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Research Report

Divided versus selective attention: Evidence for common processing mechanisms

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ABSTRACT

The current study revisited the question of whether there are brain mechanisms specific to divided attention that differ from those used in selective attention. Increased neuronal activity required to simultaneously process two stimulus dimensions as compared with each separate dimension has often been observed, but rarely has activity induced by a divided attention condition exceeded the sum of activity induced by the component tasks. Healthy participants performed a selective-divided attention paradigm while undergoing functional Magnetic Resonance Imaging (fMRI). The task required participants to make a same-different judgment about either one of two simultaneously presented stimulus dimensions, or about both dimensions. Performance accuracy was equated between tasks by dynamically adjusting the stimulus display time. Blood Oxygenation Level Dependent (BOLD) signal differences between tasks were identified by whole-brain voxel-wise comparisons and by region-specific analyses of all areas modulated by the divided attention task (DIV). No region displayed greater activation or deactivation by DIV than the sum of signal change by the two selective attention tasks. Instead, regional activity followed the tasks' processing demands as reflected by reaction time. Only a left cerebellar region displayed a correlation between participants' BOLD signal intensity and reaction time that was selective for DIV. The correlation was positive, reflecting slower responding with greater activation. Overall, the findings do not support the existence of functional brain activity specific to DIV. Increased activity appears to reflect additional processing demands by introducing a secondary task, but those demands do not appear to qualitatively differ from processes of selective attention.

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Abbreviations: AC–PC, anterior commissure – posterior commissure; AFNI, Analysis of Functional NeuroImages; ANOVA, analysis of variance; BOLD, Blood Oxygenation Level Dependent; EPI, echo planar imaging; FA, flip angle; fMRI, functional Magnetic Resonance Imaging; FOV, field of view; MPRAGE, magnetization-prepared rapid acquisition with gradient-echo; ROI, region of interest; TE, echo time; TR, repetition time; Sel-A, selective attention — angle discrimination task; Sel-C, selective attention — color discrimination task; DIV, divided attention task; DT, display time; RT, reaction time; VRT, visuomotor reaction time; IFG, inferior frontal gyrus; IOG, inferior occipital gyrus; MFG, middle frontal gyri; MOG, middle occipital gyrus; SMA, supplementary motor area; SOG, superior occipital gyrus; SPL, superior parietal lobule

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1. Introduction

The concept of attention is traditionally closely linked to the resource theory and its central premise that an organism possesses limited processing capacity and has to select from the multitude of available sensory input (Broadbent, 1958). Attended information is selected and further processed, while unattended input is filtered out. The term selective attention describes the process of focusing resources on specific aspects of all input. Concepts of divided attention are concerned with limitations of performing more than one information-processing task simultaneously. Divided attention thus relates to the optimal allocation of resources between different sets of input by splitting or rapidly shifting the attentional focus, given the inability to process all available information in parallel (Parasuraman, 1998). Attention can be divided between locations in space, between features of a single or of several objects, and between stimuli in one or several sensory modalities (Braun, 1998).

Several neuroimaging studies have investigated whether dividing attention recruits the same brain structures as selective attention, or whether there are mechanisms specific to divided attention. Prefrontal, posterior parietal and premotor cortical areas were more activated by divided attention to two stimulus dimensions than by selective attention to each separate dimension (Corbetta et al., 1991a; Vandenberghe et al., 1997; Rees et al., 1997; Herath et al., 2001; Loose et al., 2003; Nebel et al., 2005; Weerda et al., 2006; Johnson and Zatorre, 2006). Enhanced activity in the anterior cingulate cortex (ACC) has also been reported, although, where performance accuracy was not equated, this may be explained by differences in error processing and response uncertainty between the selective and divided attention conditions (Carter et al., 1998, 2000; Botvinick et al., 1999). In most studies, activations during divided attention did not exceed the sum of activity induced by the component selective attention tasks. Thus, the increase in neural activity may reflect additional processing demands by introducing a secondary task, but not necessarily qualitatively different processes above and beyond demands on selective attention. Only a few studies provided evidence for activity specific to divided attention.

When participants concurrently discriminated two stimulus features, left superior parietal, left frontal and temporal activations exceeded the summed activity in the single discriminations (Vandenberghe et al., 1997). Analyses were restricted to stimuli presented in the left hemifield. The predominantly right lateralized activations during single discriminations (in accordance with stimulus presentation on the left) may thus explain the mostly left-hemispheric recruitment of additional activity as attentional load increased. Another study presented two successive stimuli in different modalities and identified right inferior frontal activation only when stimuli appeared in close temporal succession and created behavioral interference (Herath et al., 2001). Activation in the single-task conditions was not significant, but activity levels were not reported, thus precluding a direct comparison with the interference condition. Johnson and Zatorre (2006) presented participants with a melody and a shape stimulus “drawn” over the same time frame. Attending to both stimuli activated left dorsolateral prefrontal cortex, with zero activity in the single-task conditions. Subjects were aware that a memory test for the stimuli would follow. The encoding of two simultaneous information streams may have introduced particular control demands to coordinate the continuous update of both streams in working memory.

This raises the question of which specific cognitive processes differentiate divided from selective attention conditions. Beyond the need to divide attention between stimulus dimensions, such conditions introduce uncertainty regarding the response-relevant stimulus feature, and the need to maintain two sets of behavioral goals and to control attentional resources allocation. There does not appear to be a clear division between divided attention and dual-task interference at an executive level (Braun, 1998). Dividing attention becomes more difficult with increasing executive control demands (Posner and DiGirolamo, 1998), and control demands can be expected to increase with the complexity of the component tasks. Thus, task characteristics appear to influence the processes necessary to divide attention.

The aim of the present study was to determine if brain activations specific to divided attention could be identified under conditions that induce minimal demands on executive control processes and working memory. A task setting was developed that enabled performance accuracy to be equated between the selective and divided attention conditions in order to minimize differences in error processing and response uncertainty. A single foveally-presented circular stimulus accommodated three tasks related to decisions about each of two stimulus dimensions and about both dimensions combined. The circle contained two wedges, each divided into three rings of color (Fig. 1). Participants had to decide whether either the color order of the rings (selective color, SEL-C) or the angles of the wedges (selective angle, SEL-A) or both of these features (divided attention, DIV) were the same. Participants performed these tasks in two identical fMRI sessions, throughout which performance accuracy was held at 75% for each task by manipulating the time that the stimulus was on the screen (display time, DT).

2. Results

2.1. Behavioral performance

Fig. 2A shows the average DT of the circle stimulus across the three tasks. A main effect of TASK [$F(2,48) = 262.8$, $P < 0.001$] in

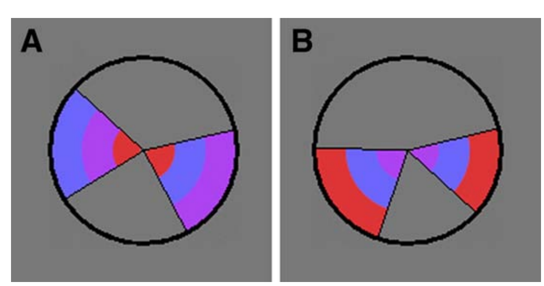

Fig. 1 – Examples of the task stimulus. Participants were instructed to detect a difference in either the angles of the two wedges, in the sequence of color across the three rings, or in either aspect. In (A), there is a difference in the color dimension. In (B), there is a difference in the angle dimension.