The Role of Working Memory Resources in Mind Wandering: The Difference Between Working Memory Capacity and Working Memory Load

Jason Seiichi Tsukahara
California State University - San Bernardino

THE ROLE OF WORKING MEMORY RESOURCES IN MIND WANDERING: THE DIFFERENCE BETWEEN WORKING MEMORY CAPACITY AND WORKING MEMORY LOAD

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Jason Seiichi Tsukahara

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Approved by:

Hideya Koshino, Committee Chair, Psychology

Robert Ricco, Committee Member

John Clapper, Committee Member

ABSTRACT

There is no consensus on the relationship between working memory resources and mind wandering. The purpose of the current study is to investigate whether mind wandering requires working memory resources to be sustained. The resource-demanding view is that mind wandering requires working memory resources to sustain an internal train of thought (Smallwood, 2010). The resource-free view is that mind wandering is a result of executive control failures and this internal train of thought proceeds in a resource-free manner (McVay & Kane, 2010). Participants were presented with thought probes while they performed a Simon task in single and dual task conditions. From the resource-demanding view, individuals with high WMC should experience more Task unrelated thought (TUT) in single and dual task conditions compared to those with low WMC. From the resource-free view, individuals with high WMC should experience fewer TUT compared to low WMC individuals. Results indicated that, WML eliminated the Simon effect for high WMC and reduced it for low WMC group. Mind wandering was decreased in dual task conditions however there was no effect of working memory capacity on mind wandering. Also, mind wandering correlated with task performance measures for the low WMC but not high WMC group. The results of the current study do not provide strong support for either a resource-demanding or resource-free view and are discussed in terms of a context dependent relationship between WMC and mind wandering

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

The experience of having one's mind drift from a task into daydreaming, rumination, or planning is a common experience most are familiar with, and can be referred to as mind wandering. It is interesting that this phenomenon of mind wandering has only recently made it into mainstream psychology research, given its ubiquitous nature. 96% of adult Americans report daydreaming of some kind every day (Singer & McCraven, 1961). Additionally, as many as 30% of thoughts that people experience in a day can be classified as mind wandering (Kane et al., 2007). The prevalence of mind wandering may be an under-recognized influence on human behavior and performance in a variety of areas, such as education (Smallwood, Fishman, & Schooler, 2007). Furthermore, research investigating the nature of mind wandering is and may continue to reveal important cognitive functions of the human mind. There are two things that must be considered before discussing the empirical research on mind wandering; 1) the terms used to characterize mind wandering and 2) the various methods developed to measure mind wandering.

Defining Mind Wandering

While research in psychology has viewed human thought as a goal-directed phenomenon, recent interest in mind wandering and the default mode network (e.g., Christoff, 2012) has begun to consider the undirected and spontaneous nature of thought. Since this research is in its early stages, there is still uncertainty as to the terminology that should be used to classify various forms of undirected spontaneous thought. Christoff (2012) defines undirected thought as “not deliberately directed” by the thinker yet it may be implicitly biased by the individuals current concerns or emotional state. The important distinction between undirected and directed thought is that undirected thought does not proceed by conscious effort towards a particular outcome, characteristic of goal-directed thought. Spontaneous thought is defined as unintended thoughts that come to mind unbidden and effortlessly (Christoff, 2012). This can occur in several forms such as daydreaming or mind wandering, although the distinction between different forms of spontaneous thought is not yet clear. Nevertheless, the most recent research prefers the term mind wandering, operationally defined as task-unrelated thought (TUT) (Christoff, 2012). While the term stimulus-independent thought (SIT) is often used in place of mind wandering, especially in the cognitive neuroscience literature, a distinction between SIT and mind wandering should be made (Christoff, 2012). TUT is simply defined as any thought that is not related to a current task, and is contrasted with task-related thought. SIT is defined as thought that is decoupled from current sensory information. SIT is contrasted with stimulus-oriented thought, which is thought directed towards the external sensory environment. TUT can be directed internally, as SIT, to the current concerns of the individual; or externally, as stimulus-oriented thought, toward stimuli in the environment not related to the task (e.g. footsteps from the floor above). While SIT may be unrelated to a current task, it can also be related to the task but not current perceptual stimuli, such as during memory recall tasks. Therefore, TUT and SIT should be considered as two independent dimensions of mind wandering. Whatever the content of TUT, be it stimulus-independent or stimulus-oriented, the experience of having ones mind drift away from a current task and towards unrelated concerns is typically referred to as mind wandering (Christoff, 2012).

Measuring Mind Wandering

Methods for directly measuring in-the-moment mind wandering can be classified into two categories, *probe-caught* and *self-caught* methods (Smallwood & Schooler, 2006). In the *probe-caught* method, individuals are interrupted (probed) during a task and are asked what they were thinking about, at the moment the probe occurred. How the individual is asked to respond can vary depending on what the researchers are investigating. In the *experimenter-classified* probe method, participants are asked to report the content of their thoughts, either verbally or written, and the experimenters can later code these reports into task-unrelated and task-related thought (Smallwood, Obonsawin, & Reid, 2003). An alternative to this is the *self-classification* probe method, in which participants classify their own subjective experience into a set of given response options (Smallwood & Schooler, 2006). There are typically at least two response options such as task-related or task-unrelated thought, but again this can vary depending on the nature of the experiment. In the *self-caught* method, individuals are asked to monitor their awareness for mind wandering thoughts, and report when they experience TUT. Since this method is confounded with awareness of mind wandering, the probe-caught method is a better measure of the overall frequency of mind wandering. Nevertheless, as Smallwood and Schooler (2006) point out, the use of both self-caught and probe-caught methods may be useful for distinguishing between mind wandering with and without awareness. Another method that is used to directly measure mind wandering is the use of retrospective reports where participants, after completing a task, fill out a questionnaire to measure their subjective experience during the task (Smallwood, Riby, Heim, & Davies, 2006).

Numerous studies have found reliability among these different self-report measures of mind wandering (Schooler, Reichle, & Halpern, 2004; Smallwood, Baracaia, Lowe, & Obonsawin, 2003; Smallwood, O'Connor, Sudberry, Haskell, & Ballantyne, 2004; Smallwood & Schooler, 2006). Behavioral and physiological indices of mind wandering on the sustained attention to response task (SART) have also been investigated (*fMRI activity*: Christoff, 2012; Mason et al., 2007, *EEG activity*: Smallwood, Beach, Schooler, & Handy, 2008, *Response times*: Smallwood, McSpadden, Luus, & Schooler, 2008; Smallwood, Davies, et al., 2004, *pupil diameter:* Smallwood et al., 2011; *Galvanic skin response and heart rate*: Smallwood et al., 2003).

The (SART) is a common task used to investigate the nature of mind wandering (Smallwood, Davies, et al., 2004). During this task, participants are to make a response to frequent non-target stimuli (go trials) and withhold their response to infrequent target stimuli (no-go trials). This creates a prepotency to make a response on all trials since no-go trials are infrequent (e.g. 11% of trials). Failure to withhold a pre-potent response on no-go trials is referred to as action slips and thought to result from attentional lapses (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). An attentional lapse implies that attention has shifted away from task-relevant information to task-irrelevant information, leading to more automatic pre-potent responding. Similar experiences can be found in daily life such as automatically driving on the typical route home from work instead of stopping at the supermarket to pick up dinner. The similarity this laboratory task shares with everyday occurrences of attentional lapse is one reason the SART has been used in research on mind wandering. The interruption of mind wandering thoughts can be seen as an example of an attentional lapse where one's attention has shifted away from a current task and towards internal trains of thought. Additionally, certain response behaviors on the SART have been associated with the occurrence of mind wandering that is also characteristic of attentional lapses, such as accelerated reaction times (Smallwood, Davies, et al., 2004).

Models of Mind Wandering

Studies have revealed that mind wandering may have an unrecognized influence on our behavior. For instance, mind wandering while reading impairs comprehension of the text, which may have important implications in education (Smallwood, Fishman, et al., 2007). Unsworth and McMillan (2012) found that motivation and topic interest influence mind wandering while reading, and these factors influence scores on reading comprehension tests. The occurrence of mind wandering even impacts an individual’s score on measures of WMC and general fluid intelligence (Mrazek et al., 2012). Also, the negative impact stereotype threat has on cognitive performance may partly be mediated by an increase in mind wandering (Mrazek et al., 2011). Since researchers have been interested in the detrimental effects mind wandering may have on task performance, models of mind wandering attempt to explain what causes it to occur and why it leads to poor task performance (Smallwood, 2013). Four main models of mind wandering that explain either what causes it to occur or the processes involved in its maintenance are discussed as follows (Smallwood, 2013).

Perceptual Decoupling Model

The *perceptual decoupling* model seeks to address the processes involved in maintenance of mind wandering, and not necessarily what factors lead to its occurrence. This model explains performance decline as reflecting domain-general resource competition between external task events and internal trains of thought (Smallwood, 2013). As mind wandering ensues, attention is decoupled from external events and directed towards internal thoughts and feelings. Initial evidence for this came from studies showing reduced mind wandering as task demands increased. For instance, faster stimulus presentation rates and increased memory load, decrease frequency of stimulus-independent thought (SIT) (Teasdale, Proctor, Lloyd, & Baddeley, 1993). Therefore as task demands increase, resources are deployed to processing external events rather than internal trains of thought.

As a result of this decoupling, processing of external events is going to be degraded during mind wandering compared to when attention is focused on the task (Smallwood, O'Connor, Sudbery, & Obonsawin, 2007). A number of studies have shown decreased task performance during mind wandering episodes. For instance, it has been shown that during periods of SIT, participants perform worse by making more stereotypic responses on a random number generation task (Teasdale et al., 1995). Smallwood, McSpadden, and Schooler (2008) found that zoning out (mind wandering without awareness) while reading reduced text comprehension. More direct evidence for decreased processing of external events during mind wandering comes from studies looking at pupil diameter (PD) and EEG cortical activity. Smallwood et al. (2011) examined PD activity during periods indicative of online (external task processing) and offline (internally generated thought processing) thought. In a choice reaction time task, during online thought PD activity changed in response to processing external task stimuli whereas during offline thought PD activity was decoupled from task events. In addition Smallwood, Beach, et al. (2008), using the SART, found a reduction in the amplitude of the P300 (an index of attention directed toward stimulus processing) for non-targets during TUT compared to during on-task thoughts. The assumption of the perceptual decoupling model is that domain-general resources are shared between both external and self-generated trains of thought. For example, in the same way as working memory resources are involved in the control of external task information, working memory resources are also required for the continuity of self-generated thought (Smallwood, 2013). From this perspective, working memory resources do not directly control the occurrence of mind wandering, but once attention shifts to internally generated thought, executive processes act to ensure its continuity by preventing interruption from external stimulation.

