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CHAPTER 11

Working Memory and Self-Regulation

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The purpose of this chapter is to apply insights from cognitive psychology on working memory to everyday self-regulation. We first introduce contemporary views surrounding the multicomponent view of working memory. Our emphasis is on the central executive as the component that is assumed to orchestrate perceptual, cognitive, and motor processes in the service of goal pursuit. We then spell out in more detail how working memory may benefit self-regulation. Research pertaining to momentary fluctuations in working memory capacity are reviewed, as well as research highlighting the role of working memory capacity in the control of attention, thought, emotion, and action. We conclude by discussing why, in our view, there is no simple mapping of working memory operations on the distinction between conscious and nonconscious processing.

WHAT IS WORKING MEMORY?

Current frameworks of working memory (for an overview, see Miyake & Shah, 1999) originated from earlier models of short-term memory (e.g., Broadbent, 1958). Contemporary models typically go beyond these earlier models by assuming a multicomponent cognitive architecture rather than a unitary storage system. They also emphasize the function of such an architecture in complex cognition, such as the control of attention and the manipulation of information—hence, the term *working* memory—rather than information storage per se. One of the most influential frameworks for working memory in cognitive science is the multicomponent model proposed by Baddeley and Hitch (1974). The updated model (Baddeley, 2000, 2007) assumes an attentional control system, the

central executive, and three storage subsystems, the *phonological loop*, the *visuospatial sketchpad*, and the *episodic buffer*. The phonological loop holds verbal and acoustic information. The sketchpad holds visual and spatial information. The *episodic buffer* forms an interface between long-term memory, the other storage systems, and the central executive. It is assumed to provide a common coding mechanism (i.e., a common "language") for the exchange and manipulation of information from different modalities. It thus may serve as a basis for a temporary and flexible *workspace* in which diverse information can be combined into meaningful chunks under the attentional control of the central executive. The episodic buffer, like the phonological loop and the visuospatial sketchpad, is limited by the number of chunks of information it can maintain (Baddeley, 2007).

The Central Executive

The central executive is the most elusive and difficult component to conceptualize (e.g., Baddeley, 2003; Miyake & Shah, 1999). Even though there is no generally agreed upon definition of the *central executive* to date, most researchers regard it as a broad system (or collection of subsystems) that has evolved to allow the flexible, controlled processing of information in the service of one's goals. More specifically, the central executive is often thought to subsume a number of executive functions or capacities: (1) to allocate attention to task- or goal-relevant information, thus keeping this information in an active state; (2) to enable the flexible, context-relevant manipulation and updating of the contents of working memory; and (3) to inhibit prepotent, irrelevant responses that interfere with the present task or goal at hand (Smith & Jonides, 1999). The debate surrounding the central executive is in no way finished (Miyake & Shah, 1999). Yet from the broader perspective of this chapter, one can state that at least some consensus has been reached regarding the conceptualization, underlying neurological substrates, development, and assessment of central executive functions.

First, most researchers would agree that executive control involves the flexible allocation of "top-down" or "endogenous" attentional resources in a goal-directed manner. This view is perhaps most prominently endorsed by Engle and colleagues, who use the term *executive attention* to emphasize this contention and have provided convincing evidence for the close connection between the control of attention and central executive working memory operations (Engle, Kane, & Tuholski, 1999; Kane, Bleckley, Conway, & Engle, 2001; see also Knudsen, 2007).

A second issue concerns whether the central executive is a unitary construct, or whether it can be decomposed/fractionated into more specialized subfunctions. Probably the best-known decompositional approach is Miyake, Friedman, Emerson, Witzki, and Howerter's (2000) attempt to isolate such subfunctions on the level of latent variables. Administering a large battery of executive tasks to a larger sample, Miyake et al. identified three latent factors of central executive functioning, *shifting* between task sets, *updating* (including maintaining) relevant information in working memory, and *inhibiting* prepotent responses (see Shimamura, 2000, for a related distinction). However, these three latent factors all shared considerable overlap in variance (i.e., latent correlations between .40 and .60). Although distinguishable, these factors therefore seem to share considerable underlying commonality. Moreover, little is known yet about how these discernible subfunctions interact in complex task performance or goal pursuit.

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Third, with the advent of neuroscientific methods of inquiry, researchers have begun to explore the neural subsystems underlying working memory (Baddeley, 2007; Kane & Engle, 2002; see Wager & Smith, 2003, for a meta-analysis). There is no doubt that the frontal lobes are the primary region involved in central executive function (Miller & Cohen, 2001; Smith & Jonides, 1999; Stuss & Knight, 2002) or dysfunction (Baddeley & Wilson, 1988). Mirroring the previously discussed three-factor distinction, Collete and colleagues (2005) found that shifting, updating, and inhibiting involve both factor-specific brain regions and common areas of activation. However, common activity was not restricted to regions in the frontal cortex alone but was also present in more parietal regions (see also Wager & Smith, 2003). This finding suggests that central executive functions involve the orchestration of more widely distributed areas than the frontal lobes alone.

Fourth, there is converging evidence from developmental psychology that executive functioning undergoes marked developmental changes over the lifespan. Improvements during childhood and adolescence are paralleled by growth spurts in the development of the frontal lobes. Full maturation is reached only at around age 19 (see Jurado & Rosselli, 2007, for a review). Conversely, there is a decline in executive functioning at the other end of the lifespan (Hasher & Zacks, 1988; von Hippel, 2007). It has been associated with, among other things, anatomical changes (e.g., volume reductions) in the frontal lobes due to normal aging (West, 1996). However, age declines may not be inevitable because recent research suggests that working memory functions can still be trained in older adults (Dahlin, Nyberg, Backman, & Neely, 2008).

