CHAPTER 9

Working Memory Capacity: Self-Control Is (in) the Goal

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ABSTRACT

Self-control is defined in relation to current goals of an organism. Working memory capacity (WMC) is defined as a cognitive system for maintaining access to goal representations as needed. Self-control depends on cognitive control, which depends in large part on WMC. We discuss the proposal that WMC reflects the abilities to control attention and to control retrieval from long-term memory. From within this dual-component framework (Unsworth & Engle, 2007) we discuss research that has examined relations between WMC and some types of mental self-control failure like over-general autobiographical memories, intrusive thoughts, and mind-wandering. We also discuss research examining the relation between WMC and delay discounting, a popular experimental paradigm for assessing self-control (Rachlin, 2000). Evidence suggests that for some of these phenomena, WMC is a more primary factor than the associated clinical disorders. In other cases, WMC appears to be secondary to other factors such as intelligence. Across these mixed findings at least two generalities can be derived. The positive findings demonstrate that individual differences in WMC can be a confounding "third variable" for a proposed relation between, for example, depression and over-general autobiographical memories (Dalgleish et al., 2007). On the other hand, the negative findings illustrate that individual differences in WMC can obscure more primary influences in a situation like delay discounting (Shamosh et al., 2008). In either case it would be advisable for researchers to measure WMC as a participant factor, if only to control a major source of interindividual variability in their data. Overall, we hold to our position that WMC is critically important for maintaining good self-control in support of a wide variety of goals.

Keywords: Individual differences, working memory capacity, goal-directed behavior, over-general autobiographical memories, intrusive thoughts, mind-wandering, delay discounting, self-control

Working memory is defined as a system for maintaining access to goal-relevant information in support of ongoing complex behavior and cognition. Functional limits of the working memory system define its capacity and this differs between individuals. Self-control is defined in relation to goals and it is also a goal for its own sake. The working memory system has survival value for the self because it selectively processes and records information that is goal-relevant. Working memory capacity has been closely identified with the ability to control attention (Engle, 2002; Engle & Kane, 2004), an ability that would seem to be critical for self-control and self-regulation. Self-regulation is closely related to self-control, except that the "correct answer" is not clearly defined. Self-regulation and self-control must interact in important ways, and we suggest that working memory capacity supports both of these functions. In this paper we explore the implications of this line of reasoning and suggest how individual differences in working memory capacity might be related to individual differences in the ability to exercise self-control and to self-regulate.

A goal is a reference point around which behavior is organized. Self-control becomes relevant when a person has to make a choice between actions that lead to incompatible goals. Experimental psychologists study how people handle this problem in special situations where the correct choice is defined by the experimenter. When incorrect choices are reflexive, habitual, or salient, then an individual must resist these sources of interference to ultimately make correct choices. To the extent that he or she is successful, the person has maintained good self-control. Otherwise the person has ceded some degree of control to the interfering stimulus or habit.

We are interested in the mental processes that enable a person to deal with interference and distraction to avoid passing control outside the self. These processes depend on executive control, "the process by which the mind reprograms itself" (Logan, 2004, p. 227). In our discussion of how working memory might support self-control we emphasize the function of selection, "the very keel on which our mental ship is built" (James, 1890, p. 680). Working memory maintains access to relevant information and suppresses irrelevant information. We believe the selective function of working memory is important for mental control generally and self-control particularly when a person is tempted to pursue conflicting goals. First we discuss working memory capacity in terms of selective attention and memory processes, mainly in the contexts of laboratory situations in which the experimenter defines both the interference and the goal. Afterward we explore possible links to cognitive control problems that are examined out of concern for psychological health and well-being.

