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BRAIN MECHANISMS OF PROACTIVE INTERFERENCE IN WORKING MEMORY

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Abstract—It has long been known that storage of information in working memory suffers as a function of proactive interference. Here we review the results of experiments using approaches from cognitive neuroscience to reveal a pattern of brain activity that is a signature of proactive interference. Many of these results derive from a single paradigm that requires one to resolve interference from a previous experimental trial. The importance of activation in left inferior frontal cortex is shown repeatedly using this task and other tasks. We review a number of models that might account for the behavioral and imaging findings about proactive interference, raising questions about the adequacy of these models.

Key words: left inferior frontal gyrus, proactive interference, executive function, neuroimaging, interference-resolution, inhibition.

What is it that limits our intellectual success? Clearly, there are large differences in performance on many tasks that engage cognitive skills. What is at the heart of these performance differences? Dating back to the very beginning of psychology, this has been a central issue in understanding the nature of human cognitive achievement. In the past 50 years, the concept of "capacity" has dominated discussions of cognitive success, and this concept has achieved an important status as an explanatory construct that might account for variations in cognitive performance. Although the idea of capacity varies in its conceptualization, one popular account describes capacity as the ability to use controlled attention to maintain information actively (Barrett et al., 2004). In particular, the capacity to store information in working memory has moved to center stage as an account of a host of important cognitive functions.

One reflection of the perceived importance of working memory is the sheer number of published studies that focus on this cognitive system. A count of papers in MEDLINE that cite "working memory" in their titles or abstracts reveals that this number has grown from 22 in 1984 to 137 in 1994 to 565 in 2004. Why is it that working memory has become so prominent an object of study? The reasons are two. First, working memory has been documented as an important basic component of such acclaimed human intellectual achievements as reasoning, language-processing, and problem-solving (e.g. Just and Carpenter, 1999; Daneman and Merikle, 1996; Fry and Hale, 1996). Second, variation in working memory capacity has often been cited as a cause of variation among individuals in many cognitive tasks (Kyllonen and Christal, 1990). Related to this second issue, variation in working memory capacity has been considered a basic cause of the decline in cognitive skills with normal aging (e.g. Salthouse, 1996). Thus, if one can understand the mechanisms that determine working memory capacity, one will have a firmer understanding of an important component of many respected higher cognitive skills and a firmer understanding of why individuals differ from one another on these skills.

In this paper, we review the effect of a critical variable, proactive interference from previously relevant material (PI), which exerts significant control over the amount of information that can be retrieved from working memory. Specifically, we are concerned here with reviewing research on the brain mechanisms that are involved in the resolution of proactive interference. We concentrate on the resolution of proactive interference because it is not just an experimental curiosity. As the classic study by Keppel and Underwood (1962) demonstrated, it is possible that forgetting from working memory would be minimal or nonexistent were it not for the interference caused by prior material. Also, Whitney et al. (2001) have shown that a measure of susceptibility to proactive interference is a strong predictor of performance on the working memory span test, suggesting that span performance is at least in part a function of proactive interference effects. And, May et al. (1999) have shown that span performance on later trials is worsened by performance on earlier trials of the test, indicating that at least some of the variance in span performance is a function of susceptibility to proactive interference. Furthermore, it has been shown that working memory span is a good predictor of the ability to resolve proactive interference in a variety of tasks (e.g. Conway and Engle, 1994; Chiappe et al., 2000; Rosen and Engle, 1998; Whitney et al., 2001). In short, if working memory is critical to normal cognitive functioning, then proactive interference is an important determinant of the success of working memory.

Let us summarize: Working memory appears to be a critical ability underlying many higher cognitive functions, as revealed by the value of the working memory span test in predicting performance in language-comprehension, reasoning, and problem-solving tasks (Daneman and Carpenter, 1980; Just and Carpenter, 1999). Performance levels on the working memory span test, in turn, appear to be closely related to the ability to resolve proactive inter-

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Abbreviations: ACC, anterior cingulate cortex; gF, fluid intelligence; IFG, inferior frontal gyrus; PI, proactive interference from previously relevant material.

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ference from previous information. In fact, people who are relatively successful on the working memory span test are also relatively successful in resolving interference of various types. Indeed, Engle (2005) has gone so far as to claim that "working memory is a system that evolved to deal with proactive interference." All in all, then, resolving interference among items in memory appears to be a critical cognitive skill that has important implications for a host of other cognitive skills.

What brain mechanisms resolve interference? That is the focus of our review, and so we turn to this question now.