Fifth, there is wide consensus that individuals differ with regard to the effectiveness of their central executive (Barrett, Tugade, & Engle, 2004; Engle et al., 1999). Individual differences in central executive functioning are often referred to under the label of *working memory capacity* (WMC), and the assessment of these differences has been a major research enterprise over the last decades. Special attention should be allocated to the meaning of the word *capacity* as we use it here: WMC is not so much about memory capacity in terms of storage volume per se, which may be primarily determined by the storage capacity of the phonological loop, the visuospatial sketchpad, and the episodic buffer. Rather, WMC is about the capacity (in terms of effectiveness) with which the central executive can perform task-relevant operations on the stored information, in the service of the task or goal at hand. WMC limitations may therefore primarily reflect resource limitations rather than information storage limitations (Engle et al., 1999). To be sure, resource limitations can in turn lead to subsequent loss of information. For instance, information may be lost due to the inability to shield task-relevant information from interference. Given that these individual differences in WMC are likely to relate to important real-world outcomes, we now turn to the question of how such differences in WMC can be adequately assessed.

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Measuring WMC

Cognitive psychologists have put a lot of effort into developing good measures of WMC, and a wide range of tests has been suggested. However, it is not always clear what exactly is measured by these tests (for a summary and critique, see Jurado & Rosselli, 2007). There will probably never be a single test of WMC because it is notoriously difficult to

map the complex nature of central executive functions onto structured tests or test batteries. Nevertheless, the last decades have seen considerable advances in the development and validation of such measures. For instance, one widely used method to assess WMC is operation span (OSPAN; see Conway et al., 2005, for a review). In OSPAN tasks, participants have to engage in a primary processing task (e.g., memorizing presented information). At the same time, they have to engage in an interfering secondary processing task (e.g., indicating via keypress whether a presented equation is true or false). Participants taking an OSPAN task would see items such as: IS 3 + 5 = 9? (keypress) "HOUSE." After three to eight items are presented in a sequence, the participant would then be asked to recall the words in their serial order. Hence, participants have to update the information relevant to the primary task (i.e., the words) and shield this task-relevant information from interfering information imposed by the secondary task. The number of trial items correctly solved, weighted by trial length, serves as a measure of WMC. Individual differences measured with OSPAN tasks have been shown to predict performance on a wide range of real-world, higher-order cognitive abilities, such as reading comprehension, language comprehension, reasoning abilities, and lecture note taking (e.g., Daneman & Carpenter, 1980; Kiewra & Benton, 1988; for a review, see Barrett et al., 2004).

From a decompositional perspective (e.g., Miyake et al., 2000), one could say that most specialized experimental tasks primarily tap into one of the three executive functions identified earlier. OSPAN measures, for instance, have been found to load primarily on the updating factor, which is consistent with the high task demands of maintaining and updating task-relevant information (Miyake et al., 2000). Conversely, Stroop (1935) or stop-signal task performance (Logan, Cowan, & Davis, 1984) is typically more strongly associated with the inhibition factor, as would be expected given that participants have to inhibit a prepotent response. More complex executive tasks, however, such as the Wisconsin Card Sorting Test (Berg, 1948) or the Tower of London (Shallice, 1982), appear to tap into a combination of factors (Jurado & Rosselli, 2007; Miyake et al., 2000).

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BRIDGING WMC AND SELF-REGULATION RESEARCH

In our view, the working memory literature from cognitive psychology and the social and personality psychological literature on self-regulation have largely led separate lives (Baddeley, 2007; for a notable exception, see Barrett et al., 2004). This is regrettable since both fields may benefit greatly from each other's insights and expertise. Although recent years have seen significant advances in bridging the two areas, much work needs to be done. The purpose of this section is to spell out how working memory may aid self-regulatory goal pursuit. To build such a bridge, two pillars need to be constructed. First, we propose that the working memory mechanisms identified in basic cognitive research relate directly to the mechanisms involved in self-regulatory goal pursuit. Second, we attempt to explain how working memory—traditionally a "cool" cognitive concept—may be involved in the regulation of "hot" processes. Such hot processes make up an essential part of everyday self-regulation, especially the regulation of emotions, desires, and cravings. In the following we first explore this latter question of how cold and hot cognition might meet. We then highlight several working memory mechanisms that we believe are central to the self-regulation of everyday behavior.

Hot Cognition: Working Memory and the Regulation of Emotions and Desires

The main line of thinking we adopt here is that emotions, desires, urges, and cravings all initiate as phenomenal *primitives*, that is, relatively automatic processing outcomes that typically involve bodily sensations and crude feelings or "core affect" (Frijda, 2005; Hofmann & Wilson, 2010; Russell, 2003). The extent to which such basic phenomenal experiences gain access to working memory and its resources may depend (1) on the strength of bottom-up activation (i.e., the strength of the initial signal produced by affective and reward-related processing modules in lower regions of the brain) and (2) on whether the "spotlight" of (top-down) attention is allocated to the signal, thereby amplifying and maintaining it above a critical threshold necessary for its mental representation in working memory (Dehaene & Naccache, 2001; Hofmann & Wilson, 2010). Once in the focus of executive attention, immediate affective reactions may develop into more full-blown emotions because they are endowed with a richer set of cognitions generated by attribution and appraisal processes (Baumeister, Vohs, DeWall, & Zhang, 2007; Russell, 2003). These accompanying cognitions in working memory may help to shape, sustain, or even amplify the emotional experience at hand (Bradley, Cuthbert, & Lang, 1996). However, the effective deployment of working memory resources away from phenomenal cues, such as through distraction, may prevent the development of affective reactions into full-blown emotional episodes (Van Dillen & Koole, 2007; see also Koole, Van Dillen, & Sheppes, Chapter 2, this volume). In a similar vein, the flexible cognitive (re-)appraisal of affective information may help to alter significantly how an emotional episode unfolds over time (Gross, 1998).

