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Neural correlates of dual-task performance after minimizing task-preparation

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Previous dual-task neuroimaging studies have not discriminated between brain regions involved in preparing to make more than one response from those involved in the management and execution of two tasks. To isolate the effects of dual-task processing while minimizing effects related to task-preparatory processes, we employed a blocked event-related design in which single trials and dual trials were randomly and unpredictably intermixed for one block (mixed block) and presented in isolation of one another during other blocks (pure blocks). Any differences between dual-task and single-task trials within the mixed block would be related to dual-task performance while minimizing any effects related to preparatory differences between the conditions. For this comparison, we found dual-task-related activation throughout inferior prefrontal, temporal, extrastriate, and parietal cortices and the basal ganglia. In addition, when comparing the single task within the mixed block with the single task presented in the pure block of trials, the regions involved in processes important in the mixed block yet unrelated to dual-task operations could be specified. In this comparison, we report a pattern of activation in right inferior prefrontal and superior parietal cortices. Our results argue that a variety of neural regions remain active during dual-task performance even after minimizing task-preparatory processes, but some regions implicated in dual-task performance in previous studies may have been due to task-preparation processes. Furthermore, our results suggest that dual-task operations activate the same brain areas as the single tasks, but to a greater magnitude than the single tasks. These results are discussed in relation to current conceptions of the neural correlates of dual-task performance.

Keywords: Dual task; Preparation; Task-switching; fMRI; Brain; Inferior prefrontal; Superior parietal

Introduction

Performing two tasks concurrently is commonly considered one of the hallmark examples of a cognitive process or set of processes that requires executive functioning. Specifically, dual-task processing requires the allocation of top–down (i.e. central executive) attentional control for the coordination and management of multiple tasks in working memory (Baddeley, 1986). Recently, neuroimaging studies have examined the neural substrates of dual-task processing and have reported a pattern of prefrontal, parietal, temporal, and subcortical activation associated with concurrently performing two tasks (Adcock et al., 2000; Bunge et al., 2000; D'Esposito et al., 1995; Herath et al., 2001; Jiang, 2004; Schubert and Szameitat, 2003). However, despite these important contributions to understanding the neural substrates of dual-task processing, a number of important questions remain unanswered.

Previous neuroimaging studies using dual-task or psychological refractory period (PRP) paradigms have typically employed block designs (e.g. Adcock et al., 2000). One inherent limitation of block designs is that only one trial type is typically presented per block. This allows participants to predict and prepare for the particular task presented during that block. Therefore, comparing the brain activation from two different blocks of trials may result in some activation unrelated to the cognitive process being investigated, such as greater levels of task-preparation. For example, in blocked dual-task studies, dual-task blocks require greater executive and attentional control, enhanced motor and attentional preparation, greater working memory demands, and greater cognitive flexibility than single-task blocks. Motivation may also differ between blocks. Therefore, a comparison of dual-task and single-task blocks may show activation associated with differences due to any number of cognitive processes. Although many different cognitive processes are probably important for successful dual-task performance, some of them may be unnecessary for the coordination and sequencing of multiple tasks. For example, numerous behavioral studies have suggested that at least a proportion of the processing associated with dual-task performance reflects a

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limitation in the ability to keep two or more tasks prepared at the same time, even though the effects of preparation are not limited to dual-task conditions (Gottsdanker and Shragg, 1985; Koch et al., 2004; Pashler, 1984, 1994; Pashler and Johnston, 1998).

Other neuroimaging studies have employed block designs in which the blocks varied by the interval separating the tasks rather than the number of tasks performed. For example, some studies have compared neural activation during a block of trials in which the stimulus-onset asynchrony (SOA) between the first and second stimulus is very short to a block of trials in which the SOA between the first and second stimulus is longer (Herath et al., 2001; Jiang et al., 2004; Jiang, 2004; Schubert and Szamietat, 2003; Szameitat et al., 2002). The benefit of employing this type of design is that it compares activation from two types of dual-task blocks (e.g. dual-task with short SOA versus dual-task with long SOA) and circumvents some of the problems when trying to directly compare dual-task blocks to single-task blocks. However, findings from SOA manipulations in block designs could produce results that are related to forcing participants to prepare two tasks with a short SOA in one block but allowing participants to prepare for each task one at a time in blocks with long SOAs (Dreher and Grafman, 2003). Therefore, similar to dual/single-task blocked studies, preparation-related activation (as well as other factors) could have contributed to previous results that have employed SOA manipulations.

