Mapping the Functional Anatomy of Task Preparation: Priming Task-Appropriate Brain Networks

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Abstract: The present study used functional magnetic resonance imaging (fMRI) and a cued version of a flanker paradigm to elucidate the effects of task preparation on subsequent brain activation patterns. A mixed block and event-related design was employed to examine activations associated with the cue periods themselves and the cued and un-cued correct responses to incongruent flankers. A number of areas were active during the cues, most notably left dorsolateral prefrontal cortex (DLPFC), which was interpreted as subserving a role in task-set maintenance. Widespread activity was noted for correct responses to incongruent flankers, including bilateral parietal and frontal regions, consistent with previous studies. Activation was increased in these regions for correct responses after cue periods. An overlapping network of regions was also noted for cues and correct responses, suggesting preparation of task-appropriate anatomical regions during the cue period. These results suggest that cue periods allow participants to prime task-relevant areas within the brain and highlight the importance of left DLPFC in top-down control. *Hum Brain Mapp* 27:819–827, 2006. © 2006 Wiley-Liss, Inc.

Key words: fMRI; behavior; cognition; top-down control; flanker

INTRODUCTION

Control over behavior is facilitated by a number of separate yet interacting cognitive functions [Fassbender et al., 2004; Garavan et al., 2002]. Processing and integration of bottom-up sensory information, inhibition of inappropriate task sets and distracting stimuli, detecting situations under which an error in performance may be likely, and the subsequent adjustment of levels of available attentional resources or top-down control are all thought to interact in the facilitation of everyday behavior. One paradigm that has often been used to investigate these processes is the flanker task in which typically irrelevant peripheral stimuli interfere with task-relevant stimuli presented centrally. Eriksen and Eriksen [1974] first introduced this task in its letter form but subsequent studies have used modified versions of this to

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increase interference effects [Botvinick et al., 1999; Casey et al., 2000; Fan et al., 2003; Ullsperger and von Cramon, 2001].

The flanker task has been used in a number of studies to examine response conflict. Flanking stimuli in the incongruent condition cause interference in that they trigger an inappropriate motor response. This is co-activated with the correct response triggered by the central stimulus. Co-activation of competing motor responses is thought to result in response conflict. Accordingly, flanker tasks often produce activity in dorsolateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC), a network that has been implicated in the detection and resolution of response conflict and the enforcement of top-down attentional control [Badre and Wagner, 2004; Botvinick et al., 2001; MacDonald et al., 2000]. Increased amounts of top-down control are thought to decrease levels of response conflict, as activation of the appropriate response channel is thought to be increased due to more efficient allocation of attentional resources [Botvinick et al., 2001]. For example, MacDonald et al. [2000], using the Stroop paradigm to examine response conflict, noted activation in DLPFC and ACC during incongruent trials. They also noted that increased levels of activation in left DLPFC were associated with reduced levels of conflict as indexed by behavioral reaction times.⁶

Left lateral PFC has been implicated in cognitive control in a number of additional studies. Recently [Fassbender et al., 2004], we found a correlation between left PFC and a mid-line region, the pre-supplementary motor area (pre-SMA), during situations of increased conflict (commission errors in a GO/NOGO task). Additionally, participants with larger amounts of top-down control as indexed by greater amounts of activation in left PFC showed less conflict-related activity as detected by pre-SMA. Evidence exists that the pre-SMA, along with or perhaps rather than the ACC, may be an important medial structure for monitoring response conflict [Braver et al., 2001; Garavan et al., 2003; Hazeltine et al., 2000; Rushworth et al., 2004; Ullsperger and von Cramon, 2001, 2003]. Ullsperger and von Cramon [2001], for instance, used fMRI and ERPs to illustrate that while error detection appeared to be the domain of the ACC, response competition, or conflicts, was accompanied by activation of the pre-SMA and medial Brodmann area 8. Brass and von Cramon [2002] also found left lateral PFC and pre-SMA to be particularly important in task preparation. They suggested that lateral PFC was involved in the "selection of cue-related task rules," whereas pre-SMA implemented "these rules on a higher-order level of motor control" (p. 913). They also suggested that cue-related activation in their study reflected the preparation of task-related areas. Garavan et al. [2002] interpreted left DLPFC as being involved in task-set maintenance as they found evidence for this region's involvement in behavioral adjustment that immediately followed errors. Finally, in another GO/NOGO study from our lab [Hester et al., 2004a], activation in DLPFC and in dorsal ACC/pre-SMA was seen during task preparation. Activation during a cue period before a correct withhold produced activity in similar regions to those required for the response withhold

itself, a pattern that was interpreted as reflecting preparation of task-relevant areas in anticipation of the response [Hester et al., 2004a].

