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Working Memory Capacity and Self-Regulation

Malgorzata Ilkowska and Randall W. Engle

Self-regulation and working memory possess at least one common feature: the dynamic nature of information processing as we pursue a goal. In order to self-regulate behavior or keep information active in working memory, we need to monitor the behaviors leading us to a relevant goal and allocate our attention towards that goal. At the same time, we have to resist or discard any attention capture by the information not relevant to the pursued goal. In order to succeed, we usually proceed through a series of steps including planning, maintaining a goal in active memory, updating information about the current activities according to the changing situation, and changing the goal when needed. In each of these steps, we differ in how we deal with conflicting situations in pursuing the goal. We also differ in how much information we can keep available in, or for, quick access to working memory, an ability that may help substantially improve or impair self-regulatory behaviors.

The aim of this chapter is to review the research on individual differences in working memory capacity and connect it to relevant research on self-regulation. We argue that individual differences in working memory capacity (WMC) results from both trait and state aspects of differences in the ability to control information being attended to, and therefore the contents of working memory, and believe there might be important similarities and links between successful self-regulation, self-regulatory failure, and working memory capacity.

We begin by defining self-regulation and discussing the more global concept of higher order cognitive processes as executive functions. We next briefly describe how executive processes develop and how their development may be relevant to self-regulatory behaviors. We next turn to a discussion of the concept of working memory capacity and the relevant tasks and research pertaining to it. Our discussion then turns to how to connect the research on working memory and self-regulatory behaviors by examining possible relationships between them and looking at studies that explore these concepts.

Self-Regulation

The goal of self-regulation is to monitor and adjust behaviors in order to meet a goal state and at a more general level fulfill our constant endeavor towards well-being (Marques, Ibanez, Ruiperez, Moya, & Ortet, 2005). Overall, self-regulation represents an effort to alter our reactions in order to guide subsequent behaviors and thoughts (Schmeichel, 2007; Vohs & Baumeister, 2004). We define self-regulation as the process by which one monitors, directs attention, maintains, and modifies behaviors to approach a desirable goal. This definition of self-regulation relates quite closely to another important attainment in the way of behavior regulation—self-control.

Self-regulation research takes two routes of defining self-regulation. In both, self-regulation relates closely to self-control. According to one view, researchers relate self-regulation to self-control, yet treat them both as different forms of volition (cf. Kehr, Bles, & von Rosenstiel, 1999; Kuhl, 1996). According to this view, self-regulation fulfills positive and cooperative needs leading towards the goal. Self-control, on the other hand, engages in inhibitory and control processes. However, other researchers define self-regulation and self-control as two terms roughly equivalent in meaning. In this chapter, we consider self-regulation and self-control as similar constructs presented by the second definition of self-regulation. As Vohs and Baumeister elegantly note, one may treat self-control and self-regulation as the same entities using both terms interchangeably in describing behaviors requiring effortful control. According to this point of view, self-regulation and self-control, or self-discipline and effortful control, are similar constructs serving as a control over a wide range of behaviors (Carver & Scheier, 1981; Rothbart & Posner, 1985; Vohs & Baumeister, 2004). Moreover, these control processes require feedback in order to monitor and adjust behaviors according to the current circumstances (Carver & Scheier, 1981).

Without a doubt, the instances of successful self-regulation improve our subjective well-being (Jensen-Campbell, Waldrip, & Campbell, 2007). However, self-regulatory difficulties are not rare and often result in one of many kinds of self-regulatory failure (Baumeister, Heatherton, & Tice, 1994; Vohs & Baumeister, 2004). Self-regulatory failure manifests itself as a misregulation, for example, because of counterproductive behaviors arising from wrong assumptions. Another way self-regulatory failure can occur is under-regulation, a consequence of self-destructive behaviors, for example, inability to concentrate on the task due to intrusive thoughts. The extreme form of self-regulatory failure is simply a cessation of regulation, such as quitting the task, sometimes leading to states of helplessness. In this chapter, we mainly focus on the instances of self-regulatory failure. We attempt to convince the reader that one of the causes that lead to self-regulatory failure stems from issues concerned with working memory, limitations in its capacity, and the ways people use its limited resources.

Working Memory, Executive Processes, and Developmental Path

We define working memory (WM) as a system comprising encoding, maintaining, and retrieving from long-term memory the information, goals, and strategies necessary to perform a task (Unsworth & Engle, 2007). This system consists of storage buffers, rehearsal or re-storage processes, and a supervisory attention mechanism (Norman & Shallice, 1986) or a control network (Chein & Schneider, 2005). According to Baddeley and colleagues, the working memory system contains a speech-based phonological store dealing with verbal information, a visual spatial store for processing visual and spatial information, and an episodic buffer (Baddeley & Hitch, 1974) in which information from different domains is represented, during which time it is bound together, a process neuroscientists call binding. We have argued, however, that there are as many storage buffers as there are types of information (Engle & Kane, 2004). Thus we would argue that there are likely storage buffers for information such as acoustic, olfactory, and motoric experiences just as there are for articulatory and spatial information.

Before discussing working memory in finer detail, we refer to the commonly used, if poorly specified, term, *executive functions.* Executive functions describe the entirety of cognitive processes important for higher level cognition (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Rueda, Posner & Rothbart, 2005). In the broadest sense, executive function is an umbrella term for all processes recruited for managing and controlling cognition, encompassing also working memory. The purpose of executive functions is to monitor and regulate cognitive processes while performing complex cognitive tasks, employing different strategies, or performing a search process. Because in most instances complex cognitive tasks require control of attention, analysis of the content of these tasks requires an engagement of multiple processes, including but not limited to judging and decision making, broken down further into action planning, selection, resolution of conflict, and correction of errors. When a person inhibits a prepotent response to comply with task demands, attention control is brought into service. We use attention control also in demanding situations towards a goal state in attempts to delay gratification, as well as when dealing with complex tasks tapping executive processes.