Current Concerns

The perceptual decoupling model explains the processes involved in mind wandering but there is still the question of “what factors lead to the occurrence of mind wandering in the first place?” Recall that mind wandering was defined as undirected thought that is “not deliberately directed” by the thinker yet may be directed by the thinkers current concerns. According to Klinger's (2009) *current concerns* theory, daydreaming and mind wandering occur when there is a discrepancy between a current state and unresolved goal. Watkins' (2008) control theory approach states that all behavior, including repetitive thought, is a process of feedback control where one's current state is compared with a reference value such as an unresolved goal. If there is a discrepancy between the current state and an unresolved goal, then the behavior will be adjusted to bring it closer to the goal state. Internally generated thought focused on resolving a discrepancy will persist, and may result in mind wandering, until either the goal is attained or it is abandoned. Klinger (2009) indicates that the persistence of current concerns is continuous and automatic, "Thus, having a goal entails a covert mental process that persists over the life of the goal pursuit." (Klinger, 2009, p. 229). Additionally one's current concerns may be automatically triggered by salient cues either in the environment or by other internal processes such as memories and will form the content of mind wandering thoughts.

Meta-awareness

Another characteristic of mind wandering is that the experience is often accompanied with a lack of awareness of its occurring, in which one may suddenly catch oneself in such a state without having realized it. Schooler et al. (2004) used both self-caught (awareness of mind wandering) and probe-caught (not aware of mind wandering) methods to measure mind wandering during text reading, and found that mind wandering often occurred without awareness. Using thought probe methods in addition to assessing awareness of one's immediately prior experience, Christoff, Gordon, Smallwood, Smith, and Schooler (2009) found that performance on the SART was impaired more during mind wandering without awareness compared to with awareness. Schooler (2002) explains this *meta-awareness* (meta-consciousness) model of mind wandering from a framework of the relationship between meta-awareness and basic conscious experience. While conscious processes continuously occur and are monitored largely by non-conscious processes, meta-awareness is only intermittent. Meta-awareness is a re-representation of the contents of conscious experience, in which one can report or interpret one's state of mind. For example, while reading a text, attention may become decoupled and directed towards an internal train of thought. This decoupled attention may not be corrected until meta-awareness detects the discrepancy between the intended goal (reading a text) and the content of experience (mind wandering) (Schooler et al., 2011). Therefore, the absence of meta-awareness may explain the occurrence of some mind wandering episodes in addition to moderating the detrimental effects of mind wandering on performance.

Control Failure

McVay and Kane (2010) proposed a Control Failure x Concerns model of mind wandering. According to this model, one's current concerns may automatically activate task-unrelated thoughts and then, failure to maintain attention on a current task is what will lead to mind wandering. From this perspective, greater control of executive attention allows one to maintain task goals and avoid attention drifting away from the task towards task-unrelated thoughts. For instance, under conditions of reduced executive control, such as fatigue and alcohol inebriation, rates of TUT increased (McVay & Kane, 2009;

Sayette, Reichle, & Schooler, 2009; Smallwood, Davies, et al., 2004). The control-failure model claims that, while mind wandering occurs because of executive control failures, it does not require working memory resources to be sustained. Evidence for this comes from McVay and Kane (2009), in which they found that TUT decreased as executive attention abilities (working memory capacity) increased.

Default Mode Network

Interest in the phenomena of mind wandering also comes from the cognitive neuroscience literature trying to understand the role of a network of brain regions, now referred to as the default-mode network (DMN). The DMN includes areas in the medial parietal cortex (posterior cingulate and precuneus), posterior lateral cortex (Parietal lobe: BA 40 and 39; temporal lobe: BA 22), medial prefrontal cortex (BA 6, 8, 9 and 10) (Gusnard & Raichle, 2001). This network of brain regions was shown to be functionally active at rest (a passive state when not engaged with a task) and decreased activation during task engagement (Gusnard & Raichle, 2001). Because of this pattern of activation the DMN has been implicated in activities such as mind wandering that are likely to occur during periods of non-task engagement. In fact, activity in the DMN has been shown to be associated with stimulus-independent thought and the occurrence of mind wandering (Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Christoff, 2012; Mason et al., 2007). Consistent with this evidence current concerns theory posits daydreaming and mind wandering as a mental default state arising from activity in the DMN (Klinger, 2009). Furthermore, as executive network regions (such as the dorsal anterior cingulate cortex, and dorsal lateral prefrontal cortex) show increased activation, the DMN shows decreased activation during task engagement. Even in the absence of an ongoing task these two network regions have been shown to be anti-correlated (Fox et al., 2005). Koshino et al. (2011) found medial prefrontal cortex (DMN region) activation during task preparation and deactivation during task execution, within a single trial. These results suggest that activation and deactivation of default mode and executive network regions are influenced by the allocation of attentional resources due to task demands.

The Relation Between Working Memory and Mind Wandering

Smallwood (2013) integrates the perceptual decoupling, current concerns, meta-awareness and control failure models into a *Process-Occurrence* framework of mind wandering and discusses how these models explain different, though not competing, mechanisms for the occurrence and processes underlying mind wandering. The current concerns, meta-awareness, and control failure models explain what may lead to the occurrence of a mind-wandering episode, while the perceptual decoupling model explains the processes involved once mind wandering has ensued. Nonetheless, the decoupling and control failure models explain a different relationship between working memory resources and mind wandering. The *decoupling* model claims that working memory resources support the continuity of internal trains of thought; this hypothesis will be referred to as the resource-demanding view. On the other hand, the *control failure* model claims that internal trains of thought are automatically cued by current concerns, sustained in a resource-free manner and that mind wandering is a result of executive control failure; this will be referred to as the resource-free view.

In order to understand these two competing perspectives on mind wandering, the concept of working memory resources and its relation to mind wandering needs to be discussed. While several models of working memory have been proposed, it is widely considered to represent a mental workspace and consist of at least two resource limited systems; temporary memory stores (i.e. phonological loop and visuo-spatial sketchpad:) and the central executive (Baddeley, 2000). The central executive system is responsible for coordinating what information can gain access to limited-capacity memory stores as well as the maintenance and manipulation of items in working memory. In this way, the central executive system controls the allocation of attentional focus, such as when switching attention from one task to another, maintaining information in memory while performing an independent task or inhibition of processing distracting information and selection of task relevant information.

Working Memory

The concept of working memory capacity (WMC) is not well defined. One view refers to WMC more generally as the amount of working memory resources available for both temporary memory storage and executive processes

(Baddeley, 2010; Lavie, Hirst, de Fockert, & Viding, 2004). As more working memory resources are allocated towards maintenance of information held in working memory, fewer resources are available for executive processes. This resource view of working memory capacity has been investigated on a wide variety of distractor interference tasks. By loading working memory with items to be maintained in memory while performing a concurrent task, the ability for executive processes to reduce distractor interference is diminished (for a review; de Fockert, 2013). Also consistent with this view is that individuals with higher WMC have a greater amount of working memory resources at their disposal compared to those with lower WMC (Unsworth & Spillers, 2010). Generally, tasks that measure individual differences in working memory capacity are dual tasks requiring the participant to hold information in memory while performing an attention demanding task, such as complex-span tasks (Redick et al., 2012). Individuals with more working memory resources should therefore score higher on complex-span tasks than individuals with fewer working memory resources.

An alternative view of WMC is that it mainly reflects control of executive attention. Individual differences in WMC are thought to mainly reflect differences in the ability to control attention, especially in contexts of competing demands, such as dual task situations. For instance, individuals with high WMC, compared to those with low WMC, are better able to inhibit irrelevant distractor information (Heitz & Engle, 2007; Shipstead, Harrison, & Engle, 2012), maintain task goals (Kane & Engle, 2003), and allocate visual attention (Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003). WMC is also correlated with general fluid intelligence and performance on a number of cognitive tasks (Engle, Tuholski, Laughlin, & Conway, 1999; Engle, 2002; Kane, Hambrick, & Conway, 2005). Because of the correlation of WMC with attentional control and higher order cognitive tasks, working memory is believed to represent a more general cognitive system reflecting control of executive attention (Engle, 2002).

Working Memory Capacity and Mind Wandering

The nature of the association between WMC and mind wandering differs between the resource-demanding and resource-free views of mind wandering. The hypothesis that mind wandering is resource demanding considers WMC as the availability of domain-general resources and shares similarities with Baddeley's (2000) model of working memory. For example, Smallwood (2010) argues that domain-general resources support the continuity of internal trains of thought in a multimodal workspace. Therefore, higher WMC (more domain-general resources) should be associated with more mind wandering, from the resource demanding view.

In fact, Levinson, Smallwood, and Davidson (2012) did find that as WMC increases so does mind wandering in low-demanding tasks, such as low perceptual load conditions. To further understand the role of working memory resources in mind wandering, Smallwood, Nind, and O'Connor (2009) investigated the proportion of future and past-oriented thoughts in a choice reaction time (CRT) task, with a working memory load manipulation. They argue that future-oriented mind wandering requires more working memory resources because it requires planning or creating a potential scenario, whereas past-oriented mind wandering simply requires recollecting past experiences. To determine this, TUT was further classified into past, present or future-oriented while performing no working memory load and working memory load tasks. In the no working memory load, task participants responded to rare target numbers and responded as to whether the number was even or odd. In the working memory load condition on rare target numbers, they had to decide if the previous number was even or odd. They found that future-oriented mind wandering decreased under working memory load, whereas past-oriented mind wandering was not affected, suggesting that future-oriented mind wandering requires working memory resources. Furthermore, in a non-demanding CRT task, WMC was positively associated with future-oriented mind wandering, and negatively associated with past-oriented mind wandering, though not correlated with overall reports of mind wandering (Baird, Smallwood, & Schooler, 2011). Therefore, these results are consistent with a resource-demanding view of mind wandering; where future-oriented mind wandering is reduced, as fewer working memory resources are available, due to either increased working memory load or lower WMC.

Alternatively, the hypothesis that mind wandering occurs in a resource-free manner considers WMC as reflecting control of executive attention. From this perspective, mind wandering is a result of failures of goal maintenance.

Higher WMC represents more control of executive attention, and therefore less mind wandering (McVay & Kane, 2010). McVay and Kane (2009) investigated the association between WMC, mind wandering and performance on a SART task. As WMC increased, TUT decreased, and higher WMC and fewer TUTs predicted better SART performance (McVay & Kane, 2009). Furthermore, individual differences in WMC also predict propensity to mind wander outside the laboratory and in daily life. Kane et al. (2007) gave participants Personal Digital Assistants (PDAs), and the PDA would signal them to report whether their thoughts had wandered from whatever they were doing at that time, randomly throughout their day for seven days. They found that higher WMC was also associated with less mind wandering in daily life.