Working Memory Capacity: Background

The study of individual differences in working memory capacity was initiated with the development of the reading span task (Daneman & Carpenter, 1980), intended to measure the ability to simultaneously store and process information. Individuals read a series of sentences for comprehension and attempt to remember the final word of each sentence for later testing. Daneman and Carpenter showed that performance on the reading span task correlated with a measure of complex cognition (reading comprehension) but performance on a simple word span task did not. Numerous variations on the reading span procedure have been devised, referred to collectively as complex span tasks. In the operation span task (Turner & Engle, 1989; Unsworth et al., 2005), participants solve a series of simple math equations, with each equation followed by an unrelated item for later recall. Regardless of content domain of the memoranda or difficulty of the interleaved processing tasks, performance on complex span tasks has shown to be predictive of a wide range of higher- and lower-order abilities (Ackerman, Beier, & Boyle, 2005; Conway et al., 2002; Engle & Kane, 2004; Engle et al., 1999; Kane et al., 2007; Turner & Engle, 1989).

Engle et al. (1999) hypothesized that performance on simple span tasks reflects contributions from short-term memory, but performance on complex span tasks reflects contributions from short-term memory plus the control of attention. This notion is reasonable because in complex span tasks a person must frequently divert attention away from to-be-remembered items to do the processing task, and then back again to encode a new item for later recall. Engle et al. (1999) formed a latent variable to represent the ability to control attention by separating the variance unique to complex span tasks from the variance shared with simple span tasks. The residual variable representing control of attention was more strongly related to a latent variable for intelligence than was the variable for short-term storage. This supported the proposal that the ability to control attention determines how much a person can remember in a complex span task and is also responsible for relationships between such performance and complex cognition. This conclusion leads to the further hypothesis that individuals who perform differently on complex span tasks should also perform differently on tasks that do not require much remembering but make heavy demands on attending. The theory of working memory capacity defined as the executive control of attention has been presented fully in other publications (Engle & Kane, 2004; Kane, A.R.A. Conway, Hambrick, & Engle, 2007). We review a few important empirical studies comprising support for that view.

Working Memory Capacity and the Executive Control of Attention

Antisaccade

Kane et al. (2001) used an extreme-groups design to compare participants who had scored low on a complex memory span task (low spans) to those who had scored high (high spans) in the antisaccade procedure (Hallett, 1978). Participants must inhibit a reflexive-orienting response to an attention-capturing, sudden-onset stimulus, to quickly and accurately perform a simple task such as detecting a letter subsequently appearing in a different location. Low spans were slower and less accurate to detect letters appearing in a location opposite to a flashing stimulus than high spans were. High and low spans did not differ in detecting letters that appeared in the same location as a flashing stimulus (prosaccade condition). In Unsworth, Schrock, and Engle (2004), the experimental task entailed merely looking away from the flashing stimulus in antisacccade conditions, or toward it in prosaccade conditions. Eye tracking data showed that low spans were more likely to incorrectly look first toward, rather than away from, the abrupt-onset stimulus in antisaccade conditions. Low spans also were slower than high spans to initiate correct eye movements away from the stimulus. As in the study by Kane et al., low spans and high spans did not perform differently in prosaccade conditions, however, when looking toward the flash was the correct response.

These results illustrate how working memory capacity differentiates individuals in reference to specific goals. Working memory capacity differentiates individuals when attention-capture interferes with goal-attainment in the antisaccade conditions (detect the letter or look away from the flash). Working memory capacity does not differentiate individuals when attention-capture actually facilitates goal-attainment in prosaccade conditions (detect the letter or look toward the flash). These results indicate that working memory capacity is important for either inhibiting prepotent behaviors that are incorrect with respect to current goals, or for activating correct behaviors that are weakly supported in the current environment. Either approach leads to the conclusion that maintaining robust goal representations in working memory is decisively important for self-control in this sort of situation.

