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Evaluating Self-Generated Information: Anterior Prefrontal Contributions to Human Cognition

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The anterior or rostrolateral prefrontal cortex (RLPFC) is frequently recruited during complex cognitive tasks across a wide range of domains, including reasoning, long-term memory retrieval, and working memory. The authors report an event-related functional MRI study, indicating that the RLPFC is specifically involved in the evaluation of internally generated information—or information that cannot be readily perceived from the external environment but has to be inferred or self-generated. The findings are consistent with a hierarchical model of lateral prefrontal organization, with RLPFC contributing only at the highest orders of cognitive transformations. This characterization of RLPFC function may help explain seemingly disparate findings across multiple cognitive domains and could provide a unified account of this region's contribution to human cognition.

More than a century of patient studies has indicated that the lateral prefrontal cortex is closely linked to some of the highest cognitive abilities in humans. Thus, lesions to lateral prefrontal cortex are known to impair thinking, planning, and problem solving (Duncan, Burgess, & Emslie, 1995; Luria, 1966; Mesulam, 1985; Milner, 1964; Shallice, 1982; Stuss & Benson, 1986). Although a number of distinctions have been made between processes mediated by the lateral prefrontal cortex and those mediated by the medial and orbitofrontal subdivisions (e.g., Cummings, 1993; Mesulam, 1985; Stuss & Benson, 1986; Wise, Murray, & Gerfen, 1996), systematic analysis of the contribution of different lateral prefrontal subregions began only relatively recently, first through research in nonhuman primates (Goldman-Rakic, 1995; Petrides, 1994), and later through neuroimaging studies in humans (D'Esposito et al., 1998; Owen, 1997).

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Most subregional characterizations of the lateral prefrontal cortex have focused on posterior regions, including the ventrolateral (VLPFC) and dorsolateral (DLPFC) prefrontal cortices (see Figure 1). In contrast, the functions of the anterior, or rostrolateral, prefrontal cortex (RLPFC) have proven more elusive to characterization. There are virtually no suggestions as to its functions from nonhuman primate research. At the same time, functional neuroimaging studies in humans have demonstrated frequent RLPFC recruitment across a wide range of domains, including reasoning, long-term memory retrieval, and working memory. These studies have suggested multiple possible characterizations of RLPFC function: from sequence selection (Baker et al., 1996), relational integration (Christoff et al., 2001), and rule induction (Strange, Henson, Friston, & Dolan, 2001) during reasoning; to postretrieval evaluation (Rugg, Fletcher, Frith, Frackowiak, & Dolan, 1996), strategic engagement of monitoring (Wagner, Desmond, Glover, & Gabrieli, 1998), and prospective memory (Burgess, Quayle, & Frith, 2001) during long-term memory retrieval; to cognitive branching (Koechlin, Basso, Pietrini, Panzer, & Grafman, 1999) and subgoal processing (Braver & Bongiolatti, 2002) during working memory.

A unifying hypothesis linking these disparate functional characterizations is that the RLPFC is involved in processing self-generated information (Christoff & Gabrieli, 2000). Such self-generated information can be a plan for solving a problem, a retrieved past episode, or a working memory subgoal—in all instances, information that cannot be readily perceived from the immediate external environment but needs to be generated internally before it can be processed.

To test this hypothesis, we performed an event-related functional magnetic resonance imaging (fMRI) experiment, using a simple matching task designed to contrast directly the processing of internally versus externally generated information (see Figure 2). The internal (Figures 2A and 2B) and external (Figures 2C and

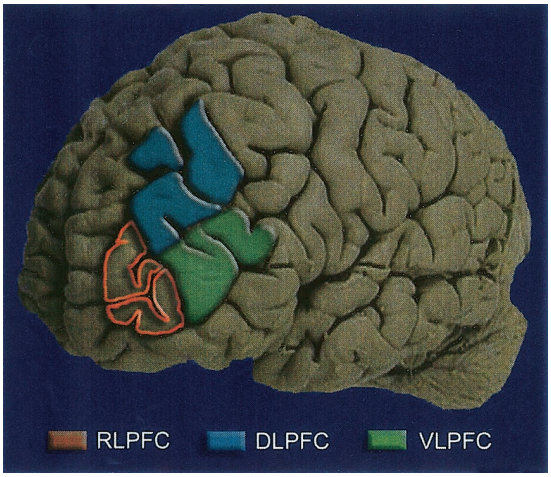

Figure 1. Schematic illustration of subregions of the lateral prefrontal cortex. RLPFC = rostrolateral prefrontal cortex; DLPFC = dorsolateral prefrontal cortex; VLPFC = ventrolateral prefrontal cortex.