Contrary to studies finding that higher WMC is associated with more mind wandering during non-demanding tasks (Levinson et al., 2012), and specifically for future-oriented mind wandering (Baird et al., 2011), McVay and Kane (2012) failed to find a correlation between WMC and mind wandering during a non-demanding task. Challenging the findings, from Baird et al., (2011), that higher WMC is associated with more future-oriented mind wandering; McVay, Unsworth, McMillan, and Kane (2013) report results from two independent studies, using a much larger sample size and broader off-task thought classification. They found a lack of correlation between WMC and future-oriented or past-oriented mind wandering while performing the standard SART and a reading task. Therefore, these null results support a resource-free view of mind wandering.

It should be recognized that mind wandering occurring as a result of control-failures is not entirely inconsistent with a resource-demanding view. Where the resource-demanding and resource-free views differ is on the role of executive processes involved in maintaining mind wandering. Smallwood (2010) has proposed that while mind wandering may occur as a result of executive control-failures, once it has started executive processes act to ensure it's continuity. Furthermore, he has suggested that there may be a context dependent relationship between WMC and mind wandering. Under non-demanding contexts, the need for executive control is low and one's current concerns may easily gain access to domain-general processes. In this case, the context is conducive to mind wandering and executive control processes act to ensure the continuity of internal trains of thought. Therefore, higher WMC individuals will show more mind wandering in non-demanding task contexts. However, in demanding task contexts, the need for executive control is high and executive control processes must act to maintain attention on the task and away from mind wandering thoughts. In this case, mind wandering is a result of executive control failures. Therefore, higher WMC individuals will now show less mind wandering. Nevertheless, the context dependent relationship does assume that mind wandering requires working memory resources. However, most of the support for this context dependent relationship between WMC and mind wandering comes from separate studies looking at either demanding or non-demanding task contexts individually.

Working Memory Load and Mind Wandering

In order to investigate the components of Baddeley's (2000) working memory model in the production of stimulus-independent thought (SIT), Teasdale et al. (1995, 1993) have investigated the relationship between working memory load and mind wandering. Initial studies revealed that increasing task demands, by increasing memory load, decreased reports of mind wandering (Teasdale et al., 1993). To further investigate this relation, Teasdale et al. (1995) measured the frequency of stimulus-independent thought (SIT) during tasks that require different components of Baddeley (2000)'s working memory model. While they found a reduced rate of SIT during tasks that require the phonological loop subsystem and visuo-spatial sketchpad, this is likely due to the use of domain-general resources of working memory such as the central executive. Support for this comes from Experiment 3 of Teasdale et al. (1995), in which they found an increase of SIT during a task that participants had previous practice on compared to a novel task. Additionally, in Experiment 4, the occurrence of SIT interfered with performance on a random number generation task, a task that relies on central executive processes. They found that not only do increased demands on the central executive reduce the occurrence of SIT but also when SIT does occur, it impairs performance on a concurrent task requiring the central executive. Therefore Teasdale et al. (1995) concluded that the production of SIT requires working memory resources and more specifically central executive processes. This conclusion is consistent with a resource-demanding view of mind wandering. As the demands of executive control processes increase; the fewer resources will be available to support the maintenance of task-unrelated thoughts.

McVay and Kane (2010), however, explain the consistent findings of reduced mind wandering with increased task demands from the control-failure model. They argue that tasks requiring more working memory resources are confounded with task set to maintain engaged with the task. As a task becomes more demanding, increased proactive control will act to prevent task disengagement; and therefore, interference from TUT is reduced. The results from these studies, then, are interpreted as not a competition of working memory resources devoted to the task and mind wandering; but rather, that greater task demands require more proactive control to keep distracting information (such as TUT) from interfering with task performance. While most of the evidence is consistent with either the resource-demanding or resource-free hypothesis, McVay and Kane (2010) point out evidence that is difficult to explain in terms of the resource-demanding view. This evidence comes from studies that keep task demands constant but manipulate the amount of working memory resources that are available. For instance, if alcohol and fatigue reduce executive control (Muraven & Baumeister, 2000), then according to the resource-demanding view, there should be fewer resources for TUT; and therefore, TUT should decrease with fatigue or inebriation. However, according to the control-failure view, reducing executive control should lead to more control-failures; and therefore, TUT should increase with fatigue or inebriation. In support of the control-failure view, studies have found an increase of TUT with alcohol consumption and fatigue (McVay & Kane, 2009; Sayette et al., 2009; Smallwood, Davies, et al., 2004).

Another way to manipulate the amount of attentional resources in a task is perceptual load. In a typical perceptual load task, participants are instructed to search an array of letters for a target letter (e.g. either N or X) among a set of irrelevant letters. A response-related distractor will appear outside of the search array and can be either compatible (same response as target letter) or incompatible (alternative response as target letter). According to the perceptual load theory (Lavie & Tsal, 1994), if perceptual load is low (homogenous irrelevant letters, e.g. all O's), spare attentional resources will automatically process task-irrelevant information; therefore, there is distractor interference. Whereas when perceptual load is high (heterogeneous irrelevant letters e.g. HKMLP), capacity-limited attentional resources are consumed for processing of the target stimulus, and therefore, the distractor interference is not found. Forster & Lavie (2009) were interested in whether perceptual load also minimizes distracter interference from internal sources such as mind wandering, and investigated the amount of task-unrelated thought (TUT) under low and high perceptual load. They found that increasing perceptual load not only decreases processing of external distractors but also of TUT, suggesting a central attentional resource for external and internal information. Thus, the more attentional processes devoted to task-relevant information the less interference from TUT. Additionally, they found that as TUT increased, the amount of distracter interference also increased. This finding suggests that the experience of mind wandering interferes with resolving response conflict in the perceptual load task.

Using the same high and low perceptual load display as Forster and Lavie (2007), Levinson et al. (2012) found that higher WMC was associated with more mind wandering under low perceptual load conditions but found no correlation between WMC and mind wandering under high perceptual load conditions.

It is, however, important to point out the differences between working memory load and perceptual load manipulations. Lavie et al. (2004) found that perceptual load and working memory load can actually have opposite effects on distractor interference. While increasing perceptual load is found to decrease distractor interference, increasing working memory load leads to increased distractor interference. The purpose of the current study is to investigate the role of working memory load on mind wandering, during a distracter interference task.

The Simon Task

Another task that has been widely used to understand distracter interference is the Simon task (Proctor, 2011). In the Simon task, response interference is due to correspondence between an irrelevant stimulus location and a response location. For instance, a response is made to a target stimulus (i.e. Left response/red square and right response/green square) that appears on either the left or right side of the stimulus display. Even though the stimulus location is irrelevant and to be ignored, response times are shorter when the location of the stimulus is congruent with the response location (left/left) and longer when incongruent with the response location (left/right); this difference is referred to as a Simon compatibility effect (Hommel, 2011; Proctor, 2011; Rubichi, Nicoletti, Iani, & Umiltà, 1997). Research on Simon effects has addressed a wide variety of issues such as the role of attention and working memory in generating stimulus and response codes, how task contexts influence Simon effects and the role of automatic and cognitive processes (for a review; Hommel, 2011; Proctor, 2011).

The Simon effect is commonly explained from dual-route models of response selection (Kornblum, Hasbroucq, & Osman, 1990; Kornblum & Lee, 1995). According to these models, response codes are activated by way of direct (automatic) and indirect (controlled) routes. In the Simon task, the irrelevant stimulus location produces a spatial stimulus code, which automatically activates a corresponding spatial response code. Thus, there is a tendency to make a left response to a stimulus appearing on the left side of a visual display and a right response to a stimulus appearing on the right side of a visual display. The relevant stimulus code (red or green square) is used to determine the correct response via the controlled route based on task instructions (i.e. “press the left hand key if the stimulus is a red square”). On congruent trials, the response activated by the automatic route corresponds to the correct response; responding can continue along the automatic route. Whereas, on incongruent trials, the automatic route activates a response that is incongruent with the correct response, creating a response conflict; therefore, cognitive control is required for correct responding on incongruent trials.

Recent challenges to the dual-route model of the Simon effect have been made in favor of a response discrimination account. According to the response discrimination account activation of spatial response codes are not automatic but instead are formed in working memory (Ansorge & Wühr, 2004). However, if spatial response codes do require working memory resources, then increasing working memory load should reduce the Simon effect. Evidence for the response discrimination account comes from studies showing a reduced or eliminated Simon effect under working memory load (Wühr & Biebl, 2011; Zhao, Chen, & West, 2010). Zhao et al. (2010) found that the Simon effect was eliminated with verbal working memory load but not affected by spatial working memory load. Wühr and Biebl (2011), however, found that spatial working memory load eliminated the Simon effect whereas verbal load only reduced the Simon effect. Even though these two studies differ on the type of working memory load that has the greatest impact on the Simon effect, they both provide support for a response discrimination account.

In the present experiment, the Simon task will be used as the main task. Since the Simon task simply requires responding to the presentation of a single target, it can be considered as a non-demanding task, and therefore will be conducive to mind wandering. In a more demanding context, the Simon task will be performed with working memory load (dual task). The Simon task can be used to determine the amount of distracter interference by an irrelevant spatial location; therefore, measuring mind wandering on the Simon task can assess distraction by external as well as internal goal-irrelevant information.

CHAPTER TWO

THE CURRENT STUDY

Hypotheses

Simon Task

In the current study, the effects of working memory load on the Simon effect will be crossed with individual differences in WMC. Previous research (Wühr & Biebl, 2011; Zhao et al., 2010) has found that verbal working memory load decreases or even eliminates the Simon effect. Therefore, it is expected that there will be a Simon effect in single task conditions and a decreased or eliminated Simon effect in dual task conditions (with working memory load). If the Simon task is a measure of distractor interference, then individuals with high WMC should show a smaller Simon effect in single task conditions. Furthermore, the effect of working memory load on the Simon effect should be greater for low WMC individuals. The main analysis on the Simon task will be on reaction times (RTs) as a 2 (WMC: low-span vs. high-span) x 2 (Task: single vs. dual) x 2 (compatible vs. incompatible) mixed design ANOVA with task and compatibility as within-subject variables and WMC as a between-subject variable.