Next, we consider the developmental path of executive attention and self-regulation, functions that during the process of child development gradually become more complex, fully developed in puberty. Many developmental researchers have addressed the issue of interplay of executive attention and self-regulation by studying the development of executive function (Klenberg, Korkman, & Lahti-Nuuttila, 2001; Miyake et al., 2000; Rueda, Posner, & Rothbart, 2005; Posner & Rothbart, 1998; van der Sluis, de Jong, & van der Leij, 2007; for a review see Garon, Bryson, & Smith, 2008). As Posner and Rothbart (1998) argue, "the same mechanisms used to cope with self-regulation of emotion are then transferred to issues of control of cognition during later infancy and childhood" (p. 1922). We next turn to a brief description of what these processes are and how they are measured.

Children acquire ability to regulate conflict and deal with competing stimuli through inhibitory processes as they explore the world around them more and more deliberately. The simplest control processes emerge at the end of the first year of life when a child is capable of inhibiting prepotent responses concerning basic behaviors, such as crying because of a stressful or ambiguous situation. At age 18–30 months, children show basic self-control behaviors, for example, compliance with maternal directives (Vaughn, Kopp, & Krakow, 1984) or delay of gratification for stimuli attractive to a child when asked to do so. In a delay of gratification task, a child has to restrain its willingness to respond quickly to get a desired reward. The measure of how long a child is able to delay this response indicates the ability to control and restrain gratification temptation.

With increasing age, children show significant improvements in working memory and executive attention as they acquire basic perceptual and sensorimotor capabilities. These changes parallel physiological maturation and establishment of the neural bases allowing integration of complex processing demands important in working memory and self-regulatory behaviors (Klenberg et al., 2001; Luciana & Nelson, 1998). This improvement allows toddlers to effectively inhibit and keep under control certain motor and reflexive responses, or to deploy attention to cope, for example, with separation from the mother. Further evidence using a delay of gratification task shows that preschool children using strategic attention deployment earlier on are able to delay gratification for a longer time later on (Eigsti et al., 2006; Mischel, Shoda, & Peake, 1988; Sethi, Mischel, Aber, Shoda, & Rodriguez, 2000). Working memory and executive attention improvements in school-age children can also predict and help in how children do in school in general. For example, changes in processing speed or increasing capacity of WMC may help children to improve strategies in problem solving and reasoning tasks (Kail, 2007) and their later overall cognitive functioning (Cowan et al., 2005; Fry & Hale, 1996; Kail & Hall, 2001).

Nigg, Goldsmith, and Schadek (2004) demonstrated, however, that a disruption in directing attention away from attention-capturing stimuli or inability to resist a salient temptation for a reward in children as young as 6–8 months might possibly indicate attention-deficit hyperactivity disorder (ADHD) or similar disorders. Research also supports the claim that toddlers not able to divert attention away from rewards in the delay of gratification task are more impulsive and exhibit poorer self-regulatory behaviors. Furthermore, they are more likely to struggle with difficulties in dealing with frustration and distractions as adolescents (Shoda, Mischel, & Peake, 1990). Therefore, attention problems and poor performance in working memory tasks in school-age children, such as keeping track of places, managing instructions, solving mental arithmetic, or writing, are likely to be a sign of worse executive functioning later on (Diamond, 2005; Friedman et al., 2007; St Clair-Thompson & Gathercole, 2006) and possible problems with implementing and persevering in self-regulatory behaviors.

Working Memory Capacity as Controlled Attention

Unsworth and Engle (2007) argue that individual differences in working memory capacity (WMC) originate from variations in the ability to maintain information active in primary memory while being able to successfully and efficiently search and retrieve recently active, but currently inactive, information stored in the secondary memory. Working memory capacity is important in our daily life challenges as it allows for updating and maintaining information at the same time. In fact, efficient information processing in WM, limited by the finite capacity of WM, demands the ability to maintain, update, and retrieve information relevant to the task goal while ignoring or suppressing competing information not relevant at the moment (Kane & Engle, 2002). As a result, WM requires both processing and storage resources accessed at the same time (Engle, 2002). For example, in the presence of conflicting information, one maintains current information active in short-term memory, at the same time monitoring and resolving conflict as in the Stroop task (Stroop, 1935), where saying the color in which a word is printed (a correct answer) conflicts with comprehending the meaning of the word (automatic process) that represents another color; or in the antisaccade task, where looking away from a flickering cue conflicts with our primordial drive to look at flicker since it affords movement. A basic assumption in examining individual differences in WMC is that people differ in their ability to use top-down control of attention to perform all these varied functions. These differences, furthermore, emerge in the ability to be flexible in allocation of attentional resources to relevant stimuli and to suppress inappropriate responses (Engle, 2001; Engle & Kane, 2004; Engle, Kane, & Tuholski, 1999; Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2002, 2003). Furthermore, WMC is a state variable that is affected by fatigue, sleep deprivation, and conditions such as stereotype threat (Schmader & Johns, 2003; Unsworth, Heitz, & Engle 2005) and the corresponding reduction in WMC would affect self-regulation and self-control.

Top-down control is important for executive attention as well as for processing and storing information. Since the ability to control attention during active processing involves both attentional and memory processes, this ability is crucial in an efficient use of available WM resources in daily life. It is important to note, however, that individual differences in WMC manifest themselves only in specific situations, such as under interference, when we have to decide among competing responses or override prepotent responses. Similarly, factors such as a high cognitive load, dealing with multiple tasks at once, or situations involving anxiety or stress, often create conflicting situations and, therefore, require extensive use and sharing of a limited WMC between multiple components of the task (Ashcraft & Kirk, 2001; Bishop, Duncan, Brett, & Lawrence, 2004; Steele & Josephs, 1990).

