Chapter 18
Trait and State Differences in Working Memory Capacity

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Everyday, we use the limited resources of working memory (WM) across situations. For example, we use them as we drive to work attempting to create and maintain a list of tasks and meetings for the day. In this situation, imagine that an unexpected phone call informs us that two meetings have been rescheduled: a first one for a different time today and a second one for tomorrow. After receiving this message, we attempt to update our newly created task list within WM to incorporate the new meeting times. At the same time, we resist interference from the new information we have received from the recent phone call and from other thoughts that this call has brought to mind. Bear in mind that all this happens while we are driving a car, a task that is entirely different from creating, maintaining, and updating our schedule for the day. Some of us manage these tasks simultaneously without much effort, whereas some of us cannot perform this sequence successfully, forgetting half of today's tasks or making the wrong turn. To complicate this picture, individual differences in managing information in WM partly stem from temporary states of mind that influence a successful management of the task at hand. Let us imagine that the driver had to prepare a talk for one of today's meetings and spent the whole night preparing. In addition, she might have had an argument with her spouse in the morning. Thus, she might have experienced sleep deprivation, stress, anxiety, and fatigue, which are additional factors that often worsen our ability to utilize WM.

As the example above shows, the ability to effectively use and share the resources of WM is influenced by both stable and variable characteristics. In the complex WM system, different representations are temporarily stored in various formats, where attention control processes also interact to maintain and update temporarily active information. In our example, the driver's daily schedule is the maintained information, and the rescheduling is updating the existing information to the new situation. Additionally, this example includes other information, such as thoughts unrelated to either driving or the daily schedule, extraneous information treated as irrelevant to the task. Such information usually accompanies the current goal and most of the time has to be suppressed or inhibited.

Our chapter reviews research that examines individual differences in working memory capacity (WMC) across variety of tasks. We argue that these individual differences may reflect both a person's abiding traits as well as factors related to momentary fluctuations in a person's behavior and thoughts. We also look at possible implications in normal individuals as well as those suffering from psychopathology.

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Processes Important in Working Memory

In our example, we have named only a subset of processes crucial for proper functioning of a complex WM system. WM comprises not only the processes needed for exerting proper memory strategies in order to complete a specific goal, such as encoding, maintenance, and retrieval, but also controlled attention. Controlled attention allows focusing on the relevant information. WM differs from short-term memory by the presence of this attention component. Attentional control influences performance on complex executive tasks differently at subsequent stages of processing, from encoding, maintenance, shifting, updating, and making decisions to responding.

Maintenance and updating are crucial components of WM. The maintenance of a current goal involves keeping information active for temporary processing and using that information for completing the task. Updating, on the other hand, allows focusing attention on new information, so that we can change our strategies or ways to approach the goal state. Furthermore, updating allows new information to become the focus of attention. Thus, information focused previously is either overwritten or allowed to decay. Therefore, the ability to successfully maintain and update information is pivotal in utilizing WM resources, especially in the face of distractors and other irrelevant material usually accompanying the relevant information. Later in processing, using the maintained information to guide selection of the appropriate response becomes especially important when an alternative option is prepotent but contextually inappropriate. In our example, the driver may need to stop to get coffee after having such a rough night. However, she must tum right at an intersection where she normally turns left to get to work. If she is temporarily distracted, she may fall into the habit of getting in the left lane before realizing she had intended to pick up her coffee.

In sum, WM differently influences performance on complex executive tasks whether we keep goals active in memory, update, or manipulate its content by inhibiting prepotent responses or switching between tasks. Inhibiting irrelevant information usually interleaves with maintaining relevant information and with updating the content in order to accommodate a new situation. How to study such a complex net of interrelated processes?

Researchers choose an array of approaches to examine WM processes and its relation to cognitive functioning. Some researchers focus on examining distinct subsets of processes important in successful functioning of WM. For example, Nigg (2000; Nigg, Carr, Martel, & Henderson, 2007) focuses on one specific process of inhibitory control to examine functioning of WM in healthy and in attention-deficit hyperactivity disorder (ADHD) patient population. He discusses a related process of disinhibition to denote it as one of the major impairments of executive control in ADHD. Other researchers attempt to reconcile all the processes important in WM in a more general framework of executive functioning and treat this general frame as a starting point in disentangling the most important processes in higher-order cognitive functioning (Barkley, 200I; Friedman & Miyake, 2004; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Shimamura, 2000). For example, Miyake and colleagues (2000) proposed three processes important in executive control: inhibiting prepotent responses, updating WM, and shifting between tasks. Schmeichel (2007), on the other hand, contrasts inhibition and updating with maintenance claiming that attention control as well as response inhibition and exaggeration have similar effects on executive control and on subsequent task performance. Finally, Oberauer, Süß, Wilhelm, and Wittman (2003) distinguish three processes important in WM: simultaneous storage and processing, supervision important in task switching, and coordination of different task elements important in process monitoring.

Working Memory Models

A common feature of numerous working memory models (cf. Miyake & Shah, 1999) is the presence of a central control unit that controls types and lcvels of processing, disposing commands executed by subordinate components. Probably the most influential amongst a variety of WM models is the model proposed by Baddeley and Hitch (1974). This model assumes that WM is a multicomponent system important for variety of cognitive tasks. Comprising storage and processing, the model has three components: the central executive and two slave systems. The slave systems are responsible for processing of verbal, speech-based information (articulatory loop) and visual-spatial information (visual-spatial sketchpad). The central executive, on the other hand, flexibly allocates the processing and storage components of the WM system. Norman and Shallice (1986) introduced similar conceptualization of the executive component, based on the concept of spreading activation, which they labeled the supervisory attentional system (SAS; see also Shallice & Burgess, 1993). In this model, automatic activation of schemas driven by goals and contextual information provides the base for information intended for different levels and spreading activation. This results in higher activation of some schemas and inhibition of others. In some situations, the limited capacity SAS intervenes by redirecting and giving schemas appropriate priorities, inhibiting those incompatible with a current goal. Finally, Cowan's model (1988, 1997) introduces the central executive and a limited capacity focus of attention that controls processes and levels of activation of various memory representations within long-term memory.

Not all models, however, implicate the presence of a central control unit. For example, Schneider and Detweiler (1987) proposed a model based on parallel distributed processing that differentiates between automatic and controlled processes (see also Posner & Snyder, 1975; Feldman Barrett, Tugade, & Engle, 2004; Shiffrin & Schneider, 1984). In this model, controlled processes have replaced the central control unit. These processes distributed across modules of a specific modality and context decide what information to transmit and in what order. Recent conceptualizations refer to the mutual existence of controlled and automatic processes and the most recent model incorporates a control network at the neural level comprising multiple brain areas that play a crucial role in controlling a range of cognitive operations (Chein & Schneider, 2005; Schneider & Chein, 2003).

Working Memory Capacity

WMC as a Control of Attention

Top-down control is important for executive attention as well as for processing and storing information, especially under interference. Our view of WM as control of attention in an online fashion tics together two cognitive processes, attention control and memory (Engle, 2001; Engle, Tuholski, Laughlin, & Conway, 1999; Engle & Kane, 2004; Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2002). Attention control mechanism is alike the concept of limited-capacity central executive in the three WM models described earlier: Baddeley and Hitch's (1974), Norman & Shallicc's SAS as well as the control network (Schneider & Chein, 2003).

According to Unsworth and Engle (2007), individual differences in WMC stem mainly from fluctuations in the ability to maintain information active in primary memory and from efficient search and retrieval of information stored in the secondary memory. The authors suggest that individuals low in WMC are poorer in executing these two processes and, as in our example, they may take the wrong tum while simultaneously driving and updating the daily schedule. Thus, both primary memory and secondary memory play a vital role in active maintenance and retrieval of goal-related information.

Trait and State WMC

WMc is important across different domains, contexts, and perspectives, including cognitive, social, and emotional information processing (Redick, Heitz, & Engle, 2007; Unsworth, Heitz, & Engle, 2005). Thus, we deploy resources reserved for WM and attention across numerous situations.

If we presume that WM is crucial in situations where controlled processing must take the precedence upon automatic processing, we thus assume that controlled processes are executed while maintaining and retrieving relevant information. Execution of control processes allows discarding irrelevant representations and resisting temptation to respond in a prepotent way (Conway & Engle, 1994· Rosen & Engle, 1997). Attention control prevents opting for prepotent responses inappropriate to the current task, facilitating selection of responses of a low strength when needed (Kane & Engle, 2003). However, the same resources used in cognitive control are most likely influenced by a variety of situational factors. As our example shows, at the same time we inhibit task-unrelated thoughts and resolve conflict between the priorities of driving a car and updating the daily schedule.

Given the conceptualization of WMC as the ability to control attention involved in active information processing in primary memory and retrieval from secondary memory, we introduce further differentiation of the processes important in conceptualization of WMC as a state and trait. Next, we discuss how the execution of effortful control influences the resources used for temporary states and those determined by biological factors. We describe WMC as a trait and state looking at genetic, neurotransmitters, and brain structures important in higher-order cognition, as well as biological and personality situational factors influencing cognitive abilities in a temporary fashion.

Measures of WMC: Revealing Trait Underpinnings of Individual Differences in WMC

Individual differences in the ability to control attention are especially pronounced while attempting to resist a prepotent response when not desired, resist interference of irrelevant information, or when WM demands are high. Tasks measuring individual differences in WMC attempt to mimic these exact situations. Studies examining this phenomenon divide the sample into groups based on the performance on complex tasks, such as operation span, reading span, and symmetry span, using serial recall as a measure of how much person can hold in memory while also performing a secondary task. Then, high and low WMC individuals are compared on a target task examining processes important in WM functioning. People high in WMC usually outperform those low in WMC on a wide array of cognitive tasks. Specifically, when under cognitive or emotional load, people low in WMC are worse in inhibiting irrelevant information, or in other words, are worse in keeping just relevant information active in memory, whether it is updating or maintaining a goal defined by the task.

The pioneering research started from Daneman and Carpenter's (1980) investigation of the relationship between reading comprehension and scores from the Scholastic Aptitude Test (SAT). High correlations between scores on WMC task and performance on the verbal SAT showed by Daneman and Carpenter (1980) prompted researchers to investigate the relationship between WMC and cognitive performance across different tasks and domains. The studies overall agree that the WMC construct is domain general as shown by similar relationships holding across domains and for simple and complex tasks (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Conway & Engle, 1996; Engle, Kane, & Tuholski, 1999; Engle, Tuholski, et al., 1999; Feldman Barrett et al., 2004; Kane et al., 2004). Similarly, as Schneider and Chein (2003) proposed, cognitive control mechanisms are domain general, too.

Complex span tasks arc dual tasks engaging both processing and storage components. In Daneman and Carpenter's (1980) reading span task (RSPAN), participants read sentences and recall the last word from each sentence in sets from two to seven. In another complex span task, the operation span task (OSPAN; Turner & Engle, 1989; see also Conway et al., 2005), participants solve math problems and remember words placed after each equation in the set, as in the following example: "Is 8/2 + 5 = 67 (yes/no), TREE". At the end of each set, participant recalls all words from the set in a correct serial order.

Again, individual differences in WMC are observed in situations requiring controlled attention, such as when deciding between conflicting responses involving automatic versus controlled mode of responding and when the circumstances require dealing with interference between relevant and to-be-ignored information. If we assume that low WMC individuals are more likely to use automatic way of responding, they should be hurt more when pushed to respond in a less habitual manner. On the other hand, high WMC individuals should perform better in such situations due to their better ability to inhibit prepotent response in favor of a more controlled choice when a situation requires it. Indeed, the results of various studies examining individual differences in WMC show this pattern of performance differences between extreme WMC groups across different tasks and domains. Next, we tum to the more detailed discussion aimed at investigating individual differences in WMC as controlled attention.

