Supplementary content for:

Functional Reorganization of Spatial Transformations After a Parietal Lesion

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Behavioral Task Performance

Response times in the same-different, left-right, and which-side tasks were pre-processed by removing error trials and responses that were (a) faster than 300 ms or (b) slower than three standard deviations from that participant's mean in a given task. (This resulted in elimination of between 5 and 11 responses for each control participant, and 10 responses for the patient.) We then collapsed clockwise and counterclockwise rotations and submitted each participant's mean response time for each combination of task and orientation to a repeated measures analysis of variance (ANOVA). To compare the patient's performance to that of the controls, we calculated the amount that each participant's mean trimmed response time differed from the patient's for each combination of task and orientation, and performed analyses of the same form as for the control participants' raw scores. Statistical analyses of the effects of orientation on performance were conducted only on the left-right and same-different tasks, because they were of primary interest and because the which-side task did not include the full complement of stimulus orientations. All behavioral analyses were performed with an alpha level of .05.

Performance of the control participants in the same-different and left-right tasks was similar to that previously reported for these tasks (1, 2). As can be seen in Figure 2 in the main article, responses in the left-right task were relatively fast and independent of stimulus orientation. For the same-different task, however, response times increased with increasing stimulus orientation. Responses in the which-side task were fast for all orientations tested. This led to statistically significant main effects of task [$F(1, 10) = 18.5$, $p < .001$] and orientation [$F(6, 60) = 12.9$, $p < .001$], and a significant interaction [$F(6. 60) = 13.1$, $p < .001$]. Follow-up analyses showed a significant main effect of orientation on response time for the same-different task [$F(6, 60) = 23.6$, $p < .001$] but not the left-right task [$F(6, 60) = 1.0$, $p = .44$].

As can be seen in Table 1, error rates for the control participants were low across all three tasks. Error rates were analyzed by collapsing over orientations within each task, because the small numbers of errors did not provide suitable error rate distributions for analysis at the single-orientation level. Error rates in the same-different and left-right tasks were not significantly different [$t(10) = 1.48$, $p = 0.17$]. Note that error rates were lowest for the which-side task, which was performed most quickly, and highest for the same-different task, which was performed most slowly. In other words, there was no indication of a speed-accuracy trade-off.

To characterize the patient's pattern of performance, his behavioral data were trimmed as for the control participants and analyzed with an ANOVA using trials, rather than participants, as the repeated measure. Figure 2 in the main article indicates that the patient's performance was qualitatively similar to that of the control participants, responding more slowly in the same-different task, especially as stimulus orientation increased. However, the figure also indicates that the patient's response times increased with orientation in the left-right task as well as in the same-different task, although the pattern was non-monotonic and smaller in magnitude. This led to significant effects of task [$F(1, 326) = 86.2$, $p < .001$] and orientation [$F(6, 326) = 7.22$, $p < .001$], but no significant interaction [$F(6, 326) = 1.39$, $p = .22$]. Follow-up analyses showed that orientation had a statistically significant effect on response time in both the same-different task [$F(6, 145) = 5.53$, $p < .001$] and the left-right task [$F(6, 181) = 3.10$, $p = .007$].

The patient performed the left-right and same-different tasks more slowly than the control participants. The intercept of the difference score ANOVA showed this to be statistically reliable [$F(1, 10) = 36.4$, $p < .001$]. He was particularly slow relative to the control participants in the same-different task [$F(1, 10) = 8.18$, $p = .02$]. There was also a statistically significant effect of orientation [$F(6, 60) = 12.1$, $p < .001$] and a task by orientation interaction [$F(6, 60) = 8.3$ $p < .001$].

The patient made very few errors in the which-side or left-right tasks, but was quite error-prone in the same-different task, a pattern similar to that for the controls but more exaggerated (see Table 1). The intercept of an ANOVA on the difference scores between each participant's error rate and the patient's error rate indicated a reliable overall difference between the patient and the controls [$F(1, 10) = 38.0$, $p < .001$] as well as a reliable effect of task [$F(1, 10) = 76.7$, $p < .001$].

The fact that the patient made a high number of errors in the same-different task and was especially slow relative to the control participants is somewhat puzzling, given that his error rate for this task on the day after his surgery was only 8.3% (2). Inspection of the individual trial data revealed that the patient's 192 trials of the same-different task include one run each of 3, 4, and 5 consecutive errors. These account for almost half of the patient's errors in the task. One possibility is that while performing without feedback in the novel scanner environment, he occasionally lost track of the task instructions or response button mappings, affecting his speed and accuracy. (It should also be kept in mind he performed these tasks overall more slowly and with more errors than the control participants. This could reflect general side-affects of his brain injury, anticonvulsant medication, or biases in selection of the control participants.)

In sum, the patient performed somewhat more slowly than the control participants in both the left-right and same-different tasks, and made more errors in the same-different task.

Functional Activation Details

As predicted, BOLD activity during the spatial reasoning tasks was reduced in the patient in regions overlapping the surgical lesion, and increased in regions contralateral to the lesion, compared to controls (Table 2). The patient also showed significantly greater brain activity than controls during spatial reasoning in the cerebellum, bilateral thalamus, midbrain, and right superior frontal cortex (Table 3). Throughout regions that decreased during spatial reasoning in controls, the patient showed smaller decreases in activity (Table 4).