Stroop

In the studies by Kane and Engle (2003) high- and low-span participants were instructed to name the color in which a color-word appeared (Stroop, 1935). On incongruent trials, the color-word was different from the color in which it appeared. On congruent trials, the color-word and color matched. Measures of interference were derived by comparing response times and errors on incongruent trials to those on congruent trials. Low-span individuals showed more Stroop interference than high spans, suggesting that low-span individuals were less able to maintain the goal to name the color, particularly when that goal was only weakly supported by the environment. To more fully test this hypothesis, Kane and Engle (2003) varied the proportion of incongruent trials across blocks. They reasoned that the goal of naming the color would be easier for low spans to maintain in blocks in which incongruent trials were more frequent because such trials could serve to remind the goal (Logan & Zbrodoff, 1979). Therefore, differences in interference effects between span groups should be reduced. In contrast, responding to the incorrect stimulus dimension (i.e., the name of the word) would be coincident with a correct response on a majority of trials in blocks in which congruent trials were more frequent. In these blocks low spans should be more likely to lose the goal of color-naming and lapse into word-reading responses. As predicted the magnitude of Stroop interference was greatest during blocks in which only a small percentage of trials were incongruent and so too was the difference between high and low spans in interference. Similarly to the anti-saccade studies, these data suggest that in the absence of environmental or contextual support, low working-memory-capacity individuals have difficulty executing novel behaviors when these conflict with habitual responses.

Dichotic Listening

Individual differences in working memory capacity predict the ability to block the capture of attention by strongly associated cues. A.R.A. Conway, Cowan, & Bunting (2001) instructed participants to repeat aloud a continuous message presented in one ear while ignoring the message presented in the other ear (Moray, 1959). During the course of the procedure, each participant was presented with his or her own first name in the unattended message. Of the high-span participants, only 20% reported hearing their own name in the unattended message, whereas 65% of the low spans reported doing so. High spans more effectively ignored the attention-capturing stimulus to concentrate their efforts on the goal of shadowing the attended message.

Comparison of Successive Visual Arrays

Control of attention allows high spans to restrict access to immediate memory, protecting to-be-remembered information from interference from irrelevant material (Engle, 2002). Some evidence consistent with this hypothesis was obtained by Vogel, McCollough, & Machizawa (2005). In the visual arrays task (Luck & Vogel, 1997) participants are briefly shown a target display containing a number of colored rectangles. After a delay period, participants view a probe display that might be identical to the first one or changed with respect to some attribute of one of the rectangles (e.g., its color or orientation). Cowan et al. (2005) used this task as a measure of working memory capacity and reported strong correlations with performance on complex span tasks.

Participants in the studies by Vogel et al. (2005) were cued to attend only the right or left side of each target array, knowing they would be probed for memory concerning the cued side only. There were either four items on the relevant side and no items on the irrelevant side, or else two items on each side of the target display. For individuals with low working memory capacity (measured in a separate arrays task), slow cortical potentials measured by EEG during the delay period between standard and test arrays were indistinguishable whether there were four items on the relevant side and none on the irrelevant side, or two items on the relevant side and two on the irrelevant side. For high working-memory-capacity individuals, slow cortical potentials during the delay period showed an orderly relationship to the number of items on the relevant side of the target display only. Behavioral results were correlated with the EEG results (Vogel et al., 2005).

Working Memory Capacity and Controlled Retrieval

Individuals differing in working memory capacity also differ in the ability to selectively focus on goal-relevant information and ignore goal-irrelevant information, even in situations where memory demand is low. In many cases there is only one critical thing to remember, the goal of the task. The next section focuses on studies that have examined working memory capacity in terms of controlled, effortful retrieval, in contexts rich in interference.

Proactive Interference

One kind of interference in memory that has been extensively studied is called proactive interference (Wickens, Born, & Allen, 1963). This refers to reduced learning during the course of a memory experiment resulting from interference from earlier learned items. Recall declines when people are exposed to successive lists composed of words from the same category (e.g., farm animals). Individual differences in working memory capacity predict susceptibility to proactive interference (Kane & Engle, 2000; Rosen & Engle, 1998). Proactive interference can be demonstrated in scores from complex span tasks used to measure working memory capacity, and correlations with intellectual abilities are reduced when complex span lists are manipulated to reduce proactive interference (Bunting, 2006).

Low spans in the studies by Kane and Engle (2000) showed greater decrements in recall across lists than high working memory capacity individuals. Participants were also required to perform an attention-demanding, finger-tapping task during list encoding, recall, or both. This additional mental-motor load caused high-span individuals to show proactive interference effects equivalent to low spans regardless of when the load was imposed. This suggested that high working-memory-capacity individuals normally used executive control processes unavailable to low-capacity individuals to resist proactive interference, but such control processes were no longer available to high spans when under a load.