Special consideration in the context of self-regulation should be given to an important class of hot cognition, desires (see also Herman & Polivy, Chapter 28, this volume). A *desire* can be defined as "an affectively charged cognitive event in which an object or activity that is associated with pleasure or relief of discomfort is in focal attention" (Kavanagh, Andrade, & May, 2005, p. 447). As Kavanagh and colleagues (2005) pointed out in their elaborated *intrusion theory of desire*, external (e.g., tempting objects in the environment) and internal factors (e.g., deprivation) may trigger desire-related thoughts and emotional reactions in a spontaneous, bottom-up fashion. Such automatically driven reactions are transitory events. Once in the focus of attention, however, they may receive additional elaboration in working memory and develop into "elaborated desires" (Kavanagh et al., 2005). Such elaborations may include processes of motivated reasoning (e.g., why it may be a good idea to smoke a "last" cigarette; see Sayette & Griffin, Chapter 27, this volume) and planning (e.g., how to get to the next cigarette dispenser even though it is miles away). Due to their effortful nature, elaborated desires usurp considerable working memory resources (Kemps, Tiggemann, & Grigg, 2008; Zwaan & Truitt, 1998) and may finally drive self-regulatory goal representations out of working memory (and sometimes, as the saying goes, "common sense out the window").

Working Memory Mechanisms and Self-Regulatory Goal Pursuit

A quick browse through the chapters of this handbook shows that one of the central foci of self-regulation research is how well people manage to pursue personally endorsed, long-term goals, such as getting good grades, maintaining a healthy diet, remaining faith-

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ful to one's partner, or staying clean of drugs in the presence of tempting alternatives. There is no a priori reason why the working memory operations involved in the performance of simple experimental rules, task sets, or processing goals should not also be crucial for the effective pursuit of everyday self-regulatory goals. We do not tackle here the difficult question of where these self-regulatory goals actually stem from or what determines whether or not they are personally endorsed. However, given a personally endorsed self-regulatory goal, a number of key features can be derived from the perspective of a working memory framework as to when and how self-regulatory goal pursuit may be successful.

Active Representation of Goal-Relevant Information in Working Memory

First, successful self-regulation involves the active representation of goals and goal-relevant information in working memory (Kane et al., 2001; Kuhl, 1983; Miller & Cohen, 2001; Smith & Jonides, 1999). This point is related to what has been referred to as the *standards* ingredient of self-regulation (Baumeister & Heatherton, 1996; Carver & Scheier, 1981). Goals involve a mental representation of the desired end state (i.e., the goal standard), and, typically, also a mental representation of the means by which and the circumstances under which the goal can be attained (Kruglanski et al., 2002; Miller & Cohen, 2001). Without a clear goal standard as a reference point, self-regulation is directionless and doomed to fail.

Clarity of goal standards can refer to a number of parameters. We focus here on accessibility and duration as the most central ones: The more accessible the mental representation of a goal in working memory and the longer a sufficiently high level of accessibility is maintained over time, the more likely it is that the goal can exert its "biasing" influence in the top-down control of behavior (Miller & Cohen, 2001). However, powerful distractions and temptations may cause a self-regulatory goal to drift out of working memory, thereby losing its biasing influence on attention, thought, and action (Duncan, 1995; Kavanagh et al., 2005). By directing attention to the goal, goal representations may receive renewed activation, thereby forestalling the natural decay to which all representations in working memory are subject. This is what seems to happen when people "remind" themselves (or are reminded by contextual or social cues) about their self-regulatory goals.

Directing and redirecting executive attention to goal-relevant information may be the primary mechanism by which self-regulatory goals are "shielded" from competing goals or other distractions in working memory (Shah, Friedman, & Kruglanski, 2002). In this view, goal shielding is the "passive" consequence of sustained attention to a goal or task (see also Dreisbach & Haider, 2009). Its effects are akin to the way a flashlight illuminates the particular objects at which it is pointed and at the same time leaving all other things in the dark. As a consequence of sustained attention, access to working memory may be directed toward highly goal-relevant information and divorced from possible distractions. Such a working memory state may closely correspond to what has been called an *implementation mindset* (Gollwitzer & Bayer, 1999; see Gollwitzer & Oettingen, Chapter 9, this volume). A second mechanism that may contribute to goal-shielding effects is the active inhibition of mental contents or behavioral schemas that are unrelated or incompatible with the focal goal in working memory. These inhibitory mechanisms are discussed in more detail below.

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Flexible Updating of Goal Representations

Self-regulatory success may also depend on the context-relevant, flexible updating of goal representations in working memory. Updating of goal representations refers to the "monitoring" ingredient of self-regulation (Baumeister & Heatherton, 1996; Carver & Scheier, 1981). Monitoring involves the analysis of the current context, one's inner states, and one's actions. Discrepancies between the actual state and one's goal standards can thus be detected, and working memory resources can be allocated to solve the conflict at hand (Botvinick, Braver, Carter, Barch, & Cohen, 2001)—for instance, when realizing that drinking the cocktail one was just handed at a party is not a good idea in light of one's intention to drive home safely.