Auditory domain. The amazing feature of a human auditory system is the ability to attend selectively to relevant information by quickly directing attention to important information and filtering out all irrelevant information treated as a noise. Individuals vary in the ability to detect an important stimulus in the presence of a noise, but we do not always know when or where this critical information will appear. For example, in one situation a person may need to attend selectively to one stimulus instead of another, whereas another situation requires the person to divide attention between two stimuli of an equal importance. In some situations, being suddenly captured by a salient stimulus from the environment is advantageous, as when somebody is calling your name and you are able to direct your attention to the person that have just called you. This effect of noticing your own name among the host of the surrounding sounds defines the famous "cocktail party effect" (Cherry, 1953). The nature of the dichotic listening task that acts upon this effect is to have participants repeat aloud words heard in one ear while attempting to ignore information fed into the other ear (Moray, 1959). At one point in the experiment, the participant's own name is fed to the to-he-ignored auditory channel. Studies indicate that the number of those reporting hearing their name differs for high and low WMC spans. Specifically, in one version of the task just outlined, Conway, Cowan, and Bunting (2001) found that high spans report hearing their name less frequently than low spans (20 and 65%, respectively). Thus, low WMC individuals show poorer ability to block distracting, task-irrelevant information. Interestingly, in a follow-up study, Colflesh and Conway (2007) observed an opposite pattern, showing that 67% of high spans and 35% of low spans reported hearing their name during a dichotic listening task. However, in this version, participants were told in advance to listen for their own name to appear at some point during the experiment.

Thus, when comparing the results of these two studies, in the shadowing task that requires recruiting selective attention to one channel, WMC is thought to be important in focusing on the shadowed channel and blocking signal processing of the ignored channel. As was shown, low spans are more likely to report hearing their name, likely because they are less able to sustain focused attention to the appropriate auditory input. Interestingly, the only shadowing errors that low spans exhibited were around the time their name was presented in the to-be-ignored channel. Therefore, not all distractors impair performance of low spans but only those of a particular salience, such as their own name. In contrast, successful performance on the divided attention task requires simultaneous monitoring of multiple sensory inputs. High spans reported hearing their name more often, suggesting that they used the advanced instruction to change their method of processing for the competing auditory information. Thus, although the pattern of results changed across the two experiments, the findings make sense when one considers that in both cases high spans utilized attention in a flexible manner to achieve the task goal successfully.

Visual domain. Focusing towards a new stimulus in the environment is a natural response that can be elicited even in newborns. Similarly, an attempt to search efficiently and quickly for a particular feature among various other stimuli may be a matter of life and death in a natural environment. Researchers investigating individual differences in WMC in visual selective attention tasks report similar patterns of results as in auditory selective attention. If high WMC spans have better ability to focus on relevant information or, in other words, are better at filtering out the irrelevant information they should be less distracted by stimuli that are incompatible with the correct response. This hypothesis has been investigated in the flanker task (Eriksen & Eriksen, 1974). In the flanker task, participants are instructed to identify a central target letter surrounded by distractor letters. Distractor letters are either the same (compatible) or differ from the neighboring letters (incompatible). Heitz and Engle (2007) demonstrated that, given sufficient amount of time, high and low spans were both able to achieve high accuracy, even on incompatible trials. However, when instructions encouraged faster processing, high spans achieved ceiling performance on incompatible trials much faster than low spans did. Heitz & Engle interpreted their results as indicating the importance of WMC in selective attending to targets, as the group differences were only obtained with the interfering incompatible distractors.

Assuming that WMC describes the ability to control attention, comprising elements of memory and attention, the simpler explanation that high spans just learn faster due to more resources used seems not likely (see discussion in Heitz & Engle, 2007; Engle & Kane, 2004; Conway et al., 2002; Kane et al., 2001; but see Norman & Bobrow, 1975). As noted earlier, individual differences in WMC emerge for conflicting trials, for example, on incompatible trials bearing high interference. It might well be that high spans simply are able to better utilize and allocate resources to light interference, not differing in the amount of resources available. Thus, considering faster learning, if high spans were simply faster, the differences between the span groups would have been seen across trial types, for example both incompatible and compatible trial types. In another words, span differences are seen in situations requiring effortful control, such as the ability to overcome habitual response or suppress irrelevant information. Note that span differences dissipate in compatible trials where no conflict is involved and response that is more automatic is facilitated.

Another characteristic that differentiates high and low spans is the ability to suppress a prepotent response when a task requires it. In the antisaccade task (Hallett, 1978), a visual stimulus is presented that indicates where the participant is going to direct attention. The direction of looking differs across trials being towards (prosaccade) or away (antisaccade) from the flickering cue. The natural reaction is to look at novel and changing stimuli in the environment, and, as such, the antisaccade condition defines a situation where one must prevent being captured by the prepotent response (Kane et al., 2001; Unsworth, Schrock, & Engle, 2004).

In Kane et al. (2001), participants saw a flickering cue to either side of a fixation point. Next, they saw a letter at the same location as the cue shown previously (prosaccade condition) or at the location on the other side of the screen (antisaccade condition). As predicted, low spans were less accurate only in the antisaccade condition, suggesting that they had more difficulty than high spans suppressing the automatic response of orienting toward the cue. Instead, they surrendered to the attention-capturing stimulus. The performance difference between high and low spans disappeared for prosaccade trials, a condition not introducing response conflict.

Interestingly, if participants performed a prosaccade block after a few antisaccade blocks, low spans were slower to identify the correct letter in the prosaccade condition and to change the strategy after accommodating and establishing a new automatic way of responding. That indicates further that low spans are impaired not only when selecting the contextually appropriate response in the presence of a competing habitual response, as their worse performance in the antisaccade trials shows, but also in updating instructions, as shown by their worse performance in a prosaccade block following a number of antisaccade trials. More direct evidence that low spans are prone to orient attention toward the cue instead of away from it as in the antisaccade condition was obtained by a follow-up study (Unsworth et al., 2004). Participants did not have to discriminate letters; instead, while their eye movements were recorded, they were instructed to simply look towards or away from the peripheral cue. Even in this simpler task version, low WMC spans made more errors and were slower in the antisaccade condition than high spans.

We should note, however, that high-span superiority is not universal. In the flanker and anti saccade tasks, the span groups performed equivalently when the "natural" response was correct, namely, in the compatible trials in the flanker task and the prosaccade trials in the anti saccade task. In addition, span-group equivalence has been obtained in visual search tasks, task switching, or involving switch costs (see Unsworth & Engle, 2007, for review).

Verbal domain. The Stroop task (Stroop, 1935) is a classic interference paradigm that requires active maintenance of a goal inconsistent with a more natural response. Thus, instead of naming or reading the word (congruent trial), the correct response is to name the color of the ink in which a word is printed (incongruent trial representing conflict). One variation of the Stroop task differentiating between high and low spans manipulates the proportion of congruent and incongruent trials (Kane & Engle, 2003; Logan & Zbrodoff, 1979). When the majority of trials are congruent, participant has to exert the strongest overt control over the more habitual response of word reading. Thus, infrequent change of the response type requires more effortful control than exertion of automatic responding, unlike when presented with an equal number of congruent and incongruent trials or with only one trial type. Indeed, experimental results confirmed that a condition involving infrequent number of incongruent trials appeared the most difficult for low spans. They made twice as many errors as high spans and were faster in responding to congruent trials, indicating that low spans, indeed, prefer responding automatically (Kane & Engle, 2003).

As we mentioned earlier, interference from a similar material or situations encountered previously often prompts errors and poorer performance. When we park our car each day in the same parking lot, it gets harder each time to remember the specific location where the vehicle was parked. Here, the familiar context that recently or repeatedly occurs does not allow discriminating well between new and old information. This effect is called proactive interference (PI). In one version of the PI task, participants attended to a three-letter stimulus and counted backward during the delay periods from 0 to 18 s, making the task to remember the letters more difficult (Brown, 1958; Peterson & Peterson, 1959). This secondary counting task caused a significant decrease in remembering the letters after just a few seconds of the delay, and nearly a complete forgetting at longer delays. Kane and Engle (2000) examined the effects of the PI on WMC, determined by the performance on the OSPAN task, in recalling word lists task intermixed with another, unrelated task preventing rehearsal of the to-be-remembered material. The argument behind the task was that similar material occurring consecutively, for example, by introducing two lists of words belonging to the same semantic category, will cause the most interference, especially when participants are told to remember the words for further recall. The more similar lists, the greater the drop in performance most likely caused by the interference from similar previous lists (Keppel & Underwood, 1962). Kane & Engle introduced the PI buildup by presenting three lists of semantically related words, in succession. After the PI had built up by interference between semantically related words from the lists, a new, semantically unrelated list was presented. The last list served as the release from PI since semantically unrelated words do not induce interference to the previously presented material. If high spans use controlled attention that can be used to fight the effects of PI, they should be better from the low spans in exhibiting superior recall rates. However, when introduced to additional load that prevents from using controlled attention, there should be drop in the performance level of the high spans. On the other hand, if low spans use automatic processing more often, additional load should not affect them further (see also Rosen & Engle, 1997). Indeed, low spans experienced more PI progressing through the experiment than high spans did. This implies that, indeed, they do not use the controlled attention to fight with the effects of the PI. Low spans produced a steeper decline in the number of remembered words. They also experienced more dual-task costs even before the increase of interference from a similar material built up by the PI. On the other hand, when introduced to an unrelated secondary task, both groups performed similarly. Interestingly, high spans recalled even less information than previously and their performance decreased to the level of low spans. Similar results report studies examining sensitivity to PI in young and older adults. Here, older adults experienced greater susceptibility to PI (Lustig, May, & Hasher, 2001; May, Hasher, & Kane, 1999).

In short, the likely explanation of the effects of PI on WMC is that, because low spans do not allocate attention to relieve the effects of interference, they experience stronger PI buildup than high spans do. In contrast, high spans are negatively affected by the secondary task because they use attentional resources additionally to diminish the adverse effects of PI (Kane & Engle, 2000; Engle, 2002; see also Bunting, 2006). Interesting implication of the PI buildup studies is that since PI disappears under no interference, such as with no secondary task or when remembering unrelated memory lists, to-be-recalled information is not lost over the delay period. Thus, rehearsing material, changing context or differentiating stimulus type may serve as possible mechanisms releasing from the PI leading to better remembering (Bunting, 2006).

Finally, aggregation of interference or its increase over a recall period is another example that introduces the PI buildup that makes retrieval of information more difficult. This situation was examined in a verbal fluency task. In the verbal fluency task, participants generate animal names during a specified period of time (Rosen & Engle, 1997). This kind of task requires incorporating strategic search from secondary memory to prevent repetition of already recalled words. More importantly, the words recalled first are usually the most frequently used exemplars from a given category. Thus, as the time passes, participants search for less frequently used words. In Rosen and Engle (1997) study, high spans produced more names since they had sufficient resources to control for names already chosen and still were able to use cues allowing them to produce more exemplars. However, the situation changed under divided attention condition. High and low spans performed similarly, because the load from additional task reduced temporarily the fluency capability of the high span group.

In sum, the results presented in this section suggest that low spans most of the time perform worse than high spans in situations involving interference. Specifically, in various situations that require responding in a less habitual way, high spans utilize controlled attention more successfully and engage more efficiently in the search process from the secondary memory. Researchers have tested numerous other theories aimed to explain individual differences in WMC including differences due to cognitive factors, such as processing speed, mental effort, rehearsal, word knowledge, motivational and strategic factors, task difficulty, or task-specific components.[1]

Trait WMC: The Brain Structures, Genetic Underpinnings, and Neurotransmitters

As we have already pointed out, individual differences in WMC are most pronounced when choosing among competing responses, overriding habitual responses under situational factors, such as anxiety, or when under a high cognitive load as when performing a dual task (cf. Ashcraft & Kirk, 2001; Steele & Josephs, 1990; Bishop, Duncan, Brett, & Lawrence, 2004). In the following section, we consider how genetic and neural factors may shape the capacity of WM. We also show that individual differences in cognitive and neural mechanisms relate to the differences in temperament and personality. However, the scope precludes us from inclusion of more detailed description of all the situational factors that may influence WMC as a trait or state. This includes additionally external and internal factors influencing the experiment outcome, even as trivial a state variable as sitting in an uncomfortable chair in the experiment room, or factors pertaining to mind wandering (see McVay & Kane, this volume). Thus, the next section briefly discusses the specific brain structures that may

[1] For extended discussion concerning alternative hypotheses of what might cause individual differences in WMC, see Engle and Kane (2004) and Engle et al. (1992).

relate to the performance differences between high and low WMC individuals. The section that will follow demonstrates that these biological factors are only a subset of factors influencing WMC task performance in the laboratory and in everyday situations requiring utilization of the scarce and fragile WM resources.