Mind Wandering

The main issue addressed in this study is whether mind wandering requires working memory resources. Studies investigating the role of working memory resources in mind wandering either look at WMC related differences or the effects of working memory load, but not both in the same study. For example, Levinson et al. (2012) did investigate WMC related differences in non-demanding and demanding task context, specifically low and high perceptual load. However, a perceptual load manipulation is different from a working memory load manipulation (WML), as they can result in opposite effects on distractor interference (Lavie et al., 2004). The purpose of the current study is to further investigate this issue by crossing WMC related differences with a working memory load manipulation. Specifically, high and low WMC participants will perform the Simon task without verbal working memory load (single task) and with verbal working memory load (dual task) while being intermittently probed about the contents of their thought. The main analysis will compare the proportion of TUT as a 2 (WMC: low-span vs. high-span) x 2 (Task: single vs. dual) mixed-design ANOVA with task as a within-subject variable and WMC as a between-subject variable.

According to the control-failure model, mind wandering is a result of executive control failures and is sustained in a resource-free manner (McVay & Kane, 2010). The hypotheses of the resource-free, control-failure model are as follows. If mind wandering is a result of executive control failure and proceeds in a resource-free manner, then individuals with high WMC will experience fewer TUT in single and dual task conditions compared to those with low WMC, because higher WMC is related to better control of executive attention. This difference may be more pronounced in dual task conditions because demand to prevent TUT interference on task performance is greater; therefore, control of executive attention differences should be more pronounced. Overall, there should be less TUT in a dual task compared to a single task; again, because demands to prevent mind wandering interference on task performance is greater for a dual task than a single task.

An alternative view is that working memory resources are required to sustain an internal train of thought during mind wandering (Smallwood, 2010). The hypotheses of the resource-demanding view are as follows. If working memory resources are required to sustain mind wandering, then individuals with high WMC will experience more TUT compared to those with low WMC, in single and dual task conditions. More working memory resources are required to perform a dual task compared to a single task; therefore, there should be less mind wandering in a dual task compared to a single task.

Mind Wandering and Task Performance

Given the findings from Wühr and Biebl (2011) and Zhao et al. (2010) on the effects of working memory reducing the Simon effect, some predictions can be made regarding the effect of mind wandering on the Simon effect. From the resource-free view, mind wandering should increase the Simon effect because control-failures result in mind wandering, on one hand, and impair resolving response conflict in the Simon task, on the other (Weldon, Mushlin, Kim, & Sohn, 2013). From the resource-demanding view, mind wandering should have the same effect as working memory load by decreasing the Simon effect because it requires working memory resources.

Furthermore, the two views of mind wandering can be dissociated by the effects of WMC on the relation between mind wandering and task performance (McVay & Kane, 2012). If mind wandering does not require working memory resources, then there should be no effect of WMC on relation between mind wandering and task performance. This is because the experience of mind wandering is a result of control-failures, regardless of WMC. If mind wandering does require working memory resources and low WMC individuals have fewer working memory resource, then mind wandering should have more of an impact on task performance for low WMC individuals compared to those with high WMC because low WMC individuals have fewer resources to split between mind wandering and task performance and therefore more interference.

CHAPTER THREE

METHOD

Participants

28 female students from California State University, San Bernardino, who completed the screening sessions of the working memory study participated in the current experiment. The screening sessions consisted of two, one-hour sessions in which participants completed measures of working memory and general fluid intelligence. The working memory measures included; portions of the Wide Range Assessment of Memory and Learning (finger windows, number letters, verbal working memory, symbolic working memory) (Sheslow & Adams, 2003), operation-span and symmetry span tasks (Redick et al., 2012). The general fluid intelligence measures included; Raven's Advanced Matrices (Raven, Raven, & Court, 1998), Inferences and Letter Sets (Ekstrom, French, Harman, & Dermen, 1976). Based on the Operation span partial score (described below), they were recruited from the top 25% (high WMC group) and bottom 25% (low WMC group) of the participant pool, resulting in 15 high WMC and 13 low WMC participants. Participants were compensated with a $10 gift card. All participants signed the consent form approved by the IRB, and were be treated in accordance with the Ethical Principles of Psychologists and Code of Conduct (American Psychological Association, 2010).

Stimuli

Working Memory Capacity

Participants completed the automated operation span (OSPAN); a dual task where participants need to remember presented memory items for later recall while performing an unrelated processing task (Redick et al., 2012). For the processing task, participants need to verify solutions to mathematical equations (yes or no response). OSPAN memory items consisted of 12 letters. After participants make a verification response, a random letter appears, and the participant is to remember it for later recall. This sequence, processing task followed by a memory letter, is repeated 3-7 times. Following this, all 12 letters are displayed and participants need to identify the presented memory letters in their serial order, the order in which they appeared. Each set length (3-7) was presented three times, randomly ordered for each participant.

Scores on the OSPAN task were calculated as the sum of correct items recalled in their serial position (partial span scores), with a maximum score of 75 (Redick et al., 2012). Participants were divided into low-span and high-span groups based on the percentile distribution of partial OSPAN scores presented in Redick et al. (2012). Low-span participants were selected from the bottom 25^{th} percentile and high-span participants from the top 75^{th} percentile.

Simon Task

Stimulus presentation and data collection were controlled by E-Prime (Psychology Software Tools, Pittsburgh, PA) on a PC-compatible computer.

Stimuli were presented on a 17-inch monitor. In the single task condition, participants performed the Simon task. For the stimulus display, a target stimulus (red or green square) was presented to the left or right of a central fixation point. Participants were instructed to press the “n” key with their right index for a green square and the “x” key with their left index finger for a red square. They were also instructed to ignore the location of the target stimulus, as it was irrelevant. The target stimulus location could either be compatible or incompatible with the response location. In a dual task condition, participants performed the same Simon task, however with working memory load. The memory task manipulation was a verbal working memory load of 6 digits, ranging from 1-9. For the memory display, the memory items were displayed horizontally above the central fixation point. In the memory probe display, a single digit (1-9) was presented. Participants were instructed to press the “m” key, with their right middle finger, if the single digit was among the memory items and to press the “z” key, with their left middle finger, if the single digit was not among the memory items. Reaction times (RT) and error rates on the Simon task and memory task were analyzed as a 2 (WMC: low-span vs. high-span) x 2 (Task: single vs. dual) x 2 (compatible vs. incompatible) mixed-design ANOVA with task and compatibility as within-subject variables and WMC as a between-subject variable.

Thought Probes

When a thought probe appeared on the display, participants were asked “what were you thinking just now?” along with the following response options, 1)

Task-related thought 2) A memory from the past 3) Something in the future 4) Current state of being 5) Other. Before beginning the experiment, participants were given an explanation or example of each option. Participants were to report what was passing through their mind by pressing the corresponding number key. Option 1 was coded as on-task thought while options 2-5 were considered as TUT (McVay et al., 2013). Proportion of responses to thought probes were analyzed as a 2 (WMC: low-span vs. high-span) x 2 (Task: single vs. dual) x 2 (Thought type: on-task vs. TUT) mixed-design ANOVA with task and thought type as within-subject variables and WMC as a between-subject variable. Proportion of past and future-oriented mind wandering were also compared as a 2 (WMC: low-span vs. high-span) x 2 (Task: single vs. dual) x 2 (Thought orientation: past vs. future) mixed-design ANOVA with task and compatibility as within-subject variables and WMC as a between-subject variable.

Procedure

The experiment took place in a dimly lit room. The following description of the experimental procedure is depicted in Figure 1. In the single task condition, a central fixation point was presented for 1000 msec followed by a mask (######) for 3000 msec. Another fixation display was presented for 500 msec followed by a stimulus display for 2000 msec or until participants made a response to the target stimulus by pressing their right index finger for a green circle and left index finger for a red circle, ignoring target location. After the stimulus display, a central fixation point was presented for another 500 msec followed by a mask (#) for 1000 msec. In the dual task condition, a central fixation point was presented for 1000 msec. Then the memory display, containing six memory items, was presented for 1500 msec followed by a mask (######) for 1500 msec. Next another fixation point was displayed for 500 msec followed by the stimulus display for 2000 msec or until participants made a response. Another fixation point was displayed for 500 msec followed by the memory probe display for 2000 msec or until a response was made. Note that the trial durations were the same for single and dual tasks, the only difference being that in the single task the memory items were replaced with a #. Practice blocks consisted of 3 blocks for the single task, 2 blocks for memory task only, and 3 blocks dual task with 8 trials in each block followed by a thought probe. In the experimental session, the single and dual tasks were counterbalanced in an ABBA fashion for a total of 20 blocks of 20 trials. Thought probes were presented at the end of each block.

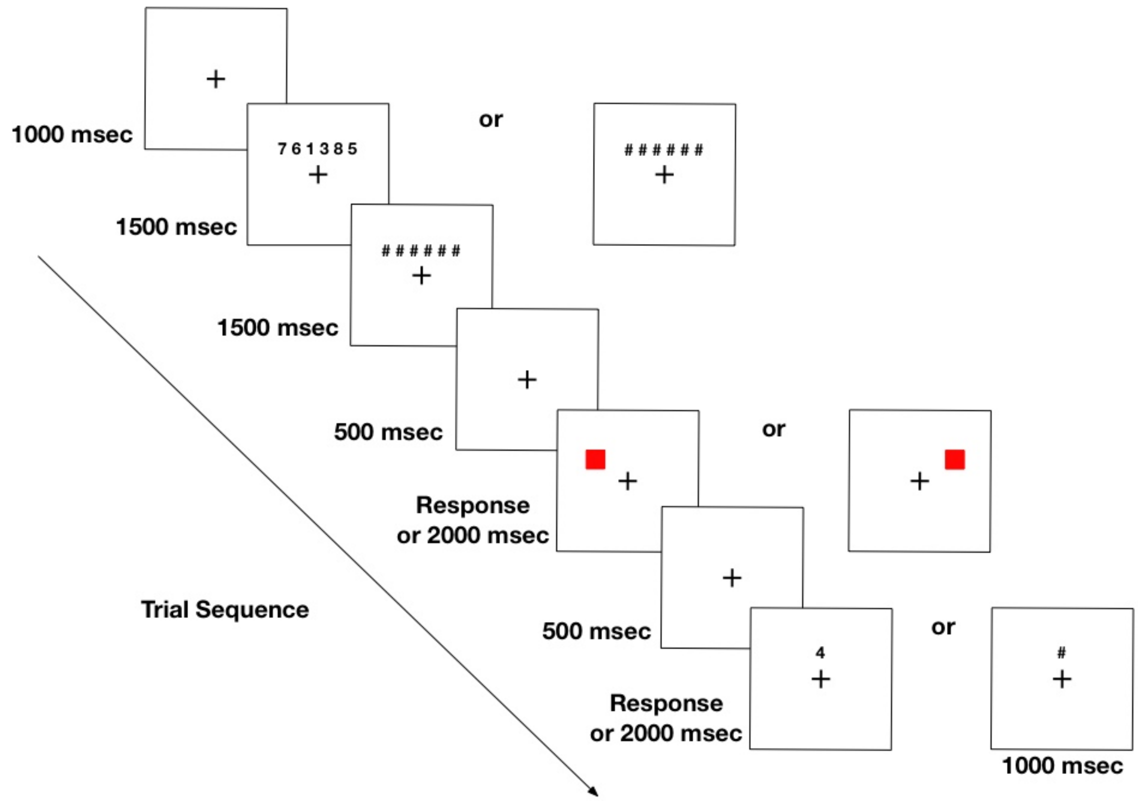

Figure 1. Trial Sequence For Dual Task and Single Task Conditions.