However, this type of conflict monitoring is probably only half the story of the updating mechanism subserved by working memory. At least as important for self-regulatory success is the capacity to adjust one's goal representation flexibly as new information about the current state keeps coming in. Whereas it is generally beneficial for one's goal persistence to actively maintain the respective goal standards in working memory, it is counterproductive to set rigidly the *means* (i.e., the plans) by which one expects to attain the goal. As one navigates through the (social) world in space and time, unforeseen obstacles may suddenly block the planned course of action, or new opportunities may present themselves. Intelligent self-regulation may benefit from the capacity to adjust plans flexibly to the changing circumstances (Vallacher & Wegner, 1987). To be sure, there is a practical question—with philosophical undertones—about the point at which, instead of adjusting means, it may be better to adjust one's standards or to disengage from the goal altogether (as when the person with whom one has always wanted to be marries someone else). Hence, goal adjustment or goal disengagement will become increasingly functional as the perceived chances for success fall below a certain threshold (Jostmann & Koole, 2009; Wrosch, Scheier, Miller, Schulz, & Carver, 2003).

Inhibition of Interfering Thoughts and Emotions

Earlier, we discussed a passive form of inhibition through attention. Self-regulation may also involve active attempts at suppressing unwanted thoughts and emotional reactions. For example, to maintain a harmonious relationship with one's partner, it may occasionally be necessary to suppress one's immediate anger to a level at which constructive responses are possible (Finkel & Campbell, 2001). The need to fence off interfering thoughts and emotions may be particularly relevant for the regulation of desires and cravings, which typically combine intrusive thoughts and hedonic feelings (Kavanagh et al., 2005).

Research by Wegner and colleagues, however, suggests that the active suppression of mental contents is a risky self-regulatory enterprise (for a review, see Wegner, 1994). First, active suppression may bring the very target of suppression into the focus of a monitoring process searching for goal-inconsistent information (Wegner, 1994). Ironically, being the focus of the current attentional task set may give the critical information an accessibility advantage in the competition for access to working memory and result in further intrusions that need to be suppressed. Second, even though it can be successful in the short run, active suppression may result in rebound effects (Wenzlaff, Wegner, & Roper, 1988) and create physiological and psychological side effects, such as increased somatic arousal

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and negative affect (Gross & Levenson, 1993; Polivy, 1998). Third, active suppression is a highly effortful process that saps available resources (e.g., Baumeister, Bratslavsky, Muraven, & Tice, 1998; Vohs & Heatherton, 2000). Active inhibition of mental contents may therefore be inferior to passive inhibition through selective attention, and only work reasonably well among high WMC individuals—those who have ample resources.

Behavioral Inhibition (Impulse Control)

A final hallmark of successful self-regulation is the inhibition or overriding of unwanted behavioral responses, such as habits and impulses. Although habits and impulses can be differentiated in terms of their affective qualities or "hotness" (e.g., Hofmann, Friese, & Strack, 2009), both concepts are typically used to denote prepotent behavioral responses that are activated automatically given certain context and stimulus configurations in the environment. Habits and impulses presumably activate behavioral motor schemas. These may be expressed in behavior given that a certain threshold of activation is reached (Norman & Shallice, 1986; Strack & Deutsch, 2004). However, habitual and impulsive behavioral schemas (e.g., picking one's nose) may often be incompatible with a given self-regulatory goal (e.g., appearing intelligent to others). A supervisory attentional system (SAS; Norman & Shallice, 1986) may provide a "last resort" control of behavior by inhibiting task-irrelevant or goal-incompatible schemas. At the same time, the SAS may direct extra activation to behavioral schemas that are compatible with the task or goal at hand but not yet sufficiently activated (e.g., scratching one's head instead). Baddeley (1986) and others have assigned the SAS an integral part of the central executive. It is not entirely clear, though, whether working memory should be best seen (1) as fully supervising the voluntary control of motor behavior or (2) as a mediator of behavioral control in the prefrontal cortex that closely communicates with a more specialized (and potentially separable) behavioral inhibition system at the late-output stage of information processing (e.g., McNab et al., 2008). For the sake of parsimony we do not make a distinction here and include behavioral inhibition as one of the primary functions subserved by the central executive.

Whether attempts at impulse control are successful depends on the *relative* strength of impulsive and inhibitory mechanisms (see also Herman & Polivy, Chapter 28, this volume). As William James (1890/1950; citing Clouston) put it, impulse control may fail because either "the driver may be so weak that he cannot control well-broken horses, or the horses may be so hard-mouthed that no driver can pull them up" (p. 540). In some rare cases, such as extreme temptation or compulsive disorders, impulses may simply be too strong to be controlled, even with inhibitory mechanisms fully intact. More probably, impulses that are normally held in check may break through when WMC is temporarily or dispositionally reduced (Hofmann, Friese, & Strack, 2009).

Summary

In summary, working memory processes appear to be involved in a host of mechanisms that may promote successful self-regulation. Specifically, working memory may be involved in directing and maintaining attention to goal-directed processing (thus shielding the goal from interference), in flexibly updating goal representations in accordance

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with changing states of the environment, and in the inhibition of interfering thoughts and emotions, as well as prepotent behavioral tendencies (Barrett et al., 2004).

In specifying the interplay between hot cognition and working memory, special consideration has been given to the idea that self-regulation often involves the regulation of desires. We have discussed two main mechanisms by which desires may influence behavior. First, tempting stimuli in the environment may often automatically activate impulsive behavioral tendencies (e.g., approaching or consuming an object of desire). What may be most needed in such circumstances is the capacity for conflict monitoring (i.e., becoming aware of potentially goal-incompatible behavior) and behavioral inhibition (i.e., stopping the problematic act). A second, perhaps more insidious route by which desires may compromise self-regulation is by "hijacking" working memory in the service of short-term hedonic fulfillment. Via this route (automatically triggered), desire-related thoughts and feelings may develop into elaborated desires that commandeer considerable working memory resources (Kavanagh et al., 2005). This case is trickier because, although desire springs from genuinely automatic processes, it may seize the control processes of planning and behavior execution that were originally harnessed by one's long-term self-regulatory goal.