Brain Structures

The prefrontal cortex (PFC), anterior cingulate (ACC), and basal ganglia (BG) have been identified as the most important brain structures for functioning of the executive attention component of WM (Kane & Engle, 2002; Miller, 2000; Shallice & Burgess, 1993; Bush et a!., 1998; Smith & Jonides, 1998; 1999; McNab & Klingberg, 2008; but see Reitan & Wolfson, 1994). The PFC is important in WM functioning, as its activity in various WM tasks shows (Goldman-Rakic, 1987; Kane & Engle, 2002; Shimamura, 2000). An example task widely used in imaging studies ofWM is the n-back task (Jonides et a!., 1997). Participant sees string of stimuli (verbal, nonverbal, spatial) consecutively appearing on the screen. The task is to report for each consecutive stimulus, whether the stimulus on screen is identical to the item n-stimuli back.

In addition, the PFC plays a role in various other cognitive processes including goal-directed behavior, practice, automaticity and rewards (Miller, 2000; Miller & Cohen, 2001). Furthermore, the PFC dysfunction especially has been implicated in development of neurodegenerative diseases, multiple sclerosis (Albin, Young, & Penney, 1989; D'Esposito et a!., 1996; Nebel et al., 2007), psychopathology (e.g., schizophrenia; Perlstein, Dixit, Carter, Noll, & Cohen, 2003; Barch, 2005; 2006), and has been linked to age-related cognitive decline (Hasher & Zacks, 1988).

Dorsolateral PFC (DLPFC) is especially important for the processes related to control and executive attention. DLPFC regulates goals and guards cognitive control processes, such as action, planning, reasoning, decision-making, dynamic filtering of information, as well as segregation and integration of information related to emotional functioning (De Pisapia, Slomski, & Braver, 2007; Do1cos & McCarthy, 2006; Kerns et al., 2004; Shimamura, 2000). Furthermore, it guides various processes important in WMC reviewed earlier, such as resisting interference, maintaining the goal despite distractions, inhibiting irrelevant information, resolving conflict, or interference caused by the PI (left inferior frontal cortex in particular, Jonides & Nee, 2006; Kane & Engle, 2002; Mecklinger, Weber, Gunter, & Engle, 2003; Baddeley, 1996; Shallice & Burgess, 1993; Perlstein, Elbert, & Stenger, 2002; Botvinick, Braver, Barch, Carter, & Cohen, 2001). An increase in DLPFC activation is also present in dual tasks, observed during increasing task loads, and sometimes explained as an increase in mental effort (Jaeggi et al., 2003). Interestingly, Jaeggi et a!. (2007) observed the apparent change in the DLPFC activation especially for low-performing participants, while high-performing participants did not show such substantial changes in activation. The authors attributed these smaller changes to more efficient processing utilized by high spans. Mecklinger et al. (2003) demonstrated that high spans are less prone to interference than low spans in a letter and object memory task. Participants decided if a probe belonged to the set of stimuli presented earlier. Overall, high spans were less prone to interference, whereas low spans showed substantial interference costs in the letter task. Interestingly, high spans made more errors than low spans in object interference trials. In this study, the PFC activation in the high span group was observed for both interference and control trials in the letter task, whereas in the low span group, it was true *only* during the interference trials, suggesting that high WMC spans are able to allocate attention in a controllable way across situations.

The ACC, another important brain structure here, is responsible for monitoring and resolution of conflict followed by error corrections (Braver, Barch, & Gray, 200I; Weissman, Giesbrecht, Song, Mangun, & Woldorff, 2003). The ACC is important as well in response selection across modalities

(Braver et aI., 200 I; Bush et aI., 1998). In social contexts, the ACC has been implicated in conflict resolution involving emotional stimuli, especially when reacting to conflict from emotionally salient, irrelevant distractors (Bishop et aI., 2004). Similarly, suppression of unwanted thoughts or inhibition of threat-related distractors involves the ACC activation as well (Mitchell et aI., 2007).

According to dual-system models of cognitive control, the ACC and PFC usually show simultaneous activation during task processing, where the ACC represents conflict monitoring or error-detection system and the PFC acts as a regulatory system suppressing incompatible responses (Kerns et al., 2004). Furthermore, Michell et aI. (2007) argue that whereas the ACC is responsible for transient processes during cognitive control, for example, during thought suppression, the PFC is responsible for sustained processes involving cognitive control. Following this approach, the ACC is a secondary control process enabling successful suppression of unwanted thoughts. It is worth noting, however, that activity observed in both areas has been inversely related. For example, in the emotional valence task, Perlstein et al. (2002, 2003) showed that more activation in the PFC accompanied less activation in the ACe.

Finally, the basal ganglia (BG) controls access to WM. The BG is activated in planning and set shifting, and contributes to a selective gating mechanism that chooses relevant information for attention biased encoding. Additionally, this selective gating mechanism has been shown to be regulated by dopaminergic system (Albin et aI., 1989; McNab & Klingberg, 2008). Importantly, McNab and Klingberg (2008) argue that activity in the BG is important in the ability to exert control during encoding and guarantees that only relevant information is processed. Indeed, researchers observe joint activity in the PFC and BG during WM encoding, just before filtering out irrelevant stimuli.

This short section barely touches the complicated matter of how exactly our brain processes information related to various aspects of WM. Still, many questions exist in the neurocognitive area to determine the relations and the involvement of specific brain areas or neural net activation patterns in particular WM processes. For example, it is still an ongoing debate whether the nature of activation of particular brain areas proceeds in terms of different WM processes as proposed by Petrides (1996) in two levels of mnemonic executive processing with ventrolateral frontal cortex for active retrieval and middorsolateral frontal cortex for WM monitoring, or by the type of information, for example, verbal or visuospatial, as suggested by Goldman-Rakic (1995).[2] Another interesting issue refers to whether the superiority of performance on WM and tluid reasoning tasks stems from the volume of active brain areas or the functional activation of the specific networks (e.g., Lee et aI., 2006; Chein & Schneider, 2005).

Influence of Genetics and Neurotransmitters

Recently developed methods allow targeting specific neurotransmitters and linking their functioning to particular cognitive processes. Although still in its early stages, the research establishes clear paths as to which neurotransmitters and genes playa role in cognitive functioning, including WM and intelligence (Ando, Ono, & Wright, 2001; Cools, Gibbs, Miyakawa, Jagust, & D'Esposito, 2008; Luciano et al., 2001; Toga & Thompson, 2005).

Dopamine (DA) is a key neurotransmitter regulating a variety of cognitive functions comprising WM, cognitive tlexibility, abstract reasoning, temporal analysis of information, and action planning, to name a few (Fossella et al., 2002; Glatt & Freimer, 2002; Johnson, 2007; Mehta & Riedel, 2006; Previc, 1999; Savitz, Solms, & Ramesar, 2006). DA also mediates cognitive functioning and the PFC activity. However, the relationship between DA and cognition is complex. One illustration

[2] We thank the editors to point that out.

is that, as commonly observed, for example, in schizophrenia, ADHD, depression and aging, either too low or too high levels of DA may disrupt cognitive functioning (Kellendonk et al., 2006; Manor et al., 2002; but see Swainson, Oosterlaan, et al., 2000; DiMaio, Grizenko, & Joober, 2003; Hartlage, Alloy, Vazquez, & Dykman, 1993; Suhara et al., 1991). The inverted "U" shape function explanation of DA influence on cognitive functioning allows understanding different relationship between cognitive task performance and DA. For example, impaired cognitive flexibility might stem from too little DA levels (e.g., Nolan, Bilder, Lachman, & Volavka, 2004; Swainson, Oosterlaan, et al., 2000; Swainson, Rogers, et al., 2000). This relationship depends among others on the task characteristic and cognitive demands and can be manipulated pharmacologically (Cools, Barker, Sahakian, & Robbins, 2001; Goldman-Rakic, Muly III, & Williams, 2000; Swainson, Rogers, et al., 2000).

Research examining the role of DA in WM concentrates on DA agonists as targeted in older adults' cognitive functioning. Among the five kinds of DA receptors, there are two distinct groups characterized by excitatory (DI-like) or inhibitory (D2-like) effects (cf. Savitz et al., 2006; Mehta & Riedel, 2006; Gibbs & D'Esposito, 2005). D1 receptor has been linked to a control gating mechanism in the PFC at the encoding stage of WM processing. D2 concentrates on a reward-based information and plays a role in WM updating. However, the crucial aspect appears to be the ratio of D1 to D2 that keeps the amount of DA in a state of equilibrium. Surely, DA is not the only neurotransmitter related to cognitive function. For example, glutamate has been involved jointly with DA in cognitive functioning as well (Kodama, Hikosaka, & Watanabe, 2002) and serotonin with memory and amnesia (cf. Meneses & Perez-Garcia, 2007).

Catechol-O-methyl transferase (COMT) is one of the enzymes important in cognitive functioning that regulates levels and transmission of DA within the PFC. Two variants of the COMT gene have been examined in relation to WM. These are *val* allele and *met* allele; the *val* allele is associated with lower synaptic levels of DA (Savitz et al., 2006) and represents a high activity, whereas *met* is a low activity genotype. Most studies have found that the *met* allele *(met/met)* is associated with better performance on WM tasks (for an extended review see Savitz et al., 2006; Fossella et al., 2002), whereas the *val (val/val)* allele is often associated with worse performance on WM tasks. *Val/val* has also been associated with a greater number of perseverative errors across different WM tasks that implement high attention control (Blasi et al., 2005; de Frias et al., 2005; MacDonald, Carter, Flory, Ferrell, & Manuck, 2007). However, Williams-Gray and colleagues (2008) in an attentional control task showed that the early PD patients with *met/met* genotype had difficulty with forming an attentional set, which was revealed additionally in the diminished activation in frontoparietal brain areas. Similarly, *met/met* patients executed longer times for planning, related to lowered activation across the frontoparietal network (Williams-Gray, Hampshire, Robbins, et al., 2007). Interestingly, Nolan and colleagues (2004) suggested that the disparate results of cognitive performance of *met/met* and *val/val* genotypes might stem from the observation that the *met* allele participants might perform better on tasks characterized by cognitive stability (akin to WM maintenance), whereas they perform worse on tasks requiring switching, requiring cognitive flexibility. Thus, both dopaminergic drugs and the type of the COMT genotype likely influence both the brain activation and WM-related behaviors. As such, the influence of DA levels on cognitive task performance and a disparate influence of L-dopa on the activity of frontal brain regions in Parkinson's disease is a promising research on the nature of processes influencing cognitive performance (Owen, 2004; Swainson, Oosterlaan, et al., 2000; Swainson, Rogers, et al., 2000; Williams-Gray, Hampshire, Barker, et al., 2008).

Finally, monoamine oxidase A (MAOA) is another enzyme that, together with dopamine receptor D4 (DRD4), influences error and conflict monitoring associated with the ACC functioning. For example, Fan, Fossella, Sommer, Wu, and Posner (2003) showed that the amount of activation in the ACC during an executive attention task differed depending on the DRD4 and MAOA gene polymorphisms and with better performance associated with higher ACC activity.

State WMC as Transient Changes from the Baseline Trait WMC

Various temporary factors may affect the level of performance on WMC tasks, such as transient changes in mood states, but they do not affect the overall correlation between these tasks and higher order cognition (Engle & Kane, 2004; Schmeichel, 2007; Wegner, Erber, & Zanakos, 1993; Turley-Ames & Whitfield, 2003; but see Beilock & DeCaro, 2007).

Different biological, personality, and cognitive factors can induce state-related changes in WMC. Biological factors relate to fatigue, sleep deprivation, or physiological effects of threat-related changes in the organism. Personality factors relate to a person's characteristic pertaining to reactions to the effects caused by induction of anxiety, stress, or affect, as well as the person's characteristic way of processing those states. Finally, cognitive temporal factors are performance-related factors pertaining to high cognitive load or to cognitive effects induced by a task in internal states, such as dealing with negative thoughts, ruminations, or compulsions. Next, we briefly describe these various factors and discuss how they influence WMC.