Rosen and Engle (1998) tested high and low spans with lists of paired-associates in A–B, A–C, A–B form. High spans were faster to reach criterion learning and produced fewer first-list intrusions than low spans when learning the second list (A–C) that shared cues with the first list (A–B). High spans were slower than other high spans in a control condition to relearn the A–B list when presented a second time after learning the A–C list. These results were proposed to reflect suppression of the earlier list by high spans (Rosen & Engle, 1998). Conversely, low-capacity individuals were faster to relearn the A–B list than their matched controls, suggesting an ironic benefit from not doing the mental work necessary to combat interference while learning the A–C list.

Fan Interference

Participants in Cantor and Engle (1993) were shown lists of sentences to study for later recognition memory testing in the fan paradigm (Anderson, 1974). Some sentences uniquely mapped persons to places—for example, "The artist is in the house." Learning sentences that together violated one-to-one mapping—for example, "The fireman is in the store; the fireman is in the zoo; the doctor is in the house"—created fan interference, which increases with increasing cue-overlap. Generally when people are shown the studied and new sentences for recognition, response times are slower and people make more errors as fan increases. In Cantor and Engle (1993) individual differences in fan-related slowing were strongly related to working memory capacity. So much so in fact, that the two measures redundantly predicted verbal aptitude in regression analyses.

Working Memory Capacity As Primary and Secondary Memories

Unsworth and Engle (2007; 2006b) proposed that individual differences in working memory capacity reflect the contributions of two processes: *(1)* active maintenance of information in an attention-like primary memory and *(2)* controlled, cue-driven retrieval from a secondary memory. A participant in a memory experiment is able to code his or her experiences as belonging to a global context (or experimental context), a list context, or an item-level context. Contextual features or attributes are associated in secondary memory with the attributes of the to-be-remembered list items. Contextual levels may be distinguished by their specificity along the temporal dimension. When it is time to retrieve the needed information, participants use retrieval cues to point with greater or lesser precision at the context in which the information was encoded. Similar proposals are found in many existing memory models (e.g., Atkinson & Shiffrin, 1968).

Over-general retrieval cues result in the inclusion of irrelevant information in the searched areas of secondary memory, resulting in more forgetting. Low-span individuals suffer more from proactive and other kinds of interference because they fail to constrain search of secondary memory to relevant information. Consistent with this idea, low spans tend to commit more errors than high spans by incorrectly recalling items from previous lists (Unsworth & Engle, 2006). Failing to access information specific to appropriate contexts is another potential source of variability in cognitive control that might have implications for self-control.

Working Memory Capacity, Self-Control, and Self-Regulation

We have sketched a picture in which individual differences in working memory capacity reflect individual differences in the interrelated abilities to selectively attend and remember information, and use that information effectively to achieve simple goals defined within controlled experimental environments. We believe that such abilities are critical for living successfully outside the laboratory as well. In this section we review three ways the construct of working memory capacity has been applied to questions about controlling the contents of the mind: *(1)* retrieving autobiographical memories, *(2)* suppressing unwanted thoughts, and *(3)* keeping the mind from wandering. We conclude by examining working memory capacity in a situation requiring bona fide self-control.

Working Memory Capacity and the Self-Memory System

The self is undoubtedly a powerful organizing framework for memories. Macrae and Roseveare (2002) showed that self-oriented memories were relatively immune to retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994) compared to memories oriented toward other people. If accessible, autobiographical memories can be used to support current goal seeking (Williams et al., 2007). Disorders of over-general autobiographical memory retrieval have been associated with clinical problems like depression and post-traumatic stress disorder (Brewin, 1998) as well as diminished working memory capacity and problem-solving ability (Williams et al., 2006). In the Autobiographical Memory Test (Williams & Broadbent, 1986), participants are shown lists of word cues and are asked to respond to each cue by reporting a specific memory (an event occurring at a particular place and time, lasting less than one day). Errors other than omissions are judged incorrect with respect to one of these two requirements. ("I always enjoyed going to the beach" is too general because it does not specify a particular beach and "I went to the beach all last year" is too general because it does not specify a particular time).