It should be noted that we did not emphasize the switching component of the central executive in our discussion (Miyake et al., 2000). From the perspective of everyday self-regulation, quickly switching between two or more task sets appears to be less important for goal pursuit than maintaining and updating one's long-term goals and inhibiting distraction. We would, however, be ready to switch over to another opinion in case this factor proves to be important in explaining variance in everyday self-regulatory behavior—for instance, with regard to the balancing of multiple self-regulatory goals.

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EMPIRICAL EVIDENCE

In the following, we review empirical evidence that has directly addressed the relationship between working memory and self-regulation. We start with evidence supporting the limited and fluctuating nature of WMC. Subsequently, we review research on the relationship between individual differences in WMC and the regulation of attention, thought, emotion, and action.

WMC as a Limited Resource: Cognitive Load and Depleting Aftereffects

One of the basic assumptions of the working memory model is that the capacity of the central executive is severely limited (Baddeley, 2007). Such resource limitations may manifest in two ways. A first way, primarily investigated by cognitive psychology, is related to the idea that central executive functioning is compromised by secondary task loads because the attentional resources of the central executive have to be shared between the primary and the secondary tasks. In support, numerous studies show that imposing a secondary (or dual) task reduces performance on tasks of executive control (e.g., Baddeley, Emslie, Kolodny, & Duncan, 1998; Lavie, Hirst, de Fockert, & Viding, 2004). Cognitive load manipulations have also been fruitfully applied to study the degree to which certain types of cognition and behaviors depend on cognitive control (e.g., Gilbert & Hixon, 1991; Ward & Mann, 2000). A number of "risk" situations in which

people's success at self-regulation is often at stake, among them stress (Schoofs, Preuss, & Wolf, 2008), stereotype threat (Schmader & Johns, 2003), or alcohol intoxication (Saults, Cowan, Sher, & Moreno, 2007), may be functionally equivalent to cognitive load effects due to the preoccupation with task-irrelevant thoughts that they produce; that is, their documented detrimental impact on self-regulation may be mediated by temporary reductions in WMC.

A second way by which the limited capacity of the central executive may manifest itself has been illuminated by the seminal research program on ego depletion by Baumeister and colleagues (1998; for a review, see Bauer & Baumeister, Chapter 4, this volume), who argued that self-regulatory capacity may be akin to a muscle. The exertion of self-control depletes self-regulatory resources temporarily, which may compromise *subsequent* efforts at self-control (e.g., Baumeister et al., 1998; Vohs & Heatherton, 2000). Because self-regulatory resources are assumed to be domain-independent, any act of self-control may negatively affect any subsequent act of self-control. The depletion effect has been replicated with regard to a broad range of depletion manipulations and self-regulatory domains, including eating (Vohs & Heatherton, 2000), drinking (Muraven, Collins, & Neinhaus, 2002), sexual behavior (Gailliot & Baumeister, 2006), and aggression (Dewall, Baumeister, Stillman, & Gailliot, 2007). It was first conceptually related to central executive functioning in a series of studies by Schmeichel, Vohs, and Baumeister (2003), who showed that only complex, higher-order cognitive activities are negatively affected by prior depletion, such as taking the Analytical subtest of the Graduate Record Exam—a test many of us still remember with horror. In contrast, simple cognitive activities involving only information retrieval from long-term memory are unaffected by resource depletion (Schmeichel et al., 2003). These findings yielded clear evidence that ego depletion primarily drains the type of mental resources underpinning the central executive. Subsequent research has taken this idea one step further into the cognitive domain. If different facets of central executive functioning, such as shifting, updating, and response inhibition, all draw on a general resource, Schmeichel (2007) argued, each of these forms of executive control may have negative aftereffects on each other. Four experiments involving different executive tests supported this general prediction (Schmeichel, 2007). The finding that a common depletable resource may underlie all tasks of executive control may be one explanation for the relatively high degree of commonality among the subcomponents of the central executive identified by Miyake et al. (2000).

In sum, both the work in the cognitive load tradition and more recent work on the depleting aftereffects of prior self-control point to the importance of the central executive in mediating the controlled expression of behavior. Both lines of work also attest to the fluctuating nature of available WMC. Such fluctuations can result either from secondary task load or preceding demands on central executive processing.

WMC and the Self-Regulation of Attention, Thought, Emotion, and Action

There is abundant literature on the relationship between WMC and indicators of cognitive task performance, such as reading comprehension, writing (e.g., taking lecture notes), and reasoning (e.g., Barrett et al., 2004; Daneman & Merikle, 1996). However, research that relates these measures to the types of everyday self-regulatory outcomes that are the focus of this handbook appears to be still in its infancy. In reviewing this

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intersecting area here, we focus on studies that assessed individual differences in WMC and related these differences to the everyday self-regulation of attention, thought, emotion, and action. These four areas can be assigned to three different stages of information processing: (1) early attentional processing, (2) the regulation of internal states via thought control and emotion regulation, and (3) the control of behavior, especially the control of prepotent impulses.