Biological Factors: Sleep Deprivation, Fatigue, Physiological Effects of Threat and Anxiety

Sleep deprivation has been linked to overall impairments in decision-making, judgment, and finally, to worse cognitive performance on achievement tests. Meanwhile, sleep deprivation impairs WMC-related processing that involves the PFC, especially maintaining and updating information relevant to the task (Harrison & Home, 2000; Killgore, Balkin, & Wesensten, 2006; Smith, McEvoy, & Gevins, 2002). Likewise, we can relate WM impairments due to sleep deprivation to situations when a person attempts to exert control, but in addition to maintaining the goal to do well and retrieving needed information, the person needs to allocate extra resources simply to stay awake. The importance of these effects as causing cognitive impairments has been stressed further in sleep disorders and evaluated especially in the assessment of alertness and cognitive performance impairments that sleep disorders likely cause (Smith et aI., 2002).

Researchers observe significant changes in cognitive performance even after only a moderate sleep loss beyond changes related to a general slowing due to prolonged sleep deprivation. For example, performance and judgment problems may occur after just one or two nights of sleep deprivation. Interestingly, after one night of sleep deprivation, researchers report loss related to impairments in encoding and even in forming memories (Chee & Choo, 2004). Furthermore, the effects of practice of WM task over time are simply not seen for individuals with less number of hours of sleep during a few consecutive days as compared with people sleeping 8 h a night (Casement, Broussard, Mullington, & Press, 2006). Interestingly, the impairment patterns are similar to patterns seen in prefrontal patients (Yoo, Hu, Gujar, Jolesz, & Walker, 2007) and those observed in older adults (Chee & Choo, 2004; Harrison, Horne, & Rothwell, 2000). However, we should note that the changes and patterns of brain activation after just 24 h of sleep deprivation are quite complex. They involve different behaviors as shown in the PFC and ACC activation patterns and depend on the time, task, age, and exact period of sleep deprivation. In psychopathology, additional impairments may include dissociative symptoms, such as elevated or strengthened symptoms in the dissociative identity disorder (Giesbrecht, Smeets, Leppink, Jelicic, & Merckelbach, 2007; Killgore et aI., 2006).

Another temporary factor influencing WM is mental (cognitive) fatigue. Its effects also include temporal impairment in WM functioning. Mental fatigue describes cognitive effects of a long and sustained exposure to a cognitively demanding task (Lorist, Boksem, & Ridderinkhof, 2005).

For example, Persson, Welsh, Jonides, and Renter-Lorenz (2007) demonstrated these compromised effects in tasks involving resolving conflict or resisting interference. Mental fatigue may also act as a resource depletion that impairs WM functioning in a similar fashion to depletion effects observed in a stereotype threat situations or in a self-regulatory failure (Richeson et al., 2003; Vohs & Heatherton, 2000). Additionally, as in sleep deprivation, temporal impairment related to mental fatigue has been linked to different activation levels in the ACC, leading to less error detections and corrections, and higher overall error rate. For example, similar pattern has been observed in individuals with mental fatigue and with chronic fatigue syndrome (Caseras et al., 2006; Lorist et al., 2005). Finally, Lorist et al. (2005) linked mental fatigue with DA functioning, explaining problems related to mental fatigue by fluctuations of the DA levels with too high or too low levels of DA impairing cognitivc control and the ACC activity, resulting in more errors.

Threat is another biological factor, the effects of which may relate to difficulties in WM performance, and is associated mostly with physiological changes in arousal levels caused by threatening situations. Research demonstrates that threat, similarly to stress, narrows the focus of attention and acts on WMC depending on the task demands and task goals. For example, in addition to cognitive impainncnts under threatening conditions, threat elevates anxiety levels and an overall physiological arousal (Osborne, 2007). This, in addition, can be related further to how a person can overcome the adverse effects of these biological factors on WM functioning, that is, by looking at the influence of personality factors.

Personality-Related Factors: Threat, Anxiety, Stress, "Choking" Under Pressure, and Affect

When we consider a threat from a personality perspective, we take into account social and cognitive effects of threat-related anxiety ascribed to specific threatening situations. The literature agrees that a stereotype threat makes salient the fear if a person believes in a particular stereotype (behavior or idea) and eventually leads to diminishing of available resources for successful utilization of WMC and attention. For example, anxiety and threat-evoked anxiety have been implicated as having disruptive performance effects on spatial WM tasks (Lavric, Rippon, & Gray, 2003; Shackman et al., 2006). Other examples include stereotype threat induced during cognitive or skilled performance, or during interracial interactions (Beilock, Jellison, Rydell, McConnell, & Carr, 2006; Beilock, Rydell, & McConnell, 2007; Quinn & Spencer, 2001; Richeson & Shelton, 2003; Schmader & Johns, 2003; Trawalter & Richeson, 2006).

However, when distracted away from thoughts and actions that induce and maintain the threatening stereotype threat state, its negative effects are substantially reduced and its activation weakens. On the other hand, focusing on particular situational factors or a purpose for performing a task that activates a stereotype may impair performance on a cognitive task. In one study, participants performed Ravens Progressive Matrices test under two different conditions (Croizet et al., 2004). The authors induced stereotype threat situation by implementing different instructions pertaining to the purpose of taking the test. Participants who received information that the test measures their cognitive ability had performed at a similar level as controls. However, the performance significantly dropped for participants who were told that the test measures their reputation of lower ability. Croizet et al. (2004) indicated that additional mental load that disrupts performance in the reputation condition is a possible mechanism responsible for group differences in this study.

Similar effects arise when examining the relationship between stress and WM task performance, For example, Klein and Boals (2001) reasoned that more life event stress causes worse performance on WM task. Similar explanatory mechanisms implementing stress as an additional load may act with respect to stressful events. In another example, Beilock et al. (2007) showed that elevated stress lead high span individuals to perform worse, at a similar level as the low span group. However, when stress was taken off the task, high spans improved their performance, whereas low spans remained at the same level as under stress.

The characteristic pattern of impaired performance of high spans under specific circumstances is referred to as a "choking under pressure" (Beilock & Carr, 2001; 2005; Beilock, Kulp, Holt, & Carr, 2004). The authors argued that this phenomenon might stem from different strategies implemented by high and low WM span individuals. In fact, they noticed that low spans use simple strategies irrespectively of the presence or absence of a stressful stimulus, whereas high spans perform better under low-stress condition simply because they implement strategies that are more efficient. Conversely, high spans cannot implement these strategies under high-pressure situations that force them to use simpler strategies, which do not always result in a correct solution (Beilock et al., 2007). Beilock et al. (2004) argued that one possible way out from that conundrum is to practice problems. When participants practiced their problems, they were able to reduce the negative effects of "choking under pressure". This is in line with emerging research on WM training (e.g., Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Jaeggi et al., 2007; Klingberg, Forssberg, & Westerberg, 2002; Klingberg et al., 2005; Thorell, Lindqvist, Bergman, Bohlin, & Klingberg, 2009).

Affect and regulating emotions also induce temporal changes in WMC. For example, high cognitive control can diminish resources available for a subsequent task and impair the ability to update, ignore distractors, or ability to inhibit predominant writing tendencies (Schmeichel, 2007). However, Klein and Boals (2001) showed that the mutual influence of emotion and cognition is not straightforward. Thus, task goals and the nature of the processes also influence this relationship since different emotional processes depend differently on a task context (Gross & Levenson, 1997; Kensinger & Corkin, 2003; Richards & Gross, 2000).

Cognitive Factors: Cognitive Control Under Load, WMC Improvement

As reviewed earlier, Kane and Engle (2000) and Rosen and Engle (1997) have demonstrated that load diminishes scarce WM resources. As the load increases, even high spans experience performance decrease when required to divide their attention between two tasks. Thus, it might be implied that when WM load increases, the executive control of attention decreases (Hester & Garavan, 2005). This causes temporary impairment in the ability to fight distraction, resist interference, or inhibit irrelevant information. Furthermore, similar adverse effects on WMC should be seen across verbal and nonverbal task, as the inhibitory mechanisms sensitive to high load are domain free (Conway et al., 1999).

Applying this way of reasoning to unsuccessful suppression of ruminations often observed in depression and other mood disorders, ruminations and other extraneous thoughts may serve as an additional cognitive load as well. A decreased ability to inhibit irrelevant or unwanted thoughts results in fewer available resources for maintaining important goals or for resisting interference from irrelevant distractors. Intrusive thoughts and ruminations in depression can be activated by extraneous cues relevant to these ruminations picked up from the environment, the mechanism also observed in drug addictions (Brewin & Beaton, 2002; Brewin & Smart, 2005; Hester & Garavan, 2005). Since these ruminations are not relevant to the task, the result is worse task performance (cf. Dalgleish et al., 2007). Finally, depressive individuals also exhibit impairments in effortful processing. Instead, they often implement more automatic cognitions in their thought processes. Therefore, their performance decreases; firstly due to lower utilization of effortful processing and secondly, resulting from diminished ability to tight interference. Again, these processes may be mediated by DA functioning (Hartlage et al., 1993).

WMC Improvement

WMC can be temporarily increased as the effect of extensive training and practice, mimicked by practice-related changes in brain activation (Jaeggi et al., 2007; 2008; Olesen, Westerberg, & Klingberg, 2003). These practice effects can even transfer to nontrained tasks as Klingberg et al. (2002; 2005; see also Thorell et aI., 2(09) showed in children and young adults with ADHD. In addition, other studies claim to observe effects of training in expanding focus of attention (Verhaeghen, CerelIa, & Basak, 2004; but see Oberauer, 2006).

WM tasks show good reliability and stability at the test-retest sessions 6-weeks apart (e.g., Klein & Fiss, 1999; Waters & Caplan, 2003). They also show practice effects, which might be applied to deliberate WM training important in improving rehabilitation outcomes or cognitive performance in environments highly relying on WM processes. In this fast-emerging literature, example studies examine learning difficulties in neurodevelopmental disorders (Gathercole & Alloway, 2006), the influence of L-dopa on learning by repetitive training (Knecht et aI., 2004), or applied as a part of a rehabilitation in stroke (Westernberg et aI., 2007) and traumatic brain injury patients (Serino et aI., 2007). Training usually lasts about 5 weeks. The studies not only report training-related improvements in behavioral results lasting a number of months in comparison to control groups but also related changes in cortical activity (Dahlin, Stigsdotter Nelly, Larsson, Backman, & Nyberg, 2008; Westerberg & Klingberg, 2007). Moreover, the transfer effects are observed for tasks engaging similar processes, for example, other WM, attention, reasoning tasks (Dahlin et aI., 2008; Westerberg & Klingberg, 2007; Westernberg et aI., 2007), or ability to resist interference (Persson & Reuter-Lorenz, 2008). Some of the positive effects of such training sessions include reduced symptoms (Klingberg et aI., 2005; Serino et al., 2007; Westernberg et aI., 2007) or even improvements of patients' everyday life functioning (Serino et aI., 2007).

Various studies have examined the effects of cognitive performance on different executive attention tasks by looking at the effects of administration of DA drugs. DA antagonists, such as pergolide and bromocriptine (Mehta & Riedel, 2006, for a review) and L-dopa (Knecht et aI., 2004) are often used for treatment of Parkinson's disease. Yet, the results so far are mixed and the reports of higher WMC improvements differ across tasks, groups, or even in whether high or low WMC span improvements are reported (high; Kimberg & D'Esposito, 1997; 2003; or low spans; Gibbs & D'Esposito, 2005). Additional caution in interpretation of the results of the training studies is concern over a low number of participants reported in majority of the studies, which also might be a reason of inconsistent results.

Implications

Discovering and assessing the sources of any cognitive impairment considering WM and its capacity is especially important in diagnosis of illness or even a mild impairment, as well as in achievement tests. Differentiating between state and trait WMC may be beneficial in looking at the ways of approaching and recognizing cognitive problems that either stem from temporary factors, such as anxiety, or biological factors, such as disruptions in neurotransmitter functioning.