In the present study we sought to examine preparatory activation and top-down attentional control using a simple cued and un-cued version of the Eriksen flanker task [Eriksen and Eriksen, 1974]. In our previous work, left DLPFC was observed to be particularly important in the allocation of top-down attention or task set maintenance [Fassbender et al., 2004; Garavan et al., 2002]. With a particular focus on left DLPFC, we therefore wished to examine the cortical mechanisms in which top-down control is implemented during task preparation.

PATIENTS AND METHODS

Subjects

Subjects included 9 men and 8 women (age range, 18–39 years; mean age, 28.1 years). Two female subjects subsequently were excluded from the analyses due to excessive movement (new mean, age 27.3 years). All participants were right-handed, were free of neurological disorder, psychiatric problems, or head trauma, and were not under any medication. All subjects provided written, informed consent, and were paid for their participation. The Institutional Review Board of the Nathan Kline Institute, where the imaging was conducted, approved all procedures.

Task

Stimuli consisted of 5 letters, the central letter being the one to which subjects were required to respond. Half of the subjects were required to respond with a right button press to the letter S and a left button press to the letter C. The remaining half used the reverse stimulus-response mapping. Congruent stimuli were SSSSS and CCCCC and incongruent stimuli were SSCSS and CCSCC. All stimuli were presented at a frequency of 1 Hz, with the stimuli being on screen for 500 msec followed by a 500 msec mask (#####), which was immediately followed by the next stimulus. The paradigm consisted of 12 blocks of, on average, 212 stimuli per block. In 6 blocks, participants were cued to expect an incongruent stimulus. Cues were from 4 to 10 sec in duration (varying in 2-second increments) and consisted of the stimuli and mask changing font color from white to green. Subjects were instructed to continue responding as normal to all trials during the cue periods. To make the onset of an incongruent stimulus completely predictable to allow for maximal contrast with the un-cued condition, the trial immediately preceding presentation of the incongruent trial changed to pink font (Fig. 1). Participants were told before each block whether it would be a cued or an un-cued block and were instructed to respond as quickly as possible while performing as accurately as possible. Participants were given 4 training blocks (2 cued and 2 un-cued) before they entered the scanner. Stimuli were presented and responses recorded using *E-prime* (Psychology Software Tools, Inc., Pittsburgh, PA).

Figure 1.

Sample trials taken from a portion of the cued condition of the flanker paradigm. All trials were presented at a rate of 1 Hz; each trial consisted of a 500-msec stimulus followed by a 500-msec mask. The cue period consisted of the font color of the stimulus and subsequent mask changing from white to green. The stimulus and mask just before a target changed from green to pink. The entire cue period therefore, lasted from 4 to 10 seconds, varying in 2-second intervals.

Incongruent stimuli were separated from each other by at least 20-second periods to allow the hemodynamic response to decay after each event. Incongruent stimuli consisted of 20 cued and 32 un-cued events. Of the 32 un-cued incongruents, 12 were considered “catch” events that fell close together to ensure that participants did not simply “switch off” and allow their attention to wane in between the spaced incongruent trials. These 12 events subsequently were excluded from further analysis (and were censored from the time-series analysis). Each block was preceded by a 5-second fixation followed by 5-second screen displaying information as to whether or not there would be cues in that particular run, and ended with a 10-second fixation cross.

Functional Magnetic Resonance Imaging Scanning

Scanning was carried out on a 1.5-T Siemens (Erlangen, Germany) scanner in which foam padding was used to restrict head movements. We acquired 202 T1-weighted sagittal slices for each subject (slice thickness = 1 mm, field of view = 256 mm). Functional images were single-shot, T2* weighted, echo-planar imaging sequences. For each subject, 22 axial slices (5-mm slice thickness) were acquired (repetition time [TR] = 2,000 msec; echo time [TE] = 50 msec, flip angle = 90 degrees, 64 mm × 64 mm matrix size, field of view = 256 mm) and 667 and 722 volumes were acquired in the cued and un-cued conditions respectively. Stimuli were presented through an LCD screen, which was mounted on the head coil and was directly in the subjects’ line of vision.

