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Efficient cognitive operations predict skill acquisition

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ABSTRACT

The present study examined the relationship between performance on the ALTM task and improvement in Stroop task performance across trials. Prior research indicated that the ALTM task may be capturing individual differences in facilitation of procedural memory but has often been confounded with long-term semantic priming due to the nature of the task. The Stroop task was chosen because related semantic information is largely irrelevant to performance. Path analysis revealed that ALTM task performance accounted for 11.3% of the variance in improvement in color–word Stroop improvement over two sessions. No other hypothesized relationships were significant in the path model. Results are discussed in light of the apparent relationship between ALTM task performance and an individual's ability to acquire new procedural memory traces. Implications of these findings are discussed and future directions for continued research are proposed.

1. Introduction

In recent years a number of theorists have noted that typical attention-driven working memory models alone cannot account for a wide range of complex cognitive tasks, such as language comprehension, in which large amounts of information must be maintained to perform the task at hand (Anderson, 1983; Cowan, 1999; Ericsson & Delaney, 1999; Just & Carpenter, 1992). Even Baddeley's model, the original working memory model to postulate attention-driven components, now includes an episodic buffer, which recruits long-term memory elements to support cognitive activities (Baddeley, 2000). Indeed, a variety of alternative models of working memory have been proposed which include long-term memory when considering complex cognition (see Miyake & Shah, 1999). It is now widely accepted that working memory and long-term memory work together to facilitate a wide range of cognitive tasks.

One such way that working memory and long-term memory may collaborate is through the facilitation of procedural memory (FPM). Procedural memory traces are the basis for skilled performance of cognitive operations. As defined by Woltz and Was (2006, 2007), FPM may be considered as the strengthening of persistent memory for prior cognitive operations. Important to this definition is that semantic and declarative information are not the focus of FPM. It is the procedures that take place, such as searching memory or applying appropriate procedures to stimuli, which are strengthened.

Of the numerous theories that include elements of long-term memory in the performance of cognitive tasks, the most relevant is the ACT-R architecture as it provides the most direct parallel to FPM in the present study. While not strictly speaking a model of working memory, Anderson's ACT-R model is able to explain human performance during cognitive activities that could not otherwise be explained given the conventional limits of short-term memory (Anderson, 1983). Within the ACT-R framework there are two definitions of working memory. The first definition is that working memory is primarily the content that is maintained during processing whereas the second definition is any of the processes that allow memory elements to be maintained concurrently (Lovett, Reder, & Lebiere, 1999). The contents of working memory are those declarative and procedural nodes that are more highly activated and can thus be easily accessed relative to other less activated declarative nodes. Both declarative memory and procedural memory rely on the spreading of source activation based on the goal of the cognitive system.

The ACT-R system contains multiple buffers used to coordinate the cognitive system including both a goal module and a declarative memory module, but the driving force for cognition within the framework is the production rule system (Anderson et al., 2004). The production rule system is a complex system that recognizes patterns of information presented within the buffers from the goal module, declarative memory module, and a perceptual-motor module and uses this information to select one production rule to apply based on prior experience and expected utility. As tasks are repeatedly performed, the expected utility for any production rule is altered based on prior success and failure. If a production routinely results in success it would receive greater priority in the future when similar information is loaded into the buffers from goal modules and declarative memory modules.

Although this brief presentation of the ACT-R model does not explain the calculations behind the model in depth, it relates the concepts of the model to the goals of the present study. Given the goals of predicting skill acquisition, the Stroop color–word task was

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chosen to measure improvement in performance across trials. Considering repeated performance on the Stroop task, the ACT-R framework has already been used to model performance on the Stroop task (Altmann & Davidson, 2001). In Altmann and Davidson's modeling of Stroop task performance, it is assumed that the automaticity of reading causes initial discrepancy in responses to incongruent trials. Further exposure to the Stroop task allows the ACT-R framework to adjust the utility value for the production rule for responding to the printed word in order to favor color naming over repeated trials. This adjustment in utility value for a procedure results in facilitation of the procedural memory. Put differently, as procedures result in success they are likely to be favored in future trials. Adjusting utility values over time for successful procedures strengthens prior successful cognitive operations. If the ALTM task is truly capturing a measure of content-specific but item-general FPM, it may be the case that this measure may also relate to the degree of transfer between the color–word Stroop task and the number Stroop task.

