The neural implementation of task rule activation in the task-cuing paradigm: An event-related fMRI study

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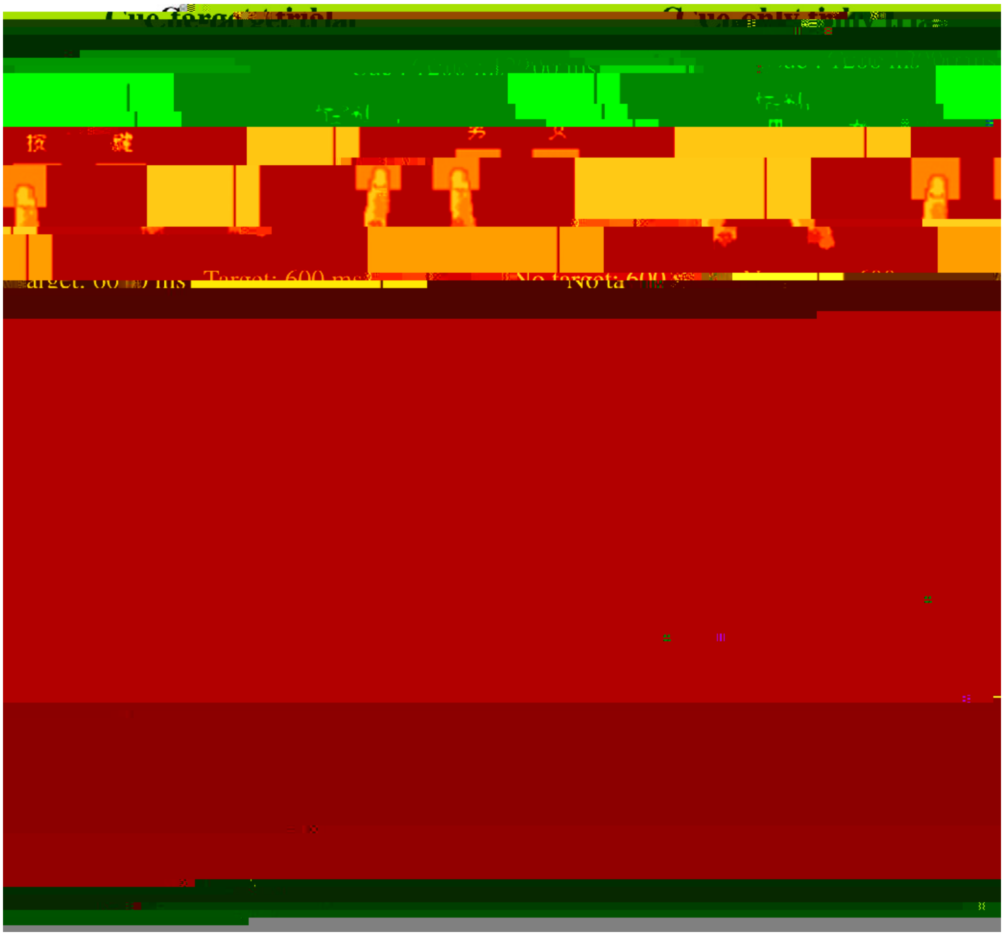
to 12.5 s) and, therefore, their findings may have been compromised by memory load confounds (


Cue-target trial
Cue-only trial
Cue: 1200 ms
Cue: 1200 ms
Target: 600 ms
Target: 600 ms
No target: 600 ms
No target: 600 ms

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participated in the study. Six participants were female; participants' ages ranged between 20 and 26 years, and all had normal or corrected-to-normal vision. Prior the fMRI scanning session, they gave informed consent about the investigation according to the Helsinki guidelines and the approval of the Academic Committee of the Department of Psychology, Peking University. Participants were paid 50 yuan (about EUR 5) for their service.

One participant's response error rate was more than 20%. Hence this participant's behavioral and fMRI data were removed from the data set. There was also a loss of the behavioral data from one participant, due to data recording error. Thus, ultimately, 14 participants' image data sets and thirteen participants' behavioral data sets were available for analysis.

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The task to be performed by the participants was either color discrimination or gender discrimination. Each trial began with the presentation of a cue for a fixed duration of 1200 ms, which could either be a rule-cue or a task-cue (Fig. 1). Both cues displayed an instruction for the upcoming task; however, a precise instruction about the required task rule was provided only in the rule-cue condition (for more details, see Fig. 2). On cue-only trials (= 160 trials, of which 80 presented a rule-cue and 80 a task-cue), there was no target following the cue offset, but only a black screen that lasted for 600 ms, and there was no need for participants to make a response (Fig. 1, right panel).

In contrast, on cue-target trials (= 280, of which 140 presented a

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Then the image data were modeled by applying a general linear model (Friston et al., 1995). In event-related single-subject analyses, the four cue-only and the four cue-target conditions were modeled as separate volumes (resulting from the factorial combination of the two cue type (rule-cue vs. task-cue) and the types of task transition (task switch vs. task repetition). Additionally, all error trials were selected to form an error trial volume. The resulting nine volumes were convolved with the hemodynamic response function (HRF), and then beta values of these regressors were estimated according to the ordinary least-squares (OLS) method.

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For group statistics, one-sample t-tests of contrast maps across subjects (random-effects model treating subjects as a random variable) were computed to indicate whether observed differences between conditions were significantly different from zero.

