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Does Working Memory Capacity Moderate the Interleaving Benefit?

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Interleaving examples of different categories, rather than blocking examples by category, often enhances the learning of those categories, but does this benefit vary by learner? On one hand, it could be argued that interleaving places increased demands on a learner's working-memory capacity (WMC), which could foster suboptimal learning for those with lower WMC than for those with higher WMC. On the other hand, studies show that learners with higher WMC seem to process information in more effective ways, in which case lower-WMC learners may benefit more from interleaving than higher-WMC learners. To test these two hypotheses, across five studies, participants studied examples of perceptual categories (artists' styles) or text-based categories (non-parametric statistics) presented either blocked or interleaved. On a final test, participants classified new examples of the studied categories. We found a robust benefit of interleaving across both domains, but this benefit did not vary by WMC.

Keywords: Category induction, Learning, Interleaving, Working memory capacity

Concept and category learning is pervasive throughout all levels of learning—from learning how to identify different animals as a child to learning how to diagnose different diseases as a doctor. Learning can often involve abstracting general principles of a concept via study or practice of multiple examples. For instance, when learning to identify multiple cases of depressive disorders, medical students see many cases of depression—from bipolar to major to psychotic depression—and they have to induce from these cases the symptoms that define a given depressive disorder. Contrary to popular intuitions, research has demonstrated that presenting examples from multiple categories (e.g., cases of several related disorders) in a systematically random sequence (cases of the same disorder are not presented in immediate succession) produces better learning than presenting all examples from one category at a time (cases grouped by disorder). This finding is referred to as the interleaving effect.

In laboratory-based category-learning studies, participants are typically asked to study a series of examples from several categories that are presented either blocked by category or interleaved with examples from different categories, and then asked

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to classify new examples as members of the studied categories on a final test. In majority of the studies, interleaving examples from different categories produces better final-test performance than does blocking examples by category. This finding is well documented across multiple domains, stimuli, and age groups. For instance, interleaving has been shown to be more effective than blocking for the learning of motor skills (e.g., Goode & Magill, 1986; Hall, Domingues, & Cavazos, 1994), cognitive procedures in mathematics (e.g., Rohrer, Dedrick, & Burgess, 2014; Taylor & Rohrer, 2010), perceptual categories (e.g., Kornell & Bjork, 2008; Birnbaum, Kornell, Bjork, & Bjork, 2013), and text-based concepts (e.g., Mayfield & Chase, 2002; Sana, Yan, & Kim, 2017; Zulkiply, McLean, Burt, & Bath, 2012). It has been shown with older adults (Kornell, Castel, Eich, & Bjork, 2010) and with children as young as three years old (Vlach, Sandhofer, & Kornell, 2008).

However, these prior studies have focused on group mean differences in learning. Given that interleaving has great potential for improving student learning in educational settings, it is critical to examine individual differences among learners as possible sources of variability in the effectiveness of interleaving. Students may want to know whether or not it will work for them, and teachers may want to know whether or not the learning gains will be confined to a subset of students. In the current paper, we examined just that—whether individual differences in working memory capacity moderate the interleaving effect during category learning.

Working Memory Capacity (WMC) is an Important Individual Difference Measure

We focused on working memory (WM) because it is one of the main cognitive factors underlying thinking and learning, and an important predictor of academic success (see Cowan, 2014 for a review; Dehn, 2008; Kane & Engle, 2000). WM can be considered as consisting of two distinct processes on which individuals may differ: (a) controlled attention, which serves to maintain a few distinct representations for on-line processing in WM and to sustain attention and prevent attention being captured by irrelevant information; and (b) controlled search of long-term memory (LTM; e.g., Unsworth & Engle, 2007; Unsworth & Spillers, 2010). The extent to which information can be retrieved from LTM will depend on overall encoding ability, the ability to reinstate the encoding context at retrieval, and the ability to focus search on target information and exclude interfering information (Unsworth & Engle, 2007). Working memory capacity (WMC) is an individual-difference variable, which demonstrates that higher-WMC individuals are better than lower-WMC individuals at both maintaining information in WM, strategically integrating it with existing information in LTM, and retrieving related information from LTM (Engle & Kane, 2004; Unsworth & Spillers, 2010).

An individual's WMC can be considered the bottleneck for learning because incoming information must pass through WM before it can be integrated with LTM. Thus, one hypothesis that we tested in the current study is that individuals with higher WMC have sufficient WM resources to better utilize interleaving than individuals with lower WMC. A contrasting hypothesis is that interleaving may compensate for the lack of between-category comparisons and control search and retrieval from LTM with which lower-WMC individuals struggle. As such, individuals with lower WMC may be more responsive to interleaving than their counterparts with higher WMC because it helps the former compensate for their WM limitations.

Interleaving May Optimize Learning for Individuals with Higher WMC More Than for Individuals with Lower WMC

Interleaving examples from different categories can draw learners' attention to the features that vary between categories (see discriminative-contrast hypothesis of interleaving, Birnbaum et al., 2013; Carvalho & Goldstone, 2015; Goldstone & Steyvers, 2001; Kang & Pashler, 2012). But it requires that individuals hold in mind the associated features from multiple categories. Given that higher-WMC individuals are better able to control attention for maintenance of relevant information, ignore irrelevant distractions, and withhold habitual responses than are lower-WMC individuals (Unsworth & Engle, 2007), lower-WMC individuals should benefit less from an interleaved schedule: they may be less likely to resolve and benefit from the contextual interference inherent to interleaving, because the number and complexity of features, and categories to which they must attend and retain for comparison may exceed their WMC, resulting in impaired inductive learning.

To the extent that interleaving also involves retrieving information from LTM about a previously presented example from a given category among distracting examples from other categories (e.g., Bjork, 1975; Hintzman, 2004), those with lower WMC are also disadvantaged: individuals with higher WMC are better at retrieving related information from LTM in the face of distraction (Capaldi & Neath, 1995; Unsworth & Engle, 2007). Lower-WMC individuals may more often fail to utilize appropriate retrieval strategies to access cues and have difficulty in resolving cue overload (Unsworth, Spillers, & Brewer, 2012), resulting in noisier context cues that include both relevant and irrelevant information. If to-be-retrieved features of a given category are associated with multiple contexts (e.g., features of other categories), as would be the case during an interleaved schedule, learners must retrieve target features from LTM through controlled search using only relevant context cues (Unsworth & Engle, 2007), while successfully combating interference to prevent intrusions from other contexts—qualities that are observed among individuals with higher WMC (e.g., Kane & Engle, 2000).

Interleaving May Optimize Learning for Individuals With Lower WMC More Than for Individuals with Higher WMC

On the other hand, prior research suggests that individuals with higher WMC are more likely to report using effective encoding strategies (e.g., grouping) and are more likely to retrieve relevant information from LTM than individuals with lower WMC (e.g., Unsworth, Brewer, & Spillers, 2013; Unsworth & Spillers, 2010). Therefore, it is possible that the

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