CHAPTER FOUR

RESULTS

Demographics

Demographic information for the WMC groups were compared and no differences were found on Age (High WMC: $M = 24.4$, $SD = 6.08$, Low WMC: $M = 22.5$, $SD = 2.9$), class standing (High WMC: $M = 3.4$, $SD = 0.91$, Low WMC: $M = 3.1$, $SD = 0.75$), number of credits earned (High WMC: $M = 123.2$, $SD = 58.00$, Low WMC: $M = 117.9$, $SD = 49.28$) and GPA (High WMC: $M = 3.2$, $SD = 0.54$, Low WMC: $M = 3.0$, $SD = 0.40$). Mean OSPAN partial scores were significantly difference between the high WMC group 68.5 ($SD = 2.48$) and the low WMC group 39.9 ($SD = 7.98$), $t(26) = 13.25$, $p < .001$.

Simon Task

For all analyses on RTs, incorrect responses were excluded. The same exclusion criteria was used as Zhao et al. (2010); for single task conditions, RTs shorter than 150ms and longer than 1500ms were excluded from analyses and for dual task conditions, RTs shorter than 250ms and longer than 2500ms were excluded. Mean RTs and error rates on the Simon task are shown in Table 1, and were analyzed separately as 2 (WMC) × 2 (Task) × 2 (Compatibility) mixed-design ANOVAs.

Table 1.

Mean Reaction Times and Error Rates on the Simon Task with Working Memory Load Conditions for Low and High Working Memory Capacity Participants

	Low WMC				High WMC			
	No WML		WML		No WML		WML	
Compatibilty	RT	% Errors	RT	% Errors	RT	% Errors	RT	% Errors
Compatible								
M	569	1.3	679	2.3	486	0.3	608	1.0
SD	125.6	1.25	141.5	2.39	94.2	0.46	125.0	1.07
Incompatible								
M	619	2.8	695	4.9	523	1.6	608	2.0
SD	121.6	3.11	146.7	4.80	84.8	2.29	124.9	2.07
I-C	50.2		16.3		37.3		0.0	

Reaction Times

For RTs, There was a main effect of Task, in which RTs were shorter for single task conditions than dual task conditions, $F(1, 26) = 73.03$, $p < .001$, partial $\eta^2 = .737$. There was a main effect of compatibility, RTs were longer for incompatible than for compatible conditions, $F(1, 26) = 54.08$, $p < .001$, partial $\eta^2 = .675$; thus, there was a Simon compatibility effect. There was no main effect of WMC, although it was marginally significant with high WMC participants showing shorter RTs overall, $F(1, 26) = 3.66$, $p = .067$, partial $\eta^2 = .123$. A WMC × Compatibility interaction was significant, $F(1, 26) = 4.26$, $p = .049$, partial $\eta^2 = .141$, in which there was a larger Simon effect for low WMC compared to high WMC participants, see Figure 2. A Task × Compatibility interaction was significant, $F(1, 26) = 18.18$, $p < .001$, partial $\eta^2 = .412$, see Figure 3. There was no Simon effect for the dual task condition, t(27) = 1.63, p=.114, whereas the Simon effect was significant for the single task condition, t(27) = 688, p < .001.There was neither a WMC × Task interaction, $F(1, 26) = 0.19$, $p = .667$, nor a WMC × Task × Compatibility three-way interaction, $F(1, 26) = .04$, $p = .841$. The lack of a thee-way interaction was due to a similar reduction in the Simon compatibility effect from single to dual task conditions, for both high WMC (Mean dual task reduction = 37.3 msec) and low WMC participants (Mean dual task reduction = 33.9). However, even though reductions in the Simon effect were similar between WMC groups, the Simon effect in dual task conditions was eliminated for the high WMC participants ($M = 0.03$, $SD = 22.37$), $t(14) = .01$, $p = .995$, and only reduced yet still significant for the low WMC participants ($M = 16.31$, $SD = 24.98$), $t(12) = 2.35$, $p = .036$.

Error Rates

For error rates, there was a main effect of WMC, $F(1, 26) = 6.81$, $p = .015$, *partial* $\eta^2 = .208$; high WMC participants made fewer errors compared to low WMC participants. There was a main effect of Task, $F(1, 26) = 9.36$, $p = .005$, partial $\eta^2 = .265$. More errors were made in dual task conditions compared to

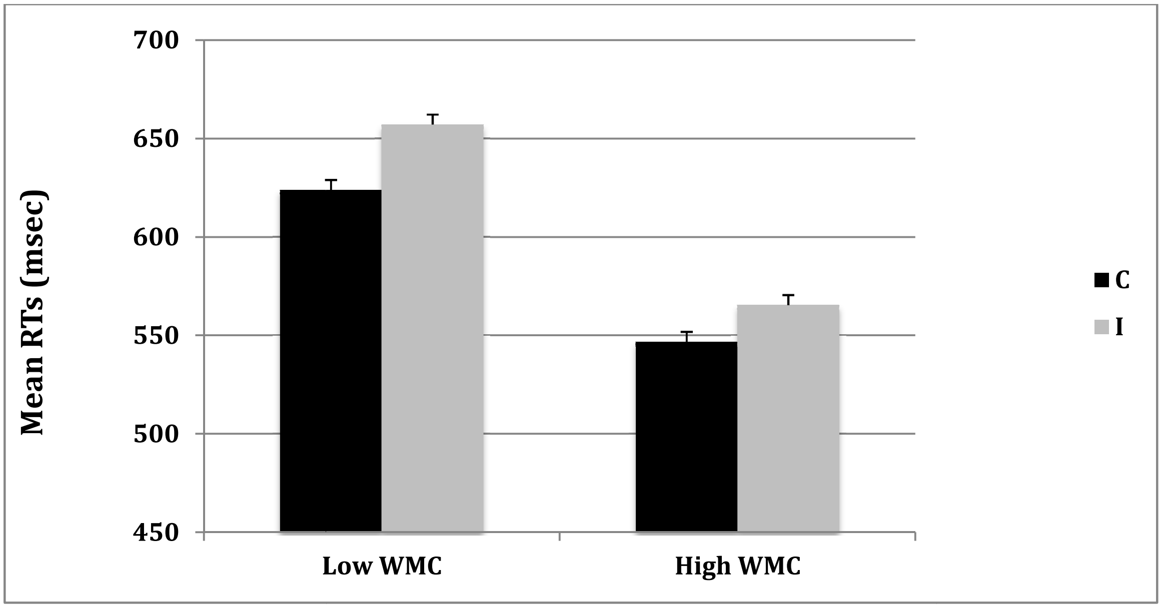

Figure 2. Mean Reaction Times on Compatible and Incompatible Trials for Working Memory Capacity Groups, Collapsed Across Task Conditions.

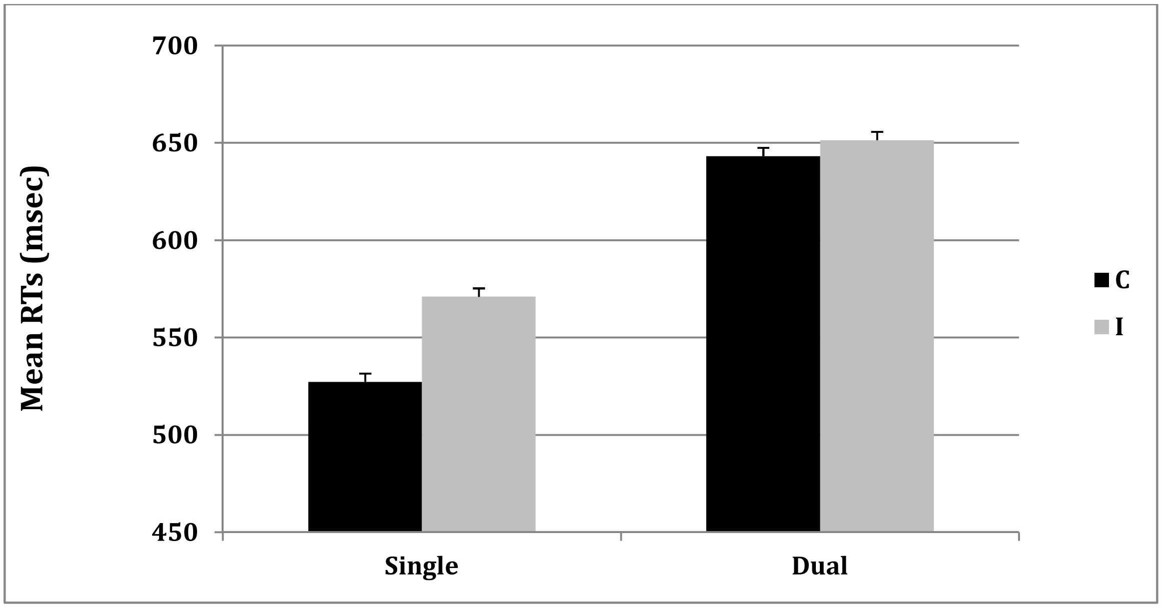

Figure 3. Mean Reaction Times on Compatible and Incompatible Trials for Working Memory Load Conditions, Collapsed Across Working Memory Capacity Groups

single task conditions. There was also a main effect of compatibility, $F(1, 26) = 10.02$, $p = .004$, partial $\eta^2 = .278$, in which more errors were made on incompatible compared to compatible trials; thus, there was a Simon effect in error rates as well. However, there were no significant interactions anywhere; in other words, there was no effect of WMC or Task on the magnitude of the Simon effect when looking at error rates.