In order to manage incoming information, we use both controlled (accurate but slow) and automatic (error-prone but quick) processing. Both types of processing are important in implementing self-control behaviors, focusing attention on the task, validating available information, as well as being flexible when a particular solution does not work. Controlled processing, as opposed to automated processing, requires deliberate, deep analysis of incoming information before choosing a particular response (Schneider & Chein, 2003). On the other hand, the processes just described help to resolve conflict between automatically activated information and controlled processes. The way that automatic and controlled processes operate might be illustrated by making the decision about the correct response in the Stroop task. The part of the task that involves conflict requires saying the name of the ink in which a word is printed, but not naming the word itself. Making a correct response in that instance requires employment of controlled processes. However, if the task is performed primarily using the automatically activated representation, the word would be named since it typically reaches threshold before the representation for the color name, which in this instance would be incorrect behavior. Since both working memory and self-regulation processes are involved in decision making required to achieve a goal, both may therefore share the same limited resources, especially in complex or conflicting situations. Yet these are precisely the situations where problems with self-regulation and WM are most pronounced.

Individual Differences in Working Memory Capacity

The results of various studies examining individual differences in working memory capacity have shown that people differ in their ability to control attention across different tasks and domains (Engle & Kane, 2004; Kane & Engle, 2003; Unsworth et al., 2005). Examining individual differences usually involves dividing participants into groups of high and low WMC (and middle when the analysis involves the whole range of scores) depending on the performance on a previously administered working memory span task. Subsequently, researchers use these scores as a baseline for comparison on a target task. Research provides ample evidence that people performing poorly in WMC tasks score lower also on many other cognitive tasks. Specifically, evidence shows that low spans are usually worse at maintaining information active in memory, inhibition of irrelevant information, or updating rules after changing them (Kane et al., 2001; Miller, 2000). Under certain circumstances, however, low and high WMC spans perform at equivalent levels. One possible way to overcome the disadvantage of low spans might be extensive practice to overcome the influence of factors not allowing for efficient performance (Beilock & DeCaro, 2007).

Individual differences in WMC manifest as different behavior not only in specific situations induced in laboratory settings, but also present in everyday life. Researchers examining WM implement tasks that induce such situations, for example, competition for attention or an answer deadline as a part of the response process (Conway & Engle, 1994; Feldman-Barrett, Tugade, & Engle, 2004). WM tasks make use of the influence of proactive (and possibly retroactive) interference where previously learned information (or most recently learned, respectively) interferes with similar material activated simultaneously. Consequently it is more likely to forget material or to intermix it with interfering information. Many classic cognitive tasks that have been found to depend on individual differences in WMC require an ability to selectively attend to target information and not to interfering distractors. Similar manipulations are implemented in the dichotic listening task (Cherry, 1953), or paradigms examining the "cocktail party effect" (Conway, Cowan, & Bunting, 2001; Moray, 1959). Further manipulations focus on retrieval competition (Rosen & Engle, 1997) and situations requiring controlled search from memory, such as recall tasks including operation and reading span (Conway & Engle, 1994; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Kane et al., 2004; Unsworth & Engle, 2007).

Complex span tasks, such as operation (OSPAN) and reading span tasks (RSPAN) involve remembering words, digits, letters, or spatial locations, interleaved with another task. Examples include reading sentences (as in RSPAN), solving math problems (as in OSPAN), counting figures, or judging figural symmetry (Daneman & Carpenter, 1980; Engle, 2002; Turner & Engle, 1989; Unsworth et al., 2005). For example, in the OSPAN task, participants judge the correctness of a mathematical equation at the same time as trying to remember a word appearing at the end of each equation. At the end of each set comprising different number of such equation–word combinations, usually two to five, participants recall words from the most recent set in the correct order.

Early research on individual differences in WMC and reading comprehension (Daneman & Carpenter, 1980) that initiated and influenced further research on individual differences in WMC revealed high correlations between scores on WMC tasks and performance on the verbal part of the SAT test. Following these findings, further research indicated that individual differences in WMC emerge in both complex and simple span tasks across various domains. Such a wide scope conveys that WMC is, in fact, a domain-general construct (Conway et al., 2002; Conway & Engle, 1996; Engle & Kane, 2004; Feldman Barrett et al., 2004; Kane et al., 2004). In the following section, we discuss studies aimed at investigating individual differences in WMC as controlled attention using the tasks described above.

Working Memory Capacity Tasks

The family of tasks sensitive to individual differences in WMC examines the ability to inhibit a prepotent way of responding to stimuli of strong internal interference and environmental salience. Furthermore, these tasks require maintaining a novel goal that conflicts with a strongly predisposed action or mode of functioning. We focus on three tasks: the antisaccade (Hallett, 1978), the Stroop (Stroop, 1935), and the flanker task (Eriksen & Eriksen, 1974). All three of them generally require processes engaged in the active decision-making process, such as inhibition, updating, maintaining, resisting the effects of interference, and blocking unnecessary information from entering WM. If these tasks reflect the individual differences between low and high WMC, then we can state that if WMC as attention control is important in situations of conflict and responding in favor of a less salient response, low spans should perform worse.

During each of these tasks, the participant suppresses or inhibits a prepotent response, or selectively chooses relevant information surrounded by attention-capturing, but irrelevant information. Thus the difficulty here rests within incompatible trials dealing with a choice between two alternatives. One alternative represents a prepotent choice, whereas the other one is less dominant but usually correct. For example, the antisaccade task (Kane et al., 2001; Unsworth, Schrock, & Engle, 2004) requires suppressing a prepotent, naturally salient response of looking toward a flickering visual cue and requires looking *away* from the cue instead. In contrast, a prosaccade condition intermixed with the first allows a natural reaction of looking at a changing stimulus in the environment.