2D) task conditions were similar in terms of overall demands but differed in the critical requirement for processing self-generated information. During the sample phase, two objects were presented in the top part of the screen. In the internal condition, subjects had to infer the dimension of change between the objects (shape or texture), whereas on external trials, they had to encode the objects in terms of their perceptual features. During the delay phase, the sample objects either remained on the screen (no-load trials) or were removed from the screen (load trials). In the latter case, subjects had to retain the relevant information in working memory. During the test phase, one or two match stimuli were presented. On internal trials, subjects had to infer the dimension of change between the bottom two objects and decide whether it matched the previously inferred dimension of change between the top objects. On external trials, subjects had to decide whether the bottom object matched any of the top objects along a specified dimension (shape or texture). Thus, the test phase of each trial required evaluating either externally generated information about objects' features, or internally generated information about the dimension of change between objects' features. The contrast between the test phases of internal and external trials was designed to identify brain regions preferentially involved in evaluating internally generated information.

Half of the trials (Figures 2A and 2C) posed no maintenance requirement, whereas the other half (Figures 2B and 2D) required maintenance of relevant information about the sample set in working memory. The purpose of this load manipulation was twofold: first, to examine the processes of generation and maintenance of self-generated information (occurring during the sample and delay phase of load trials, respectively), and second, to assess the contrast between evaluating different types of information in the

