frontal network, Experimental Brain Research 146(3) (2002) 273-281.

[6] T. Hanakawa, M. Honda, N. Sawamoto, T. Okada, Y. Yonekura, H. Fukuyama, H. Shibasaki, The Role of Rostral Brodmann Area 6 in Mental-operation Tasks: an Integrative Neuroimaging Approach, Cerebral Cortex 12 (2002) 1157 – 1170.

[7] I.H. Jenkins, M. Jahanshahi, M. Jueptner, R.E. Passingham, D.J. Brooks, Self-initiated versus externally triggered movements II. The effect of movement predictability on regional cerebral blood flow, Brain 123 (2000) 1216-1228.

[8] C. Lamm, C. Windischberger, U. Leodolter, E. Moser, H. Bauer, Evidence for Premotor Cortex Activity during Dynamic Visuospatial Imagery from Single-Trial Functional Magnetic Resonance Imaging and Event-Related Slow Cortical Potentials, NeuroImage 14 (2001) 268-283.

[9] H. Leuthold, I. Jentzsch, Neural correlates of advance movement preparation: a dipole source analysis approach, Cognitive Brain Research 12 (2001) 207-224.

[10] S. Van Oostende, P. Van Hecke, S. Sunaert, B. Nuttin, G. Marchal, FMRI Studies of the Supplementary Motor Area and the Premotor Cortex, NeuroImage 6 (1997) 181-190.

[11] R.E. Passingham, Functional Specialization of the Supplementary Motor Area in Monkeys and Humans, Advances in Neurology 70 (1996) 105 – 116.

[12] G. Pellizzer, Mental transformations in motor cortex, Cognitive Brain Research 5 (1996) 123 – 130.

[13] N. Picard, P.L. Strick, Imaging the premotor areas, Current Opinion in Neurobiology 11 (2001) 663 – 672.

[14] M.I. Posner, S.E. Petersen, The attention system of the human brain, Annual Review of Neuroscience 13 (1990) 25-42.

[15] W. Richter, K. Ugubil, A. Georgopoulos, S.-G. Kim, Time-resolved fMRI of mental rotation, NeuroReport 8 (1997) 3697-3702.

[16] W. Richter, R. Somorjai, R. Summers, M. Jarmasz, R.S. Menon, J.S. Gati, A.P. Georgopoulos, C. Tegeler, K. Ugurbil, S.-G. Kim, Motor Area Activity During Mental Rotation Studies by Time-Resolved Single-Trial fMRI, Journal of Cognitive Neuroscience 12(2) (2000) 310-320.

[17] J.B. Rowe, A.M. Owen, I.S. Johnsrude, R.E. Passingham, Imaging the mental components of a planning task, Neuropsychologia 39 (2001) 315-327.

[18] M.F.S. Rushworth, M. Krams, R.E. Passingham, The Attentional Role of the Left Parietal Cortex: The Distinct Lateralization and Localization of Motor Attention in the Human Brain, Journal of Cognitive Psychology 13(5) (2001) 698 – 710.

[19] R.I. Schubotz, D.Y. von Cramon, Dynamic patterns make the premotor cortex interested in objects: influence of stimulus and task revealed by fMRI, Cognitive Brain Research 14 (2002) 357 – 369.

[20] R.N. Shepard, J. Metzler, Mental rotation of three-dimensional objects, Science 171 (1971) 701-703.

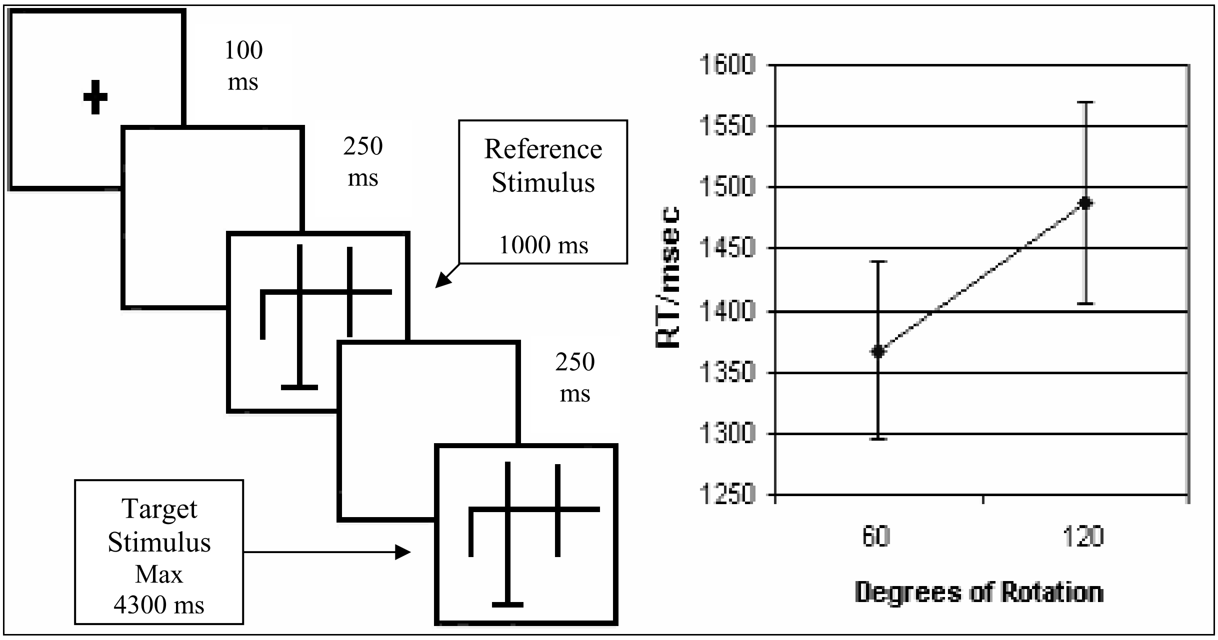
[21] M.J. Tarr, S. Pinker, When does human object recognition use a viewer-centred reference frame? Psychological Science 1 (1990) 253 – 256.