Image Analysis

Data were analyzed using AFNI software [Cox, 1996; <http://afni.nimh.nih.gov/afni>]. Images were time-shifted using Fourier interpolation to correct for differences in slice acquisition time, edge-detected by creating a mask of activation within the brain and then setting any activation outside this mask to zero and 3D motion corrected. Individual subjects that displayed excessive motion were excluded from further analyses, as were the first three images in each run. An event-related analysis was employed whereby separate impulse response functions (IRF) were calculated for correct responses to cued incongruent stimuli, correct responses to un-cued incongruent stimuli, errors to cued incongruent stimuli, errors to un-cued incongruent stimuli, errors to congruent stimuli in the cued blocks, and errors to congruent stimuli in the un-cued blocks. A non-linear regression program determined the best-fitting γ -variate function for these IRFs [Cohen, 1997; Ward et al., 1998]. The area under the curve of this γ -variate function was expressed as a percentage of the area under the baseline (baseline reflects tonic activation level, having first removed variance associated with event-related activation). Cue periods themselves were analyzed in a block-design manner, whereby mini-blocks (ranging from 4 to 10 seconds) were calculated as a percentage change score, again against baseline. Cue periods before correct responses to incongruent stimuli and cue periods before errors on incongruent stimuli were calculated separately. Comparable periods were also analyzed in the no-cue condition. These were periods of the same length as the cue periods in the cued condition, before correct and incorrect incongruent targets in the un-cued condition. The percentage area (event-related activation) and percentage change maps (cue block activation) were then warped into standard Talairach space [Talairach and Tournoux, 1988] and spatially blurred using a 3-mm isotropic RMS Gaussian blur.

Separate t tests against the null hypothesis of no percentage activation change were then carried out for block and event-related activations with a voxel-wise threshold of $P \leq 0.0001$ and a cluster-size criterion of 57 μL of contiguous significant voxels. These thresholds, determined by Monte Carlo simulations, resulted in a corrected 0.05 probability of a significant cluster surviving by chance. Activation maps for cue periods before correct and incorrect responses to incongruent stimuli were then combined into OR maps so that a voxel was included if it was significant in either map, and mean activation was then calculated for each of the resulting functionally defined regions of interest (ROIs). As the comparable periods in the un-cued block did not show any activation at this threshold they were not included in the OR map. A similar procedure was undertaken for the cued and un-cued correct responses, which resulted in one correct response OR map. Although both errors to incongruent and congruent stimuli were included in the deconvolution analysis to control for the variance associated with these events, they were excluded from further analysis as there were very few such events. Differences between the conditions in mean

TABLE I. Cue-Related Activations

Brain region	Brodmann area	Hemisphere	Volume (μL)	Talairach coordinates (center of mass)			P $t(14)$
				x (RL)	y (AP)	z (IS)	
Frontal lobes							
MFG	9	L	419	-53	13	28	<0.001
	9	L	111	-39	11	23	<0.01
	9	R	223	35	19	29	<0.001
	9	R	208	39	6	35	<0.001
	6	R	156	23	-6	55	<0.01
PRCG	6	L	239	-41	1	37	<0.001
Parietal lobes							
IPL	40	R	1,617	31	-53	46	<0.0001
IPL	40	L	280	-34	-52	49	<0.0001
	40	L	138	-48	-40	44	<0.001
SPL/precuneus	7	L	409	-22	-60	42	<0.001
Temporal lobes							
PHG	19	R	481	29	-47	-6	<0.01
Additional regions							
Cingulate gyrus	32	R	169	8	22	29	<0.01
		R	127	11	-16	27	<0.04
Insula		L	101	-31	19	8	
Insula/claustrum		R	302	30	21	3	

Statistical tests refer to pair-wise t test comparisons between cue periods prior to a correct response and comparable periods in the un-cued condition prior to a correct response. MFG, middle frontal gyrus; PRCG, precentral gyrus; IPL, inferior parietal lobe; SPL, superior parietal lobe; PHG, parahippocampal gyrus.

activation for these ROIs (i.e., activation was averaged over the voxels within an ROI) were then tested with paired t -tests. These t tests were carried out at an α level of 0.04 when corrected for multiple comparisons using a modified Bonferroni correction [Keppel, 1991]. To examine whether cues activated task-relevant areas, a combined cue and correct response map was also created and areas of spatial overlap between these two maps identified.