Williams et al. (2007) proposed a complicated system including affect-regulation mechanisms interacting with memory processes (*see also* Conway & Pleydell-Pearce, 2000) to explain the phenomenon of over-general autobiographical memories in depression. In its broad outlines, the theory borrows from general memory models (e.g., Atkinson & Shiffrin, 1968), so it is also similar in many respects to the working memory capacity frameworks presented by Unsworth and Engle (2007) as well as those that place more emphasis on executive control (Engle & Kane, 2004). The self-memory system is composed of two major components: a long-term memory called the autobiographical knowledge base and a working memory called the working self (Conway & Pleydell-Pearce, 2000). The autobiographical knowledge base is organized according to global, intermediate, and specific levels of description. Strategic, top-down search of autobiographical memory uses appropriately specific cues to sample information level by level. Direct spontaneous retrieval depends on associative processes (Conway & Pleydell-Pearce, 2000) that are subjected to inhibiting or filtering by the working self. The working self sets up retrieval plans to guide search of the autobiographical knowledge base, compares recovered candidate memories, and allows output of approved memories. These activities are all constrained by active goals of the self-system. Williams and colleagues (Williams, 2006; Williams et al. 2007) proposed several specific processes to explain the phenomenon of over-general autobiographical memories.

Through related processes of capture and rumination, intrusive thoughts gain control of the self-memory system. Through related processes of functional avoidance and mnemonic interlock (Williams, 1996) intermediate-level information tends to cue only other intermediate-level information, and strategic search of associative memory cannot proceed to access memories represented at specific-event levels. Some memories at the specific-event level are related to traumatic events, and the threats to self recorded in such memories may become over-generalized to other specific-event level memories. If this is the case, a depressed person will be unable to access specific-event level memories resulting from a generalized protective habit of avoiding threatening cognitions.

Evidence suggests that the over-general retrieval phenomenon is more directly related to working memory capacity than to affective disorders. This suggests further that some of the more specialized mechanisms proposed by Williams et al. (2007; Williams, 2006) may not be necessary to account for relevant data. For example, Dalgleish et al. (2007) found that reporting over-general autobiographical memories was strongly predicted by performance on a verbal fluency task, a test of executive function shown to be related to working memory capacity (Rosen & Engle, 1997). The relationship held even after removing the variance shared with depression, suggesting that the over-general autobiographical memory disorder is not an outcome of depression. Participants in Dalgleish et al. (2007) were also given a reversed version of the test, in which they were instructed to respond with general memories instead of specific ones. Results were likewise reversed: More depression and less working memory capacity were related to more overly specific memories.

Depressed participants in Dalgleish et al. (2007) erred by recalling too many specific autobiographical memories, but they should not have been able to do this at all according to the theory of over-general autobiographical memories outlined above. These results suggest a general observation: Working memory capacity will be helpful for producing a memory on demand, whether the goal is to produce a series of very general memories (e.g., name all the animals you can think of that start with the letter "f") or very specific ones (e.g., name all the cities you have visited this year and when).

Working Memory Capacity and Suppressing Unwanted Thoughts

Brewin and Beaton (2002) studied the ability to suppress unwanted thoughts in relation to working memory capacity and intelligence using the "White Bear" paradigm (Wegneret al., 1987). Participants were left alone in a room to continuously verbalize their thoughts over three consecutive sessions. In the first session, participants were just instructed to freely verbalize. Before the second session participants were instructed not to think about white bears and to report any such thoughts (suppression condition). Before the third session, participants were instructed to think about white bears and report the occurrence of such thoughts (expression condition). Working memory capacity and intelligence were negatively related to the number of reports of white bear thoughts in the suppression condition but not in the expression condition. Generalizing these results, Brewin and Smart (2005) found working memory capacity–related differences in intrusive thoughts of a more personally relevant nature, independent of mood.