Brain mechanisms of proactive interference in working memory revealed by the recent-probes task

One experimental paradigm has dominated brain studies of the resolution of proactive interference in working memory. We shall call this the "Recent-Probes" task. The paradigm is due originally to the work of Monsell (1978) and is schematized in Fig. 1. The task is based on the item-recognition task of Sternberg (1966). Participants are given a series of trials in which they are presented a target-set of items to commit to memory (e.g. letters), and they store these items for a retention interval of several seconds, after which they are given a single probe item and must decide whether this probe matches one of the items in that trial's target-set. Some probes will match one of the target-set items, thereby eliciting a positive response while some will not match and will elicit a negative response. Monsell (1978) introduced into this paradigm an opportunity for past trials to influence the current one. On some of the trials, a probe that had not been a member of the current trial's target-set was drawn from the previous trial's target-set (called "recent negative probes"). On other

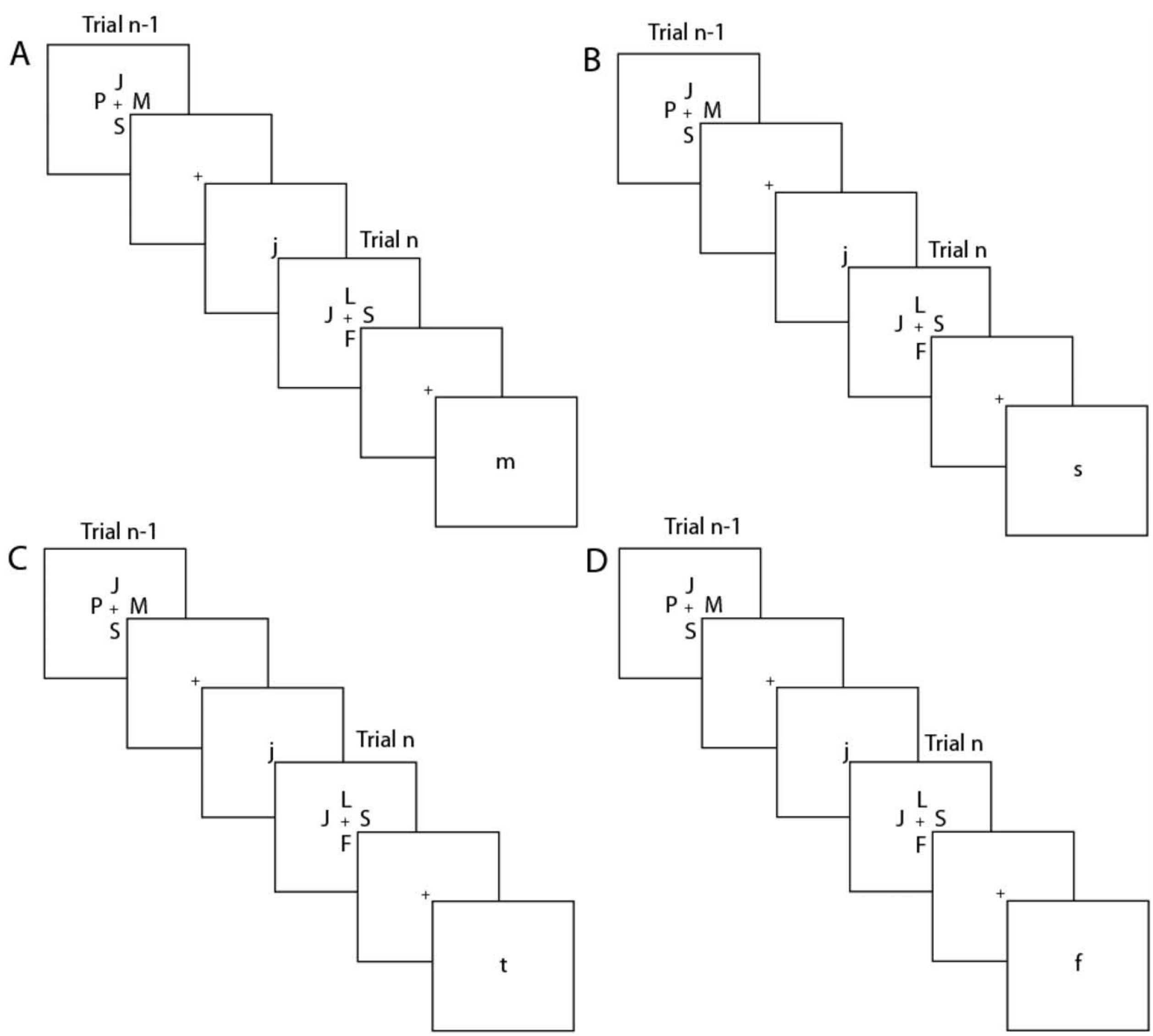

Fig. 1. A schematic of the Recent-Probes task. The four panels show the four central conditions. Panel A represents the recent-negatives; Panel B represents recent-positives. Panel C represents non-recent negatives; and Panel D represents non-recent positives.