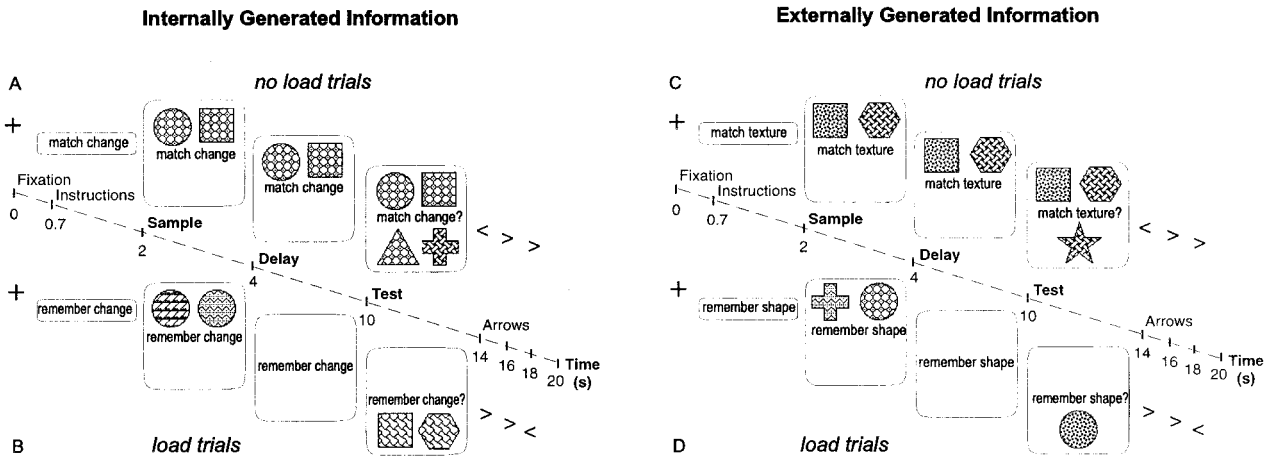

Figure 2. Behavioral task. Stimuli were objects of six possible geometric shapes, filled with one of six possible textures. Each trial started with a fixation cross, followed by an instruction cue. During the sample phase, a target set of two objects was presented at the upper part of the screen for 2 s. This was followed by a 6-s delay phase, during which the target set either remained on the screen (no-load trials) or was removed (load trials). During the test phase, a probe set of one or two objects was presented at the bottom half of the screen and subjects had to match it to the target set according to the instructions. On internally generated information trials (A, B) subjects had to infer the dimension of change between the top two objects (shape or texture) and decide whether the bottom two objects also change along this dimension. On externally generated information trials (C, D) subjects had to decide whether the bottom object matched any of the top objects along a specified dimension (shape or texture). On no-load trials (A, C) all objects were available on the screen during the decision, while on load trials (B, D), only the bottom set of objects was present and matching had to be performed from memory. Subjects responded with a "yes" or "no," by pressing one of two buttons on a handheld button box. The probe remained on the screen until the subject's response, but no longer than 2 s. During the 8-s baseline period at the end of each trial, an arrow appeared at the center of the screen every 2 s, pointing randomly to the right or to the left. Subjects had to respond within 500 ms by pressing a key corresponding to the arrow's direction.

absence and presence of concurrent maintenance requirements (occurring during the test phase of no-load and load trials, respectively).

Method

Subjects

Data were acquired from 12 right-handed, healthy volunteers (6 women and 6 men, aged 18–25 years, mean age = 19.7). All subjects gave informed written consent to participate in the study, which was approved by the Institutional Review Board at Stanford University.

Stimuli and Behavioral Procedure

Stimuli were objects of six possible geometric shapes, filled with one of six possible textures. Each trial started with a fixation cross, followed by an instruction cue. During the sample phase, a target set of two objects was presented at the upper part of the screen for 2 s. This was followed by a 6-s delay phase, during which the target set either remained on the screen (no-load trials) or was removed (load trials). During the test phase, a probe set of one or two objects was presented at the bottom half of the screen, and subjects had to match it to the target set according to the instructions. Subjects responded during the test phase of each trial with a "yes" or "no," by pressing one of two buttons on a hand-held button box. The probe remained on the screen until the subject's response, but no longer than 2 s. During the 8-s baseline period at the end of each trial, an arrow appeared at the center of the screen every 2 s, pointing randomly to the right or to the left. Subjects had to respond within 500 ms by pressing a key corresponding to the arrow's direction. At the end of the experiment, this baseline task was compared with the more commonly used resting baseline (for results of this comparison, see Christoff, Ream, & Gabrieli, in press).

Experimental Design

The task was administered in six 11-min long scanning sessions. Each trial type appeared eight times per session, yielding a total of 48 replications per condition type throughout the experiment. The different trial types were presented in a pseudorandom order, consistent across participants. This order was 1-back history counterbalanced so that each trial type was preceded by all different trial types in equal proportion, thus minimizing differences between conditions that may be caused by residual lag of the hemodynamic response.

MRI Acquisition

Data were acquired at a 3T GE Signa scanner, using a T2* sensitive gradient echo spiral sequence (TR 1 s, TE 30 ms, FA 70°, FOV 24 cm × 24 cm, matrix size 64 × 64). Seventeen contiguous 7-mm thick axial-oblique slices were acquired, parallel to the anterior commissure/posterior commissure line and covering the whole brain. Anatomical images were obtained by using a T1-weighted spin echo sequence (TR 600 ms, TE 14 ms, FOV 24 × 24 cm, matrix size 256 × 256). In each session, 660 functional volumes were obtained. The first 20 volumes of each session were later discarded, thus allowing for maximum T1 stabilization and minimizing the effect of any task-unrelated psychological processes that may have occurred in response to the sudden onset of scanner noise. Head movement was minimized by using a bite-bar. An automated spiral shim procedure was run to improve B_0 magnetic field homogeneity in the area of the frontal lobes.