The Stroop color-naming task was first developed to measure interference in serial verbal responses (Stroop, 1935). In the years since the first report of the Stroop effect, it has received a great deal of attention in the literature and has still not been adequately explained though it is often interpreted as a subject's ability to inhibit a prepotent response, reading the displayed word, in favor of a slower controlled response (MacLeod, 1992). It is the very automaticity of reading words that is thought to produce the conflict when subjects are asked to name the color of the ink in incongruent trials (MacLeod & MacDonald, 2000). Because the Stroop task represents a subject's ability to maintain a goal and select an appropriate procedure, color naming, in the face of a more automatic response makes it an ideal task to evaluate facilitation of procedural memory. Increased performance, in the present study, is operationalized as a decrease in latency on incongruent trials on the Stroop task.

1.1. The ALTM task

In an attempt to measure the construct of available long-term memory, Woltz and Was (2006) developed the ALTM task. The experimental task as initially employed included four discrete components (see Fig. 1). The first was a memory load in which a subject is presented words to compare and maintain in working memory. The second component in the initial experiments was a selection instruction asking subjects to focus on or ignore one of the types of items presented. Recall of the appropriate items was a third component of the experiment. Finally, subjects were asked to make comparisons between both old and new exemplars as either similar or dissimilar. The assumptions behind the logic of this task are based on the idea that attention-driven processing in working memory should lead to greater accessibility of long-term memory elements, in concordance with a

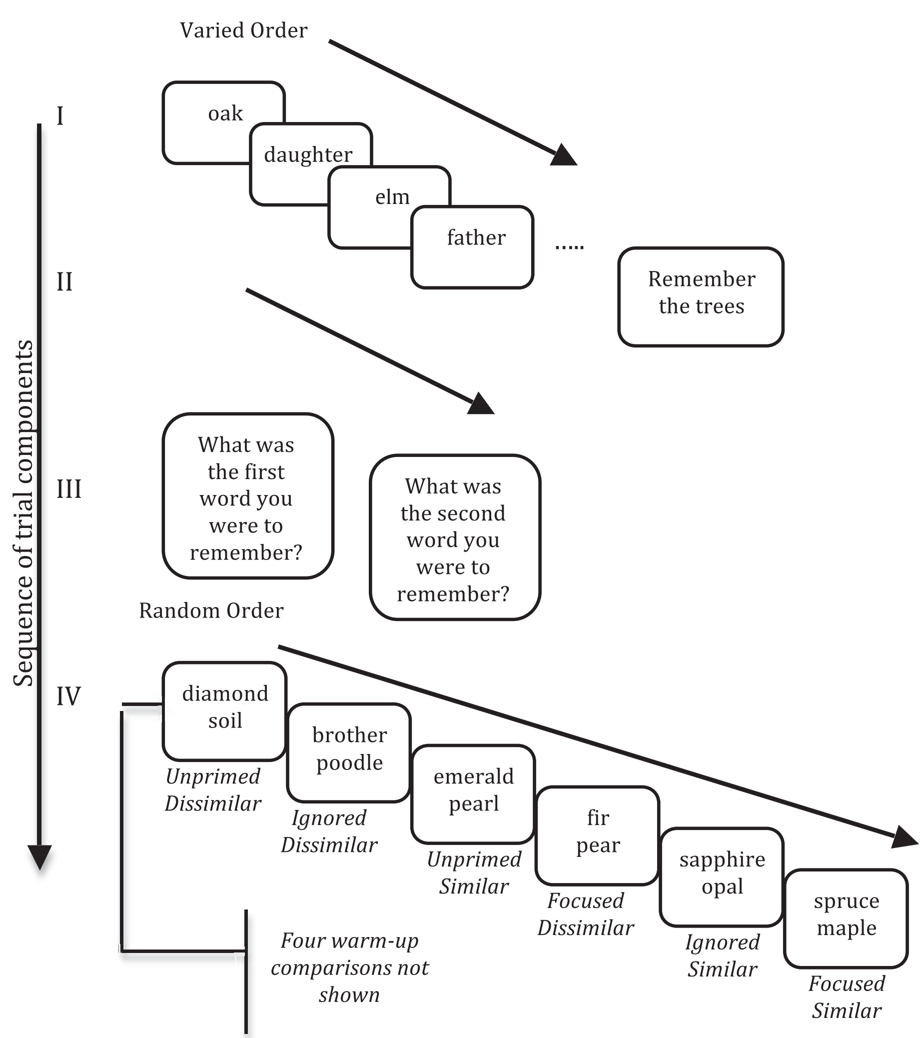

Fig. 1. Example of a trial adapted from Woltz and Was (2006).