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Why does lag affect the durability of memory-based automaticity: Loss of memory strength or interference?

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ABSTRACT

In Rickard, Lau, and Pashler's (2008) investigation of the lag effect on memory-based automaticity, response times were faster and proportion of trials retrieved was higher at the end of practice for short lag items than for long lag items. However, during testing after a delay, response times were slower and proportion of trials retrieved was lower for short lag items than for long lag items. The current study investigated the extent to which the lag effect on the durability of memory-based automaticity is due to interference or to the loss of memory strength with time. Participants repeatedly practiced alphabet subtraction items in short lag and long lag conditions. After practice, half of the participants were immediately tested and the other half were tested after a 7-day delay. Results indicate that the lag effect on the durability of memory-based automaticity is primarily due to interference. We discuss potential modification of current memory-based processing theories to account for these effects.

1. Introduction

Intuitively, practice makes perfect. Whether skill acquisition involves children learning to read, pilots learning a new flight control system, computer programmers learning new programming languages, or employees at a restaurant learning a new point of sale operating system, practice is required to master a new skill. Indeed, one of the most robust findings in the literature on cognitive skill acquisition and automaticity is that practice substantially improves response speed (e.g., Anderson, Fincham, & Douglass, 1999; Logan, 1988; McAndrews & Moscovitch, 1990; Rawson, 2004; Rawson & Middleton, 2009; Rawson & Touron, 2009; Schneider & Shiffrin, 1977; Touron & Hertzog, 2004; Touron, Swaim, & Hertzog, 2007; Wilkins & Rawson, 2010, 2011). Two general types of speed gain have been identified, and different underlying mechanisms have been proposed to account for these two types of gain (e.g., Anderson, 1982; Anderson & Lebiere, 1998; Haider & Frensch, 1996; Logan, 1988; Palmeri, 1997; Rickard, 1997). *Item-general* gains are speedups with practice that accrue to all stimuli of a given type, including both practiced and novel stimuli of that type. Several different mechanisms have been proposed to account for item-general gains, most of which involve improvements in the efficiency of algorithmic processes that interpret items of a given type. *Item-specific* gains are speedups with practice that accrue only to the particular items that have been practiced and not to novel items of the same type. Item-specific gains have primarily been accounted for by the mechanism of memory retrieval. Item-specific gains are of greatest interest here, with specific interest in the durability of item-specific retrieval after initial practice.

Memory-based automaticity theories (e.g., Logan, 1988; Palmeri, 1997; Rickard, 1997) assume that improvements in the speed of responding are due to a strategy shift from item-general algorithmic processing to item-specific retrieval from memory. For example, when first attempting to solve the problem 24 × 7, the answer (168) is computed using algorithmic rules of multiplication, which are item-general rules that can be applied to any multiplication problem. However, after multiple exposures to the same problem, the answer may instead be directly retrieved from memory, which will be faster than algorithmic processing. Faster responding is item-specific because retrieving the answer for this problem will not help answering other multiplication problems (e.g., 32 × 8).

Of course, practice is only one component of learning a new cognitive skill. Learners also need to retain the gains they make during practice to become proficient at a cognitive skill. Although memory-based automaticity theories account for speed gains during practice, these theories are silent concerning what happens to speed gains after practice. However, Wilkins and Rawson (2010; also see Experiment 1 of Rickard, 1997) found that, relative to item-general algorithmic gains, item-specific retrieval gains are less durable over delays. Given

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that rapid and reliable memory retrieval is important for performance in many cognitive tasks, the current study investigates one factor that has been shown to influence the durability of item-specific retrieval gains in explicit memory tasks. Specifically, the current study investigates the effect of lag during practice on the durability of item-specific retrieval gains after practice.

For present purposes, lag refers to the number of intervening items between presentations of a specific stimulus during practice (for review, see Cepeda, Pashler, Vul, Wixted, & Rohrer, 2006). Although the current experiment investigates lag effects for implicit/incidental memory, lag effects have mostly been examined in explicit/intentional memory research. However, we briefly discuss general results from explicit memory research in which participants are required to repeatedly study a list of words or word-pairs for a later recall test. When testing occurs immediately after practice, recall accuracy is often greater for items practiced with a short lag versus a long lag. However, when a delay occurs between practice and test, recall accuracy is worse for items practiced with a short lag than with a long lag (e.g., Balota, Duchek, & Paullin, 1989; Glenberg & Lehmann, 1980; Karpicke & Roediger, 2007; Rawson, 2012; Rawson & Kintsch, 2005; Spieler & Balota, 1996). Thus, durability of memory is greater for items practiced with a long lag versus a short lag.

In contrast to the extensive work on lag effects on the accuracy of explicit memory, minimal research has addressed lag effects on memory-based automaticity. In one recent study, Rickard, Lau, and Pashler (2008) had participants repeatedly solve 24 multiplication items. During practice, half of the items were repeatedly practiced with a short lag and the other half were practiced with a long lag (2 versus 11 intervening items between trials, on average).[1] After practice, participants completed a test session seven days later. During test, all 24 items were repeatedly practiced as one set. Thus, all items had the same lag during test (23 intervening items, on average). In addition, immediately after each trial for the last five blocks of practice and each trial of test, participants reported which process they used to respond on that trial (algorithm only, retrieval only, or other).