Working Memory Capacity and Mind Wandering

An alternative approach to suppressing unwanted thoughts is to practice mindfulness (Sīlānanda, 2002). Trying to suppress unwanted thoughts can ironically cause them to persist (Wegner, 1997). Instead of trying to fight off intrusive thoughts, invite them to stay as your guest and they will lose their power to dominate the mind (Sīlānanda, 2002). The opposite of remaining mindful is to let one's mind wander. "Mind wandering represents a state of decoupled attention because, instead of processing information from the external environment, our attention is directed toward our own private thoughts and feelings" (Smallwood, Fishman, & Schooler, 2007). Kaneet al. (2007) used an experience-sampling methodology to look at whether working memory capacity is related to frequency of task-unrelated thoughts. Reports of task-unrelated thoughts were moderated by working memory capacity when people were involved in challenging tasks compared to routine activities, with higher span people less likely than lower spans to let their thoughts wander off-task.

Mindfulness-based cognitive therapy (Williams et al., 2000) incorporates traditional Buddhist methods of training the mind to stay focused on moment-to-moment experiences and to avoid rumination and distractibility. Williams et al. (2000) assigned formerly depressed patients to either treatment-as-usual or mindfulness-based cognitive therapy, administering the autobiographical memory test before treatment and again after. Patients in the mindfulness group reported more specific autobiographical memories when tested the second time. The control group did not show any change. The groups did not differ in mood at either time, suggesting that performance on the autobiographical memory test may be more directly related to cognitive control abilities than to mood (see also, Brewin & Smart, 2005; Dalgleish et al., 2007).

Working Memory Capacity and Impulsive Decision Making

Delay discounting is a choice situation for studying self-control (Rachlin, 2000). Participants are offered hypothetical choices between two sums of money. The smaller sum is available immediately but the larger one is not available until after a specified delay. People consistently prefer the smaller-sooner reward to the larger-later one (Rachlin, 2000). A measure of the degree to which a person is impulsive and "myopic" regarding future consequences can be obtained by offering various sums at various delays and plotting the individual's discounting function (Rachlin, 2000; p. 10).

Working memory capacity has seemed like a plausible source of variation across individuals in delay discounting and related "gambling" tasks (Fellows & Farah, 2005; Frank & Claus, 2006). Like the flash in the antisaccade task (Unsworth, Schrock, & Engle, 2004) or the drink now as opposed to sobriety over time (Rachlin, 2000), the small but immediate reward may serve as a salient cue that requires executive control to resist (Stout et al., 2005). Results occasionally have suggested a role for working memory capacity in delay discounting (Hinson, Jameson, & Whitney, 2003; but *see* Franco-Watkins, Pashler, & Rickard, 2003). However, the weight of the evidence at present suggests that impulsive decision making is related more directly to intelligence than to working memory capacity (Finn & Hall, 2004; Shamosh et al., 2008; Whitney, Jameson, & Hinson, 2004).

Conclusion

We have presented results of experimental and correlational studies indicating that working memory capacity is most of all about controlling the contents of the mind by selectively attending and remembering goal-relevant information. We have suggested how these processes might be central to the general problems of self-control and self-regulation, and reviewed some recent applications of the working memory capacity construct to these problems.

Working memory capacity appears to be a more central factor than the associated clinical ailments for some phenomena (e.g., over-general autobiographical memories). In contrast, working memory capacity is apparently not central to the paradigmatic self-control problem of impulsive decision making. It is somewhat counterintuitive to observe that working memory capacity predicts counting (Tuholski, Engle, & Bayliss, 2001; Unsworth & Engle, 2008) but not delay discounting (Shamosh et al., 2008), but such anomalies can guide future research to establish boundary conditions for the working memory capacity construct (see also, Kane, Poole, Tuholski, & Engle, 2006). Meanwhile there remain strong theoretical reasons and a growing body of empirical findings to suggest that working memory capacity is important for maintaining self-control in support of a wide variety of goals.

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