[22] A. Wohlschlager, A. Wohlschlager, Mental & Manual Rotation, Journal of Experimental Psychology: Human Perception and Performance 24(2) (1998) 397 – 412.

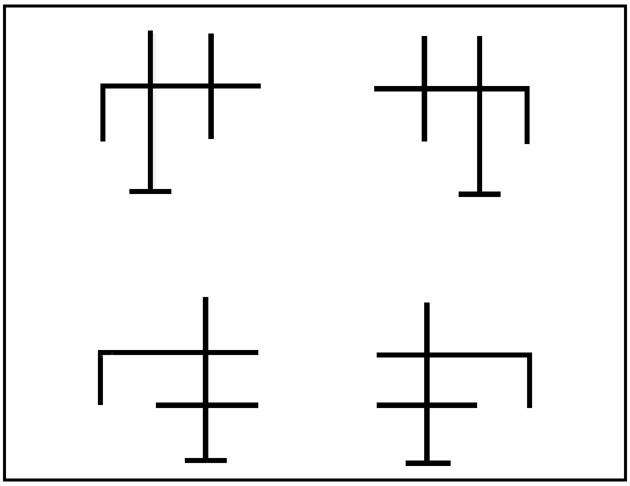
Figure 1: Diagrammatic representation of the procedure for the delayed matching task. A Fixation cross was followed by an inter-stimulus interval (ISI) a reference stimulus, a second ISI and finally the target stimulus. Subjects had to determine whether the target stimulus was a mirror-reflection of the reference stimulus. The mean RT for each condition is shown on the right hand side of the figure. Bars show standard error of the mean.

Figure 2: The two types of stimulus (Tarr & Pinker, 1990) that were used in the matching task. On the left are the 'normal' versions, on the right are the mirror reflections.

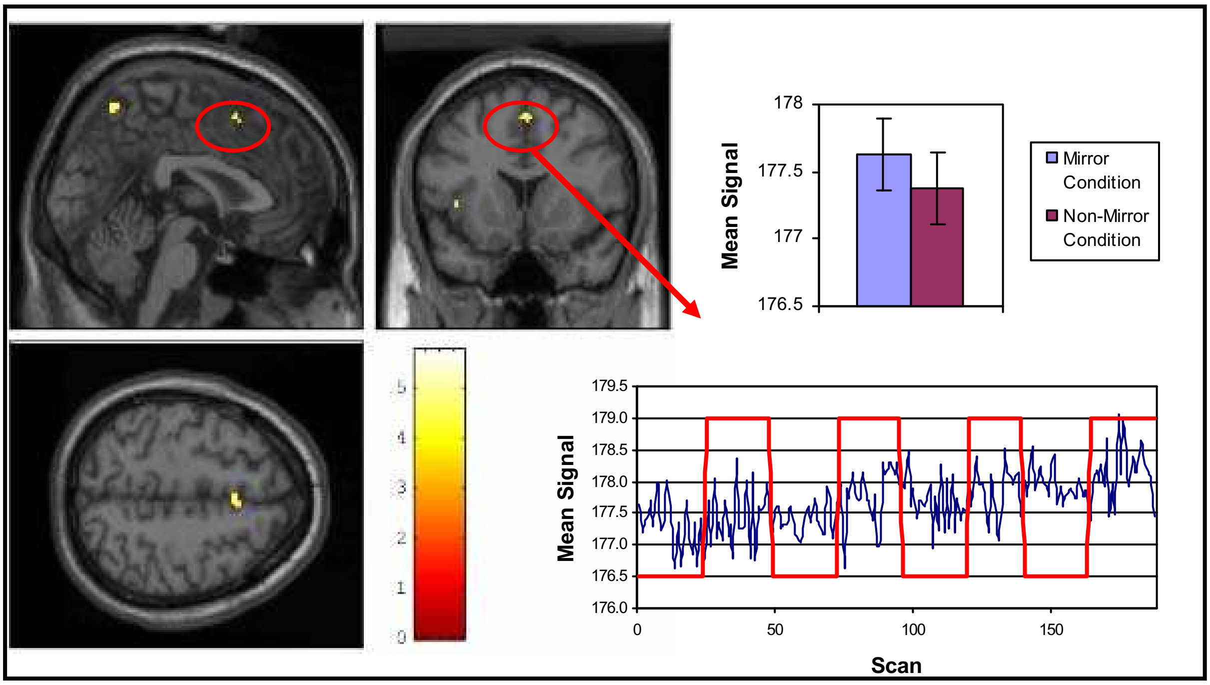
Figure 3: Activations in medial BA6 are shown superimposed on a standardised structural T1 brain image. Estimated signal in each region in each condition is shown in the Bar Chart (Blue: Mirror Condition; Red: Non-Mirror Condition) and the time course of the mean activation level superimposed on the reference box-car function is also shown.



Stephen Johnston Figure 1



Stephen Johnston Figure 2



Stephen Johnston Figure 3