RESULTS

Performance Results

Responses to incongruent trials (including cued incongruent trials) were significantly slower than were responses to congruent trials (520.1 vs. 471.8 msec, respectively; $t[15] = 3.9$; $P \leq 0.002$) suggesting that incongruent trials did engender response conflict. Responses to incongruent trials were also significantly slower in the cued over the un-cued condition (540.3 vs. 498.5 msec; $t_4 [14] = 2.3$; $P \leq 0.04$). The cue was successful in improving performance; there were significantly more successful responses in the cued compared to the un-cued condition (86.7% vs. 76.4% respectively; $t[14] = 2.7$; $P \leq 0.02$) and response times to congruent stimuli in the cued condition were significantly slower than response times in the un-cued condition although the effect was quite small (476 vs. 468 msec, respectively; $t[14] = 4.6$; $P \leq 0.001$). There was no significant difference in mean reaction times in errors on incongruent trials or in omission errors in the cued and un-cued conditions (407.6 vs. 396.6 msec, $t[14] = 1.3$, $P \leq 0.2$, and 46 vs. 52, $t[14] = -1.5$, $P \leq 0.2$, respectively).

Although there was no significant difference in reaction time between the cue period preceding a correct response to a target and the cue period preceding an incorrect response to a target (504.8 vs. 503.7 msec, respectively; $t[14] = 0.2$, $P \leq 0.9$) the average reaction time during the cue period preceding a correct target in the cued condition was significantly slower than was a comparable period before a correct response in the un-cued condition (504.8 vs. 467.2 msec, respectively; $t[14] = 6.2$, $P \leq 0.0001$). A number of subjects did not make any errors in either the cued or un-cued condition. For this reason, there are different degrees of freedom between these reported t tests.

Cue-Related Activation

Three regions were active for cue periods before correct and incorrect responses to incongruent targets. These were right inferior parietal lobe (IPL), right hippocampal gyrus, and left DLPFC (Table I; Fig. 2). Activation in these regions was significantly greater for the cue period before a correct response than for the comparable period in the un-cued condition (see Table I for levels of significance).

We were interested to examine if any additional areas were active during the cue periods so we lowered the threshold to a less conservative voxel-wise threshold of $P \leq 0.005$ at a cluster size criterion of 100 μL , again resulting in a 0.05 probability of any voxel surviving by chance. This analysis was carried out for the cue period only. At this threshold we saw 12 extra clusters (see Table I) including a number of additional left frontal regions, left IPL, two areas in cingulate gyrus and bilateral insula. One region, left

Figure 2.

Activations during correct responses to incongruent flankers and cue periods. Cue activations represent regions of interest derived from the more liberal voxel-wise threshold used in the analysis of cue periods. Areas activated during cue periods (shown in red) included bilateral inferior parietal lobe (IPL), right insula, two regions in cingulate cortex, and a number of regions in left dorsolateral prefrontal cortex (DLPFC). Areas activated during correct responses to incongruent flankers (shown in green) included bilateral IPL, left motor cortex, left insula, medial PFC, precuneus, a number of areas in right DLPFC and a region in pre-supplementary motor area (SMA). Most of these areas were significantly more active when preceded by a cue period. Areas that were significantly active during both cues and correct responses are shown in yellow. These include bilateral DLPFC, right insula and right IPL. **A:** Coronal views showing bilateral DLPFC, left IPL/superior parietal lobe (SPL), bilateral insula, and a number of areas in the midline, including cingulate gyrus. **B:** Sagittal views of left and right hemisphere activations including bilateral parietal and dorsolateral prefrontal activations as well as the two regions in the cingulate gyrus.

DLPFC (Brodmann area [BA] 9, Talairach coordinates, $x = -39$, $y = 11$, $z = 23$), showed significantly greater activation for the cued period before a correct response than before an incorrect response ($t[14] = 2.41$; $P \leq 0.03$). This analysis may not be reliable, however, as there were very few errors to targets in the cued condition, hence few pre-

ceding cue periods to examine. All regions showed greater activation for the cue period before a correct response than for the comparable cue period in the un-cued condition (see Table I for levels of significance) except the left and right insula, both of which showed a trend in this direction ($t[14] = 2.06$, $P \leq 0.06$, and $t[14] = 1.94$, $P \leq 0.07$, respectively).