Trait WMC: *Neurodegenerative* ***Disorders and Psychopathology***

Assessing the severity of WM impairments is crucial in a variety of brain-related diseases, such as traumatic brain injuries and other instances where patients experience problems with maintaining goal directed behavior in WM and attention. The assessment of the severity of impairment is of extreme relevance since problems related to inhibition, attention control, and suppression of unwanted thoughts occur across various mental and neurodegenerative disorders. Examples include Alzheimer's disease (AD), Parkinson's disease (PD), Mild Cognitive Impairment (MCI), traumatic brain injury (TBI), schizophrenia, depression, ADHD, Obsessive-Compulsive Disorder (OCD), or autism (Diamond, 2005; Pennington & Ozonoff, 1996).

Most psychopathology is characterized by impairments related to inhibitory mechanisms. For example, mood disorders and depression are concerned with inhibiting ruminations (Wenzlaff, Wegner, & Roper, 1988). Often, these ruminations are subject to perseveration and are signs of attentional inflexibility. However, due to their different inlluence mechanisms on attentional control, variety of forms of ruminations may represent different cognitive mechanisms. For example, inhibitory problems are associated with depressive ruminations, whereas angry ruminations relate to problems with task switching (Whitmer & Banich, 2007).

Another example of a mental disorder where researchers observe impaired inhibition and attention control is OCD. The OCD inhibitory impairments may be explained by a mechanism related to attentional bias (Muller & Roberts, 2004). Attentional bias primes threatening information related to compulsions and obsessions, the main symptoms of OCD, causing problems with inhibiting these threatening or negative thoughts. For example, Muller and Roberts (2004) found that the Stroop task interference correlates with the amount of OCD symptoms.

Neurodegenerative disorders include impairments in inhibitory control as well. In one study, Alzheimer's disease patients made more errors in the antisaccade condition due to problems with correcting errors and inhibiting a habitual response of not looking towards the cue (Crawford et al., 2005). Additionally, this impairment was positively correlated with cognitive measures of dementia. In another study, researchers compared performance of patients with AD and those with MCI (Belleville, Chertkow, & Gauthier, 2007). Whereas MCI patients exhibited impairments only in some WM tasks, AD patients had problems with all administered WM tasks. Thus, even patients with the MCI show some level of WM impairment such as poorer planning and executing goals (Altgassen, Phillips, Kopp, & Kliegel, 2007). This may imply existence of a continuum of progressive cognitive impairments. As the authors argued, by showing such a continuum of attentional control problems from the MCI to AD, WM tasks can be used to monitor and diagnose early stages of the disease and prompt clinical attention early enough to slow down its progress. Implications may also be important for rehabilitation programs. As described in a case study by Vallat et al. (2005), they can be used for attenuating the cognitive impairments caused by brain injuries or strokes and targeted specifically at improving WM. Finally, similarly to PD patients, TBI patients experience the biggest challenge with planning, formulation, and execution of goals. In one study, TBI patients were assigned to either "assigning specific goal" condition or "do your best" condition. Interestingly, when assigned to a specific goal, patients were able to improve their performance significantly in comparison to the less specific assignment to "do your best" (Gauggel & Billino, 2002).

State WMC: Achievement Tests and Stereotype Threat

How well one can perform on the tasks measuring WMC predicts performance on a variety of higher-order cognitive tasks. The common factor of these tasks aimed at capturing individual differences in WMC is the ability to draw inferences about numerous higher order cognitive functions. Examples include various processes important in learning and language processing, such as reading and listening comprehension (Daneman & Carpenter, 1980), vocabulary learning (Daneman & Green, 1986), language comprehension (King & Just, 1991) as well as complex learning (Kyllonen & Stephens, 1990), writing, and note-taking (Kiewra & Benton, 1988). Other situations include reasoning and fluid abilities (Kyllonen & Christal, 1990; Conway et al., 2002; Engle, Kane, & Tuholski, 1999; Engle, Tuholski, et al., 1999; for review see also Orzechowski, this volume), and various other skills (Engle, 2001; Engle & Kane, 2004).[3]

Achievement tests constitute one area of possible implications of state differences in WMC. Research has shown that test anxiety influences performance of some individuals to a greater extent than others. As Ashcraft and Kirk (2001) and other researchers demonstrate, high math anxiety negatively influences cognitive performance on a math test by impairing performance by temporarily shrinking WMC resources. The authors reason that worries consume WMC resources needed for solving math problems in a similar fashion as focusing attention on a threat impairs processing of nonthreat information (Borkovec & Inz, 1990; Borkovec, Lyonfields, Wiser, & Diehl, 1993; Lavric et al., 2003; Mathews & Mackintosh, 1998; Mathews, Mackintosh, & Fulcher, 1997). For example, such adverse effects may be seen in performance on math problems in high WMC individuals. As they arc subjected to a high-pressure environment, their performance deteriorates to the level of performance of low spans (Beilock & Carr, 2005; Beilock et al., 2007; Osborne, 2007). These facts call for a need to take into account gender or ethnic group differing in the strength of influence caused by the relevant temporary threatening situation. Similarly, it should be taken into account in academic performance and test anxiety in order to diminish the negative outcomes not related to actual level of ability or knowledge of a subject.

Similar mechanisms that preclude successful performance are seen in intelligence tests of different ethnic groups and in women solving math tests. **In** such situations, stereotype threat associates the test with a specific stereotype making it salient at the time of the test (Schmader & Johns, 2003). Furthermore, in studies researching inferiority of women math performance when a stereotype was made salient, Krendl and colleagues (2008) observed less activation in prefrontal regions and other brain regions associated with math learning normally active during math performance. What they observed instead was a higher activation of the brain regions normally active during processing of social and emotional information, including ventral ACC (see also Richeson et al., 2003).

Another implication pertains to stereotype threat involving situations other than achievement tests, such as interracial stereotyping after interaction with a different race (Richeson & Shelton, 2003; Trawalter & Richeson, 2006) or similar mechanisms induced in situations of stress and test anxiety. These states distract through material irrelevant to the task, such as threat inducing intrusive thoughts or anxiety caused by inability to discard the threatening information. This, in tum, leaves less attentional resources available for the task (Keogh & French, 2001).

Overcoming Capacity Limits

As stated earlier, practice frees WM resources, especially under a high load (Beilock & DeCaro, 2007; Beilock, et al., 2007; Chein & Schneider, 2005). Practice reduces the load by making practiced problems more automatic, thus leaving more resources for complex processing. Studies show that merely introducing to a high load may lead to reduction in distractor interference due to narrowed focusing on a task (Forster & Lavie, 2007). Specifically, individuals that are more distractible in a daily life are usually more vulnerable to interference due to this distractibility. When under a high load, however, they focus their attention on the task. That leads to better performance due to reducing the interference normally present where there is no load. The opposite is true for individuals usually reporting low levels of interference. For them, the performance worsens in a similar fashion that high spans' in "choking under pressure" situations.

[3] Interested readers are directed to Wilhelm and Engle (2005; see also Shamosh et al., 2008; Wright et al., 2000).

Interestingly, under specific circumstances, moderate levels of stress lead to reconfiguration of strategies and adaptation to the depleted resources of WM (Steinhauser, Maier, & Hubner, 2007). In addition, focusing attention on task relevant information may also help to alleviate the negative effects of stress. In fact, research shows instances where focusing attention on relevant information due to narrowing attention under stress lead to less interference under high rather than low stress situations; that time, unlike in "choking under pressure" (Chajut & Algom, 2003; Hockey, 1997).

Finally, Wegner (1994) discusses various implications of the mechanisms of thought suppression. When WMC is low, a person-relevant instead of task-relevant thoughts take the precedence. Relaxation techniques that may lead to inverting such mechanism may as well positively influence other aspect of a daily life. These include mood control, increased concentration, pain control, sleep, and various social interactions. Lastly, it should be noted that before implementing different techniques that may overcome the negative effects of WMC depletion, we should remember that the level of improvement and the goals are tied both to motivation and to the realistic nature of the to-be-accomplished goal (Niemivirta, 1999).

Concluding Remarks

In this chapter, we attempted to review the literature relevant to WMC seen as a trait, a stable characteristic of an individual, as well as WMC as a state relating to various situational factors that temporarily influence WMC functioning. We have also shown that in some instances WMC can be improved. Finally, we have indicated some of the implications of looking at WMC as a state and trait construct that may be useful in monitoring performance in normal individuals and in psychopathology concerned with problems related to information processing and goal-related behaviors. Still to come is a fascinating journey of discovering the entire biological mechanism and the interplay between the brain, neurotransmitters, genes, and situational factors that influence WMC and cognitive control of behavior.

References

Albin, R. L., Young, A. B., & Penney, J. B. (1989). The functional anatomy of basal ganglia disorders. *Trends in Neuroscience, 12*, 366–375.

Altgassen, M., Phillips, L., Kopp, U., & Kliegel, M. (2007). Role of working memory components in planning performance of individuals with Parkinson's disease. *Neuropsychologia*, 45, 2393–2397.

Ando, J., Dna, Y., & Wright, M. J. (2001). Genetic structure of spatial and verbal working memory. *Behavior Genetics, 31*, 615–624.

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology. General, 130*, 224–237.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–89). New York: Academic.

Baddeley, A. D. (1996). Exploring the central executive. *The Quarterly Journal of Experimental Psychology, 49A*, 5–18.

Barch, D. M. (2005). The cognitive neuroscience of schizophrenia. *Annual Reviews of Clinical Psychology, 1*, 321–353.

Barch, D. M. (2006). What can research on schizophrenia tell us about the cognitive neuroscience of working memory? *Neuroscience, 139*, 73–84.

Barkley, R. A. (2001). The executive functions and self-regulation: an evolutionary neuropsychological perspective. *Neuropsychology Review, 11*, 1–29.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: what governs choking under pressure. *Journal of Experimental Psychology. General, 130*, 701–725.

econliguration of
& Hubner, 2007).
viate the negative
evant information
zr than low stress
Hockey, 1997).
night suppression.
: the precedence.
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linical Psychology, I,
iroscience of working
.hological perspective.
.oking under pressure?

Beilock, S, L., & Carr, T. H. (2005). When high-powered peopte fail. Working memory and "choking under pressure" in math. *Psychological Science, 16*, 101-105.

Beilock, S. L., Kulp, C. A., Holt, L. E., & Carr, T. H. (2004). More on the fragility of performance: choking under pressure in mathematical problem solving. *Journal of Experimental Psychology. General, 133*, 584-600.

Beilock, S. L., & DeCaro, M. S. (2007). From poor performance to success under stress: working memory, strategy selection, and mathematical problem solving under pressure. *Journal of Experimental Psychology. Learning, Memory, & Cognition, 33*, 983-998.

Beilock, S. L., Jellison, W. A., Rydell, R. J., McConnell, A. R., & Carr, T. H. (2006). On the causal mechanisms of stereotype threat: can skills that don't rely heavily on working memory still be threatened? *Personality and Social Psychology Bulletin, 32*, 1059-1071.

Beilock, S. L., Rydell, R. J., & McConnell, A. R. (2007). Stereotype threat and working memory: mechanisms, alleviation, and spillover. *Journal of Experimental Psychology. General, 136*, 256--276.

Belleville, S., Chertkow, H., & Gauthier, S. (2007). Working memory and control of attention in persons with Alzheimer's disease and mild cognitive impairment. *Neuropsychology, 21*, 458-469.

Bishop, S., Duncan, J., Brett, M., & Lawrence, A. D. (2004). Prefrontal cortical function and anxiety: controlling attention to threat-related stimuli. *Nature Neuroscience, 7*, 184-188.

Blasi, G., Mattay, V. S., Bertolino, A., Elvevag, B., Callicott, J. H., Das, S., et al. (2005). Effect of Catchol-O-Methyltransferase *val*^{158met} genotype on attentional control. *The Journal of Neuroscience, 25*, 5038-5045.

Borkovec, T. D., & Inz, I. (1990). The nature of worry in generalized anxiety disorder: a predominance of thought activity. *Behavior Research and Therapy, 28*, 153-158.

