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Working memory capacity, strategic allocation of study time, and value-directed remembering

Matthew K. Robison *, Nash Unsworth

Department of Psychology, University of Oregon, United States

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ABSTRACT

To further elucidate the relationship between working memory capacity (WMC) and long-term memory (LTM), the present study investigated how individual differences in WMC relate to strategic encoding and subsequent retrieval in a self-regulated value-directed remembering paradigm. Participants were given 2 min to study lists of words that varied in explicit value and then were asked to freely recall the words they had just studied. In Experiment 1, participants were not given any guidance on effective encoding strategies. The strategy that led to the highest point totals was to ignore the low-value items altogether, and high-WMC participants were more likely to use this strategy. In Experiment 2, half of participants received an instruction on how to best allocate their study time at the beginning of the task, and half received this instruction after three of the six lists. Equating participants on the use of an effective strategy from the beginning of the task eliminated WMC-related differences in task performance. Together the results support the conclusion that low-WMC individuals spontaneously use effective encoding strategies less often than high-WMC individuals. But when instructed to do so, WMC-related differences are greatly attenuated. Therefore, one of the major reasons for the WMC-LTM relationship seems to be the differential development and execution of task-appropriate strategies during encoding of to-be-remembered information.

Introduction

At nearly every moment in our waking lives, we are bombarded with an abundance of information. But both our time and attention are limited. Therefore, we attend to what is important to us and we devote our time in a similar goal-directed manner. This process is not perfect. Occasionally we are captured by irrelevant information in the environment and by irrelevant internal thoughts (i.e., mind-wandering), and we occasionally waste time. But we are largely adaptive in the use of our time and mental energy. Although we all have this skill, people differ substantially in how they choose to devote their time and attention, as well as how well they maintain and execute their goals. The maintenance and execution of such goals is a crucial determinant of working memory capacity (WMC), an important individual difference at the cognitive level that correlates with a host of other important cognitive abilities (Engle & Kane, 2004). WMC correlates with fluid intelligence (Engle, Tuholski, Laughlin, & Conway, 1999) and reading comprehension (Daneman & Carpenter, 1980), as well as our ability to resist mind-wandering and external distraction (Kane et al., 2007; Robison & Unsworth, 2015; Unsworth & McMillan, 2014), especially in contexts where our attention is demanded by the task at hand.

Another instance in which WMC seems to be important is long-term memory (LTM). Prior studies have shown that

* Corresponding author at: Department of Psychology, University of Oregon, Eugene, OR 97403, United States.
E-mail address: mkr@uoregon.edu (M.K. Robison).

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individuals with greater WMC are generally better at tasks that require recalling information from LTM, and this has been demonstrated using tasks including immediate free recall (e.g., Unsworth & Engle, 2007), delayed and continuous distractor free recall (e.g. Unsworth, 2007), recognition and source recognition (e.g. Unsworth & Brewer, 2009), and verbal fluency (e.g. Rosen & Engle, 1997). Specifically, individuals with low-WMC have difficulties dealing with proactive interference and show slower recall, which suggests low-WMC individuals have an enlarged search-set compared to high-WMC individuals (Kane & Engle, 2000; Lilienthal, Rose, Tamez, Myerson, & Hale, 2015; Unsworth, 2007; Unsworth & Brewer, 2009). Low-WMC individuals also have difficulty self-generating cues for search (Unsworth & Spillers, 2010; Unsworth, Brewer, & Spillers, 2013; Unsworth, Spillers, & Brewer, 2012b), and they do not search LTM in a structured manner (Spillers & Unsworth, 2011; Unsworth, Spillers, & Brewer, 2012a).