Activation During Correct Responses to Incongruent Trials

Widespread activity was observed for correct responses to targets in the cued and un-cued conditions. These included bilateral IPL, middle frontal gyrus (MFG), right superior frontal gyrus (SFG), left postcentral gyrus, bilateral insula, middle temporal gyrus, right supramarginal gyrus, and two areas along the medial wall (Table II; Fig. 2). Most of these regions were more active for cued over un-cued correct responses (see Table II for levels of significance and Fig. 3 for graphs of the average time series over subjects). These regions included bilateral IPL, MFG, precuneus, an area of middle frontal gyrus extending into pre-SMA, right SFG, parahippocampal gyrus, left postcentral gyrus, fusiform gyrus, and middle temporal gyrus. Only one region, left insula, showed the opposite pattern, being significantly more active for un-cued correct responses to targets ($t[14] = -2.8$; $P \leq 0.01$).

Overlap Between Correct Response and Cue-Related Activation Maps

To examine whether overlapping regions were activated for cue and correct response maps, the two maps were added together and substantial numbers of overlapping and adjacent activations were identified (Fig. 2). These included bilateral DLPFC, right insula, and right IPL.

DISCUSSION

In this task, cues succeeded both in slowing reaction times and significantly improving participants' performance on incongruent flanker trials. A number of areas were seen to be active during the cue periods and this activation may represent preparation for the upcoming response. This preparation produced greater event-related activity in the following correct responses to incongruent flankers than when there was no opportunity to prepare for an upcoming incongruent trial (in the un-cued condition). A degree of overlap between cue and correct response maps suggests that cues activated task-appropriate regions. Left DLPFC seemed particularly important in preparation of an impending response, as activation was predominant here during the cue period and the (admittedly, underpowered) comparison of cue-periods that preceded correct responses to those cue-periods that preceded incorrect responses suggested that activity levels in this area may have been predictive of a subsequent correct response.

TABLE II. Event-related Activations: Cued and Un-cued Correct Responses to Incongruent Stimuli

Brain region	Brodmann area	Hemisphere	Volume (μ L)	Talairach coordinates (centre of mass)			<i>t</i> (14)
				<i>x</i> (RL)	<i>y</i> (AP)	<i>z</i> (IS)	
Frontal lobes							
MFG	9/6	R	2,250	29	7	44	<0.001
	9/6	L	1,476	-46	5	33	<0.04
	9	R	180	48	14	37	<0.01
	9	R	87	-48	21	32	<0.04
	9	R	80	49	20	23	
	9	L	345	-40	30	27	<0.001
	9	L	103	-32	-3	57	<0.04
	6	R	629	41	32	21	<0.01
IFG	46	L	68	-40	44	18	<0.01
SFG	10	R	62	24	51	9	<0.01
Medial wall	8/6	R	172	2	20	43	<0.04
	8	L	148	-3	29	40	
Parietal lobes							
POCG	40	L	205	-45	-28	45	<0.0001
IPL	40	R	4,671	34	-53	44	<0.001
	40	L	57	-35	-41	53	
IPL/SPL	40/7	L	4,489	-36	-56	42	<0.0001
SPL		R	101	21	-60	55	
SG	40	R	82	50	-40	31	
Precuneus	7	R	101	9	-60	52	<0.04
	7	R	85	22	-68	37	<0.01
	7	L	393	-10	-62	47	<0.04
	7	B	58	-2	-56	42	<0.04
Temporal lobes							
PHG	37	R	869	29	-45	-7	<0.0001
FG	37	L	240	-35	-50	-6	<0.001
MTG	37	L	648	-46	-55	0	<0.0001
Additional regions							
Insula		R	150	45	8	16	
		L	150	-34	11	12	
Insula/claustum		R	615	28	17	4	
		L	229	-27	21	3	<0.04
Caudate		R	165	10	9	9	
Red nucleus		B	67	-1	-17	-4	

Statistical tests refer to pair-wise *t* test comparisons between correct responses following cues and correct responses in the un-cued condition. MFG, middle frontal gyrus; IPL, inferior parietal lobe; SPL, superior parietal lobe; PHG, parahippocampal gyrus. IFG, inferior frontal gyrus; SFG, superior frontal gyrus; POCG, postcentral gyrus; SG, supramarginal gyrus; FG, fusiform gyrus; MTG, middle temporal gyrus.