WMC and the Top-Down Regulation of Attention

Attention can be regarded as an important first "battlefield" of self-regulation: Whatever grabs our attention will have a chance to plant the seeds for later behavior by gaining privileged access to working memory. The regulation of attention is assumed to be subject to a tug-of-war between stimulus-driven (bottom-up) influences and the goal-directed (top-down) allocation of attention (Corbetta & Shulman, 2002; Knudsen, 2007; Pashler, Johnston, & Ruthruff, 2001). In such a conception, the bottom-up allocation of attention is assumed to occur automatically and to be determined by stimulus properties, such as salience and motivational relevance (e.g., Knudsen, 2007). In contrast, the top-down allocation of attention is biased by goal representations in working memory (Corbetta & Shulman, 2002; Folk, Remington, & Johnston, 1992; Knudsen, 2007); that is, our current goals (e.g., shopping for healthy food) can selectively bias which incoming stimulus information receives a processing advantage in the competition for access to working memory (e.g., when entering the supermarket, the vegetable section visually "pops out" in the distance). Although goals greatly influence what we attend to, this does not mean that goal-irrelevant or competing stimuli cannot grab our attention at all. Specifically, certain stimuli in our environment may gain access to working memory because they are detected by automatic salience filters (Knudsen, 2007). The salience of stimuli can simply be the result of unexpectedness. More importantly, stimuli may be flagged as motivationally salient by reward-processing systems in the brain, which are fine-tuned to biological and learned needs of the organism (e.g., Field & Cox, 2008; Knudsen, 2007). Thus, despite an active self-regulatory goal, attention can be attracted by motivationally salient cues such as high-caloric foods (in the supermarket example, halfway to the cabbage shelf, our gaze gets diverted by the confectionery aisle to the side). To stay on track of one's self-regulatory goals, top-down attentional control is needed (1) to prevent attentional capture by distracting or irrelevant cues and (2) to disengage and redirect attention if it has been grabbed by these cues (e.g., Mischel & Ayduk, Chapter 5, this volume).

Corroborating the role of the central executive in allocating top-down attention, cognitive research has established that WMC is positively related to performance in the antisaccade task (Kane et al., 2001, Study 1). This task requires the participant to respond as quickly as possible to a target stimulus that is presented in the opposite location to an initial orienting cue (i.e., the "distractor"). A subsequent study using eye-tracking technology showed that high-WMC individuals were considerably less likely to make reflexive saccades to the orienting cue than were low-WMC individuals (Kane et al., 2001, Study 2). In other words, high-WMC individuals are better at resisting the attention-grabbing power of distracting stimuli (see also Fukuda & Vogel, 2009; Unsworth, Schrock, & Engle, 2004).

Two recent studies (Friese, Bargas-Avila, Hofmann, & Wiers, 2010; Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008, Study 3) applied this line of reasoning to

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investigate attention regulation in the domains of sex and drugs (rock'n'roll is still missing from that research agenda). In both of these studies, automatic affective reactions toward the stimuli of interest (pictures of seminude women or alcohol stimuli, respectively) were assessed with a version of the Implicit Association Test (IAT; Greenwald, McGhee, & Schwartz, 1998). WMC was assessed with an OSPAN task. In the Hofmann and colleagues (2008) study, heterosexual male participants' viewing time of sexual pictures relative to control pictures served as the dependent variable. Results indicated that automatic affect toward sexual stimuli predicted actual viewing time well for low- (but not high-) WMC individuals. This pattern of findings suggests that low-WMC individuals may have had more difficulties to overcome attentional biases triggered by the affective processing of the sexual material.

Friese and colleagues (2010) adopted the eye-tracking method for a more fine-grained analysis of attentional processes in the context of alcohol stimuli. The authors expected that WMC may be crucial for counteracting the bottom-up orienting and maintenance mechanisms triggered by automatic affect. Again, automatic affect was assessed with an IAT, and WMC with an OSPAN task. Then participants were presented with a series of slides depicting one alcoholic drink and one soft drink each, and their eye-gaze behavior was tracked. In line with the predictions, only the gaze behavior of those low in WMC was influenced by automatic affect: Low-WMC individuals fixated on the alcohol pictures quicker and spent more time fixating on them (in comparison to soft drink pictures), to the extent that they had more positive automatic affective reactions toward alcohol. In contrast, no relationship between affective reactions and attentional behavior emerged for high-WMC individuals. This finding suggests that the latter group may have successfully counteracted the influence of prepotent automatic associations at the early stage of attention orientation and maintenance.

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WMC and Thought Suppression

Wegner's (1994) influential theory of thought suppression distinguishes between an automatic, resource-independent thought-monitoring process and a controlled, resource-dependent operating (suppression) process. Given the resource-dependent character of WMC, it is plausible to assume that WMC may relate directly to the capacity to suppress irrelevant thoughts once they are detected. A study by Brewin and Beaton (2002) tested this hypothesis with the white bear paradigm that has often been used to investigate thought intrusions (Wegner, Schneider, Carter, & White, 1987). Participants were instructed either *not* to think of a white bear (suppression) or to think of a white bear (expression). They found a significant negative correlation between OSPAN and the number of white bear occurrences in the thought suppression condition, indicating that high-WMC individuals more capably suppressed thoughts of a white bear when instructed to do so. No such association was obtained in the thought expression condition. A similar pattern of results was obtained in an extension in which the content of the thoughts was tailored to the personally most relevant intrusive thoughts of participants (Brewin & Smart, 2005).

Inadequate suppression or inhibition of irrelevant thoughts is also assumed to be a major component underlying mind wandering. In an experience sampling study, Kane and colleagues (2007) prompted their participants eight times a day over a period of 1 week to report whether their thoughts had wandered from their current activity. The

results indicated that pretested WMC moderated the degree of mind wandering for challenging activities: High-WMC individuals maintained task-relevant thoughts better and mind-wandered less than low-WMC individuals in circumstances of high attentional demands.

