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Time-Resolved Decoding of Two Processing Chains during Dual-Task Interference

Highlights

- The brain activity was recorded while subjects performed a dual task
- Multivariate pattern analyses were applied to decompose the chains brain processes
- Chains of brain processes were initially parallel and then mutually exclusive
- A new theoretical framework for multitasking is proposed

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In Brief

Marti et al. explore the multitasking abilities of the human brain. They find a collision between brain processes when two tasks overlap in time: the chains of brain processes initially operate in parallel, but late processes are mutually exclusive.

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Time-Resolved Decoding of Two Processing Chains during Dual-Task Interference

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SUMMARY

The human brain exhibits fundamental limitations in multitasking. When subjects engage in a primary task, their ability to respond to a second stimulus is degraded. Two competing models of multitasking have been proposed: either cognitive resources are *shared* between tasks, or they are allocated to each task *serially*. Using a novel combination of magneto-encephalography and multivariate pattern analyses, we obtained a precise spatio-temporal decomposition of the brain processes at work during multitasking. We discovered that each task relies on a sequence of brain processes. These sequences can operate in parallel for several hundred milliseconds but beyond ~500 ms, they repel each other: processes evoked by the first task are shortened, while processes of the second task are either lengthened or postponed. These results contradict the resource-sharing model and further demonstrate that the serial model is incomplete. We therefore propose a new theoretical framework for the computational architecture underlying multitasking.

INTRODUCTION

However alert we may be, we can hardly focus on more than one task at any one time. The process by which the human brain selects relevant information from the environment has fundamental temporal constraints, dramatically illustrated in dual-task settings: when subjects focus on a task, this engagement impairs their ability to initiate the motor response to another stimulus (the psychological refractory period) (Pashler, 1994) or even to detect it (the attentional blink) (Raymond et al., 1992). Current models of dual-task interference agree that (1) performing a task involves at least three stages (sensory, central decision, and motor processing; Figure 1A), (2) sensory and motor stages can operate in parallel with other operations, but (3) the central stage has limited capacities. A key point of disagreement between models regards the central stage: the serial bottleneck model hypothesizes that the central stage is serial; that is, it processes only one task at a time (Pashler, 1994; Sigman and Dehaene, 2005) (Figure 1B). By contrast, the resource-sharing model proposes that the central stage can process multiple tasks in parallel but possesses limited resources that therefore have to be shared between tasks (Kahneman, 1973; Tombu and Jolicoeur, 2003). As the delay between tasks 1 and 2 shortens, the period during which resources are shared increases, therefore slowing down both tasks' processing (Figure 1C).

To understand how the human brain handles multi-task situations, we investigated three critical predictions that disentangle the resource sharing and the serial bottleneck models. First, the resource-sharing model suggests that Task 1 processing is prolonged during dual tasking, while the bottleneck model predicts that it remains unchanged. Second, resource-sharing models propose that the central stages of Task 1 and 2 are performed in parallel, while bottleneck models propose that they are performed one after the other. Third, if capacities are shared, the amplitude of brain activations associated with central stages should decrease for both tasks during task overlap. By contrast, according to the bottleneck model, activation amplitude for the task that is currently processed should be similar within or outside the interference period.

Testing these predictions is challenging as it requires simultaneously monitoring, at the whole-brain level, each of the cognitive processing stages of the two tasks, from stimulus presentation to motor response. Recent developments in magnetoencephalography (MEG) combined with multivariate pattern analysis (MVPA) may provide a first approximation of this ideal recording setup, by isolating and tracking within each subject the neural patterns specific to each processing stage. MVPA can be applied to MEG signals by fitting a different classifier on every time sample separately (Figure 1D). The resulting time course reveals whether two experimental conditions can be separated based on the succession of brain responses they elicit and how this information evolves across time. An important aspect of this technique is that each classifier trained at time *t* (thereafter referred to as "training time") can also be tested on its ability to discriminate conditions at other time points *t'* ("testing time"). Such *temporal generalization* (Figure 1D) is a good way to reveal the onset and the duration of a given pattern of brain activity, and how it varies with experimental conditions (King and Dehaene, 2014). Here, we apply this tool to the decomposition of dual-task processes. We first identify a series of classifiers that decode the successive steps of each task *outside* the interference period (i.e., at a long