Correct Responses to Incongruent Stimuli

A diffuse pattern of activation was seen for correct responses to incongruent flankers in this task. Activity in bilateral DLPFC [Hazeltine et al., 2003; Van Veen et al., 2001], right post-central gyrus [Hazeltine et al., 2003], right [Van Veen et al., 2001] and left [Hazeltine et al., 2003] IPL, and left precuneus [Van Veen et al., 2001] has been observed previously in similar flanker paradigms. Activation in right inferior frontal cortex [Hazeltine et al., 2000, 2003], left parietal cortex, SMA, and superior parietal cortex [Hazeltine et al., 2000] has been noted during a color flanker task. In addition, overlapping regions in right inferior frontal/middle frontal, superior frontal cortex and ACC have been noted for both color- and letter-style flanker paradigms [Hazeltine et al., 2003]. ACC, bilateral frontal, temporal and right inferior parietal lobe have also been found to be active in arrow flanker tasks [Fan et al., 2003; Ullsperger and von Cramon,

2001]. Aside from activity in ACC, these results fit with the broad pattern of activity witnessed in this task during incongruent flankers.

Previous research has attempted to explain the separate roles that these different anatomic regions may play in the performance of a flanker task. For example, Casey et al. [2000] used different combinations of trial types to dissociate separate networks of regions that were involved in the completion of their arrow flanker paradigm. ACC and DLPFC were associated with the resolution of conflict. A right hemisphere superior frontal, superior parietal, and cerebellar network was activated during persistent interference and was associated with selective attention. The basal ganglia and insula were associated in turn with violations in the expectancy or probability of events. Decreases in activation were seen in IPL and auditory cortex, which was interpreted as reflecting suppression of activity in "unnecessary" corti-

Figure 3.

Time series graphs for cued (diamonds) and un-cued (triangles) correct responses. Graphs represent an average over all subjects and all voxels within each region of interest. Regions of interest displayed are those that represent regions that overlapped between the cue and correct response activation maps. These regions were all significantly more active for cued correct responses (Table II).

cal networks [Casey et al., 2000]. Aside from the deactivation in inferior parietal lobe, these results are consistent with those found in the present study.

Although slowed reaction times to incongruent stimuli suggested that participants did experience response conflict, activation in ACC was not observed in this task. We did, however, see activation in medial frontal gyrus in BA 8, extending into pre-SMA. As noted earlier, several authors have found activation in pre-SMA during response conflict [Hazeltine et al., 2000; Garavan et al., 2003; Ullsperger and von Cramon, 2001, 2003]. In fact, evidence for a dissociation along the midline for conflict- and error-related processes has been found in a number of different fMRI studies [Kiehl et al., 2000; Garavan et al., 2003; Menon et al., 2001; Ullsperger and von Cramon, 2001]. In a previous review of several studies that attempted to dissociate error- and conflict-related activity in midline areas, we have shown that conflict-related activity tends to be associated with more dorsal regions of ACC extending into pre-SMA [Hester et al., 2004b]. In line with this theory, we did not observe any significant activation in ACC for correct responses to incongruent stimuli. Unfortunately, there were insufficient errors in this task to examine error-related processes. The interpretation that pre-SMA activity reflects response conflict is also consistent with the conclusions drawn in a recent article reviewing animal and human lesion, single-cell recording, and imaging literature on medial frontal cortex involvement in action-related decision making and motor learning [Rushworth et al., 2004].