Borkovec, T. D., Lyonfields, J. D., Wiser, S. L., & Diehl, I. (1993). The role of worrisome thinking in the suppression of cardiovascular response to phobic imagery. *Behavior Research and Therapy, 31*, 321-324.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review, 108, 624-652.*

Braver, T. S., Barch, D. M., & Gray, J. R. (2001). Anterior cingulate cortex and response conflict: effects of frequency, inhibition and errors. *Cerebral Cortex, 11*, 825-836.

Brewin, C. R., & Beaton, A. (2002). Thought suppression, intelligence, and working memory capacity. *Behaviour Research and Therapy, 40, 923-930.*

Brewin, C. R., & Smart, L. (2005). Working memory capacity and suppression of intrusive thoughts. *Journal of Behavior Therapy and Experimental Psychiatry, 36*, 61-68.

Brown, J. A. (1958). Some tests of the decay theory of immediate memory. *Quarterly Journal of Experimental Psychology, 10, 12-21.*

Bunting, M. (2006). Proactive interference and item similarity in working memory. *Journal of Experimental Psychology. Learning, Memory, & Cognition, 32*, 183-196.

Bush, G., Whalen, P. J., Rosen, B. P., Jenikc, M. A., McInerney, S. C., & Rauch, S. L. (1998). The counting Stroop: an interference task specialized for functional neuroimaging - validation study with functional MRI. *Human Brain Mapping, 6*, 270-282.

Casement, M. D., Broussard, J. L., Mullington, J. M., & Press, D. Z. (2006). The contribution of sleep to improvement in working memory scanning speed: a study of prolonged sleep restriction. *Biological Psychology, 72*, 208-212.

Caseras, X., Mataix-Cols, D., Giampietro, Y., Rimes, K. S., Ntsmmrt, M., Zelaya, F., et al. (2006). Probing the working memory system in chronic fatigue syndrome: a functional magnetic resonance imaging study using the n-back task. *Psychosomatic Medicine, 68*, 947-955.

Chajut, E., & Algom, D. (2003). Selective attention improves under stress: implications for theories of social cognition. *Journal of Personality and Social Psychology, 85*, 231-248.

Chee, M. W., & Choo, W. C. (2004). Functional imaging of working memory after 24h of sleep deprivation. *The Journal of Neuroscience, 24*, 4560-4567.

Chein, J. M., & Schneider, W. (2005). Neuroimaging studies of practice-related change: fMRI and meta-analytic evidence of a domain-general control network for learning. *Cognitive Brain Research, 25*, 607-623.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *Journal of the Acoustical Society of America, 25*, 975-979.

Colflesh, G. J. H., & Conway, A. R. A. (2007). Individual differences in working memory capacity and divided attention in dichotic listening. *Psychonomic Bulletin and Review, 14*, 699-703.

Conway, A. R. A., & Engle, R. W. (1994). Working memory and retrieval: a resource-dependent inhibition model. *Journal of Experimental Psychology. General, 123*, 354-373.

Conway, A. R. A., & Engle, R. W. (1996). Individual differences in working memory capacity: more evidence for a general capacity theory. *Memory, 4*, 577-590.

Conway, A. R. A., Cowan, N., & Bunting, M. F. (2001). The cocktail party phenomenon revisited: the importance of working memory capacity. *Psychonomic Bulletin and Review, 8*, 331-335.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30, 163-183.*

Conway, A. R. A., Kane, M. J., Bunting, M. E, Hambrick, D. Z., Wilhelm, O., & Engle, R. E. (2005). Working memory span tasks: a methodological review and user's guide. *Psychonomic Bulletin and Review*, 12, 769-786.
Conway, A. R. A., Tuholski, S. W., Shisler, R. J., & Engle, R. W. (1999). The effect of memory load on negative priming: an individual differences investigation. *Memory and Cognition*, 27, 1042-1050.
Cools, R., Barker, R. A., Sahakian, B. J., & Robbins, T. W. (2001). Enhanced or impaired cognitive function in Parkinson's disease as a function of dopaminergic medication and task demands. *Cerebral Corex, 11*, 1136–1143.
Cools, R., Gibbs, S. E., Miyakawa, A., Jagust, W., & D'Esposito, M. (2008). Working memory capacity predicts dopamine synthesis capacity in the human striatum. *The Journal of Neuroscience*, 28, 1208-1212.
Cowan, N. (1988). Evolving concepts of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin, 104, 103-191.*
Cowan, N. (1997). *Attention and memory. An integrated framework* (Oxford Psychology Series 26). New York: Oxford University Press.
Crawford, T. J., Higham, S., Renvoize, T., Patel, J., Dale, M., Suriya, A., et al. (2005). Inhibitory control of saccadic eye movements and cognitive impairment in Alzheimer's disease. *Biological Psychiatry*, 57, 1052-1060.
Croizet, J. C., Despres, G., Gauzins, M. E., Huguet, P., Leyens, J. P., & Meot, A. (2004). Stereotype threat undermines intellectual performance by triggering a disruptive mental load. *Personality and Social Psychology Bulletin, 30*, 721-731.
D'Esposito, M., Onishi, K., Thompson, H., Robinson, K., Armstrong, C.; & Grossman, M. (1996). Working memory impairments in multiple sclerosis: evidence from a dual-task paradigm. *Neuropsychology*, 10, 51-56.
Dahlin, E., Stigsdotter Nelly, A., Larsson, A., Backman, L., & Nyberg, L. (2008). Transfer of learning after updating training mediated by the straitum. *Science*, 320, 1510-1512.
Dalgleish, T., Williams, J. M. G., Golden, A. J., Perkins, N., Feldman Barrett, L., Barnard, P. J., et al. (2007). Reduced specificity of autobiographical memory and depression: the role of the executive control. *Journal of Experimental Psychology. General, 136*, 23–42.
Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal o] Verbal Learning and Verbal Behavior*, 19, 459-466.
Daneman, M., & Green, I. (1986). Individual differences in comprehending and producing words in context. *Journal of Memory and Language*, 25, 1-8.
De Pisapia, N., Slomski, J. A., & Braver, T. S. (2007). Functional specializations in lateral prefrontal cortex associated with the integration and segregation of information in working memory. *Cerebral Cortex*, 17, 993-1006.
Diamond, A. (2005). Attention-deficit disorder (attention-deficit/hyperactivity disorder without hyperactivity): a neurobiologically and behaviorally distinct disorder from attention-deficit/hyperactivity disorder (with hyperactivity). *Development and Psychopathology*, 17, 807-825.
DiMaio, S., Grizenko, N., & Joober, R. (2003). Dopamine genes and attention-deficit hyperactivity disorder: a review. *Journal of Psychiatry Neuroscience*, 28, 27-38.
Dolcos, E, & McCarthy, G. (2006). Brain systems mediating cognitive interference by emotional distraction. *The Journal of Neuroscience*, 26, 2072-2079.
Engle, R. W. (2001). What is working-memory capacity? In H. L. Roediger III & J. S. Nairne (Eds.), *The nature of remembering: essays in honor of Robert* G. *Crowder* (pp. 297-314). Washington, DC: American Psychological Association.
Engle, R. W. (2002). Working memory capacity as executive attention. *Current Directions in Psychological Science, 11*, 19-23.
Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. Ross (Ed.), *The Psychology of Learning and Motivation* (Vol. 44, pp. 145-199). New York: Elsevier.
Engle, R. W., Cantor, J., & Carullo, J. (1992). Individual differences in working memory and comprehension: a test of four hypotheses. *Journal of Experimental Psychology. Learning, Memory and Cognition*, 18, 972-992.
Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory: mechanisms of active maintenance and executive control* (pp. 102-134). London: Cambridge Press.
Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory and general fluid intelligence: a latent variable approach. *Journal of Experimental Psychology. General, 128*, 309-331.
Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics*, 16, 143-149.
Fan, J., Fossella, J., Sommer, T., Wu, Y., & Posner, M. I. (2003). Mapping the genetic variation of executive attention onto brain activity. *Proc Natl Acad Sci USA, 100, 7406-7411.*
Feldman Barrett, L., Tugade, M. M., & Engle, R. W. (2004). Individual differences in working memory capacity and dual-process theories of mind. *Psychollogical Bulletin, 130, 553-573.*
Forster, S., & Lavie, N. (2007). High perceptual load makes everybody equal. *Psychological Science*, 18, 377-381.

Fossella, J., Sommer, T., Fan, J., Wu, Y., Swanson, J. M., Pfaff, D. W., et al. (2002). Assessing the molecular genetics of attention networks. *BMC Neuroscience*. 3, 14-25.

de Frias, C. M., Annerbrink, K., Westberg, L., Erikkson, E., Adolfsson, R., & Nilsson, G. (2005). Catchol-O-methyltransferase val158met polymorphism is associated with cognitive performance in nondemented adults. *Journal of Cognitive Neuroscience*, 17, 1018-1025.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: a latent-variable analysis. *Journal of Experimental Psychology. General*, 133, 101-135.

Gathercole, S. E., & Alloway, 1. P. (2006). Practitioner review: short-term and working memory impairments in neurodevelopmental disorders: diagnosis and remedial support. *Journal of Child Psychology and Psychiatry. 47*, 4-15.

Gauggel, S., & Billino, J. (2002). The effects of goal setting on the arithmetic performance of brain-damaged patients. *Archives of Clinical Neuropsychology*, 17, 283-294.

Gibbs, S. E. B., & D'Esposito, M. (2005). Individual capacity differences predict working memory performance and prefrontal activity following dopamine receptor stimulation. *Cognitive, Affective and Behavioral Neuroscience, 5*, 212-221.

Giesbrecht, T., Smeets, T., Leppink, J., Jelicic, M., & Merckelbach, H. (2007). Acute dissociation after I night of sleep loss. *Journal of Abnormal Psychology, 116*, 599–606.

Glatt, C. E., & Freimer, N. B. (2002). Association analysis of candidate genes for neuropsychiatric disease: the perpetual campaign. *Trends in Genetics*. 18, 307-312.

Goldman-Rakic, P. S. (1995). Architecture of the prefrontal cortex and the central executive. *Annals of the New York Academy of Sciences*. 769, 71-83.

Goldman-Rakic, P. S. (1987). Circuitry of primate prefrontal cortex and regulation of behavior by representational knowledge. In F. Plum & V. Mountcastle (Eds.), *Handbook of physiology* (Vol. 5, pp. 373-417). Bethesda, MD: APS.

Goldman-Rakie, P. S., Muly, E. C., III, & Williams, G. V. (2000). D(I) receptors in prefrontal cells and circuits. *Brain Research Reviews*, 31, 295-301.

Gross, J. J., & Levenson, R. W. (1997). Hiding feelings: the acute effects of inhibiting negative and positive emotion. *Journal of Abnormal Psychology, 106*, 95-103.

Hallett, P. E. (1978). Primary and secondary saccades to goals defined by instructions. *Vision Research, 18*, 1279-1296.

Harrison, Y, & Home, J. A. (2000). The impact of sleep deprivation on decision making: a review. *Journal of Experimental Psychology. Applied*, 6, 236-249.

Harrison, Y., Home, J. A., & Rothwell, A. (2000). Prefrontal neuropsychological effects of sleep deprivation in young adults - a model of healthy aging? *Sleep*, 23, 1067-1073.

Hartlage, S., Alloy, L. B., Vazquez, C., & Dykman, B. (1993). Automatic and effortful processing in depression. *Psychological Bulletin*, 113, 247-278.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: a review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22, pp. 193-225). New York: Academic Press.

Heitz, R. P., & Engle, R. W. (2007). Focusing the spotlight: individual differences in visual attention control. *Journal of Experimental Psychology. General*, 136, 217-240.

Hester, R., & Garavan, H. (2005). Working memory and executive function: the influence of content and load on the control of attention. *Memory and Cognition*. 33, 221-233.

Hockey, G. R. (1997). Compensatory control in the regulation of human performance under stress and high workload: a cognitive-energetical framework. *Biological Psychology*, 45, 73-93.

Jaeggi, S. M., Buschkuehl, M., Etienne, A., Ozdoba, C, Perrig, W. J., & Nirkko, A. C. (2007). On how high performers keep cool brains in situations of cognitive overload. *Cognitive, Affective and Behavioral Neuroscience*. 7, 75-89.