Memory Task

RTs and error rates on the memory task are shown in Table 2, and were analyzed separately as 2 (WMC) × 2 (Compatibility) mixed design ANOVAs. For RTs, there was no main effects of WMC, $F(1, 26) = 1.82$, $p = .188$, or compatibility, $F(1, 26) = .251$, $p = .621$, and no interaction, $F(1, 26) = .001$, $p = .997$. For error rates, there was a main effect of WMC, $F(1, 26) = 10.00$, $p = .004$, partial $\eta^2 = .278$, error rates were lower for high WMC participants compared to low WMC participants. There was a main effect of compatibility, $F(1, 26) = 13.13$, $p = .001$, partial $\eta^2 = .336$, but no interaction, $F(1, 26) = 0.24$, $p = .627$. Error rates on the memory task were higher if the Simon trial was incompatible compared to if it was compatible.

Table 2.

Mean Reaction Times and Error Rates on the Memory Task for Low and High Working Memory Capacity Participants

	Low WMC		High WMC	
Compatibility	RT	% Errors	RT	% Errors
Compatible				
M	908	17.8	797	7.8
SD	257.2	10.36	173.7	6.30
Incompatible				
M	904	21.0	794	10.2
SD	262.2	11.68	175.5	6.89
Average	906	19.4	795	9.0

Thought Probes

The five response options to thought probes were 1) Task-related thought, 2) A memory from the past, 3) Something in the future, 4) Current state of being and 5) Other. Response option 1 was considered as on-task while response options 2-5 were considered as TUT. The percentage of TUT was calculated as the number of responses made for options 2-5 divided by 10, the total number of thought probes.

Percentage of response options are presented in Table 3 and were analyzed as a 2 (WMC) × 2 (Task) × 6 (Thought type) mixed design ANOVA. The main effect of Task, $F(1, 26) = 34.08$, $p < .001$, partial $\eta^2 = .567$, was due to TUTs and is analyzed separately below. There was a main effect of Thought type, $F(1, 26) = 33.32$, $p < .001$, partial $\eta^2 = .562$ in which there were differences in the amount of thought types reported. The effect of task was different for the six Thought types as indicated by the Task × Thought type interaction, $F(1, 26) = 24.49$, $p < .001$, partial $\eta^2 = .485$, and this interaction will also be analyzed separately below, for the Thought types of interest. No other effects or interaction were significant, $F(1,26) < .01$, $p < .05$.

Table 3.

Mean Percentage of Task-Unrelated Thought Response Options Comparing WMC in Single and Dual Tasks

WMC		On-Task	TUT	Past	Future	Current	Other
				Single			
Low	M	30.8	69.2	4.6	22.3	33.1	9.2
	(SD)	(26.0)	(26.0)	(7.8)	(14.8)	(21.4)	(12.6)
High	M	32.7	67.3	11.3	16.7	34.0	5.33
	(SD)	(24.3)	(24.3)	(13.6)	(16.8)	(23.2)	(8.3)
				Dual			
Low	M	59.2	40.8	5.4	12.3	20.8	2.3
	(SD)	(35.7)	(35.7)	(11.3)	(18.3)	(18.9)	(4.4)
High	M	72.3	28.7	8.0	4.7	14.0	2.0
	(SD)	(30.9)	(30.9)	(13.7)	(7.4)	(19.9)	(5.6)

<u>Task-unrelated Thought</u>

The percentage of TUTs are shown in Figure 4 and were analyzed as a 2 (WMC) × 2 (Task) mixed design ANOVA. There was a main effect of Task, F(1,

26) = 34.08, $p < .001$, partial $\eta^2 = .567$. The percentage of TUT was reduced in the dual task conditions ($M = 34.3\%$) compared to the single task conditions ($M = 68.2\%$). There was no main effect of WMC, $F(1, 26) = 0.54$, $p = .470$, and no WMC × Task interaction, $F(1, 26) = 0.79$, $p = .383$.

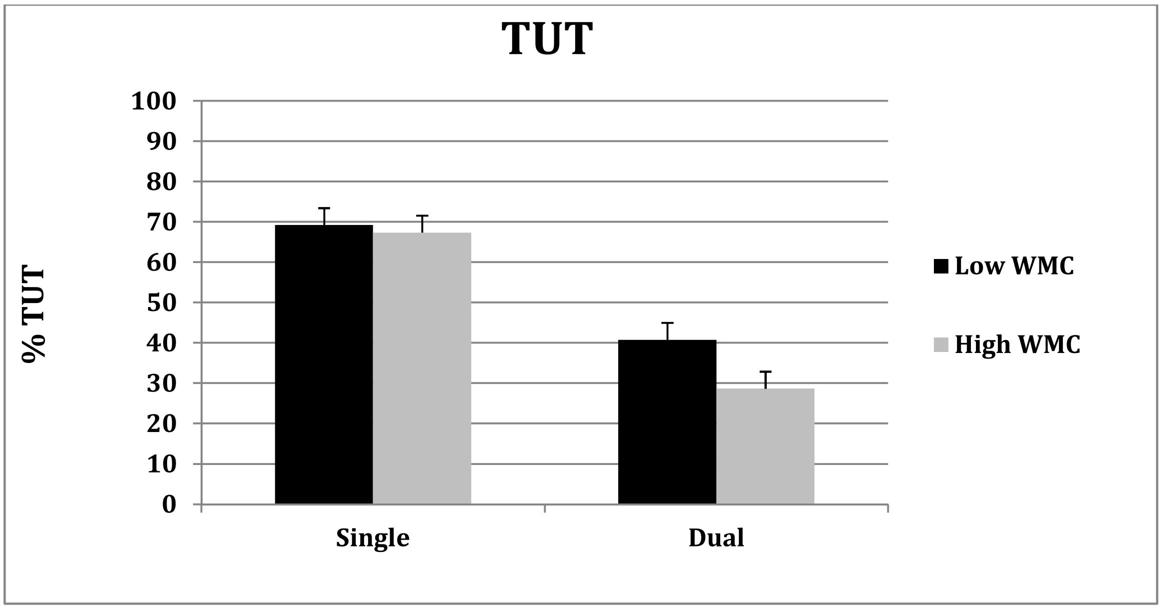

Figure 4. Percentage of Task-Unrelated Thought for Low and High Working Memory Capacity Participants in Single and Dual Task Conditions

<u>Past, Future and Current State of Being</u>

Percentage of TUT type were analyzed as a 2 (WMC) × 2 (Task) × 5 (TUT type) mixed design ANOVA. There was a main effect of Task, $F(1, 26) = 34.08$, $p < .001$, partial $\eta^2 = .567$, which was already reported above. There was a main effect of TUT type, $F(1, 26) = 56.46$, $p < .001$, partial $\eta^2 = .685$, in which there were differences in the TUT type reported. The effect of Task was different for the TUT type as indicated by the Task × TUT type interaction, $F(1, 26) = 13.49$, $p < .001$, partial $\eta^2 = .342$ and is analyzed separately for past, future and current state of being TUT below.

Proportions of past, future and current state of being TUT were calculated in two-ways in which they have been done so in previous research. First, past and future TUT were calculated as the percentage of overall thought reports, as done in Smallwood et al. (2009). This measure reflects participants overall propensity to engage in past or future oriented thought while performing the task. Percentage of past, future and current state of being TUT are presented in Table 3 and were analyzed as 2 (WMC) × 2 (Task) mixed design ANOVAs.

Thought Type / Overall Thought Report

There were no main effects of WMC, $F(1, 26) = 1.53$, $p = .227$, or Task, $F(1, 26) = 0.26$, $p = .616$, and no WMC × Task interaction, $F(1, 26) = 0.66$, $p = .424$, on percentage of Past/Total. For Future/Total, there was a main effect of Task, $F(1, 26) = 9.91$, $p = .004$, partial $\eta^2 = .276$, in which Future/Total were reduced for the dual task compared to the single task, see Figure 5. There was no main effect of WMC and no WMC × Task interaction, $F(1, 26) = 0.08$, $p = .777$, for percentage of Future/Total. For current state of being, there was no main effect of WMC, $F(1, 26) = 0.19$, $p = .665$. There was a main effect of Task, $F(1, 26) = 14.07$, $p = .001$, partial $\eta^2 = .351$, in which thoughts about current state of being were reduced for the dual task compared to the single task. There was no main effect of WMC, $F(1, 26) = 0.19$, $p = .665$ and no WMC × Task interaction, $F(1, 26) = 0.80$, $p = .380$, for percentage of current state of being/Total.

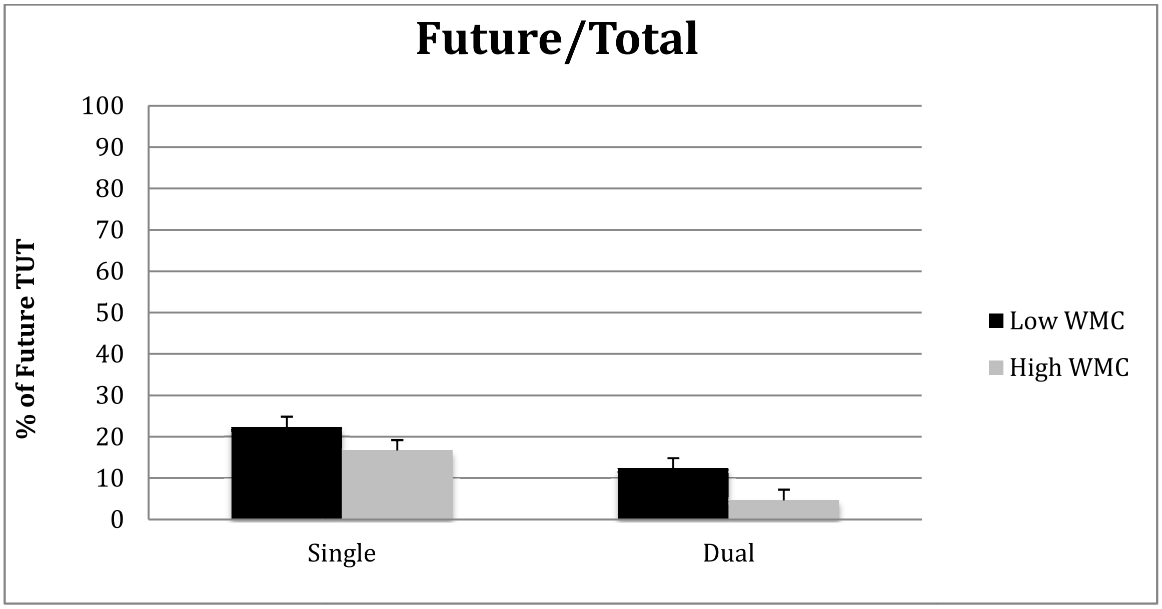

Figure 5. Percentage of Future-oriented Thought Out of Total Number of Thought Reports for Low and High Working Memory Capacity Participants in Single and Dual Task Conditions

<u>Thought Type / Task-unrelated Thought</u>

Past, future and current state of being TUT were also calculated as a percentage of overall TUT, as done in Baird et al. (2011). This reflects participants relative tendency to engage in past or future thought on the occasions in which they were mind wandering. Three high WMC participants and one low WMC participant did not report any TUTs on dual task conditions and therefore proportion of past and future TUT could not be calculated. This resulted in 24 participants (high WMC: n = 12, low WMC: n = 12) in which percentage of past, future and current state of being TUT were analyzed as a 2 (WMC) × 2 (Task) mixed design ANOVA.