The capacity to suppress interfering thoughts may be particularly relevant in the context of temptation. "Hot" thoughts about the object of desire ("This double cheeseburger looks delicious!") may intrude into consciousness and use up precious WMC resources (Kavanagh et al., 2005). Individuals able to purge working memory quickly from such tempting thoughts may have better chances to attain their self-regulatory goals ("I want to eat healthily"). We know of no research that has directly tested this assumption yet. However, data from one of our studies may speak to this idea (Hofmann et al., 2008, Study 2). At the beginning of the study, participants' automatic affect toward M&Ms candy was assessed with an IAT, and individual differences in WMC were measured with an OSPAN task. Participants were then given 5 minutes to taste a sample of M&Ms and to self-report the perceived tastiness and likability of the candy. It was found that automatic affect predicted the explicit liking of the candy more strongly for low- (than for high-) WMC individuals (Hofmann et al., 2008). This finding tentatively suggest that low-WMC individuals may have had more difficulties at suppressing or discounting intrusive, hot thoughts in response to the immediate hedonic properties of the candy during the product test.

The studies reviewed so far have shown how individual differences relate to thought suppression. A somewhat different research strategy has been pursued with regard to establishing WMC's role as a mediating factor of stereotype threat. *Stereotype threat* is the tendency of individuals to perform worse in intellectual tests after a negative stereotype about their ingroup has been made salient. Schmader and Johns (2003) hypothesized that stereotype threat may sap WMC resources because test takers must allocate parts of their resources to the suppression of negative thoughts and anxiety evoked by the stereotype threat. As a consequence, fewer working memory resources are left to be allocated to the test itself. In support of this hypothesis, participants under stereotype threat showed situationally reduced OSPAN scores in two studies (Schmader & Johns, 2003). A third study established that the reduction in WMC fully mediated the effects of stereotype threat on test performance.

WMC and Emotion Regulation

Recalling our earlier claim that working memory may also provide a mental workspace for emotion, there are a number of interesting possibilities as to how WMC may modulate the regulation of emotional experiences (see also Wranik, Barrett, & Salovey, 2007). First, high-WMC individuals may show a greater flexibility in antecedent-focused emotion regulation. Antecedent-focused emotion regulation takes place before an emotional response is fully generated. It includes strategies such as attentional deployment and cognitive change (Gross, 1998). Regarding attentional deployment, high- (as compared to low-) WMC individuals may be better at distracting themselves from an emotional aspect of a given situation or at attending only to selective parts of the emotional episode at hand. However, even though the above findings on attention regulation point in this direction, to our knowledge, no research thus far has directly tested this assumption in the emotion domain.

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Regarding cognitive change, high-WMC individuals may have a greater variety and flexibility of strategies at their disposal. Such strategies shape the cognitive framing or appraisal of an emotional episode. In support, two recent studies showed that, compared to low-WMC individuals, those high in WMC were better at appraising emotional stimuli in an unemotional manner and thereby experienced less intense emotional responses to those stimuli (Schmeichel, Volokhov, & Demaree, 2008, Studies 2 and 3). These findings support WMC's assumed role for shaping the degree of emotional responses in an antecedent manner.

WMC may also aid response-focused emotion regulation, that is, the modulation of a full-blown emotional response once it has been elicited (Gross, 1998). Specifically, high-WMC individuals may be better at suppressing or inhibiting unwanted experiential, cognitive, and behavioral emotional responses when these responses are in conflict with the endorsed self-regulatory goal. To test this conjecture, Schmeichel and colleagues (2008) instructed their participants to suppress either negative emotions in response to a disgusting film clip (Study 1) or positive emotions in response to a comical film clip (Study 2). Results revealed that high-WMC participants were better at suppressing the expression of emotions in both studies. This indicates that WMC can be harnessed for the suppression of emotion, irrespective of the specific valence of the emotional experience. Based on these findings, it is tempting to conclude that people high in WMC may generally display less intense emotions than low-WMC individuals. Additional research has shown, however, that response amplification draws on working memory resources as well (Schmeichel, 2007; Schmeichel, Demaree, Robinson, & Pu, 2006; Study 4). Thus, the crucial difference between high- and low-WMC individuals may not so much lie in emotional intensity per se but rather in the *flexibility* with which emotional responding is fine-tuned to the context and the regulatory goal at hand.

The studies reviewed thus far all imposed self-regulatory goals (suppression or exaggeration) by instruction. However, in their daily lives, people may differ with regard to the degree to which they endorse certain emotion regulation goals. For instance, people differ in how strongly they are motivated to control their anger (Spielberger, Jacobs, Russell, & Crane, 1983). A recent study (Hofmann et al., 2008, Study 3) investigated the interplay between goal standards to control anger and WMC on anger expression upon social provocation. At one point during the study, participants were provoked through negative social feedback from an anonymous interaction partner. Subsequently, they were provided with a chance to retaliate to the provocation. It was found that, on average, high-anger-control participants retaliated significantly less than low-anger-control participants. However, this main effect was qualified by a significant anger control × WMC interaction, indicating that only participants both high in anger control and high in WMC effectively controlled their anger (Hofmann et al., 2008). In contrast, participants high in anger control but low in WMC did not differ in their reactions from participants low in anger control. Hence, having the self-regulatory goal to control anger is not enough. In order for it to effectively guide one's behavior, working memory resources are required.

