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Brain mechanisms associated with background monitoring of the environment for potentially significant sensory events

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ABSTRACT

Background monitoring is a necessary prerequisite to detect unexpected changes in the environment, while being involved in a primary task. Here, we used fMRI to investigate the neural mechanisms that underlie adaptive goal-directed behavior in a cued task switching paradigm during real response conflict or, more generally, when expectations on the repetitive features of the environment were violated. Unexpected changes in sensory stimulus attributes in the currently unattended stimulus dimension thereby led to activations in a bilateral network comprising inferior lateral frontal, intraparietal, and posterior medial frontal brain regions, independent of whether these attributes elicited a factual response conflict or not. This fronto-parietal network may thus play an important role in adaptive responding to potentially significant events outside the current focus of attention.

1. Introduction

Adaptive human behavior can be conceived of as an optimization problem that requires a dynamic, context-sensitive balance between antagonistic constraints (Goschke, 2003). On the one hand, humans must be able to focus on task-relevant information while task-irrelevant, i.e. distracting information should be suppressed (Allport, 1989). On the other hand, however, it is equally important for an organism to monitor the environment for potentially significant information, even if this information is not relevant for an ongoing action. It would not be adaptive if goal-directed selection operated so efficiently as to suppress irrelevant information completely. Rather, ignored information should be processed to a level at which threats or opportunities related to an organism's goals and needs can be recognized (e.g., the smell of fire while working on a paper). This requires background monitoring mechanisms, which may eventually interrupt ongoing action and trigger an updating of working memory (Braver & Cohen, 2000; Corbetta & Shulman, 2002).

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The aim of the present experiment was to explore the neural mechanisms that enable humans to meet these antagonistic requirements on action control. For this purpose we adopted a cued task switching paradigm (Gruber, Karch, Schlueter, Falkai, & Goschke, 2006). Here, subjects are required to configure and reconfigure cognitive representations of task-sets while in each trial they have to respond to one of two feature dimensions of the presented target-stimuli. Increased reaction times (RTs) and error rates have been found whenever the currently irrelevant stimulus dimension was incongruent with respect to the response that had to be given. This effect has been attributed to a response conflict due to the simultaneous activation of incompatible responses. In addition, several previous studies have found a characteristic pattern of cortical activation associated with incongruency, which is thought to reflect the detection and resolution of behavioral conflicts resulting from the simultaneous activation of incompatible responses. This neural network mainly comprises the posterior medial frontal cortex (anterior cingulate cortex/pre-supplementary motor area), the inferior lateral prefrontal cortex, intraparietal, and inferior parietal cortices as well as occipito-temporal areas (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Durston et al., 2003; Leung, Skudlarski, Gatenby, Peterson, & Gore, 2000; Milham, Banich, & Barada, 2003; Roelofs, 2003; Ullsperger & von Cramon, 2001; van Veen & Carter, 2005; Zysset, Muller, Lohmann, & von

Cramon, 2001). Interestingly, activation of a very similar fronto-parietal network has been repeatedly observed in association with the processing of deviancy or novelty in oddball paradigms that either involved automatic (i.e. involuntary) mismatch detection (Bledowski, Prvulovic, Goebel, Zanella, & Linden, 2004; Huettel, Mack, & McCarthy, 2002; Milham et al., 2003) or voluntary target detection (Braver, Barch, Gray, Molfese, & Snyder, 2001; McCarthy, Luby, Gore, & GoldmanRakic, 1997).

This similarity of activation patterns reported for response incongruency and oddball events suggests that both situations may impose similar requirements on cognitive control operations. In this study, we directly compared these two experimental situations in the same subjects. In this way, we tested the hypothesis that both response incongruency (i.e. response conflict) and oddballs (i.e. events that violate expectations) activate common brain regions within a fronto-parietal network, which may underlie cognitive control mechanisms that ensure task-appropriate, adaptive behavior.

2. Methods

2.1. Subjects

Twelve healthy right-handed volunteers (5 females and 7 males) took part in our study (mean age = 24.1 years; SD = 3.3 years; and age range = 21–33 years). They were recruited in an academic environment and were reported to be free from neurological and psychiatric disorders. Written informed consent to participate in the study and ethical approval were obtained before the experiment.

2.2. Experimental design

Subjects underwent fMRI while performing a cued task switching paradigm, in which geometric objects differing in shape and color had to be classified according to either color or shape (Fig. 1A). A task cue indicated which dimension was relevant for the response to the subsequent target in the current trial. The respective task cue was chosen pseudo-randomly for each trial and, thus, it was unpredictable for the subject whether an upcoming trial did or did not require a task switch.