The results of Kane et al. (2001) and similar results demonstrated by Unsworth et al. (2004) revealed that participants low in WMC (low spans) have more problems with suppressing the prepotent habit of looking at the flickering cue. They made more errors and were slower than participants scoring high on WMC task (high spans) on correct trials in antisaccade condition. Moreover, low WMC spans were prone to surrender to the attention-capturing stimulus. Interestingly, the groups did not differ in the prosaccade condition where the correct response was not in conflict with the habitual response of looking towards the flashing cue. The authors concluded that low spans have trouble maintaining the goal (e.g., look away from the flickering stimulus) in working memory and in managing the conflict even when the goal is actively represented in WM. Another crucial manipulation in this study involved introduction of 1 block of prosaccade trials only after participants have already had 10 blocks of antisaccade trials (Kane et al., 2001). An intriguing result of that manipulation was that low spans had substantial trouble updating the instructions to behave in accordance with a habit on that block. The results show that low spans are worse than high spans both in maintaining the goal active and in updating the goal to new instructions.

A similar interplay between the performance of low WMC spans and the ability to overcome habitual responding occurs in the Stroop task, where a conflicting situation is to name the color of the ink in which a word is printed as opposed to the more natural response of saying the word. In this task, performance differences between low and high WMC groups are most pronounced when incongruent trials appear infrequently, for example, one in four trials. Such a ratio between congruent and incongruent trials stresses the crucial importance of a need for effortful control if one wants to answer correctly. Kane and Engle (2003) found that low spans made twice as many errors and were faster than high spans in responding to congruent trials. This situation is analogous to the one in the antisaccade task where low WMC spans experienced problems maintaining the task goals and dealing with conflict even when the goal was active (Kane et al., 2001).

Another useful task for studying conflict requiring attention control is the flanker task (Eriksen & Eriksen, 1974; Heitz & Engle, 2007). Here, participants attempt to filter out irrelevant information that would lead to an incorrect response. Heitz and Engle (2007) reasoned that if high WMC spans are better at focusing on relevant information, they should be less distracted by incompatible information. This is exactly what the authors found. High spans demonstrated better ability to focus attention on the relevant information and were faster on incongruent trials than low spans.

In sum, the studies described illustrate that individuals with high WMC are better in resisting temptation to respond in a habitual way, better at controlling attention, focusing attention on a relevant information, and better at updating the contents of working memory in case of changes in instructions. As we have seen, the crucial manipulations causing worse performance of low WMC spans in comparison to high spans were those imposing some kind of conflict, resisting effects of interference, and requiring inhibition of a prepotent response.

Working Memory and Self-Regulation

Executive control is the ability to modify and alter one's actions and thoughts by a set of interrelated abilities (Schmeichel, 2007). As such, we expect that substantial individual differences exist in the amount of that ability, as well as emerging from changes in this ability over time, with context and with other external or internal factors. Our way of linking working memory to self-regulation is probably similar to the view represented by Schmeichel (2007) who argues that self-regulation and executive attention have limited resources and modify our thoughts and behaviors. Furthermore, Gray (2001) discusses the possibility of a joint role of working memory and emotion that could lead to more effective goal management, in that "working memory could maintain active goals, and emotional states could regulate active goals on the basis of circumstances, selectively prioritizing approach or withdrawal goals" (p. 437). Thus high WMC individuals might use different strategies than low spans with respect to cognitive control, attention, and cognitive load (Beilock & Carr, 2005; Feldman Barrett et al., 2004).

Resource depletion is yet another factor that influences regulatory processes; not only intellectual achievement but also by influencing subsequent tasks. In fact, depletion of resources needed for a subsequent, unrelated task might impair self-regulation in the latter task (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Beilock, Rydell, & McConnell, 2007; Schmeichel, 2007). Failure to focus attention or inhibit irrelevant information, or inability to resolve conflict during decision-making processes may add to resource depletion in cognitive, social, and psychopathological (e.g., in overeating or impulsive aggressions) domains. Since both WMC and self-regulation have limited resources available for processing, they require flexibility in modifying thoughts and actions. Therefore, both WM and self-regulation might actually use the same available resource pool; and a scarce resource is subject to depletion. This depletion occurs both while performing a task under a high cognitive load and in demanding social situations.

As just noted, WMC plays an important role in information processing in cognitive, emotional, and social contexts (Redick, Heitz & Engle, 2007; Unsworth et al., 2005). How does effortful control of WM influence cognitive information processing and self-regulatory behaviors? Various factors influence our decisions because people use a wide variety of possible response styles, differ in impulsivity and reaction to feedback, and vary in regulation and control of emotional behaviors, including aggressive behaviors, anxiety, or anger (Steele & Joseph, 1990). Further issues include initiating a goal shift at different stages of information processing beyond individual differences accounted for by performance and WMC limits.

Let us look at one example as a possible implementation of the interplay between WM and self-regulation. Restrictions such as "Do not eat this cookie right now" or "You are not allowed to do that, it is forbidden" focus attention on the particular issue instead of moving attention away from a forbidden thing. Furthermore, we may speculate that individuals oriented *towards themselves* (or thinking about themselves) might have better self-regulatory mechanisms and attentional control, because they possess a finer executive control and a better filtering of irrelevant information than individuals oriented *towards others*, particularly when under high load or performing demanding task. In contrast, individuals oriented more towards others (e.g., worrying excessively about others) may have poorer self-regulation, because they may experience more thoughts that are intrusive. Thoughts that are more intrusive lead to poorer self-control and attentional control due to increased environmental distraction, especially when under a high load.

Working Memory and Self-Regulatory Problems

As noted earlier, both self-regulation and working memory defined as executive control involve overriding a prepotent response or even a prevention of a strongly habitual response. Furthermore, this depletion of finite self-regulatory resources may cause self-regulatory failure across social situations. This failure to self-regulate manifests itself in a variety of ways. For example, stress that adds a load to cognitive processing may lead to insufficient emotional control. This lack of emotional control may express itself when a person responds aggressively. As a result, that kind of behavior counts as a sign of poor self-regulation, of being unable to restrain from a momentary need to behave aggressively. Other situations of self-regulatory failure include alcohol problems, dependence on drugs, dependence on other people, or struggling with ruminating thoughts. For example, suppressing unwanted or negative thoughts may cause self-regulatory problems and lead to worse performance on WM tasks. Specifically, researchers have shown that high WMC spans have fewer intrusions when required to suppress their intrusive thoughts (Brewin & Beaton, 2002; Brewin & Smart, 2005; Wegner, Schneider, Carter, & White, 1987).

