Locating the Neural Correlates of the Problem State Resource: Analyzing fMRI Data on the Basis of a Computational Model

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Introduction

Multitasking often has to be investigated with experiments using complex tasks. An example is our research on the 'bottleneck' role of the problem state resource (Borst, Taatgen, & Van Rijn, 2010). The problem state resource is the part of working memory that is used to store intermediate results. Previously, we have shown that its capacity is limited to one element. Because we were interested in finding the neural correlates of the problem state resource, and fMRI data of complex tasks are difficult to analyze with classical analysis methods, we developed a novel, computational-model-based fMRI analysis method. We show that this method can be used to analyze complex tasks by locating the brain area responsible for maintaining problem states: the inferior parietal lobule.

Methods

Our participants were asked to perform a 'triple-task' in the fMRI scanner: They solved multi-column subtraction problems, entered text, and performed a listening comprehension task concurrently. Both the subtraction task and the text entry task had two versions: an easy version without problem state usage and a hard version with problem state usage. Due to the problem state bottleneck, problem states had to be replaced constantly in the hard subtraction – hard text entry condition (Borst et al., 2010). This should lead to considerably more activity in brain areas associated to the problem state in the hard – hard condition than in the other conditions. That is, we predicted an over-additive interaction effect.

This type of complex task is difficult to analyze with classical fMRI analysis methods that assume 'pure insertion'. In such a complex task cognitive resources are used at different time points in each trial, while pure insertion methods assume that a resource is active in one condition but not in the other conditions. As an alternative analysis method, we fit a computational model developed using ACT-R (Anderson, 2007) and Threaded Cognition (Salvucci & Taatgen, 2008) to the behavioral data, and subsequently regressed the model's problem state activity against the fMRI data to find regions that are sensitive to problem state activity. This gives a much finer-grained stimulus function than classical methods, as we use model behavior within a single trial. Figure 1a and 1b give a concrete example of what this means over the course of four trials in our experiment. Figure 1a shows the single stimulus function of the problem state resource that was used for the new model-based analysis and Figure 1b shows the four stimulus functions that are needed for the classical fMRI analysis of an interaction effect.

Results & Discussion

The results of the analyses are displayed in Figure 1c (model-based method) and 1d (classical method). First, the results show that the model-based analysis method outperformed the classical method: it enabled us to find the neural correlates of the problem state resource, while the classical method did not yield any significant results. Secondly, the results show that the problem state resource is located in the posterior parietal cortex, with the peak activity in the inferior parietal lobule.

These findings illustrate the applicability of a new analysis method for fMRI, which not only allows for using complex tasks in the fMRI scanner, but also for locating multiple cognitive resources in one experiment. For example, while we have shown the results for the problem state resource, the same methodology can be used for the visual resource, yielding an area in the occipital cortex. Furthermore, this model-based fMRI analysis method can be applied to every data set when there is a model available that is more detailed than the global trial structure of the experiment, showing which constructs of a model are linked to which brain areas.

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References

Anderson, J. R. (2007). *How can the human mind occur in the physical universe?* New York: Oxford University Press.

Borst, J. P., Taatgen, N. A., & Van Rijn, H. (2010). The problem state: A cognitive bottleneck in multitasking. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 36*(2), 363-382.

Salvucci, D. D., & Taatgen, N. A. (2008). Threaded cognition: An integrated theory of concurrent multitasking. *Psychological Review, 115*(1), 101-130.