fMRI Analysis

Data were preprocessed and analyzed with SPM99 (Wellcome Department of Cognitive Neurology, 1999). Preprocessing included correction for slice-timing differences (using the middle slice as a reference point), motion correction, spatial normalization into MNI space (using nonlinear transformations derived from normalizing the segmented gray matter from the anatomical images to a gray matter image of the MNI template), and spatial smoothing (using an 8-mm full-width at half-maximum isotropic Gaussian kernel). No global or grand-mean scaling was performed during analysis. To minimize noise-related components, we preprocessed the time series at each voxel using custom-built Matlab routines, by first replacing outlier values of absolute Z score > 3 with the trimmed session-specific mean value; second, performing within-session linear detrending; and last, band-pass filtering with a second-order Butterworth filter to attenuate frequencies below 0.0156 Hz and above 0.125. An anatomically defined gray matter mask was created and explicitly specified during analysis (see http://www.psych.stanford.edu/~kalina/SPM99/Tools/glm_specmask.html for details) to ensure that statistical analysis was performed in all brain regions, including those where signal may have been low as a result of susceptibility artifacts. The sample and probe phases were modeled as events, and the delay phase as a 6-s epoch. Regionally specific effects of processing internally compared to externally generated information were estimated for each individual subject in each of the three phases, separately for load and no-load trials. The six sets of contrast images obtained in this way were analyzed at the group level using linear regression, thus effecting a random-effects model across subjects. Threshold for significance in the region of interest, the RLPFC, was set at voxel-level $p < .05$ ($Z > 3.28$) corrected for multiple comparisons within the a priori (Christoff et al., 2001) anatomically defined region. Threshold for significance elsewhere in the brain was set at voxel level $p < .05$ ($Z > 4.6$) corrected for multiple comparisons across the entire gray matter volume. Anatomical regions of interest (ROIs) were constructed by using labels from the Talairach Daemon database (http://ric.uthscsa.edu/projects/talairachdaemon.html) and were transformed into MNI space, as described elsewhere (Christoff et al., 2001). ROI analyses were performed by running analyses of variance (ANOVAs) to assess the effects of type of information (internal vs. external), region (VLPFC vs. DLPFC vs. RLPFC), time (different peristimulus time points), and the corresponding interaction effects. These ANOVAs were performed outside of SPM99, using the raw percent signal change data from structurally defined ROIs. Repeated measures ANOVAs were employed, with subjects as a random effect factor and different temporal points within trial as replications. In addition, to examine lateral prefrontal subregions recruitment during the evaluation phase (Figure 3D), quadratic curve fit estimates were obtained to assess the presence of a peak in the average time courses during the last 8 scans of a trial (where the peak is expected to develop). In this case the goal was to demonstrate a peak in the average time-course, rather than a differential effect between two task conditions. These quadratic fit analyses were performed on the average time-courses acquired from each subject (yielding one observation per subject in each temporal point), treating the observation from different subjects as replications.

Results

Behavior

Subjects maintained a high level of performance throughout the experiment (Figure 4). Mean accuracy was 96.34% ($SE = 0.73\%$) and did not differ significantly across conditions. Responses occurred on the average 1014 ms ($SE = 45.96$ ms) after the onset of the test stimulus, and were 114 ms slower during internal than external trials, $F(1, 11) = 34.8$, $p < .001$, and 62 ms slower during no-load trials than load-trials, $F(1, 11) = 24.5$, $p < .005$.

Neuroimaging

A whole-brain voxel-based analysis contrasting the evaluation of internally versus externally generated information (Table 1 and