Jaeggi, S. M., Buschkuehl, M., Jonides, 1., & Perrig, W. J. (2008). Improving fluid intelligence with training on working memory. *Proc Natl Acad* Sci *USA, 105*, 6829–6833.

Jaeggi, S.M., Seewer, R., Nirkko, A.C., Eckstein D., Schroth, G., Groner, R., & Gutbrod, K. (2003). Docs excessive memory load attenuate activation in the prefrontal cortex? Load-dependent processing in single and dual tasks: functional magnetic resonance imaging study. *Neuroimage*, 19, 210-225.

Johnson, W. (2007). Genetic and environmental influences on behavior: capturing all the interplay. *Psychological Review*. 114, 423-440.

Jonides, J., & Nee, D. E. (2006). Brain mechanisms of proactive interference in working memory. *Neuroscience, 139*, 181-193.

Jonides, J., Schumacher, E. G., Smith, E. E., Lauber, E., Awh, E., Minoshima, S., et al. (1997). Verbal working memory load affects regional brain activation as measured by PET. *Journal of Cognitive Neuroscience*, 9, 462-475.

Kane, M. J., & Engle, R. W. (2000). Working-memory capacity, proactive interference, and divided attention: limits on long-term memory retrieval. *Journal of Experimental Psychology. Learning, Memory and Cognition, 26*, 336-358.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: an individual differences perspective. *Psychonomic Bulletin and Review*, 9, 637-671.

Kane, M. J., & Engle, R. W. (2003). Working memory capacity and the control of attention: the contributions of goal neglect, response competition, and task set to Stroop interference. *Journal of Experimental Psychology. General* 132, 47-70.

Kane, M. J., Bleckley, K. M., Conway, A. R. A., & Engle, R. W. (2001). A controlled-attention view of working memory capacity. *Journal of Experimental Psychology. General, 130, 169-183*.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: a latent variable approach to verbal and visuospatial memory span and reasoning. *Journal oj' Experimental Psychology. General, 133, 189-217*.

Kellendonk, C., Simpson, E. H., Polan, H. J., Malleret, G., Yronskaya, S., Winiger, Y., et al. (2006). Transient and selective overexpression of dopamine D2 receptors in the striatum causes persistent abnormalities in prefrontal cortex functioning. *Neuron*, 49, 603-615.

Kensinger, E. A., & Corkin, S. (2003). Effect of negative emotional content on working memory and long-term memory. *Emotion*, 3, 378-393.

Keogh, E., & French, C. C. (2001). Test anxiety, evaluative stress, and susceptibility to distraction from threat. *European Journal of Personality, 15, 123-141*.

Keppel, G., & Underwood, B. J. (1962). Proactive inhibition in short-term retention of single items. *Journal of Yerhni Learning and Verbal Behavior, I, 153-161*.

Kerns, J. G., Cohen, J. D., MacDonald, A. W., III, Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate, conflict monitoring, and adjustments in control. *Science, 303, 1023-1026*.

Kiewra, K. A., & Benton, S. L. (1988). The relationship between information-processing ability and notetaking. *Contemporary Educational Psychology, 13*, 33–44.

Killgore, W. D. S., Balkin, 1'. J., & Wesensten, N. J. (2006). Impaired decision making following 49h of sleep deprivation. *Journal of Sleep Research, 15, 7-13*.

Kimberg, D. Y., & D'Esposito, M. (1997). Effects of bromocriptine on human subjects depend on working memory capacity. *Cognitive Neuroreport*, 8, 3581-3585.

Kimberg, D. Y., & D'Esposito, M. (2003). Cognitive effects of the dopamine receptor agonist pergolide. *Neuropsychologia, 41, 1020-1027*.

King, J., & Just, M. A. (1991). Individual differences in syntactic processing: the role of working memory. *Journal of memory and Language, 30, 580-602*.

Klein, K., & Boals, A. (2001). The relationship of life event stress and working memory capacity. *Applied Cognitive Psychology, 15, 565-579*.

Klein, K., & Fiss, W. H. (1999). The reliability and stability of the Turner and Engle working memory task. *Behavior Research Methods, Instruments and Computers, 31, 429-432*.

Klingberg, 1'., FerneII, E., Olesen, P. J., Johnson, M., Gustafsson, P., Dahlstrom, K., et al. (2005). Computerized training of working memory in children with ADl-1D - a randomized, controlled trial. *Journal of the American Academy o] Child and Adolescent Psychiatry*, 44, 177-186.

Klingberg, 1'., Forssberg, l-l., & Westerberg, l-l. (2002). Training of working memory in children with ADHD. *Journal of Clinical and Experimental Neuropsychology*, 24, 781-791.

Knecht, S., Breitenstein, C; Bushuven, S., Wailke, S., Kamping, S., Floel, A., et al. (2004). Levodopa: faster and better word learning in normal humans. *Annals (If Neurology*, 56, 20-26.

Kodama, 1'., Hikosaka, K., & Watanabe, M. (2002). Differential changes in glutamate concentration in the primate prefrontal cortex during spatial delayed alternation and sensory-guided tasks. *Experimental Brain Research, 145*, 133-141.

Krendl, A. C., Richeson, J. A., Kelley, W. M., & Heatherton, 1'. E (2008). The negative consequences of threat - a functional magnetic resonance imaging investigation of the neural mechanisms underlying women's underperformance in math. *Psychological Science, 19, 168-175*.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working memory capacity?! *Intelligence, 14, 389-433*.

Kyllonen, P. C., & Stephens, D. L. (1990). Cognitive abilities as determinants of success in acquiring logic skill. *Learning and Individual Differences*, 2, 129-160.

Lavric, A., Rippon, G., & Gray, J. R. (2003). Threat-evoked anxiety disrupts spatial working memory performance: an attentional account. *Cognitive Therapy and Research*, 27, 489-504.

Lee, K.H., Choi, Y.Y., Gray, J.R., Cho, S.H., Chae, J-H., Lee, S., & Kim, K. (2006). Neural correlates of superior intelligence: Stronger recruitment of posterior parietal cortex. *Neuroimage*, 29, 578-586.

Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory and Cognition*, 7, 166-174.

Lorist, M. M., Boksem, M. A. S., & Ridderinkhof, K. R. (2005). Impaired cognitive control and reduced cingulate activity during mental fatigue. *Cognitive Brain Research*, 24, 199-205.

Luciano, M., Wri
among measui
Lustig, C., May, (
Experimental
MacDonald, A. W
executive coni
Psychology, 11
Manor, I., Tyano, S
confer risk to a
tinuous perfom
Mathews, A., & M
Research, 122,
Mathews, A., Mad
Cognitive Scien
May, C. P., Hasher,
759-767.
McNab, E, & K1inl
Neuroscience, 1.
Mecklinger, A., Wei
trol: effects of in
Mehta, M. A., & Ri
Design, 12, 2487
Meneses, A., & Pere
705-727.
Miller, E. K. (2000).
Miller, E. K., & Cc
Neuroscience, 24,
Mitchell, J. P., Heath!
sustained from trar
Miyake, A., & Shah, I
New York: Cambr
Miyake, A., Friedman
tive functions anc
Psychology, 41, 49
Moray, N. (1959). At
Journal of Experin
Muller, J., & Roberts
Disorders, 19, 1-21
Nebel, K., Wiese, H., S
structures in multip
Niemivirta, M. (1999)
Journal of Educatic
Nigg, J. T. (2000). On i
ity psychology and
Nigg, J. T., Carr, L. A.
chopathology. In C
American Psycholo
Nolan, K. A., Bilder, R
morphism in schiz
American Journal c
Norman, D. A., & BobIT
Norman, D. A., & Shall
G. E. Schwartz, &
4, pp. 1-18). New Y
Oberauer, K. (2006). Is
Psychology. Learnii
Oberauer, K., Sue, K.-I
processing, supervis
Olesen, P. J., Westerben
memory. *Nature Ne*

Luciano, M., Wright, M. J., Smith, G. A., Geffen, G. M., Geffen, L. B., & Martin, N. G. (2001). Genetic covariance among measures of information processing speed, working memory, and IQ. *Behavior Genetics*, 6,581-592.

Lustig, C., May, C. P., & Hasher, L. (2001). Working memory span and the role of proactive interference. *Journal of Experimental Psychology. General, 130, 199-207.*

MacDonald, A. W., III, Carter, C. S., Flory, J. D., Ferrell, R. E., & Manuck, S. B. (2007). COMT Val158Met and executive control: a test of the benefit of specific deficits to translational research. *Journal of Abnormal Psychology, 116,306-312.*

Manor, I., Tyano, S., Eisenberg, J., Bachner-Melman, R., Kotler, M., & Ebstein, R. P. (2002). The short DRD4 repeats confer risk to attention deficit hyperactivity disorder in a family-based design and impair performance on a continuous performance test (TOVA). *Molecular Psychiatry*, 7,790-794.

Mathews, A., & Mackintosh, B. (1998). A cognitive model of selective processing in anxiety. *Cognitive Therapy and Research, 122,539-560.*

Mathews, A., Mackintosh, B., & Fulcher, E. P. (1997). Cognitive biases in anxiety and attention to threat. *Trends in Cognitive Sciences, I, 341-346.*

May, C. P., Hasher, L., & Kane, M. J. (1999). The role of interference in memory span. *Memory and Cognition, 27,* 759-767.

McNab, E, & Klingberg, T. (2008). Prefrontal cortex and basal ganglia control access to working memory. *Nature Neuroscience, II, 103-107.*

Mecklinger, A., Weber, K., Gunter, T. C., & Engle, R. W. (2003). Dissociable brain mechanisms for inhibitory control: effects of interference content and working memory capacity. *Cognitive Brain Research, 18,26-38.*

Mehta, M. A., & Riedel, W. J. (2006). Dopaminergic enhancement of cognitive function. *Current Pharmaceutical Design, 12,2487-2500.*

Meneses, A., & Perez-Garcia, G. (2007). 5-HT'Areceptors and memory. *Neuroscience and Behavioral Reviews. 31,* 705-727.

Miller, E. K. (2000). The prefrontal cortex and cognitive control. *Nature Reviews. Neuroscience. 1,59-65.*

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Reviews of Neuroscience.* 24, 167-202.

Mitchell, J. P., Heatherton, T. E, Kelley, W. M., Wyland, C. L., Wegner, D. M., & McCrae, C. N. (2007). Separating sustained from transient aspects of cognitive control during thought suppression. *Psychological Science, 18,292-297.*

Miyake, A., & Shah, P. (1999). *Models of working memory: mechanisms of active maintenance and executive control.* New York: Cambridge University Press.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41, 49-100.*

Moray, N. (1959). Attention in dichotic listening: affective cues and the influence of instructions. *The Quarterly Journal of Experimental Psychology, II, 59-60.*

Muller, J., & Roberts, J. E. (2004). Memory and attention in obsessive-compulsive disorder: a review. *Anxiety Disorders, 19, 1-28.*

Nebel, K., Wiese, H., Seyfarth, J., Gizewski, E. R., Stude, P., Ciener, H.-C., et al. (2007). Activity of attention related structures in multiple sclerosis patients. *Brain Research, 1151, 150-160.*

Niemivirta, M. (1999). Motivational and cognitive predictors of goal setting and task performance. *International Journal of Educational Research,* 31, 499-513.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin,* 126, 220-246.

Nigg, J. T., Carr, L. A., Martel, M. M., & Henderson, J. M. (2007). Concepts of inhibition and developmental psychopathology. In C. MacCleod & D. Gorfein (Eds.), *Inhibition in cognition* (pp. 259-277). Washington, DC: American Psychological Association Press.

Nolan, K. A., Bilder, R. M., Lachman, H. M., & Volavka, J. (2004). Catechol O-methyltransferase val'58met polymorphism in schizophrenia: differential effects of Val and Met alleles on cognitive stability and flexilibilty. *American Journal of Psychiatry,* 161,359-361.

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology,* 7, 44-64.

Norman, D. A., & Shallice, T. (1986). Attention to action: willed and automatic control of behavior. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation: advances in research and theory* (Vol. 4, pp. 1-18). New York: Plenum.