Rickard et al.'s (2008) results are reproduced in Fig. 1a and b. At the end of practice, response times were faster for short lag items than for long lag items, which suggests that the likelihood of retrieval use was greater for short lag items than for long lag items (similar to lag effects on explicit memory during immediate tests). However, at the beginning of test, response times were slower for short lag items than for long lag items, which suggests that the likelihood of retrieval use was lower for short lag items than for long lag items (similar to lag effects on explicit memory during delayed tests). As converging evidence, reported retrieval use was higher for short lag items than for long lag items at the end of practice, whereas reported retrieval use was lower for short lag items than for long lag items at the beginning of test.

Although Rickard et al. (2008) demonstrated that lag influenced the likelihood of retrieval after a delay, their study was not designed to explore why lag influences the likelihood of retrieval after a delay. Memory-based automaticity theories are also silent as to why lag would influence the likelihood of retrieval after a delay. Thus, the specific goal of the current study was to replicate and extend Rickard et al.'s findings to explore why lag influences the durability of memory-based automaticity.

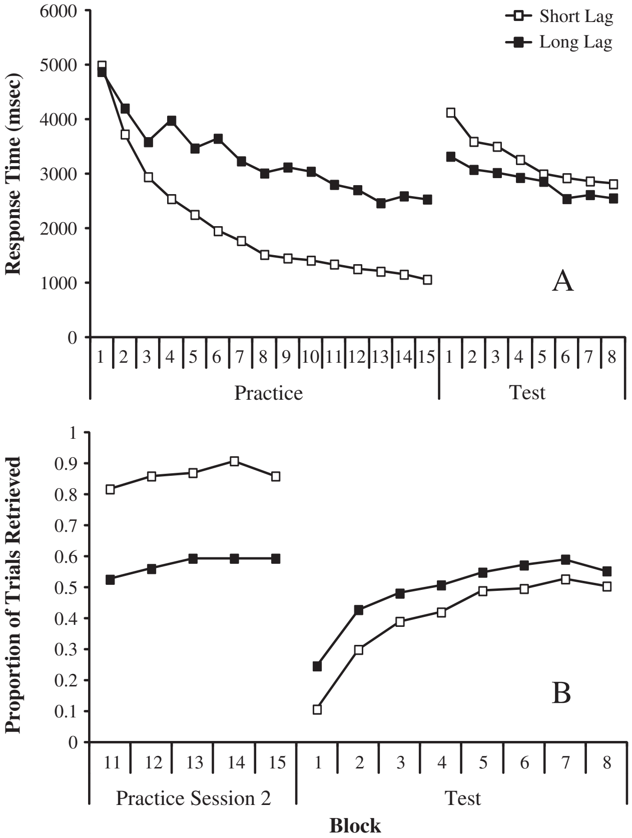

Fig. 1. (A) Mean response time as a function of lag (short or long), session (practice or test), and block from Rickard et al.'s (2008) Experiment 1. (B) Mean proportion of trials that participants reported using retrieval, as a function of lag (short or long), session (practice session 2 or test), and block (last 5 blocks of practice session 2 and all blocks of test sessions) from Rickard et al.'s (2008) Experiment 2.

The current experiment was designed to evaluate two accounts for why lag influences the durability of memory-based processing in automaticity. One possible memory-based explanation is the loss of memory strength with the passage of time. Although loss of memory strength with the passage of time has fallen out of favor as an explanation for forgetting in the explicit memory literature, renewed interest in decay-based mechanisms is emerging from recent research suggesting a biological mechanism for memory loss due to the passage of time (Hardt, Nader, & Nadel, 2013). Additionally, although most memory-based automaticity theories do not specify a mechanism for loss of memory strength, forgetting in ACT-R (e.g., Anderson et al., 1999; Anderson & Lebiere, 1998; Pavlik & Anderson, 2005) is modeled with a decay parameter. ACT-R is an architecture from which specific models can be instantiated and tested, and Pavlik and Anderson (2005) recently proposed a specific ACT-R model to account for spacing effects. Although Pavlik and Anderson modeled recall accuracy data from explicit memory tasks, the model they used provides a general explanation for the spacing effect and thus can reasonably be used to support predictions concerning response time data in an incidental memory task. Like previous iterations of ACT-R (e.g., Anderson & Lebiere, 1998), in Pavlik and Anderson's model the declarative memory strength for a given item influences the speed and accuracy of responding. Additionally, "each time an item is practiced the activation of the item receives an increment in strength that decays away as a power function of time" (p. 567). According to the model, the speed/accuracy of responses during practice is higher for items practiced with a short lag versus a long lag because less time has elapsed for memory strength to decay between encounters of short lag items versus long lag items.

Of importance here, to account for the crossover pattern of lag effects on delayed tests, Pavlik and Anderson's (2005) model modified the ACT-R mechanism for loss of declarative memory strength. In contrast to prior ACT-R models that included one decay rate for all learning events, Pavlik and Anderson's model allowed decay rate to vary as a

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[1] Although Rickard et al. (2008) characterized their work as examining spacing effects, we have adopted the lag effect terminology in our description of their work based on recent reviews that distinguish between these related but non-identical effects (Cepeda et al., 2006; Delaney, Verkoeijen, & Spirgel, 2010). In brief, practice trials for a repeated item can either be completed in immediate succession (i.e., *massed*) or separated by other items (i.e., *spaced*). When practice is spaced, the interval between successive trials for a given item (i.e., *lag*) can also be varied. The *spacing effect* refers to performance differences for spaced versus massed trials, whereas *lag effect* refers to performance differences as a function of shorter versus longer lags.