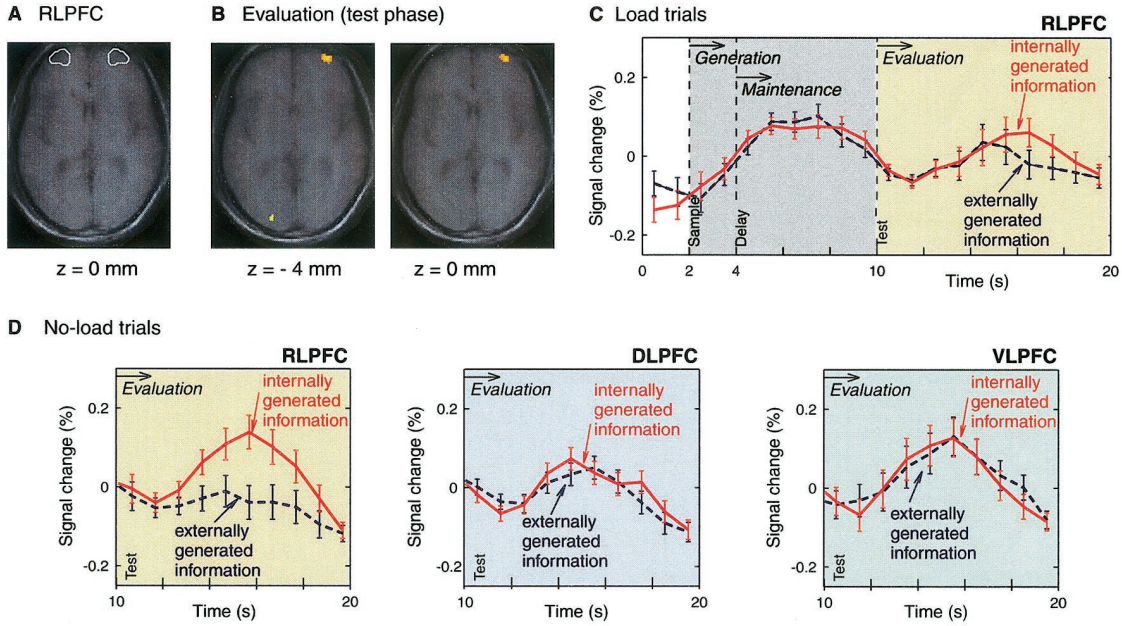

Figure 3. Anatomical prediction and functional MRI results. A: The hypothesized (Christoff & Gabrieli, 2000) region of activation, RLPFC, anatomically defined (Christoff et al., 2001) as the intersection between middle frontal gyrus and Brodmann's area 10. B: Results from a whole-brain group analysis: Regions showing significant increase during evaluation of internally generated information relative to the evaluation of externally generated information (load and no-load trials combined). Activations are overlaid on an average anatomical image and are based on a threshold of $p < .05$, corrected for multiple comparisons. C and D: Event-related responses in anatomically defined regions of interest. Plots show the median (± *SE*) percent signal change across subjects for the corresponding anatomically defined prefrontal subregion. C: Time-course observed in right RLPFC during the sample, delay, and test phases of load trials. D: Time-course observed in right RLPFC, right DLPFC, and right VLPFC during the test phase of no-load trials. RLPFC = rostrolateral prefrontal cortex; DLPFC = dorsolateral prefrontal cortex; VLPFC = ventrolateral prefrontal cortex.

Figure 3B) yielded only three areas of activation: bilateral RLPFC (strongly on the right, weakly on the left) and left primary visual cortex (presumably due to the different number of objects that had to be visually inspected). RLPFC activation was located within the predicted region (Figure 3A), anatomically defined (Christoff et al., 2001) as the region of intersection between middle frontal gyrus and Brodmann area (BA) 10.

These findings were confirmed by an independent region-of-interest (ROI) analysis of the event-related signal in RLPFC during the test phase (Figures 3C and 3D, gold panels). RLPFC signal increased during evaluation of internally compared to externally generated information both during no-load, $F(1, 11) = 7.49$, $p < .05$, and load trials, $F(1, 11) = 5.29$, $p < .05$. Furthermore, this differential recruitment was specific to the process of evaluation, and was not observed during generation, $F(1, 11) = 1.96$, $p = .19$, or maintenance, $F(1, 11) = 0$, $p = .98$, of internally generated information (Figure 3C, gray panels), a result also supported by a significant phase by condition interaction, $F(2, 22) = 6.53$, $p < .01$. These results indicate that the RLPFC is preferentially re-

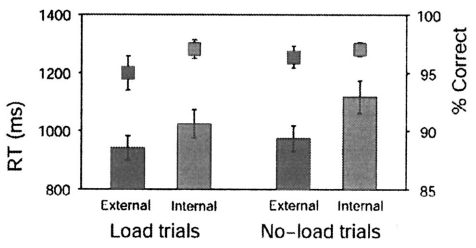

Figure 4. Behavioral performance. Bars show mean (± *SEM*) reaction times (RTs) across conditions, and symbols show mean accuracy. See Results and Discussion sections for details.