Oberauer, K. (2006). Is the focus of attention in working memory expanded through practice? *Journal of Experimental Psychology. Learning, Memory and Cognition,* 32, 197-214.

Oberauer, K., Süß, K.-M., Wilhelm, O., & Wittman, W. W. (2003). The multiple faces of working memory: storage, processing, supervision, and coordination. *Intelligence.* 31, 167-193.

Olesen, P. J., Westerberg, H., & Klingberg, T. (2003). Increased prefrontal and parietal activity after training of working memory. *Nature Neuroscience,* 7, 75-79.

Osborne, J. W. (2007). Linking stereotype threat and anxiety. *Educational Psychology,* 27, 135- 154.

Owen, A. M. (2004). Cognitive dysfunction in Parkinson's disease: the role of frontostriatal circuitry. *The Neuroscientist* 9, 1-13.

Pennington, B. E, & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry,* 37, 51- 87.

Perlstein, W. M., Dixit, N. K., Carter, C. S., Noll, D. C., & Cohen, J. D. (2003). Prefrontal cortex dysfunction mediates deficits in working memory and prepotent responding in schizophrenia. *Biological Psychiatry.* 53, 25-38.

Perlstein, W. M., Elbert, T., & Stenger, V. A. (2002). Dissociation in human prefrontal cortex of affective influences on working memory-related activity. *Proc Natl Acad Sci USA.* 99, 1736–1741.

Persson, J., & Reuter-Lorenz, P. A. (2008). Gaining control: training executive function and far transfer of the ability to resolve interference. *Psychological Science. i9, 881-888.*

Persson, J., Welsh, K. M., Jonides, J., & Reuter-Lorenz, P. A. (2007). Cognitive fatigue of executive processes: interaction between interference resolution tasks. *Neuropsychologia,* 45, 1571-1579.

Peterson, L. R., & Peterson, M. J. (1959). Short-term retention of individual verbal items. *Journal of Experimental Psychology.* 58, 193-198.

Petrides, M. (1996). Specialized systems for the processing of mnemonic information within the primate frontal cortex. *Philosophical Transactions of the Royal Society of London, 35i, 1455-1462.*

Posner, M. I., & Snyder, Ch R R. (1975). Attention and cognitive control. In R. Solso (Ed.), *information processing and cognition: the Loyola symposium.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Previc, F. H. (1999). Dopamine and the origins of human intelligence. *Brain and Cognition. 4i, 299-350.*

Quinn, D. M., & Spencer, S. J. (2001). The interference of stereotype threat with women's generation of mathematical problem-solving strategies. *Journal of Social issues,* 57, 55- 71.

Redick, T. S., Heitz, R. P., & Engle, R. W. (2007). Working memory capacity and inhibition: cognitive and social consequences. In D. S. Gorfein & C. M. MacLeod (Eds.), *inhibition in cognition* (pp. 125- 142). Washington, DC: American Psychological Association.

Reitan, R. M., & Wolfson, D. (1994). A selective and critical review of neuropsychological deficits and the frontal lobes. *Neuropsychology Review.* 4, 161-198.

Richards, J. M., & Gross, J. J. (2000). Emotion regulation and memory: the cognitive costs of keeping one's cool. *Journal of Personality and Social Psychology.* 79, 410-424.

Richeson, J. A., & Shelton, J. N. (2003). When prejudice does not pay: effects of interracial contact on executive function. *Psychological Science. i4, 287-290.*

Richeson, J. A., Baird, A. A., Gordon, H. L., Heathcrton, T. E, Wyland, C. L., Trawalter, S., et al. (2003). An fMRI investigation of the impact of interracial contact on executive function. *Nature Neuroscience.* 6, 1323- 1328.

Rosen, V. M., & Engle, R. W. (1997). Forward and backward serial recall. *intelligence,* 25, 37-47.

Savitz, J., Solms, M., & Ramesar, R. (2006). The molecular genetics of cognition: dopamine, COMT and BDNF. *Genes. Brain and Behavior,* 5, 311-328.

Schmader, T., & Johns, M. (2003). Converging evidence that stereotype threat reduces working memory capacity. *Journal of Personality and Social Psychology,* 85, 440-452.

Schmeichel, B. J. (2007). Attention control, memory updating, and emotion regulation temporarily reduce the capacity for executive control. *Journal of Experimental Psychology. General. i36, 241-255.*

Schneider, W., & Chein, J. M. (2003). Controlled & automatic processing: behavior, theory, and biological mechanisms. *Cognitive Science.* 27, 525-559.

Schneider, W., & Detweiler, M. (1987). A connectionist/control architecture for working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 21, pp. 53-119). New York: Academic.

Serino, A., Ciaramelli, E., Di Santantonio, A., Malagu, S., Servadei, E, & Ladavas, E. (2007). A pilot study for rehabilitation of central executive deficits after traumatic brain injury. *Brain injury, 2i, 11- 19.*

Shackman, A. J., Sarinopoulos, I., Maxwell, J. S., Pizzagalli, D. A., Lavric, A., & Davidson, R. J. (2006). Anxiety selectively disrupts visuospatial working memory. *Emotion,* 6, 40-61.

Shallice, T., & Burgess, P. W. (1993). Supervisory control of action and thought selection. In A. Baddeley & L. Weiskrantz (Eds.), *Attention: selection. awareness. and control: a tribute to donald broadbent* (pp. 171-187), Oxford, England: Clarendon.

Shamosh, N. A., DeYoung, C, Green, A. E., Reis, D. L., Johnson, M. R., Conway, A. R. A., et al. (2008). Individual differences in delay discounting. *Psychological Science. i9, 904-911.*

Shiffrin, R. M., & Schneider, W. (1984). Automatic and controlled processing revisited. *Psychological Review, 91,* 269-276.

Shimamura, A. P. (2000). Toward a cognitive neuroscience of metacognition. *Consciousness and Cognition. 9,* 313-323.

Smith, E. E., & Jonides, J. (1998). Neuroimaging analyses of human working memory. *Proc Natl Acad Sci USA. 95.* 12061-12068.

Smith, E. E., & Jonides, J. (1999). Storage and executive processes in the frontal lobes. *Science Review, Neuroscience*, 283, 1657-1661.

Smith, M. E., McEvoy, L. K., & Gevins, A. (2002). The impact of moderate sleep loss on neurophysiologic signals during working memory task performance. *Sleep*, 25, 784-794.

Steele, C. M., & Josephs, R. A. (1990). Alcohol myopia: its prized and dangerous effects. *American Psychologist*, 45, 921-933.

Steinhauser, M., Maier, M., & Hübner, R. (2007). Cognitive control under stress: how stress affects strategies of task-set reconfiguration. *Psychological Science*, 18, 540-545.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

Suhara, T., Fukuda, H., Inoue, O., Itoh, T., Suzuki, K., Yamasaki, T., et al. (1991). Age-related changes in human D1 dopamine receptors measured by positron emission tomography. *Psychopharmacology, 103*, 41-45.

Swainson, R., Rogers, R. D., Sahakian, B. J., Summers, B. A., Polkey, C. E., & Robbins, T. W. (2000). Probabilistic learning and reversal deficits in patients with Parkinson's disease or frontal or temporal lobe lesions: possible adverse effects of dopaminergic medication. *Neuropsychologia*, 38, 596-612.

Swainson, J., Oosterlaan, J., Murias, M., Schuck, S., Flodman, P., Spence, M. A., et al. (2000). Attention deficit/hyperactivity disorder children with a 7-repeat allele of the dopamine receptor D4 gene have extreme behavior but normal performance on critical neuropsychological tests of attention. *Proc Natl Acad Sci USA, 97*, 4754-4759.

Thorell, L. B., Lindqvist, S., Bergman, S., Bohlin, G., & Klingberg, T. (2009). Training and transfer effects of executive functions in preschool children. *Developmental Science*, 11, 969-976.

Toga, A. W., & Thompson, P. M. (2005). Genetics of brain structure and intelligence, *Annual Reviews of Neuroscience*, 28, 1-23.

Trawalter, S., & Richeson, J. A. (2006). Regulatory focus and executive function after interracial interactions. *Journal of Experimental Social Psychology*, 42, 406-412.

Turley-Ames, K. J., & Whitfield, M. M. (2003). Strategy training and working memory task performance. *Journal of Memory and Language*, 49, 446-468.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language*, 28, 127-154.

Unsworth, N., & Engle, R. W. (2007). The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. *Psychological Review, 114*, 104-132.

Unsworth, N., Heitz, R. P., & Engle, R. W. (2005). Working memory capacity in hot and cold cognition. In R. W. Engle, G. Sedek, U. Hecker, & D. N. McIntosh (Eds.), *Cognitive limitations in aging and psychopathology* (pp. 19-43). New York: Cambridge University Press.

Unsworth, N., Schrock, J. C., & Engle, R. W. (2004). Working memory capacity and the antisaccade task: individual differences in voluntary saccade control. *Journal of Experimental Psychology. Learning, Memory and Cognition, 30*, 1302-1321.

Vallat, C., Azouvi, P., Hardisson, H., Meffert, R., Tessier, C., & Pradat-Diehl, P. (2005). Rehabilitation of verbal working memory after left hemisphere stroke. *Brain Injury, 19*, 1157-1164.

Verhaeghen, P., Cerella, J., & Basak, C. (2004). A working memory workout: how to expand the focus of serial attention from one to four items in 10 hours or less. *Journal of Experimental Psychology. Learning, Memory and Cognition, 30*, 1322-1337.

Vohs, K. D., & Heatherton, T. F. (2000). Self-regulatory failure: a resource-depletion approach. *Psychological Science*, 11, 249-254.

Waters, G. S., & Caplan, D. (2003). The reliability and stability of verbal working memory measures. *Behavior Research Methods, Instruments and Computers*, 35, 550-564.

Wegner, D. M. (1994). Ironic processes of mental control. *Psychological Review, 101*, 34-52.

Wegner, D. M., Erber, R., & Zanakos, S. (1993). Ironic processes in the mental control of mood and mood-related thought. *Journal of Personality and Social Psychology*, 65, 1093-1104.

Weissman, D. H., Giesbrecht, B., Song, A. W., Mangun, G. R., & Woldorff, M. G. (2003). Conflict monitoring in the human anterior cingulate cortex during selective attention to global and local object features. *Neuroimage, 19*, 1361-1368.

Wenzlaff, R. M., Wegner, D. M., & Roper, D. W. (1988). Depression and mental control: the resurgence of unwanted negative thoughts. *Journal of Personality and Social Psychology*, 55, 882-892.

Westerberg, H., & Klingberg, T. (2007). Changes in cortical activity after training of working memory - a single-subject analysis. *Physiology and Behavior*, 92, 186-192.

Westernberg, H., Jacobaeus, H., Hirvikoski, T., Clevberger, P., Ostensson, M.-L., Bartfai, A., et al. (2007). Computerized working memory training after stroke - a pilot study. *Brain Injury*, 21, 21-29.

Whitmer, A. J., & Banich, M. T. (2007). Inhibition versus switching deficits in different forms of rumination. *Psychological Science, 18*, 546-553.

Wilhelm, O., & Engle, R. W. (2005). *Handbook of understanding and measuring intelligence.* CA: SAGE.

Williams-Gray, C. H., Hampshire, A., Barker, R. A., & Owen, A. M. (2008). Attentional control in Parkinson's disease is dependent on COMT val^{158}met genotype. *Brain*, 131, 397-408.

Williams-Gray, C. H., Hampshire, A., Robbins, T. W., Owen, A. M., & Barker, R. A. (2007). Catechol O-Methyltransferase val^{158}met genotype influences frontoparietal activity during planning in patients with Parkinson's disease. *The Journal of Neuroscience*, 27, 4832-4838.

Wright, M., De Geus, E., Ando, J., Luciano, M., Posthuma, D., Ono, Y, et al. (2000). Genetics of cognition: outline of a collaborative twin study. *Twin Research*, 4, 48-56.

Yoo, S.-S., Hu, P. T., Gujar, N., Jolesz, F. A., & Walker, M. P. (2007). A deficit in the ability to form new human memories without sleep. *Nature Neuroscience, 10*, 385-392.

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