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WMC and Impulse Control

Self-regulation may go awry because people fail to inhibit their impulses. However, a close look at self-regulation research reveals that this conclusion is often inferred indirectly from group differences in behavior (e.g., participants in the alcohol condition con-

sumed more sweets—so they must have acted more strongly on impulse). It has been suggested recently that more direct demonstrations should involve the assessment of markers for impulsive precursors, such as automatic affective reactions toward tempting stimuli (Hofmann, Friese, & Strack, 2009). The predictive validity of impulsive precursors may then illustrate how strongly individuals acted on impulse in a given situation of interest. Using such an approach, it has been found that the impact of impulses on behavior tends to increase under situations such as cognitive load (Friese, Hofmann, & Wänke, 2008), ego depletion (Hofmann, Rauch, & Gawronski, 2007), alcohol consumption (Hofmann & Friese, 2008), or mortality salience (Friese & Hofmann, 2008). Conversely, the consistency between self-regulatory goal standards and actual behavior was reduced under these circumstances.

Just as situational boundary conditions appear to shift the relative influence of impulsive versus reflective determinants on behavior, individual differences in control capacities may moderate predictive validities. Adopting such a dispositional perspective, two studies showed that individual differences in WMC moderate the relationship between automatic affect and eating behavior (Hofmann, Friese, & Roefs, 2009; Hofmann et al., 2008; Study 2): Low-WMC individuals acted more strongly in line with their automatic affective reactions, whereas high-WMC individuals acted more strongly in line with their goal to forego sweets (Hofmann et al., 2008). Analogous findings have been reported with regard to smoking behavior (Grenard et al., 2008), alcohol use among at-risk adolescents (Thush et al., 2008), aggressive behavior after alcohol intake in men (Wiers, Beckers, Houben, & Hofmann, 2009), and when using Stroop performance (Houben & Wiers, 2009) or stop-signal task performance (Hofmann, Friese, & Roefs, 2009) was employed as a more proximal measure of inhibitory control. The latter study also demonstrated that both an OSPAN and a stop-signal task interacted independently with automatic affective reactions in predicting impulsive behavior. This finding suggests that both tasks tap into separable executive components that contribute independently to impulse control (Hofmann, Friese, & Roefs, 2009). Taken together, these findings converge well on the idea that WMC is strongly involved in the "biasing" of behavior in accordance with self-regulatory goals, and in the inhibition of desire-related impulsive action tendencies that are incompatible with these goals.

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WORKING MEMORY AND NONCONSCIOUS PROCESSES

Throughout this chapter, we have purposely avoided attaching the labels *conscious* and *unconscious* to the mechanisms of working memory. This decision was motivated by three main reasons that, in our view, complicate the use of these labels. First, the conception of working memory as a multicomponent system for storing and manipulating information (e.g., Baddeley, 2007) entails components such as the phonological loop and the visuospatial sketchpad, whose operations are almost certainly not explicitly conscious. Rather, they provide information that eventually becomes conscious through attentional amplification (Dehaene & Naccache, 2001). Only information in the current focus of selective attention is fully conscious, whereas, according to the flashlight metaphor introduced earlier, a great deal of information remains in an *active* but unattended state at the fringe of consciousness. Hence, whether a goal in working memory is currently available to consciousness may fluctuate considerably from moment to moment, even though by

virtue of its accessible state it may nevertheless exert a biasing influence on information processing (Miller & Cohen, 2001). Thus, sustained accessibility rather than conscious availability should be the primary determinant of goal impact, even though the two dimensions may often be quite strongly correlated.

Second, nonconscious processes may often be the direct consequence of *conscious* goal setting (not just a long-term consequence of habit formation). Specifically, goals can be viewed as devices for "self-programming," such that conscious goal intentions configure or bias parameters in a whole range of lower-order subsystems involved in, for instance, attention allocation, stimulus encoding, response selection, and response execution (Dreisbach & Haider, 2009; Folk et al., 1992; Miller & Cohen, 2001). Hence, conscious intentions are typically translated into automatic and potentially nonconscious processes at a lower level but in a way these nonconscious processes still represent the overarching goal. From such a hierarchical perspective, the distinction between conscious and unconscious processing depends on the level of analysis, and the idea of conscious goal pursuit without supporting nonconscious processes does not seem to make much sense. However, the reverse seems probable. Recent research has shown that, given the right triggering conditions (e.g., Custers & Aarts, 2005), the nonconscious apparatus that supports goal pursuit can be set in motion even in the absence of conscious intentions (for a review, see Papies & Aarts, Chapter 7, this volume).

Third, some of the working memory mechanisms aiding self-regulatory goal pursuit may be more accessible to consciousness than others. For instance, the active suppression of consciousness-intruding thoughts or emotions appears, by definition, to be contingent on conscious awareness. Other mechanisms, such as goal shielding (Shah et al., 2002), the tuning of attention to goal-relevant information (Dreisbach & Haider, 2009), or simple updating processes (Hassin, Bargh, Engell, & McCulloch, 2009), may work just as well in the absence of conscious awareness. One possible agenda for future research is to delineate the exact features of these component processes more clearly. For instance, there is evidence that nonconscious goal priming, though completely inaccessible to conscious awareness, may nevertheless involve the allocation of WMC to the primed goal (Hassin, Bargh, & Zimerman, 2009). Although speculative at this point, one common denominator of working memory operations in goal pursuit may thus lie in their resource-consuming character, irrespective of whether the goal that is subserved by these processes is conscious or not (Aarts, Custers, & Veltkamp, 2008).

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CONCLUSION

To conclude, working memory appears to be a central component in people's everyday attempts at self-regulation. Its resource-dependent character and its demonstrated involvement in the regulation of attention, thought, emotion, and behavior render working memory a prime candidate for the limited-capacity aspect of self-regulation. Important as WMC may be, it is not everything: To self-regulate, people must form self-regulatory goals in the first place, and they must be motivated to do so. Even high-WMC individuals will fail to self-regulate in the absence of goal standards and motivation. Keeping these limitations of working memory in our limited working memories, we look forward to seeing what insights future research on the intersection of cognition and self-regulation will bring.

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