There was a main effect of WMC on percentage of past TUT, $F(1, 22) = 4.76$, $p = .040$, partial $\eta^2 = .178$, see Figure 6. High WMC participants showed more past TUTs ($M = 21.1\%$) compared to low WMC participants ($M = 5.8\%$). There was no main effect of Task on percentage of past TUT, $F(1, 22) = 1.90$, $p = .182$, and no WMC × Task interaction for past TUT, $F(1, 22) = 1.60$, $p = .220$. For percentage of future TUT, there were no main effects of Task, $F(1, 22) = 0.74$, $p = .399$, or WMC, $F(1, 22) = 1.83$, $p = .190$, and no WMC × Task interaction, $F(1, 22) = 0.99$, $p = .330$. For percentage of current state of being/TUT, there were no main effects of WMC, $F(1, 22) = 0.02$, $p = .895$, or Task, $F(1, 22) = 0.04$, $p = .837$, and no WMC × Task interaction, $F(1, 22) = 0.26$, $p = .614$.

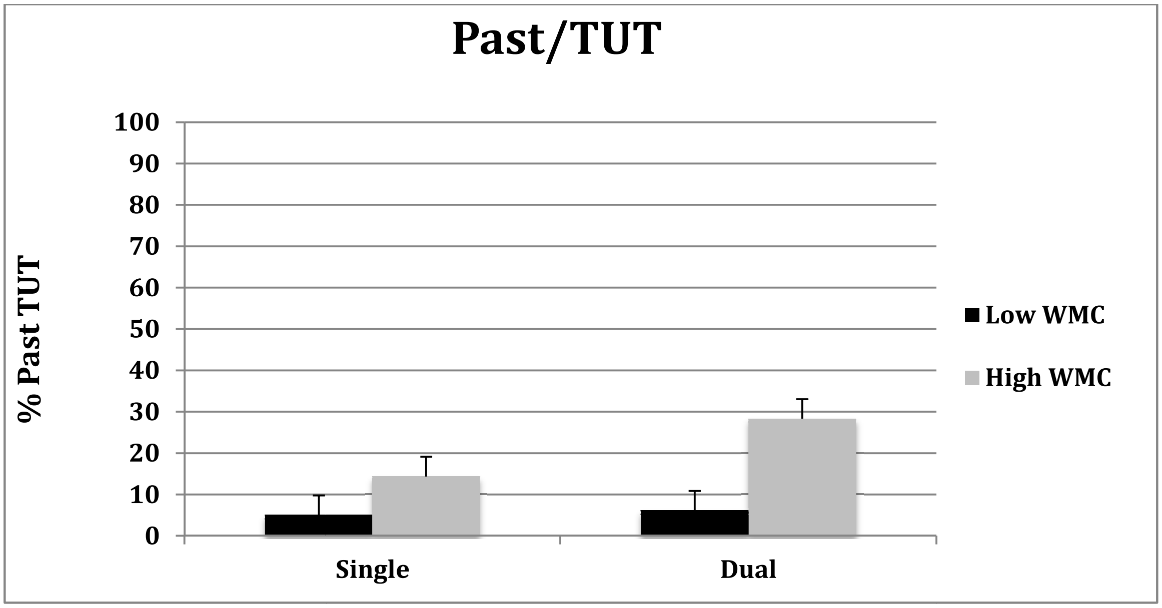

Figure 6. Percentage of Past-oriented Thought Out of Overall Task-Unrelated Thoughts for Low and High Working Memory Capacity Participants in Single and Dual Task Conditions

Correlations

Correlations between TUTs and task performance measures were conducted in order to investigate the relationship between mind wandering and task performance. Task performance measures on the single and dual tasks included; RTs, error rates, Simon effects and error rates on the memory task for dual task conditions. Correlation tables for high and low WMC groups can be seen in Tables 4 and 5, respectively. Furthermore, separate correlations were done for high and low WMC groups in order to detect any differences due to working memory capacity. For high WMC participants, TUTs did not correlate with performance in either the single or dual tasks. However, for low WMC participants TUTs did correlate with compatibility effects, $r\,(11) = -.559$, $p = .047$, and error rates, $r\,(11) = .611$, $p = .026$, in the single task conditions. As TUTs increased, compatibility effects decreased and error rates increased.

Table 4.

Correlations amongst Task-Unrelated Thoughts and Performance Measures for High Working Memory Capacity Participants

		1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	Single Task TUT	-								
2.	Dual Task TUT	.59*	-							
3.	Single Task RTs	-0.35	-0.04	-						
4.	Dual Task RTs	-.56*	-0.31	.89**	-					
5.	Single Task Simon Effect	-0.28	-.66**	-0.39	-0.12	-				
6.	Dual Task Simon Effect	-0.22	-0.07	0.13	-0.01	-0.30	-			
7.	Single Task Errors	0.14	-0.17	0.29	0.36	-0.07	-0.44	-		
8.	Dual Task Errors	-0.13	-0.05	-0.17	-0.14	-0.03	0.20	0.19	-	
9.	Memory Errors	-0.06	-0.33	-0.36	-0.37	0.36	-0.16	-0.16	0.18	-

Note. N = 15. Simon effect was calculated by taking RTs in incompatible conditions minus compatible conditions. RTs, and errors were collapsed across compatibility conditions.

* *p* < .05, ** *p* < .001

Table 5.

Correlations amongst Task-Unrelated Thoughts and Performance Measures for Low Working Memory Capacity Participants

		1.	2.	3.	4.	5.	6.	7.	8.	9.
1.	Single Task TUT	-								
2.	Dual Task TUT	0.39	-							
3.	Single Task RTs	0.25	0.04	-						
4.	Dual Task RTs	-0.00	0.06	.91**	-					
5.	Single Task Simon Effect	-.56*	-0.19	-0.10	0.26	-				
6.	Dual Task Simon Effect	0.38	-0.17	0.36	0.21	-0.11	-			
7.	Single Task Errors	.61*	0.00	0.38	0.25	-0.17	0.23	-		
8.	Dual Task Errors	0.34	-0.13	0.46	0.23	-0.45	0.14	.71**	-	
9.	Memory Errors	0.30	0.14	-0.37	-0.42	-0.00	-0.23	0.37	0.14	-

Note. N = 13. Simon effect was calculated by taking RTs in incompatible conditions minus compatible conditions. RTs, and errors were collapsed across compatibility conditions.

* $p < .05$, ** $p < .001$

CHAPTER FIVE

DISCUSSION

Summary of Results

In summary, the Simon effect was reduced in dual task conditions and to a similar degree between high and low WMC groups. However, high WMC participants showed an elimination of the Simon effect in dual task conditions; whereas, the low WMC group only showed a reduction of the Simon effect. Overall, high WMC participants had a smaller Simon effect compared to those with low WMC.

In regards to mind wandering, TUTs were less frequent in dual task compared to single task conditions and this was specifically for future and current state of being TUTs. There was no effect of WMC on overall amount of TUTs and no WMC x task interaction. High WMC participants did show more past TUTs, though only when calculated out overall amount of TUTs. For the correlations of mind wandering with task performance, TUTs did correlate with Simon effects and error rates in single task conditions but only for the low WMC group. TUTs negatively correlated with Simon effects and positively correlated with error rates.

The Role of Working Memory in the Simon Task

The response discrimination account of the Simon effect claims that interference between irrelevant spatial codes and relevant response codes arises in working memory (Ansorge & Wühr, 2004). According to this account, it was expected that the Simon effect would be reduced or even eliminated for the dual task conditions compared to the single task conditions. The results supported the response discrimination account and are consistent with previous studies by Wühr and Biebl (2011) and Zhao, Chen, and West (2010), where they found either a reduction or even elimination of the Simon effect by a verbal working memory load. Furthermore, but less confidently, it was expected that the low WMC participants would show a greater reduction in the Simon effect compared to high WMC participants. However, the reduction of the Simon effect was the same between WMC groups. Although the reduction was of the same magnitude, the Simon effect was eliminated for high WMC but not low WMC participants.

Why the Simon effect was eliminated for the high WMC participants but only reduced for low WMC participants is not clear. Although it could be due to the fact that the magnitude of the Simon effect for the high WMC was lower in the first place, the absence of a Simon effect vs. the presence of a Simon effect is an important distinction. One possibility is that the two groups used different representations for spatial response codes in working memory. Wühr and Biebl (2011) found differential effects of verbal and spatial working memory on horizontal and vertical Simon effects. Their interpretation is that the horizontal Simon task is represented by visual-spatial codes whereas the vertical Simon task is represented by verbal codes. However, it is not clear why the two groups would use different response code representations without any instruction to do so. Another explanation could be due to differential overlap of verbal working memory load with irrelevant location information and relevant stimulus-response location. Wühr and Biebl (2011) explain their results from a specialized load account (Park, Kim, & Chun, 2007). They assume that overlap between working memory load and irrelevant location information had a greater effect than overlap between working memory load and relevant stimulus-response location, in the Simon task. Overlap of the former would result in a decrease of the Simon effect and overlap of the latter would result in an increase of the Simon effect. It could be that, high WMC participants are better at minimizing the overlap of working memory load and relevant stimulus-response location; and therefore, high WMC participants showed no Simon distracter interference and low WMC participants showed only a reduced Simon effect. Further investigations would be needed to confirm this interpretation, however findings from Weldon et al. (2013) suggest that those with higher WMC more optimally adjust the level of cognitive control to resolve response conflicts on the Simon task.