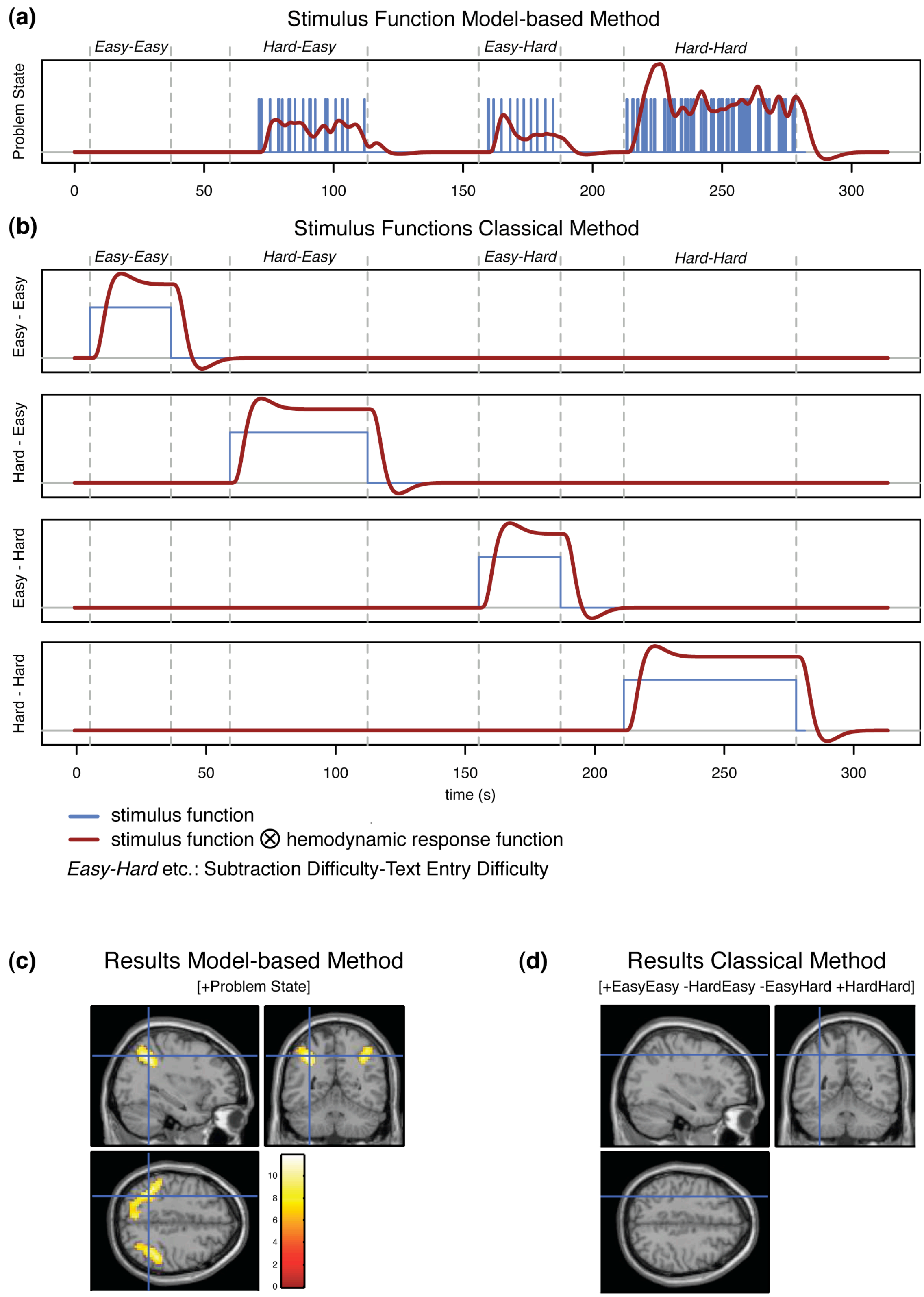

Figure 1. Comparison of the model-based analysis method and the classical method. Panel (a) shows the demand function of the problem state resource in the model in blue, and its convolution with a hemodynamic response function in red. Panel (b) shows the four stimulus functions that are necessary to analyze an interaction using the classical method. *Easy-Easy* etc. above the diagrams indicate the experimental condition. Panel (c) shows the results of the model-based method (contrast is displayed above the results), and (d) the results of the classical method.