In particular, two main contrasts were calculated: Contrast 1: For cue-only trials, rule-cue minus task-cue trials, intended to isolate extra activation for a rule-cue. Contrast 2: (cue-target trials minus cue-only trials for task-cues) minus (cue-target trials minus cue-only trials for rule-cues), intended to isolate the extra activation related to the target-processing when the cue did not specify the rule. In a subsequent conjunction analysis, SPM5 (Nichols et al., 2005) was used to locate the common task rule-rela9(whenur)13(ocessing)-4795654(w8(23r(1jee15.4780Td(t)o(53(8tnin)-296(co(volllyO[cueminusho560(t07ne)xel

As outlined in the Introduction, we expected stronger activation on rule-cue compared to task-cue trials during the preparation period, and, additionally, we assumed these regions to be associated with task rule activation. To examine for this, we calculated a whole-brain contrast of the activation in the rule-cue versus the task-cue condition specifically for cue-only trials. The results of this analysis are presented in Fig. 5 and Table 1.

Stronger activation was found for the rule-cue compared to the task-cue condition in the anterior part of the superior frontal gyrus (SFG), that is, the right aPFC, bilaterally in the premotor cortex, and in regions of the MedFC; the latter regions extended from anterior portions in the pre-SMA to posterior portions of the pre-SMA/SMA region. In addition, we found increased activation in the right superior parietal lobe (SPL) and the left precuneus. Finally, activation foci were found bilaterally in the occipital cortex (e.g., in the lingual gyrus and the fusiform gyrus) (see Fig. 5a and Table 1).

During task execution on cue-target trials, we expected stronger activation in the task-cue, compared to the rule-cue, condition in cortical regions that are associated with the activation of the task rules; this is because of the expected postponement of the rule activation under task-cue conditions. To determine the corresponding activation foci, we contrasted the target-related activation during the execution period in the task-cue and rule-cue conditions. For this purpose, we calculated the contrast: cue-target cue-only trials separately for the task-cue and rule-cue conditions, so as to derive the corresponding task execution-related activations in both types of trial. Subsequently, we calculated the second-order contrast, task-cue (cue-target minus cue-only trials) rule-cue (cue-target minus cue-only trials), to compare the target-related activation between the task-cue and rule-cue conditions.

This analysis revealed stronger target-related activity in the task-cue compared to the rule-cue condition in most regions that had proved to be rule-related during the preparation period in the above analysis (see Cue-related activation section). In particular, these regions were the right anterior part of the SFG (i.e., aPFC), the right pre-motor cortex, the MeFC (i.e., pre-SMA), the right SPL, and the bilateral lingual and fusiform gyri. In addition to these regions, activity was found in the LPFC, with peak activation in the right posterior MFG that extended into the IFJ (see Fig. 5b and Table 1).

Subsequently, we performed a conjunction analysis in order to identify the regions commonly associated with task rule activation during the preparation and the execution period (see Fig. 5c and Table 2). This analysis was calculated across the contrasts rule-cue minus task-cue of the cue-related activation in the preparation

Discussion

The present study investigated the functional neuroanatomy of task rule activation as a component process of general task suggest that this strongly depends on the amount of explicit task information provided by the cue. If the cue contains information about both the type of task and the specific task rules (and if there is suffi

Some previous fMRI studies had failed to find any additional region, or even activation, to be involved in preparing for task switches (as compared to repetitions), which was taken to cast doubt on the assumption that switch-specific control processes are operating during the preparation period (e.g., Brass and von Cramon, 2002, 2004; Gruber et al., 2006; Ruge et al., 2005; but see Chiu and Yantis, 2009, Slagter et al., 2006, and ERP studies, e.g., Lavric et al., 2008, for positive evidence). We agree that the kinds of preparatory processes occurring after cues that indicate a task repeat and cues that indicate a task switch are similar, but they are more intense in task switch situations. In other words, more control is required when preparing for switch trials, and the corresponding additional activation can be found in either the task preparation or the execution period, depending on the type of cue.

A possible reason for the discrepant findings concerning switch-related activations in the preparation period may lie in the different types of cues, or cue information, which were used in studies that failed to and that did find such activations. Studies that failed to find additional switch-related activation (see below) used arbitrary cues (e.g., in Brass et al., 2002, a square or diamond indicating an odd/even and or a number size task), whereas we used semantically unequivocal cues to indicate the upcoming task (see also Wylie et al., 2006). It would appear plausible that, if the cue is an arbitrary shape, a considerable amount of time needs to be spent to decode the cue and to represent the general task goal that is, task rule activation may be delayed and moved to the target period. This might be the reason why studies that used such arbitrary cues failed to find any larger activation in the preparation for task switches compared to repetitions (Brass and von Cramon, 2002, 2004; Gruber et al., 2006; Ruge et al., 2005).

In our study, the word symbol gender’ indicated the gender task and the symbol color’ the color task. This use of semantic cues is similar to the conditions in other studies which also reported additional switch-related activity during the preparation period (e.g., Wylie et al., 2006). In the case of semantic cues, the cue specifies the task relatively directly, making it much easier for participants to establish the task representation (Miyake et al., 2004; Wylie et al., 2006) and permitting them to activate the task rule already within the preparation period. As a consequence, the neural effort associated with the uploading of the task rule information would be increased on task switch compared to repetition trials, and this effort may be strong enough to evoke significant fMRI activation in the comparison of switch versus repetition trials during the task preparation period (Wylie et al., 2006).

Thus, these findings conform well with recent evidence from ERP studies indicating that switch-related neural activity can indeed be observed for processes associated with the task preparation (Lavric et al., 2008). Perhaps the use of more elaborate paradigms permitting e4127.8033[(si)

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