The Relation Between Working Memory and Mind Wandering

The current study investigated competing hypotheses concerning the relation between working memory resources and mind wandering. The resource-demanding hypothesis states that mind wandering consumes working memory resources; whereas, the resource-free hypothesis states that mind wandering occurs without the need of working memory resources and is a result of control failures. Under the resource-demanding hypothesis, it was expected that mind wandering would decrease in dual task conditions compared to single task conditions and high WMC participants would mind wander more than low WMC participants. The resource-free hypothesis expected the same relation between Task and mind wandering, but expected that high WMC participants would mind wander less than low WMC participants, especially in dual task conditions. While previous studies on mind wandering have not combined working memory load manipulations with working memory capacity measures, the current study did so. As expected under both hypotheses, it was found that dual task conditions reduced mind wandering. However, no differences were found between high and low WMC participants on the overall amount of mind wandering, which was not expected by either hypothesis.

Even though there was no effect of WMC on mind wandering, previous research has actually found inconsistent findings on this relationship. In non-demanding task contexts, Levinson et al. (2012) found that higher WMC is associated with more mind wandering while other studies have found no correlation at all (Baird et al., 2011; McVay & Kane, 2012). Therefore, the findings reported here that WMC does not affect mind wandering, at least in single task conditions, is consistent with some previous research. It may be that under non-demanding task contexts WMC is just not associated with mind wandering and that it requires a more demanding task for there to be an association (McVay & Kane, 2010).

More challenging to explain is the result that WMC does not affect mind wandering in dual task conditions. In fact, a consistent finding in the literature is that higher WMC is associated with less mind wandering under demanding task contexts (McVay, Kane, & Kwapil, 2009; McVay et al., 2013; McVay & Kane, 2009, 2012; Unsworth & McMillan, 2012). One possibility may be due to the differences in the demanding task used in the current study and previous studies. Most studies showing WMC related differences in mind wandering have used the SART as the demanding task while a dual-task paradigm was used here. While they both can be considered as demanding they share very little similarities. On the SART task, goal maintenance is required to prevent pre-potent or habitual responding on no-go trials; whereas, dual-task interference and resolving response conflict is the challenge on the Simon task with working memory load. It could be argued that maintaining task goals on the SART task is more directly related to mind wandering, because of control failures, than minimizing dual-task interference on the Simon task is related to mind wandering. In fact, McVay and Kane (2012) found an effect of WMC on mind wandering in only a standard SART but not a vigilance SART. In the standard SART, no-go trials are infrequent, whereas in the vigilance SART no-go trials are frequent and go-trials are infrequent. An explanation they provide for their findings is the lack of a goal maintenance component to the vigilance SART. Therefore, the differences in findings from the current study to previous studies may have to do with the differences in the type of demands on the two tasks. Perhaps working memory capacity only predicts propensity for mind wandering in tasks that place high demands on active goal maintenance, or proactive executive control. This would be an interesting area for further investigation.

The effect of task demands on reducing mind wandering is a robust finding in the literature on mind wandering and was predicted by both the resource-demanding and resource-free views of mind wandering. Where the two hypotheses differed was in their prediction on the relationship between WMC and mind wandering; however, there were no WMC related differences found in this study. Keeping in mind that although there are no significant differences, there are trends in the data that suggest an effect of WMC. While high and low WMC participants showed nearly the same amount of mind wandering in single task conditions (M = 67.2% and M = 69.3%, respectively), high WMC participants tended to show less mind wandering (M = 28.7%) in dual conditions compared to low WMC participants (M = 40.8%). This trend for high WMC participants to show less mind wandering in the dual task conditions lends more support to a control-failure model of mind wandering.

Although the current results are not able to reconcile whether working memory resources are required for maintaining mind wandering, the findings on future-oriented TUT indicate a role of working memory resources. Smallwood, Nind, and O'Connor (2009) have argued that future-oriented mind wandering requires more working memory resources than past-oriented. Future-oriented mind wandering was found to have decreased in dual task compared to single task conditions; whereas, there was no effect of task on past-oriented mind wandering, consistent with results from Smallwood, Nind, and O'Connor (2009). This finding suggests that at least future-oriented mind wandering requires working memory resources. However, there were no working memory capacity related differences on future-oriented mind wandering. Instead, high WMC participants showed more past-oriented mind wandering than low WMC participants but only when past TUT was calculated out of the overall amount of TUT.

In addition to the findings on future-oriented TUT, there is some indication that mind wandering consumes working memory resources similar to that of working memory load. Consistent with a response discrimination account of the Simon effect (Ansorge & Wühr, 2004), working memory load reduced the Simon effect. Interestingly, in the single task conditions mind wandering acted similarly to a working memory load as evident by the large negative correlation between TUTs and the Simon effect, $r(26) = -.423$, $p = .025$. Just as working memory load reduces the Simon effect, as the amount of TUTs increased the Simon effect decreased. Furthermore, this correlation was actually only significant for the low WMC group, $r(11) = -.559$, $p = .047$, but not the high WMC group, $r(13) = -.283$. This WMC related difference of mind wandering on task performance lends more support to the resource-demanding view because high WMC individuals should have more resources to distribute between mind wandering and performing the task. Whereas from the resource-free view, because mind wandering is a result of control-failures it should affect performance regardless of WMC.

While the trend in the data of WMC on mind wandering supports a resource-free view and control-failure model, the findings on future-oriented TUT and mind wandering on task performance lend more support to the resource demanding view. A possible explanation for these disparate findings is from a context dependent relationship between WMC and mind wandering, which does assume that mind wandering requires working memory resources (Smallwood, 2010). From this perspective, higher WMC leads to more mind wandering in non-demanding contexts but less mind wandering in demanding task contexts. In the current study, there was a trend towards an interaction in which higher WMC lead to less mind wandering in dual tasks but no effect of WMC in single tasks. In fact, the trend in the results are somewhat consistent with the results of a recent study (Rummel & Boywitt, 2014) on mind wandering that also combined manipulations of task difficulty with WMC measures.

Rummel and Boywitt (2014) used an n-back task to manipulate task demands, 1-n back for low task demands and 3-n back for high task demands. They found that WMC had a marginal, $p < .07$, negative correlation with TUT in low task demands and a positive correlation with TUT in high task demands. Higher WMC was associated with more mind wandering in low task demands and less mind wandering in high task demands. Within a single experiment, Rummel and Boywitt (2014) may be the first study to show support for the context dependent relationship between WMC and mind wandering, suggested by Smallwood (2010).

In the current study, the lack of WMC related differences in mind wandering was not expected and may possibly be due to some limitations. One possible limitation why no WMC related differences in mind wandering were found may be due to splitting participants into low and high WMC groups. Previous studies that have found WMC related differences in mind wandering used WMC as a continuous variable (Baird et al., 2011; Levinson et al., 2012; McVay et al., 2009, 2013; McVay & Kane, 2009, 2012). Additionally, the only measure of WMC used in the current study was the OSPAN and the use of multiple measures may provide a more accurate measure of an individuals WMC (Redick et al., 2012).

Conclusion

The role of working memory in mind wandering is not well understood and there are two hypotheses concerning this relationship, the resource-demanding and resource-free views. The purpose of the current study was to investigate the relationship between working memory capacity and mind wandering under demanding and non-demanding contexts. The results of the current study do not provide strong support for one hypothesis over the other. Although WMC related differences in mind wandering were non-significant, there was a trend towards a context dependent interaction between WMC and mind wandering and some evidence for a role of working memory resources in mind wandering. Perhaps a context-dependent explanation of the relationship between working memory capacity and mind wandering offers the most complete explanation of the results in the current study as well as previous research. The different demands a task places on proactive executive control and response conflict may further clarify the role of working memory on mind wandering. The exact role working memory plays in the experience of mind wandering will continue to be investigated in future research.

APPENDIX A

IRB APPROVAL LETTER

Human Subjects Review Board
Department of Psychology
California State University,
San Bernardino

PI: Jason Tsukahara and Hideya Koshino

From: Jason Reimer

Project Title: The Role of Working Memory Resources in Mind Wandering

Project ID: H-14WI-32

Date: 3/20/14

Disposition: Expedited Review

Your IRB proposal is approved. This approval is valid until 3/20/2015.

Good luck with your research!

Jason Reimer, Co-Chair
Psychology IRB Sub-Committee

APPENDIX B

INFORMED CONSENT FORM

The Role of Working Memory Resources in Mind Wandering: Informed Consent

You are invited to participate in a study being conducted as a Master's Thesis by graduate student Jason Tsukahara of the Psychology Department of California State University, San Bernardino (CSUSB), under the supervision of Dr. Hideya Koshino. This study is approved by the Psychology Department subcommittee of the Institutional Review Board of California State University, San Bernardino, and a copy of the official Psychology IRB stamp of approval should appear on this consent form. The University requires that you give your consent before participating in this study.

This study examines an interaction between working memory capacity and working memory load on mind wandering during an attention task. The experiment consists of single task and dual task sessions. The single task session includes an attention task, in which you will see a central fixation point followed by a stimulus display. In the dual task, you are asked to remember some memory items while you perform the attention task. Please respond as quickly and accurately as possible in the attention task. After the attention task, you will be asked to perform the memory test. At the end of each block you will be asked "what were you thinking just now?" and will be presented with several different response options. The entire session will take approximately one hour to complete.

The experiments involves no risks beyond those of daily life, and no direct benefits to the individual other than an introduction to psychological research and $10 compensation for participating. However, your data may help to increase our understanding of working memory and mind wandering. The investigator will not associate your name in any way with the research findings, and all data are anonymous. Your participation in this study is completely voluntary and you are free to withdraw at any time without negative consequences. You may receive $10 for your participation. Please feel free to ask any questions that you have. Should questions concerning the study arise at a later date, please do not hesitate to contact the principal investigator at the phone number or address below, or in the event of a research-related injury, please contact the University's Institutional Review Board at (909) 537-5027. Results of this study will be available from Jason Tsukahara after the Spring quarter of 2014 upon request.

Please read the following before indicating that you are willing to participate.

1. The study has been explained to me and I understand the explanation that has been given and what my participation will involve.
2. I understand that my participation is entirely voluntary, and that I may withdraw from participation at any time, or refuse to answer any specific question, without penalty or withdrawal of benefit to which I am otherwise entitled.
3. I understand that if I have any questions or concerns regarding this study, or if I wish to receive additional explanations after my participation is completed, I can contact Jason Tsukahara at (425) 770-8506 or tsukj304@coyote.csusb.edu.

I acknowledge that I have been informed of, and understand the true nature and purpose of this study, and I freely consent to participate. I acknowledge that I am at least 18 years of age. Please indicate your desire to participate by placing and "X" on the line below.

Participant's X _______

Date: ___________

CALIFORNIA STATE UNIVERSITY
PSYCHOLOGY INSTITUTIONAL REVIEW BOARD SUB-COMMITTEE

APPROVED 3/20/14 VOID AFTER 3/20/15

IRB # H-14WI-32 CHAIR

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