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Cognitive Brain Research 25 (2005) 760 – 776
COGNITIVE BRAIN RESEARCH
www.elsevier.com/locate/cogbrainres

Research Report

On the neural basis of focused and divided attention

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Accepted 8 September 2005

Abstract

Concepts of higher attention functions distinguish focused and divided attention. The present study investigated whether these mental abilities are mediated by common or distinct neural substrates. In a first experiment, 19 healthy subjects were examined with functional brain imaging (fMRI) while they attended to either one or both of two simultaneously presented visual information streams and responded to repetitive stimuli. This experiment resembled a typical examination of these mental functions with the single task demanding focused and the dual task conditions requiring divided attention. Both conditions activated a widespread, mainly right-sided network including dorso- and ventrolateral prefrontal structures, superior and inferior parietal cortex, and anterior cingulate gyrus. Under higher cognitive demands of divided attention, activity in these structures was enhanced and left-sided homologues were recruited. In a second experiment investigating another 17 subjects with almost the same paradigm, it was accounted for that in most dual task investigations of focused and divided attention the single tasks are easier to process than their combined presentation. Therefore, the task difficulty of focused attention tasks was increased. Almost the same activity pattern observed during division of attention was now found during focusing attention. Comparing both attentional states matched for task difficulty, differences were found in visual but not in prefrontal or parietal cortex areas. Our results suggest that focused and divided attention depend on largely overlapping neuronal substrates. Differences in activation patterns, especially in prefrontal and parietal areas, may result from unequal demands on executive control due to disparate processing requirements in typical tasks of focused and divided attention: Easier conditions begin with mainly right-sided activity within the attention network. As conditions become more difficult, left-lateralized homologue areas activate.

Theme: Neural basis of behavior
Topic: Cognition

Keywords: fMRI; Focused attention; Divided attention; Mental load

1. Introduction

Attention is not a unitary but a multidimensional concept with interacting subcomponents. A model that tries to summarize central aspects of attention has been presented by Van Zomeren and Brouwer [76]. On a superior level, they differentiate intensity and selectivity aspects of attention. The alertness with tonic and phasic arousal and the ability to sustain attention for a longer period of time are subsumed under the intensity aspect. The aspect of selectivity comprises two subcomponents, focused or selective attention, and divided attention. Focused attention describes the ability to attend only to relevant stimuli and to ignore distracting ones. The skill to distribute the limited mental resources to different sources of information is denoted as divided attention. The selectivity aspects can also be regarded as a capacity of the supervisory attentional system (SAS), that has been introduced by Shallice [64], or

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doi:10.1016/j.cogbrainres.2005.09.011

the central executive, which has been described within the concept of working memory by Baddeley [7,8]. Thus, the concepts of higher attention functions and SAS/working memory merge. The present study raises the question whether focused and divided attention, which are conceptually separated, are mediated by common or distinct neuronal substrates. The measurement of attention, however, is difficult, since attention functions cannot be measured isolated from other information processing. Indeed, their specific contribution can be isolated by comparing task conditions, which differ only in attentional demands but do not vary further task characteristics.

Focused attention has been investigated extensively using neuroimaging methods [15,18,34,39,40,58]. In a positron emission tomography (PET) study by Corbetta et al. [15], subjects had to concentrate on a defined feature of a spatial stimulus and to detect subtle changes while ignoring the remaining features. Significant activation was found in comparison to a baseline condition requiring no discrimination in orbito-frontal cortex, thalamus, insular-premotor regions, basal ganglia, and in visual regions specialized for specific stimulus features. Madden et al. [40] confronted subjects with a series of nine-letter displays. Two letters, always located in the central position of the display in the selective attention condition, were assigned as targets. The comparison with PET scans from a baseline condition using displays without targets revealed activity in the left anterior cingulate. Hopfinger et al. [34] showed that instructive cues directing spatial attention activated a network consisting of the superior and middle frontal gyrus, posterior cingulate cortex, and superior and inferior parietal regions in both hemispheres, using event-related functional magnetic resonance imaging (fMRI). Activity to target stimuli was found in ventrolateral prefrontal cortex, anterior cingulate, superior parietal lobe, and supplementary motor areas. In a PET study using non-spatial stimulus material, subjects were required to categorize serially presented stimuli by color or orientation or a conjunction of these features [58]. Increased activity was demonstrated for the conjunction relative to the single-feature tasks in the right dorsolateral frontal cortex. Coull et al. [18] instructed participants in their PET study to respond to defined non-spatial targets presented in a train of similar, thus distracting stimuli. They observed activation of the right dorsolateral prefrontal cortex and anterior cingulate gyrus, subtracting this task from a control task that required no selective attention. Vandenberghe and coworkers [74] observed significant blood oxygenation level dependent (BOLD) signal changes in structures similar to those observed in other studies on selective attention. Feature attention triggered precentral, superior and inferior parietal and basal ganglia activation. At a slightly lowered threshold additional lateral prefrontal, cingulate and occipital gyrus was observed. Lateral prefrontal and occipital activity turned out to be sensitive to the location of the attended stimulus. In another fMRI study, Loose et al. [39] utilized a visuospatial and an auditory attention task from a computerized attention test battery [80]. When attention was directed to one of theses simultaneously presented tasks, significant activation was found in primary and secondary sensory regions. Moreover, the auditory condition evoked cingulate, the visual condition cingulate, right inferior frontal, left precuneus, and right superior and inferior parietal lobe activity. For the baseline condition, the same acoustic and visual stimuli were used, and subjects should concentrate on their breathing and press the response button when exhaling. This baseline condition, however, required selective attention on internal signals, which might have had an impact on the statistical comparison with attention conditions. Although the results of the outlined studies depend on the paradigms and baseline conditions utilized, it becomes evident that particularly lateral prefrontal, superior and inferior parietal cortex, and anterior cingulate gyrus are involved in tasks on focused attention. These structures are supposed to form the basis of a higher attention related network.

In contrast to broad endeavors to detect, the neuronal correlate of focused attention, few imaging studies have examined divided attention. In the aforementioned PET study by Corbetta et al. [15], there was a condition in which subjects should attend not only to a single but to a combination of three different features of an object and discriminate subtle stimulus changes. However, one might understand this task as a further task of selective attention, as the focus of attention remains directed at a single problem, even if it is more complex due to the feature conjunction. It is not necessary to split attention to process separate, competing information input. In line with our interpretation, Rees et al. ([58], see above) regard their feature conjunction condition as a task on selective attention. In a condition declared as divided attention by Madden et al. [40], targets could occur at any instead of a fixed display position. However, one might demur that the divided attention condition formulated in this study represents a visual search task, which again requires selective rather than divided attention. According to Madden et al. [40], attention had to be divided between multiple display positions in the eligible condition, but the only mental demand that had to be processed remains the detection of two target letters. The only difference to the central condition is that a larger area had to be scanned. Loose et al. [39] used a dual task paradigm to investigate divided attention. Participants of their fMRI study had to perform in parallel the two aforementioned visuospatial and auditory tasks (see above). Similar brain regions as under conditions of selective attention were activated in comparison to the baseline condition. Additional left prefrontal cortex activity, however, was seen only in the divided attention condition. In a further dual task study, it has been considered that working memory is a confounding factor in many divided attention studies. Demands on working memory were