Anxiety- or aggression-provoking thoughts may induce negative emotions, often leading to extreme behaviors. This mechanism is similar to experiencing ruminative thoughts or delusions that represent comparable challenges to self-control (Dalgleish et al., 2007). Here, a salient detrimental thought limits inhibitory processes and diminishes accurate analysis of an actual situation (Steele & Josephs, 1990). Interestingly, people with these and similar kinds of problems having successfully overridden their "bad habit," such as overeating or obsessive drinking, often find a different "habit"— not surprisingly—replacing the old one. Thus this inability to change or update a regulatory mechanism might cause further self-regulatory problems. Other behaviors causing similar problems include emotion control or high aggression.

Imagine an alcoholic or a heavy cigarette smoker. This person might not consider drinking or smoking a problem, but treats this behavior as a habit or compensatory mechanism helping to deal with everyday problems. When that person wants to change this habit by cessation of drinking or smoking, the actual maintenance of a goal not to drink yet one more glass of wine or not to light up yet another cigarette is constantly present in working memory. Consequently, such a thought becomes salient, processed more often and with a higher strength. This mechanism inflicts a struggle in controlling thoughts. That leads to problems in self-regulation of a particular goal-directed behavior that is, in this instance, to stop drinking or smoking. In the subsections below, we look in more detail at studies examining self-regulatory behaviors and explore the relationship between self-regulatory behaviors and working memory capacity.

Alcohol-Related WM and Self-Regulatory Problems: The "Myopic" Effects on Attention

Alcohol acts as an additional cognitive load, impairing goal-directed behavior, for example, performance on a cognitive task. Alcohol intoxication narrows the range of perceived cues, meaning that a person attends to and then encodes fewer internal and environmental stimuli (Steele & Josephs, 1990). One of the paradigms investigating the effects of alcohol intoxication on cognitive processing incorporates manipulation of incentives and unexpected changing in instructions. For example, Finn and colleagues (Finn & Hall, 2004; Finn, Justus, Mazas, & Steinmetz, 1999) investigated the relationship between WMC and alcohol problems in the Go/No-Go learning task where they manipulated contingencies and incentives in four groups: high or low WMC individuals with or without alcohol consumption. Manipulation of incentives included associating a punishment and a reward with particular actions during performing a task. The critical manipulation in the Finn et al. (1999) study, however, was an unexpected change in instructions. This change involved ascribing the punishment and reward to different actions than in the earlier part of the experiment. Interestingly, switching instructions caused poorer performance of the low WMC group with alcohol ingestion. The manifestation of this lower performance was apparent in inability of low span individuals to inhibit just learned responses that became inappropriate after the contingency reversal. In a similar study, Finn, Mazas, Justus, and Steinmetz (2002) showed that low WMC participants having alcohol problems had more difficulty with inhibiting low salience cues. In other words, their attention was easily captured by infrequent cues (see also Rachlin, 2000).

Giancola and Corman (2007; see also Steele & Josephs, 1988, 1990) demonstrated that, under specific conditions, reduction of depression or anxiety is possible by directing attention away from intrusive or anxiety-provoking thoughts. Participants in the Giancola and Corman study performed a demanding cognitive task of keeping track of changing figural sequences and memorizing them for further serial order recall. The task served to direct focus of attention away from intrusive thoughts. An additional cognitive task likely occupies WMC resources but not to the extent that a person is exhausted and overwhelmed by the amount of information to process at one time. Under these conditions, less space is required for developing and maintaining anxiety or other types of intrusive thoughts actively processed in working memory (Rachlin, 2000; Steele & Josephs, 1988; but see Sher & Levenson, 1982).

Nevertheless, the amount of inhibition conflict determines whether alcohol intoxication relieves or fosters aggressive behaviors and negative thoughts (Giancola & Corman, 2007), the issue examined also in studies of alcohol "myopia" (Steele & Josephs, 1988, 1990). Alcohol myopia refers to the situation where an intoxicated person responds and reacts in a habitual and immediate way. Specifically, in Giancola and Corman's (2007) study mentioned above, participants were asked to perform a task with or without an additional task serving as a distraction. In addition, the authors analyzed whether participants' levels of aggression had changed in different distraction conditions. The number of aggressive thoughts was the same for the nonalcoholic group in both single and dual task conditions, but differed in the intoxicated group. Specifically, this group expressed less aggression in a specific distraction condition in comparison with much more aggression in a no-distraction condition. A key point here is that the intoxicated group most successfully suppressed aggression when performing a moderate-load cognitive task, whereas the influence of a difficult task had caused them to experience relapses of aggressive thoughts.

In sum, the salience of inhibitory representations and exceeding the capacity of WM increased aggression in alcohol-intoxicated group resulting in self-regulatory failure, whereas a moderate cognitive load task attenuated aggression. In the latter case, inhibitory cues acted on the behavior, leaving less capacity for processing aggressive thoughts. Steele and Josephs (1988, 1990) reported similar results in the study examining the influence of alcohol intoxication on anxiety. Intoxicated individuals were able to reduce anxiety only if an attention-demanding task—delivering a speech—distracted them from the capture of intrusive thoughts.

Anxiety, Stress, and Stereotype Threat: Additional Load Depriving both WM and Self-Regulatory Resources

As with alcohol intoxication, we may look at anxiety, stress, and stereotype threat as an additional load that consumes the resources available for WM processing, which may in turn affect the ability to self-regulate. This process may spread in a downward direction (Ashcraft and Kirk, 2001; Beilock & Carr, 2005), or conversely contribute to improving self-regulatory abilities in specific situations, for example, when under stress (Steinhauser, Maier, & Hubner, 2007). We next turn our discussion to these exact situations.