In addition to examining individual differences during retrieval, recent research has also focused on how variation in WMC relates to strategic differences at encoding. Individuals use different strategies at encoding during tasks that measure WMC, and when controlling for strategy use, the correlation between WMC and reading comprehension actually increases (Turley-Ames & Whitfield, 2003). When given effective strategies to use during encoding, participants benefit, and this is especially the case for low-WMC participants (Turley-Ames & Whitfield, 2003). Bailey, Dunlosky, and Kane (2008) found that the use of normatively effective encoding strategies during tasks measuring WMC (i.e., Operation span and Reading span) correlates with LTM tasks that lend themselves to similar strategies (i.e., paired-associates recall, free recall). Importantly, this partially mediates the relationship between WMC and performance on these measures of LTM. However there is still unique variance in LTM accounted for by individual differences in WMC independent of strategy use. Similarly, Unsworth and Spillers (2010) found that in addition to differences in contextual-retrieval, part of the WMC-LTM relation is due to strategic differences during encoding. Finally, Unsworth (2016) analyzed dynamics at both encoding and retrieval in a delayed free recall task. Greater WMC related to the use of more effective encoding strategies, such as semantic association, fewer intrusions, and better monitoring. Importantly, these various aspects of LTM completely mediated the relation between WMC and successful recall.

One open question in the WMC-LTM relationship is how strategic individuals are when asked to study information that varies in its importance, as well as how memory selectivity relates to WMC. Traditionally, the WMC-LTM relationship is investigated using immediate or delayed free recall tasks as measures of LTM abilities. Participants are given lists of items in a sequential manner and are asked to recall as many items as possible. Therefore, variation in LTM may be due to the selectivity with which participants are using their memory. For example, low-WMC participants may be well aware of their memory limitations and therefore actually choose to remember only a small subset of those items. On a typical 10-item list, low-WMC participants may acknowledge that they will only be able to recall four or five of these items and decide to rehearse these items only. When their performance is examined and we observe 40–50% accuracy, it may actually be the case that these participants are recalling 80–100% of the items that they *chose* to remember. Of course, it could also be the case that low-WMC participants try to remember all the items, and in doing so are only able to encode a rather weak representation of every item. Subsequently they have difficulty recalling many items, not because they had a strong representation of a subset of the items and a nearly non-existent representation of the remaining items, but because they have a weak representation of all items. Therefore, the typical delayed free recall task may limit our ability to understand WMC-related differences in LTM. An alternative paradigm for studying LTM is the value-directed remembering task, which has primarily been used to examine age-related differences in memory.

Using the value-directed remembering paradigm originally developed by Watkins and Bloom (1999), Castel, Benjamin, Craik, and Watkins (2002) gave older and younger adults lists of words that were each paired with a value from 1 to 12. Words were presented sequentially and the values could appear at any point during the list. At recall, participants were given points for recalling the words based on their value and were instructed to try and maximize their point totals. From this task, Castel et al. were able to compute a selectivity index (SI) for each participant. The calculation of the SI is shown below.

$$SI = \frac{\text{subject's score} - \text{chance score}}{\text{ideal score} - \text{chance score}}$$

The ideal score is the maximum number of points based on the number of words recalled. For example, if a participant recalled four words, the ideal score would be 52 (12 + 11 + 10 + 9). The chance score is the average value of items (in this case 6.5). If they recalled the words valued at 12, 10, 7, and 4, their score would be 33, and their SI would be 0.27. An SI of 1 indicates perfect selectivity, 0 indicates chance selectivity, and −1 indicates perfect selectivity for low-value information. When comparing older and younger adults, older adults were actually more selective, even though they recalled fewer words overall (Castel et al., 2002; but see also Hayes, Kelly, & Smith, 2013). These results suggest that as a consequence of a reduced ability to recall information from LTM with advanced age, older adults adapt to memory loss by becoming more selective in what they choose to remember (Castel, 2007). Although older adults and low-WMC young adults are not identical in their cognitive abilities, we may be able to use the findings from aging studies to better understand individual differences in WMC. Despite their lower overall recall abilities, low-WMC individuals may show similar patterns of recall as older adults in a value-directed remembering task. That is, they may recognize their lower LTM abilities and compensate for such by being more selective with their memory.

Despite the many insights the typical value-directed remembering task offers about memory selectivity, it does not allow individuals to differentially allocate study time