Stimuli were generated and presented using the ERTS software (Experimental Run Time System, Version 3.11, BeriSoft Cooperation, Frankfurt am Main, Germany). Each trial began with the onset of a word cue, which was presented at the center of a black screen for 500 ms indicating the relevant dimension for the subsequent response to the target stimulus. After a cue-stimulus interval of 250 ms, the target stimulus appeared for 750 ms. Subjects used their right hand to respond to the target-stimuli and were instructed to respond as fast and as accurately as possible. They had to press a left button with their index finger in response to the first object or the color red, and they had to press a right button with their middle finger in response to the second object or the color blue. Maximal response time was 1000 ms (750 ms stimulus presentation + 250 ms stimulus-cue interval) so that the total duration of one trial was 1750 ms. As only one of the dimensions was response-relevant within a single trial, the target-stimuli could be either congruent (i.e. both the relevant and the irrelevant dimension were mapped to the same response button), incongruent (i.e. both dimensions were mapped to different response buttons) or neutral (i.e. the currently irrelevant dimension was not mapped to any response). Most of the trials were neutral trials, i.e. in the shape task the objects were mostly presented in white, and in the color-task a third, different geometric figure was presented that also was not mapped to any response. Only on every fourth trial, the irrelevant dimension of the stimulus was systematically varied and could be congruent, incongruent, or neutral, in one third of cases each. These trials were called 'critical' trials of interest and were the only ones that entered into the statistical analyses whereas all other (neutral) trials served as experimental baseline. With regard to these critical trials, the experimental design was completely balanced with respect to stimulus combinations, trial transitions, switch trials or trial repetitions and response congruency. Furthermore, in order to achieve a systematic jittering of the trial onsets, trials were grouped in blocks of four and a varying time delay (of 0, 333, 667, or 1000 ms) was inserted before the cue of the first trial of a block and after the target of the last trial of a block. The lengths of the delays of one block were chosen so that they added up to 1000 ms in each case (e.g., 0 ms before the first trial in the block + 1000 ms after the last trial in the block, or 333 ms before the first trial in the block + 667 ms after the last trial in the block). This resulted in a systematic jitter-

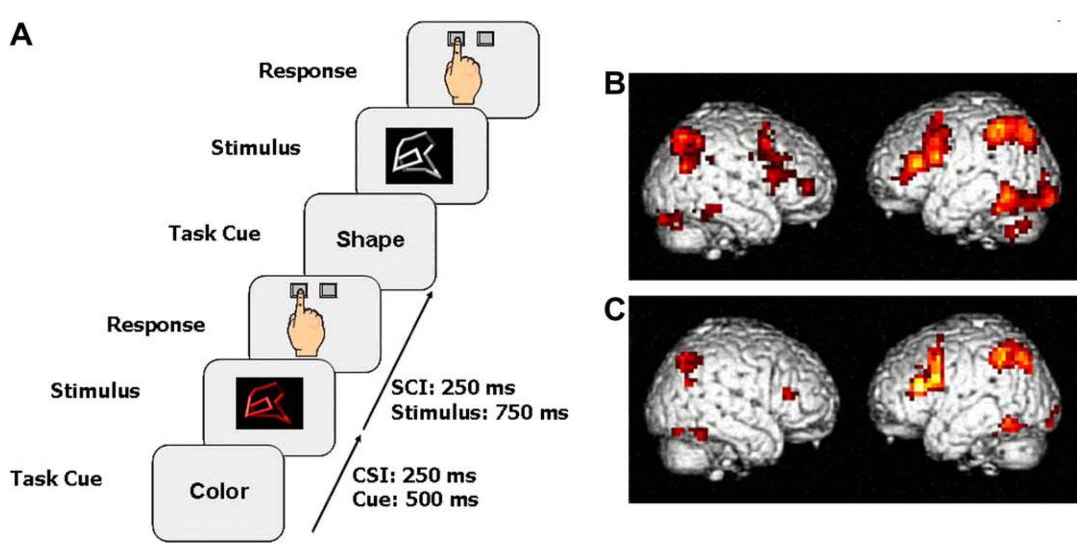

Fig. 1. (A) Example of two subsequent trials in the cued task switching experiment. (B) Activations associated with response conflict evoked by incongruent colors. (C) Activations associated with a mismatch effect evoked by contextually infrequent (congruent) colors. See Table 1 for coordinates of activation foci and statistical significances.