Ashcraft and Kirk (2001) examined the effects of anxiety on math performance in high and low WMC individuals. The authors reasoned that worries likely diminish performance on math problems by consuming WMC resources needed for intermediate operations, such as remembering what has been borrowed in a subtraction operation. In that case, beyond the similarities in span tasks, the central executive cannot perform at usual levels in solving complex math or mental arithmetic problems requiring intermediate operations. Indeed, high but not low math anxiety participants encountered more errors and had longer response times under increased memory load in a dual task condition. Therefore, anxiety served as a consumer of limited resources needed for solving problems.

Moreover, Beilock and Carr (2005) reported that deleterious effects of high pressure during performing a task negatively influenced only high spans. The drop in performance was so high that high and low span groups performed similarly. In another study, Beilock and colleagues (2007) showed that performance of high span individuals under a high stress was comparable to that of those with low spans, whereas low spans did not differ in their performance under stress and no-stress conditions. Beilock and Carr (2001, 2005; Beilock, Kulp, Holt, & Carr, 2004) named this below-optimal performance of high span individuals under a high pressure as "choking under pressure."

In a different study, Beilock and DeCaro (2007), attempting to find the cause of this "choking" behavior, reasoned that low WMC individuals may implement simple strategies and use shortcuts that do not always lead to the correct response or faster resolution of conflict. Conversely, high WMC individuals usually implement more complex strategies in task solving. In this study, Beilock and DeCaro examined the effects of pressure and strategy implementation in high and low WMC individuals. The results showed that those with high spans performed better under low pressure, but their performance under high pressure went down to a comparable level of the low span individuals' performance. The authors reasoned that being under a high pressure forced all participants to use simpler strategies. That is why under high pressure the performance of high span participants deteriorated. On the other hand, high span participants performed better under low pressure conditions, because low spans had used shortcut strategies under both high and low pressure conditions.

Another factor that may act as an additional load is stress. In one study, more life-event stress correlated with poorer performance in the OSPAN task and elicited higher amount of avoidant thinking (Klein & Boals, 2001b). Specifically, more negative life stress events resulted in fewer words remembered as a set size of to-be-remembered material increased. In sum, the time pressure leading to heightened levels of stress and anxiety consumed the available WM resources, which might otherwise have been used for problem solving, such as for mathematical operations or remembering words in the introduced examples. As a result, fewer resources are available for managing self-regulatory behaviors. Thus the results of studies just described showed that stress and anxiety negatively influence cognitive performance and self-regulatory behaviors. Actually, the research shows that the influence of stress and anxiety does not always have deleterious effects on behavior and performance. Beilock and colleagues (2004) were able to reduce the effect of "choking under pressure" when participants extensively practiced the problems. Moreover, Steinhauser and colleagues (2007) demonstrated that in specific situations selective attention might improve under stress by increasing the ability to focus on the relevant information under high stress situations. The authors showed, for example, that participants, while under stress, were able to reconfigure strategies and adopt the scarce resources to the task demands while under stress. Similarly, in a stereotype threat situation, having access to additional information or a cue needed for completing the task led to comparable performance of women and men in math (Quinn & Spencer, 2001).

Stereotype threat is a widely examined topic in social psychology. Priming negative stereotypes may serve as an additional load and reduce the amount of available attentional resources. That often results in worse performance on a variety of tasks, some of them involving working memory. A popular stereotype is that women are worse than men in mathematics. Schmader and Johns (2003) proposed that WMC might be a mediator of the stereotype threat on women's performance on math test. The authors showed that making this stereotype explicit leads women to reduce their WMC. Thus active stereotype threat serves as an additional load impairing performance on a complex cognitive task. Others have demonstrated, in stereotype threat situations, that women perform worse in generating math strategies, complex words, and problem-solving strategies than men (Quinn & Spencer, 2001). In a similar vein, high prejudiced White participants interacting with another race perform worse completing the Stroop task in comparison to the situation where they interact with the same race in an interracial stereotyping paradigm (Richeson & Shelton, 2003; Trawalter & Richeson, 2006).

In fact, the results of studies just described are similar to studies examining the effect of retrieval process on WMC (Kane & Engle, 2000; Rosen & Engle, 1997). Kane and Engle (2000) demonstrated that high and low WMC individuals equated in their level of performance under high load conditions induced by a divided attention task. Specifically, under high load induced by the requirement to perform a secondary task, high span individuals demonstrated greater proactive interference. That is, they were affected to a greater extent in their attempt to recall previously learned information, specifically material from list 1 after learning list 2. In contrast, increased load did not affect already lower performance of the low span group. Their level of proactive interference remained comparable across load and no-load conditions. The authors proposed that in order to resist the effects of proactive interference high span individuals utilized attention during both encoding and retrieval processes. That is, high spans used more controlled processes than low spans (Kane & Engle, 2000). In another examination of WMC and retrieval, Rosen and Engle (1997) found similar results. High spans outperformed low spans only during a simple retrieval task, but under divided attention both groups performed similarly. In sum, whereas low span individuals are more susceptible to interference, high span individuals utilize attention differently in comparison to low spans under divided attention by recruiting more controlled processes. That strategy makes high span individuals more prone to the effects of interference under divided attention.

Emotions, Mood, and Thought Suppression: A Fight for Resources between Emotion and Cognition

Emotion regulation requires initiation or modification of emotional responses and involves various aspects of emotions. Emotion regulation mechanisms do rely, however, on attention and effortful control (Nigg et al., 2004). Examples include inhibition of emotional responses, emotion suppression, emotion exaggeration, or their influence on health as in chronic emotional suppression of feelings (Gross & Levenson, 1997). However, no straightforward relationship between cognition and emotion exists. For example, emotional stimuli may facilitate WM in situations where attending to task-relevant information is desirable. Conversely, emotional stimuli may actually worsen performance on a cognitive task in situations of unintentionally focusing attention on task-irrelevant information. Interestingly, researchers have found a negative relationship between activation of the brain structures involved in cognitive processing and the brain structures involving emotional processing (Bush et al., 1998; Ochsner, Bunge, Gross, & Gabrieli, 2002) between and within the brain structures (amygdala, medial orbital frontal cortex, caudal and dorsal anterior cingulate, prefrontal cortex).