Table 1
Evaluation of Internally Versus Externally Generated Information

Gyrus	Coordinates x	y	z	*p*	*Z*	No. of voxels
Right MFG, BA10	34	64	−4	<.001[a]	4.57	32
Left MFG, BA10	−34	60	4	.009[a]	3.81	4
Left LingG, BA17	−20	−92	−8	<.001[b]	5.61	40

Note. Foci for activation map shown in Figure 3B. MFG = middle frontal gyrus; BA = Brodmann area; LingG = lingual gyrus.
[a] Corrected for multiple comparisons in rostrolateral prefrontal cortex (Figure 3A). [b] Corrected for multiple comparisons in the entire gray matter volume.

cruited during deliberate, evaluative processing performed upon internally generated information, independent of concurrent maintenance requirements.

To test further the regional specificity of RLPFC recruitment, the event-related signals in anatomically defined DLPFC and VLPFC regions were examined during the evaluation of internally and externally generated information (Figure 3D, blue and green panels). Only no-load trials were included to avoid effects of concurrent memory load, to which these two regions have been shown to be sensitive (D'Esposito et al., 1998; Fuster, 1980; Goldman-Rakic, 1987; Owen, 1997; Petrides, 1994). There was no difference in event-related signal between evaluation of internally and externally generated information in either DLPFC, $F(1, 11) = 0.14$, $p = .71$, or VLPFC, $F(1, 11) = 0.15$, $p = .70$. Furthermore, the regional specificity of effect in RLPFC (Figure 3D) was supported by a significant region by condition interaction, $F(2, 22) = 4.61$, $p < .05$. Although the two posterior lateral PFC subregions did not respond differentially between the internal and external conditions, both subregions were activated during both conditions, as revealed by the presence of a significant quadratic trend in DLPFC during internal, $t(94) = 3.36$, $p < .005$, and external, $t(94) = 3.46$, $p < .001$, trials, and in VLPFC during internal, $t(94) = 4.02$, $p < .001$, and external, $t(94) = 4.15$, $p < .001$, trials. In contrast, RLPFC was recruited only during internal, $t(94) = 4.08$, $p < .001$, but not during external trials, $t(94) = 0.96$, $p = .34$.

Although the comparison between internal and external trials was associated with an increase in the latency of response, the observed modulation of RLPFC response was shown to be specific to this comparison and was not observed during comparable increases in response latency associated with the load manipulation (Figure 5). To equate for increases in RT across comparisons, we examined the test phases of internal load trials (Figure 1b) and external no-load trials (Figure 1c). For this comparison the difference in RT was reduced to 51 ms, a difference comparable to the increase between load and no-load trials (62 ms). Signal in RLPFC remained higher during internal no-load trials compared to the external load trials (Figure 5A), $F(1, 11) = 5.46$, $p < .05$, but was not influenced by the load manipulation (Figure 5B), $F(1, 11) = 0.159$, $p = .70$, suggesting that the observed increase in RLPFC signal was associated with the specific the requirement for processing self-generated information, rather than with the associated increase in response latency. Furthermore, during the test phase of internal load trials, there were two objects on the screen (Figure 2B), compared to three objects during the test phase of external no-load trials (Figure 2C). The fact that signal in RLPFC remained stronger during internal load trials compared to external no-load trials (Figure 5A), therefore, rules out the possibility that the observed increase in RLPFC signal in other comparisons was due to a larger number of displayed items in internal conditions.