References

1. Zacks JM, Mires J, Tversky B, Hazeltine E. Mental spatial transformations of objects and perspective. Spatial Cognition & Computation 2002;2(4):315-322.

2. Zacks JM, Gilliam F, Ojemann JG. Selective disturbance of mental rotation by cortical stimulation. Neuropsychologia 2003;41:1659-1667.

Tables

Table 1. Mean error rates for control participants and the patient for the three spatial reasoning tasks.

Task	Control Error Rate	Patient's Error Rate
Which-Side	0.6% (SD = 1.2%, range 0.0%-4.2%)	0.0%
Left-Right	2.8% (SD = 2.2%, range 0.52%-8.33%)	1.0%
Same-Different	5.1% (SD = 4.7%, range 0.52%-15.6%)	17.7%*

* Patient differed from controls, $p < .05$.

Table 2. Functional activity in regions overlapping and contralateral to the patient's parietal lesion.

	Location of Peak				Signal Changes in Control Participants			Patient Difference from Control Participants		
	x	y	z	Description	Which-Side	Left-Right	Same-Different	Which-Side	Left-Right	Same-Different
Regions Overlapping Lesion										
A	26	-61	44	R. intraparietal sulcus (BA 7/40)	+	+	+		<	<
B	39	-36	40	R. inf. parietal lobule (BA 19)	+	+	+		<	<
Regions Contralateral To Lesion										
C	-33	-54	44	L. intraparietal sulcus (BA 7/40)	+	+	+	>		
D	-12	-71	44	L. intraparietal sulcus (BA 7)		+	+	>	>	>

NOTE: The labels "A," "B," "C," and "D" refer to Figure 3 in the main text. For comparisons of the regions overlapping and contralateral to the lesion, an alpha level of .05 was used.

"+" denotes significant BOLD increases, relative to fixation.

">" denotes BOLD activity was significantly higher in the patient than in the controls.

"<" denotes BOLD activity was significantly lower in the patient than in the controls.

Table 3. Other regions for with activity increased in control participants during spatial reasoning tasks.

Location of Peak				Signal Changes in Control Participants			Patient Difference from Control Participants		
x	y	z	Description	Which-Side	Left-Right	Same-Different	Which-Side	Left-Right	Same-Different
Patient showed larger increases than controls									
13	-72	-38	R. cerebellum		+	+	>	>	
-22	-53	-34	L. cerebellum	+	+	+	>	>	
1	-38	-30	midbrain	+	+	+	>	>	>
0	-77	-16	medial cerebellum	+	+	+	>	>	>
-17	-25	5	L. thalamus	+	+	+	>	>	
16	-25	5	R. thalamus	+	+	+	>	>	>
14	-6	50	R. med. frontal gyrus, middle frontal gyrus (BA 6)		+	+	>		
Patient showed smaller increases than controls									
26	-84	7	R. lateral occipital sulcus (BA 18/19)	+	+	+		<	<
-28	-82	11	L. lateral occipital sulcus (BA 18/19)	+	+	+			<
Patient and controls did not differ significantly									
-35	-72	-14	L. fusiform/inf. temporal gyrus (BA 18/37)	+	+	+			
35	-62	-13	R. fusiform gyrus (BA 18/19/37)	+	+	+			
29	7	18	R. sylvian fissure		+	+			
-33	-11	46	L. med. frontal gyrus, middle frontal gyrus (BA 6)	+	+	+			

NOTE: Correction for simultaneous testing of all 28 regions was performed using the Bonferroni method, overall $p < .05$..

“+” denotes significant BOLD increases, relative to fixation.

“>” denotes BOLD activity was significantly higher in the patient than in the controls.

“<” denotes BOLD activity was significantly lower in the patient than in the controls.

Table 4. Regions for which activity decreased in control participants during spatial reasoning tasks.

			Location of Peak	Signal Changes in Control Participants			Patient Difference from Control Participants		
x	y	z	Description	Which-Side	Left-Right	Same-Different	Which-Side	Left-Right	Same-Different
Patient showed smaller decreases than controls									
-23	-20	-17	L. hippocampus/parahippocampal gyrus		-	-	>	>	
43	-2	-12	R. temporal pole		-	-		>	>
-49	-23	-5	L. sylvian fissure		-	-	>	>	>
-3	24	-3	Ant. Cingulate gyrus (BA 24/32)		-	-		>	>
-21	-48	-1	L. hippocampus/parahippocampal gyrus	-	-	-			>
25	-45	0	R. hippocampus/parahippocampal gyrus	-	-	-	>	>	>
42	-25	6	R. sylvian fissure	-	-	-	>	>	>
-2	50	22	Med. frontal gyrus (BA 9/10)		-	-		>	>
-25	17	43	Sup. frontal sulcus (BA 8)	-	-	-		>	
Patient and controls did not differ significantly									
-8	-49	29	Post. cingulate gyrus (BA 23/31)	-	-	-			
-41	-73	35	L. intraparietal sulcus (BA 19/39)			-			
42	-74	35	R. intraparietal sulcus (BA 39)		-	-			

NOTE: Correction for simultaneous testing of all 28 regions was performed using the Bonferroni method, overall $p < .05$..

"-" denotes significant BOLD decreases, relative to fixation.

">" denotes BOLD activity was significantly higher in the patient than in the controls.