Verbal and nonverbal material may differentially influence emotional experiences and memory (Richards & Gross, 2000). Since emotion suppression requires more cognitive resources, not surprisingly people high in expressive suppression reported more memory lapses and less accurate memories in a cued-recall memory test for film details. Researchers showed similar effects when participants exaggerated responses by making inflated emotional expressions. In a study by Schmeichel, Demaree, Robinson, and Pu (2006), response exaggeration increased emotional expressions and led to deterioration in performance on a subsequent task measuring self-regulatory capacity independently of self-reported emotional experiences or arousal levels. Consequently, inhibiting emotional responses led to temporary reduction of regulatory strength.

We can apply the conclusions just described for alcohol intoxication, stereotype threat, stress, anxiety, and emotions to mood changes, thought suppression, and depressive states. As an example, Wegner and colleagues (Wegner, Erber, & Zanakos, 1993) showed an ironic effect of the influence of high cognitive load on mood regulation. Under a high cognitive load, participants reported moods opposite to the attempted ones. Specifically, by trying not to think about ascribed moods under a high load, they had made these moods more accessible and actually thought about them more often. This effect is similar to the famous "don't think about a white bear" paradigm (Wegner et al., 1987). In another study, depressed and nondepressed individuals imagined themselves in either positive or negative situations. Although depressed participants successfully suppressed negative thoughts, their unwanted negative thoughts had returned automatically when negative material served as a distractor (Wenzlaff, Wegner, & Roper, 1988). However, when positive distractors were introduced, these participants were able to suppress effectively unwanted negative thoughts.

Thought self-regulation also relies on the maintenance of active representation of to-be-avoided cognitions and suppression of unwanted thoughts (Bush et al., 1998; Mitchell et al., 2007). Thought suppression also influences self-regulatory processes. For example, reappraisal of negative photos may successfully diminish participants' negative affect in thought regulation (Ochsner et al., 2002). In sum, emotion and cognition influence each other, apparently by driving behaviors and competing for resources necessary for control.

Depression, Mood, and Other Disorders: Profound Effects of Lack of Control Resources

Psychopathologies represent one of the extreme categories of behavior requiring self-regulation. Examples include eating disorders, depression, mood disorders, or more specifically emotion dysregulation in major depressive disorder or bipolar disorder (Demaree, Schmeichel, Robinson, & Everhart, 2004; Demaree et al., 2006). Dalgleish and colleagues (2007) showed, for example, that performance on the Autobiographical Memory Test mediated the relationship between both depressed mood and a clinical diagnosis of eating disorder. They associated these results with the impairment in executive control very often found in depression and other clinical mood disorders. Specifically, the authors reasoned that these problems observed in people with depression might be due to their diminished inhibitory capabilities. Their difficulties with maintaining the goal active in memory in the presence of distractors could exacerbate these problems. Dalgleish and colleagues reasoned that impaired performance could also stem from priming and amplifying cue words by ruminative processes. These ruminative processes likely activate schemas salient to a depressed individual but not relevant to the task at hand. Furthermore, since the interference between effortful and automatic processing in depression depends on the severity of illness and the degree of control that tasks require, people experiencing depression may simply possess lower total cognitive capacity. This reduced capacity would diminish the effortful control, resulting in worse performance (Hartlage, Alloy, Vazquez, & Dykman, 1993).

In an analogous situation, writing about negative events may free WM resources needed for the task, improving the person's well-being. In one study, the researchers asked participants to describe their thoughts and feelings (Klein & Boals, 2001a). The group writing about college experiences improved their scores on a working memory task a few weeks later. Unrelated topic writers, however, did not show that improvement. Interestingly, those writing about their negative feelings improved their WMC and experienced a greater drop in intrusive thinking. Therefore, similar to the examples introduced earlier, life event stress is yet another factor that affects WM only when task demands are high.

WMC and Goal-Directed Behavior in the Brain: Additional Evidence for the Interplay Between Working Memory Capacity and Self-Regulation

Self-regulatory problems caused by cognitive load or by neurological and psychological problems may derail successful management of working memory resources and, consequently, cause a failure in successful execution of self-regulatory behaviors. These effects may be temporary or may last longer, even a lifetime. For example, attention problems in ADHD or extensive distraction by ruminative thoughts in mood disorders prevent successful deployment of attention control and self-regulatory behaviors (Dalgleish et al., 2007). As we could see in the examples introduced earlier, stress, anxiety, fatigue, and cognitive load lead to similar effects (Beilock & DeCaro, 2007; Steele & Josephs, 1988; Steinhauser et al., 2007). However, more profound neurological changes in the brain found, for example, in schizophrenics and Parkinson's patients cause serious problems in information processing, sometimes making their normal daily life functioning impossible. At that point it is important to note that individuals with damage to the prefrontal cortex (PFC) have normal intelligence scores and are able to perform routine tasks but experience problems with everyday behavior regulation. That makes their struggle with disease yet more tragic.

Furthermore, research stresses that the more severe the disease, the more profound deficits in attention control patients with PFC damage may experience (Belleville, Chertkow, & Gauthier, 2007). Specifically, individuals with prefrontal damage, such as in mild cognitive impairment (MCI) or Alzheimer's disease, cannot override prepotent responses to engage in certain behaviors. As a result, they often react impulsively accordingly to their reflexive schemas of responding to salient sensory cues. For example, they can learn the first rule in the Wisconsin Card Sorting Test task, but then they are unable to act flexibly to incorporate a new rule, repeatedly perseverating in an old rule (Miller, 2000). Similar patterns of behaviors are observed in low WMC spans described earlier.