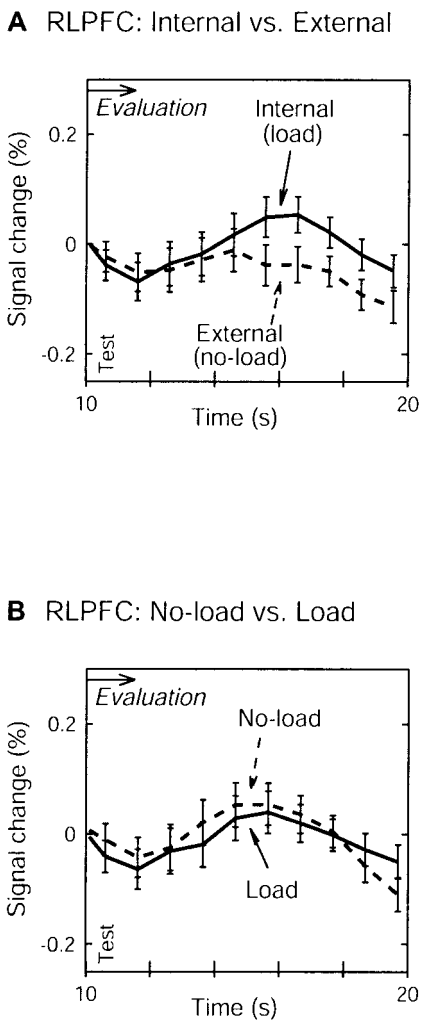

Figure 5. Process specificity of rostrolateral prefrontal cortex (RLPFC) response after equating for reaction time (RT) increases across comparisons. A: Signal increased during internal no-load trials compared with external load trials, $F(1, 11) = 5.46$, $p < .05$, associated with a 51-ms increase in mean RT. B: RLPFC signal is not modulated by the load manipulation, $F(1, 11) = 0.16$, $p = .70$, associated with a 62-ms increase in mean RT. Graphs depict median ($\pm$ *SE*) percent signal change response across participants in anatomically defined right RLPFC.

Discussion

The results presented here provide direct evidence in support of the hypothesis that the rostral region of the human lateral prefrontal cortex is involved in processing self-generated information. The fMRI signal in RLPFC showed a selective increase during processing of internally generated compared to externally generated information. This increase was specific to the evaluation phase of each trial and was not observed during the generation or maintenance of self-generated information. In contrast to RLPFC, the more posterior DLPFC and VLPFC regions did not differ in activation between the internal and external conditions, but were nevertheless recruited during both conditions. These results are consistent with a hierarchical model of lateral PFC organization (Christoff & Gabrieli, 2000), according to which DLPFC and VLPFC are involved when externally generated information is evaluated, whereas RLPFC becomes additionally recruited when internally generated information needs to be evaluated.

This characterization of RLPFC function may help relate seemingly disparate activation findings across a number of cognitive domains. Processing internally generated information would occur in at least two types of situations: first, when novel information,

such as an inference, a hypothesis, a relation, or a plan, needs to be inferred, or self-generated; and second, when previous information from an earlier episode or experience needs to be retrieved from memory, or again, self-generated. The first type of situation occurs frequently during reasoning and working memory tasks. For instance, the process of sequence selection and evaluation, associated with RLPFC activation during the Tower of London task (Baker et al., 1996), would involve evaluating internally generated plans for sequences of moves. Similarly, the process of cognitive branching, associated with RLPFC activation during working memory tasks (Braver & Bongiolatti, 2002; Koechlin et al., 1999), involves processing self-generated subgoals. The second type of situation occurs frequently during long-term memory retrieval tasks. For instance, the process of post-retrieval evaluation, proposed to characterize RLPFC activations during episodic retrieval (Rugg et al., 1996), involves the evaluation of self-generated retrieval products. Likewise, remembering to carry out an intended act after a delay, a process that has been associated with RLPFC activation during prospective memory tasks (Burgess et al., 2001), may involve considering self-generated information about prior intentions. Thus, RLPFC recruitment across reasoning, working memory, and long-term memory retrieval could be understood in terms of the requirement for processing internally generated information.

Self-generated information can be processed at different levels of elaboration. At one level, subjects can make implicit use of such information, without becoming aware of it. At another level, subjects may consider self-generated information explicitly, by deliberately focusing on it. It is this latter, explicit form of processing that seems to recruit RLPFC most consistently (Christoff & Gabrieli, 2000). For example, planning and executing self-generated sequences of moves during the Tower of London (Owen, Doyon, Petrides, & Evans, 1996) does not by itself lead to RLPFC recruitment, but when the task requires explicit evaluation of these sequences (Baker et al., 1996), such recruitment is apparent. Similarly, cued- and free-recall tests of episodic memory are much more likely to result in RLPFC recruitment than recognition tests (Christoff & Gabrieli, 2000)—a difference that parallels an increase in demand for explicit processing of retrieved material (Nolde, Johnson, & Raye, 1998). Such proposals for selectivity of involvement in explicit types of processing have been made regarding the role of the hippocampus in explicit memory (Graf & Schacter, 1985), and the role of cerebellum in explicit processing of temporal sequences during skill learning (Ivry, Spencer, Zelaznik, & Diedrichsen, 2002). Here we propose a similar account of RLPFC function: we argue that it is involved specifically during explicit processing of self-generated information, and need not be recruited when subjects make only implicit use of such information to guide behavior.