Neuroanatomy of Task Preparation

A number of regions, in particular left DLPFC, were active during the cue period. A similar region in left PFC extending into DLPFC has been linked previously to task-preparation

in a verbal working memory task [Sakai and Passingham, 2003]. DLPFC has been implicated in cognitive control in several studies [Botvinick et al., 2001; Carter et al., 2000; Ullsperger et al., 2002]. Left DLPFC in particular has been implicated in control processes [Hazeltine et al., 2000; MacDonald et al., 2000]. MacDonald et al. [2000] found that increased levels of top-down control as exercised by left DLPFC resulted in a reduction in Stroop interference. This area has been associated with the maintenance of task representations [Frith and Dolan, 1996; MacDonald et al., 2000; Ruchow et al., 2002]. It has also been linked to behavioral correction [Garavan et al., 2002; MacDonald et al., 2000; Rueckert and Grafman, 1996]. In fact, in the present study there was evidence that activation in an area of DLPFC was associated with subsequent correct performance. This is supportive of the notion that this region is involved in the top-down allocation of attentional resources or the storage of task goals and rules. A stronger representation of these rules should facilitate appropriate responding. In fact, these two notions may be interdependent; knowing how and when to exercise top-down control may be dependent upon stored task goals.

Right IPL was another region active during the cue period and was also active during correct responses. Right parietal lobe has been seen to be active in many studies across a variety of different tasks. Activation in this region has been noted in tasks of inhibition [Bunge et al., 2001; Garavan et al., 1999; Menon et al., 2001], working memory [D'Esposito et al., 1998], and sustained attention [Coull et al., 1998, 1999; Manly et al., 2003] or arousal [Kinomura et al., 1996; Sturm et al., 1999; Sturm and Willmes, 2001]. Culham and Kanwisher [2001] suggest a number of reasons why parietal cortex is active in such a wide range of seemingly diverse cognitive tasks, including that parietal cortex may simply be

an “association cortex” in which separate functions come together. This has been suggested due to the parietal lobes’ activation during multifaceted and multimodal responses. Alternatively, it may be that the parietal lobes perform a very general attentional function [Culham and Kanwisher, 2001], which ensures its activation across a wide range of paradigms. Similarly, it has also been suggested that right parietal cortex may be involved in some “fundamental low-level attentional process ...that acts as a lowest common denominator for many types of cognitive processes” [Coull and Frith, 1998]. In a recent study, Hester et al. [2004c] suggested that parietal lobes play a role in the storage of stimulus-response representations, which in their task was necessary for response inhibition. Its activation during the cue periods in the present task thus may reflect an increased attention to the task or the activation of the task’s stimulus-response representations. Although quite speculative, the latter interpretation may cohere with the hippocampal activity also seen during the cue period insofar as the hippocampus activity may also reflect mnemonic processes associated with retrieving the task rules or stimulus-response representations. Activity in the hippocampus, however, has also been linked to the detection of novel or oddball events [Lisman and Otmakhova, 2001; Strange and Dolan, 2001]. It may be that activity in this region is a reaction to the infrequent color changes associated with the onset of cue periods.

Other activated regions were noted at a lower threshold. It has been suggested that areas activated during a cue period reflect preparation of relevant areas needed to perform that particular task [Brass and von Cramon, 2002]. Hester et al. [2004a] also found that cues activated regions that were required subsequently for successful inhibitions in a GO/NOGO task. In the present results, we also noted a similar activation pattern between cues and subsequent correct responses to targets (Fig. 2). It may be that task-relevant areas are being prepared during the cue period. Consistent with this, activation was noted in left premotor and motor areas during the cue period, which may reflect motor preparation for the upcoming response (responses were always made with the right hand, albeit with different fingers of the right hand). In recent work, Wylie et al. [2005] demonstrate cue-related activation of task-relevant neural circuitry in a task-switching paradigm. They argue that this type of preparation may reflect biased competition insofar as competition may exist between competing pathways that have been associated with a particular stimulus in a given context. The pathway that eventually dominates at a given time-point is the one biased by the currently relevant goal [Wylie et al., 2005], which is consistent with the present interpretation of the role of the left PFC in task preparation.

The opportunity to prepare for an upcoming incongruent event also resulted in increased amounts of activation during the subsequent response. This lends further support to the notion that the cue allows participants to prepare areas needed for the task. The only area that was more active during un-cued correct responses to incongruents was left

insula. One speculation is that this activation may reflect an arousal response to an unexpected incongruent event.

Conclusions

A broad network of cortical areas, largely consistent with previous studies, was active during correct responses to incongruent flankers in this task. A number of similar cortical regions were also active during the cues themselves. This may reflect priming of cortical areas in preparation for the upcoming response. Left DLPFC activation was noted particularly during the cue period and during correct responses to incongruent targets themselves. Consequently, this area may be involved in exercising top-down control under situations in which there is a need for additional attentional resources.

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