In support of this argument, studies of task-preparation have frequently reported a pattern of activation in brain regions similar to those reported in dual-task and PRP studies, including the right inferior frontal gyrus (Brass and von Cramon, 2004; Dreher et al., 2002; Sohn et al., 2000), left inferior frontal junction (Brass and von Cramon, 2002, 2004), and left inferior frontal gyrus (Perianez et al., 2004), thus lending credence to the possibility that some of the dual-task-related activation in previous studies was actually associated with greater engagement of preparatory processes rather than being involved in processes necessary for dual-task performance. The current study was designed to elucidate the regions important in dual-task processing when the degree of task-preparation between single and dual tasks was minimized.

One common method to examine and minimize preparatory effects is to include a block of trials in which single-task trials are randomly and unpredictably intermixed with dual-task trials. It is thought that this type of mixed task design requires participants to always be prepared to respond to two tasks regardless of whether the task at hand is a single-task or a dual-task (Pashler, 1994, 1998). Therefore, a comparison of dual-task trials in a mixed block (DM) with single-task trials in a mixed block (SM) provides a measure of dual-task processing in which the level of preparation and working memory demands are equivalent between the two conditions. Furthermore, a comparison of the reaction time and accuracy from the single-task trials in a mixed block (SM) of dual- and single-task trials with the reaction time and accuracy of single-task trials presented in a block composed purely of single-task trials (SP) is thought to provide a measure of the slowing associated with preparatory processes (Pashler and Johnston, 1998). If the comparison between the SM task and the SP task reveals activation in areas that have been reported in previous dual-task and PRP studies, such as the inferior frontal gyrus, it would argue that these regions are not limited to dual-task processes (e.g. management of multiple concurrent tasks).

However, task-switching processes (i.e. the need to switch between two different single tasks in mixed blocks as compared to the repeated performance of a single task in pure single-task blocks) are inherent within a mixed block of dual and single trials and are not present within single-task blocks of trials. Therefore, one could argue that the activation resulting from a comparison of SM and SP trials could be due to the need for task-switching processes in the mixed block instead of differential preparation. In order to investigate this possibility, we analyzed the activation associated with a switch between one type of single-task and another type of single-task within the mixed block and compared the resulting activation to the results from a repetition of a single-task within the mixed block. This analysis will reveal which areas of activation from the SM versus SP comparison are due to task-switching processes.

We predicted that the comparison of DM versus SM conditions would reveal regions that were essential in managing and coordinating the selection and execution of multiple concurrent tasks. These regions included the parietal and prefrontal regions, which have both been implicated in similar executive (Brass and von Cramon, 2002; MacDonald et al., 2000), attentional control (Banich et al., 2000), and response selection (Milham et al., 2001) processes in other tasks. In addition, we predicted greater anterior cingulate cortex activity for the DM condition due to increased response conflict and heightened potential for error (Botvinick et al., 1999) as well as other potential roles in modulating attentional control (Weissman et al., 2003) for the DM condition. Furthermore, clinical (Brown and Marsden, 1991), split-brain (Pashler et al., 1994), and prior neuroimaging (Adcock et al., 2000) investigations report a role of subcortical structures in dual-task processing, therefore we predicted that subcortical regions such as basal ganglia and thalamus would also be found for this comparison.

In the comparison of the SM versus SP comparison, we predicted that regions uninvolved in dual-task processing would be established. Specifically, if the SM condition involved a greater degree of task-preparatory processes than the SP condition, then we should observe greater SM activity in regions commonly implicated in preparatory processes including superior parietal cortex (Corbetta et al., 2000; Corbetta and Shulman, 2002; Shulman et al., 1999), right prefrontal cortex (Brass and von Cramon, 2004; Dreher et al., 2002; Sohn et al., 2000), and premotor cortex (Adam et al., 2003; Matsumoto et al., 2003). However, if any regions from this analysis overlap with the task-switching results, then task-switching processes would provide an alternative explanation for these effects.

In the current experiment, we examined the regions involved in dual-task processes in an event-related paradigm in which we could minimize effects related to preparation. We also assessed whether any of the inferior prefrontal regions that have recently been implicated in dual-task processing could be accounted for by task-preparation. Finally, we examined whether task-switching processes could account for differences in activation between the mixed block of single trials and pure block of single trials.

Method

Participants

Thirty-three volunteers (20 female) from the University of Illinois student community between the ages of 19 and 32