Several lines of research indicate that the RLPFC is involved in processes related to establishing a "task set"—or the mental set subjects are thought to enter when they are given task instructions, but before actual task performance (Allport, Styles, & Hsieh, 1994). Thus, the RLPFC has been implicated in establishing episodic retrieval mode to guide long-term memory retrieval (Lepage, Ghaffar, Nyberg, & Tulving, 2000; Rugg & Wilding, 2000), in setting up future task operations during working memory (Sakai & Passingham, 2003), and in shifting attention from one stimulus dimension to another during visual search (Pollmann, 2001). It has been proposed, therefore, that the RLPFC is recruited when attention is directed toward abstract information (e.g., a dimension or general task operations), rather than toward concrete information (a specific item or cue; Lepage et al., 2000; Sakai & Passingham, 2003). This characterization is consistent with the present argument in that self-generated information is by definition abstract and its explicit processing would require directing attention to it.

Such explicit processing of self-generated information may exemplify some of the highest orders of transformation in which the prefrontal cortex engages during the perception-action cycle (Benson, 1993; Fuster, 1980; Mesulam, 1998; Stuss & Benson, 1986; Wise et al., 1996). It may also be one of the mental processes that distinguish humans from other primate species. There are profound disparities among different primate species in their natural ability to process internally generated information. This is demonstrated by differences in performance on tasks requiring judgments analogous to that required during the test phase of the internal condition of the task employed here (Figure 2A). Such tasks are often referred to as "relational matching-to-sample" (Premack, 1983) and can be distinguished from the traditionally employed "identity matching-to-sample" procedure, in that they require the animal to match abstract information about the relationship between a pair of objects (e.g., "same" or "different") to the relationship between another pair of objects, irrespective of object identities. Only humans and chimpanzees with a history of language (Premack, 1983) or token (Thompson, Oden, & Boysen, 1997) training can perform tasks requiring such judgments, while monkeys fail even after extensive training (Thompson & Oden, 2000). Furthermore, humans spontaneously develop this ability as early as 5 years of age (Halford, 1984), while chimpanzees demonstrate it only in adulthood and only after extensive symbol training. This evolution in ability is paralleled by a twofold increase in the relative size of BA10 from chimpanzees to humans (Semendeferi, Armstrong, Schleicher, Zilles, & Van Hoesen, 2001)—an increase that appears to be selective to this region and occurs even though the relative size of the frontal lobe remains the same between the two species (Semendeferi, Damasio, Frank, & Van Hoesen, 1997; Semendeferi, Lu, Schenker, & Damasio, 2002). Although further anatomical and cytoarchitectonic studies are needed in order to establish with greater detail and certainty the changes BA10 has undergone in the course of primate evolution, this combination of behavioral and neuroanatomical evidence is consistent with the view that BA10 may play a critical role in mental operations that have emerged at the latest stages of evolutionary development.

Finally, the present study demonstrates involvement of lateral BA10 during the evaluation of self-generated cognitive information, whereas other functional neuroimaging studies have shown that medial BA10 is activated during judgments of self-generated emotional states (Damasio, 2000; Gusnard, Akbudak, Shulman, & Raichle, 2001; Lane, Fink, Chau, & Dolan, 1997; Zysset, Huber, Ferstl, & von Cramon, 2002). This suggests that the entire region may be involved in the explicit processing of internally generated information, with lateral BA10 recruited during cognitively oriented tasks and medial BA10 recruited during emotionally oriented tasks. This ability to become aware of and explicitly process internal mental states—cognitive as well as emotional—may epitomize human mental abilities and may contribute to the enhanced complexity of thought, action, and social interactions observed in humans.

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