Engagement of the two brain areas, the PFC and anterior cingulate cortex (ACC), impose a great impact on self-control, working memory, and self-regulatory processes. Overall, lower ACC and lateral PFC activation have been associated with expressing higher anxiety for predictable threat together with less activation of the cognitive control mechanisms required for maintaining the task goals in the presence of threat-related distractors (e.g., Bishop et al., 2004; Perlstein, Elbert, & Stenger, 2002). The PFC, especially, is one of the crucial brain areas associated with higher-order cognitive processes, such as decision making, goal-directed behaviors, and complex thinking. The PFC plays an important role in executive attention and working memory across a variety of tasks involving conflict or tasks using selective attention to control the impact of interference, distraction, and inhibition of irrelevant material (Kane & Engle, 2002). Studies looking at cognitive effects of brain lesions to the PFC confirm its engagement in working memory involvement in cognitive processing and self-regulation problems.

Problems such as dysregulation of thoughts and emotions or disinhibition are prevalent in a wide range of psychopathologies and are often observed in patients with brain damage. One of the usual problems associated with PFC dysfunction is the inability to inhibit prepotent responses (Kane & Engle, 2002). Furthermore, a related mechanism, disinhibition, is also one of the characteristic impairments in ADHD and obsessive-compulsive disorder. This kind of impairment is nicely described in the definition of disinhibition formulated by Nigg, Carr, Martel, and Henderson (2007). They note that disinhibition is characterized by "speaking before one should (as in ADHD); making sudden, rash decisions, such as a major ill-advised purchase (as in mania); eating or using alcohol or drugs contrary to one's intentions or plans (as in eating disorders or substance abuse)" (Nigg et al., 2007, p. 261). It is also important to note that symptoms of both ADHD and obsessive-compulsive disorder compromise both cognitive functioning and self-regulation (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005; Diamond & Doar, 1989; Diamond & Goldman-Rakic, 1989).

Alzheimer's patients and those with MCI manifest impairments in attention control comparable with the impairments that prefrontal patients show. Specifically, Parkinson's patients exhibit poorer planning and goal execution and poorer performance on working memory tasks in comparison with healthy controls (Altgassen, Phillips, Kopp, & Kliegel, 2007). Concluding our discussion in a more positive fashion, the encouraging message is that, in some circumstances, patients with brain damage are able to employ successful self-regulation as the following example reports. Gauggel and Billino (2007) asked participants to solve equations, mentally typing answers as fast as possible. Participants received feedback after each block and a summary of how they did after completing the task. They performed three additional blocks after a "goal setting" procedure. A specific goal was assigned to one group to "improve performance by 20%," whereas the second group was told to "do your best." The results revealed that brain-damaged patients were better at solving equations in a highly specific goal condition in comparison to the "do your best" group. Therefore, under the right circumstances, improvement in attention control and self-regulatory processes is possible and within reach.

It is difficult to talk about control of the type we have described in this chapter without ascribing properties that sound homuncular in nature. Psychologists are quite comfortable discussing the distinction between automatic and controlled processing (Posner & Snyder, 1975) and between intuitive and algorithmic qualities of mind (Feldman Barrett et al., 2004); details of how control is accomplished in a mechanistic mind and brain are typically left for later. We are no different. We have chosen to describe cognitive, emotional, and behavioral control with a place marker representing the mechanistic details of control. We are quite comfortable with an attitude of "a miracle happens here" for the details because we are convinced that an answer to these issues is close at hand. While there are theories that attempt to describe the mechanisms of control (e.g., EPIC, Meyer & Kieras, 1997), they give little hope of understanding control of the complex real world of thought, emotions, and behaviors of the type we address here. Part of the difficulty is that apparently almost any human task can be proceduralized or routinized with sufficient practice and yet nearly any novel task will force us into a more algorithmic and analytical mode of thinking and responding, at least for a short period of time. Perhaps the most optimistic approach to understanding the homuncular properties of control comes from the literature on the brain mechanisms underlying control (Chein & Schneider, 2005; Miller, 2000; O'Reilly, Braver, & Cohen, 1999). In general, this literature demonstrates that there are brain mechanisms and tracts that act dynamically under circumstances of novelty requiring control of prepotent behaviors. However, with repeated practice on even a novel task, the activation patterns change in areas known to be important to more habitual behaving (Peterson, van Mier, Fiez, & Raichle, 1998). While we are hopeful and optimistic that an understanding of the mechanisms of control is forthcoming, it remains beyond the scope of our discussion and we await the "miracle."

Concluding Remarks

In sum, working memory and self-regulation show substantial individual differences, mostly found in situations dealing with interference or error correction. However, whereas working memory is a domain-general construct, self-regulation might be more specific, highly dependent on stimulus salience, relevance, and a situational context. For example, a person having an alcohol problem will be self-focused on regulating drinking behavior, whereas for another person alcohol will be neither a salient nor a relevant stimulus for incorporating self-regulatory behavior.

Furthermore, working memory and self-regulation share activation in some brain areas, but researchers often observe an inverse relationship in the respective brain substrates. Stress might lower activation in areas of PFC responsible for attentional control, whereas at the same time we may observe an increased activation in ACC responsible for self-regulation, for example, for emotion regulation processes.

In this chapter, we attempted to connect the research on self-regulation with WMC viewed as an active control of attention. We would argue that working memory and self-regulation use the same resources. Having limited capacity, they require effortful control and flexibility, especially under a high load in order to keep a relevant goal active in memory, update information when needed, shift attention away from irrelevant habitual response, and finally, inhibit all irrelevant information. In an attempt to relate these two constructs, we have shown that specific self-regulatory problems, such as alcohol-related problems, stress, anxiety, emotion regulation, and psychopathology might be only a few of many examples influencing both cognitive and social functioning of normal and abnormal populations. In some instances, however, ways exist for overcoming, if only partly, problems in working memory or self-regulation, such as engaging in extensive practice, setting a specific goal, or being involved in an additional, moderate activity that directs attention away from negative or unwanted issues.

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