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Reading between the lines: an individual difference investigation of situation model processing during narrative text comprehension

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in
Language and Communicative Disorders

by

Marguerite McQuire

Committee in charge:

University of California, San Diego

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San Diego State University

Professor Karen Emmorey
Professor Judy Reilly

2012

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The Dissertation of Marguerite McQuire is approved, and it is acceptable in quality and form for publication on microfilm:

Chair

University of California, San Diego

San Diego State University

2012

DEDICATION

This dissertation is dedicated to my wonderful parents, James McQuire and Emma Mendez-Arcidacono.

EPIGRAPH

I’m here to tell ya, this is complicated stuff!

Seana Coulson

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Cognitive neuroscience and individual differences in reading comprehension
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ABSTRACT OF THE DISSERTATION

Reading between the lines: an individual difference investigation of situation model processing during narrative text comprehension

by

Marguerite McQuire

Doctor of Philosophy in Language and Communicative Disorders

University of California, San Diego, 2012

San Diego State University, 2012

Professor Seana Coulson, Chair

In a series of 6 experiments, we investigated the impact of individual differences on mental model updating during reading of narrative texts. We presented short narratives that describe a protagonist as being spatially close (associated) or far away (dissociated) from a critical object, "George jogged home from work. He 'put on/took off' his faded 'sweatshirt'." Every narrative concluded with a sentence that anaphorically referred to the critical object, "He was sorry 'it' was torn." Experiments 1 and 2 (n=44 in each) presented word (Experiment 1) and picture probe (Experiment 2) recognition tasks at the end of each narrative. Whereas word probes were equally likely to be accurately recognized across association conditions, picture probes were more accurately recognized when the critical object was in the foreground of the situation model. Results suggest that the representational format of the picture probes was more compatible with an analogue representation of the reader's situation model of the text.

In Experiments 1 and 2, we found participants were faster to read the final sentence when the object was described as being spatially close to the protagonist. This difference in reaction times was positively correlated with verbal working memory capacity and mental rotation ability. Experiments 3 and 4 (n=44 in each) used a dual task paradigm to tax verbal (Experiment 3) and visuo-spatial (Experiment 4) working memory during comprehension of the texts. Experiment 3 revealed additive effects of association and verbal memory load on reading times for the final sentences, suggesting independent

mechanisms. Experiment 4 revealed interactive effects of association and visuo-spatial load.

Experiments 5 and 6 compared the difficulty of the concurrent load tasks on a letter search task and narrative text processing, respectively. Verbal and visuo-spatial tasks were equally disruptive in Experiment 5. In Experiment 6, visuo-spatial load led to more interference, especially in participants with fewer visuo-spatial resources. The demands of maintaining a heavy spatial load reduced the amount of visuo-spatial resources available for situation model updating, thus reducing the size of the association effect. Overall, results suggest readers recruit visuo-spatial working memory in the course of situation model updating.

Chapter 1

Introduction

Text comprehension is an ability we use every day when reading the newspaper or checking emails, for example. To literate adults, this process is so well-practiced it seems almost effortless. In fact, most people do not appreciate the complex demands it places on brain systems for visual processes to recognize printed words, demands on memory as we retrieve word meanings, and demands on the language system needed to combine the meanings of individual words to form the meaning conveyed by an entire sentence. Understanding a multi-sentence text is even more complex as readers often draw inferences based on previous experience or personal judgments. The goal of this dissertation is to examine the cognitive processes that underlie text comprehension. In addition, I examine the nature of the mental representation built during text comprehension, as well as investigate the cognitive mechanisms responsible for updating those representations.

1. Situation Models

Van Dijk and Kintsch (1983) and Johnson-Laird (1983) were among the first to suggest language comprehension entails more than linking meanings of words together. More specifically, it involves the construction of a mental

representation of the state of affairs described in the linguistic input, a mental model or *situation model*. As an alternative to the traditional proposition-based model of comprehension, Kintsch proposed the Construction Integration model for language comprehension (1988). According to this theory, comprehension of linguistic input occurs at three levels of mental representation. At the basic, or, *surface level*, linguistic units are activated and syntactic structure of the text is generated. At the text-base, or, *propositional level*, the representation contains ideas explicitly stated in the text as well as concepts required to link propositions. Kintsch and van Dijk (1978) have also described this as the first level wherein meaning comes into play. The third and highest level of representation is the *situation model*, which is now often viewed as essential for comprehension (Zwaan & Radvansky, 1998). It is a referential representation of the meaning of the situation described in the text, and includes information inferred from the reader's world knowledge (Johnson-Laird, 1983; Kintsch, 1988; van Dijk & Kintsch, 1983).

In a classic study by Bransford et al. (1972, as cited by Glenberg et al., 1987), the authors asked participants to memorize one sentence from pairs such as 1a and 1b, or 2a and 2b:

1a. Three turtles rested on a floating log, and a fish swam beneath them.

1b. Three turtles rested on a floating log, and a fish swam beneath it.

2a. Three turtles rested beside a floating log, and a fish swam beneath them.

2b. Three turtles rested beside a floating log, and a fish swam beneath it.

After a short delay, subjects who had memorized one of the sentences in pair 1 had great difficulty remembering which member of the pair had previously been presented. In contrast, participants who had memorized one of the sentences in pair 2 had little difficulty discriminating the old from the new sentence. At the propositional level, the difference between 1a and 1b is the same as the difference between 2a and 2b. Consequently, the authors argue that their participants' confusion was due to the fact that the situation described in 1a is the same as that described in 1b (if the fish swam beneath the log, it also swam beneath the turtles). By contrast, 2a and 2b describe two different situations, and so therefore are more easily distinguishable. These data suggest that the ultimate result of comprehension is not a representation of the text itself, but rather of what the text describes.

2. Situation Model Updating

Narratives often include descriptions of situations that change over time. In the constructivist view of language comprehension, the situation model must be updated to understand a narrative (Johnson-Laird, 1980). Text processing researchers have argued that people index changes in a text in a dynamic way

by tracking shifts in time and space, among other dimensions (Zwaan, Langston, & Graesser, 1995). Reading time experiments have suggested that when a narrative describes a disruption along one of these dimensions, people's reading rate is slow relative to passages that do not contain these discontinuities (Zwaan, Magliano & Graesser, 1995; Zwaan, Radvanksy, Hilliard & Curiel, 1998).

Reading times may even reflect a proportional response to the discontinuity. For example, Radvansky et al. (2003) examined the updating of situation models as a result of temporal shifts. In this study, people read passages that contained temporal shift sentences that involved either a short time shift ("a moment later") or a shift over a longer period of time ("a day later"). A short shift involved essentially the same situation, such as painting a wall. A long time shift indicated a change in situation and required more substantial updating, such as painting a whole house. The authors found that people were slower to read a sentence with a longer temporal shift than with a shorter temporal shift. Increase in reading time was thought to reflect additional cognitive effort required to update the situation model.

Shifts in the situation model may be more subtle than having a disruption. For example, in a classic study by Glenberg, Meyer, & Lindem (1987), participants read short narratives that described a protagonist moving about in a scene. In some of the scenarios, an object was described as being

close to the protagonist (e.g. being handed a menu), while in others the item was farther away (e.g. menu taken away). Reading times to a target sentence that anaphorically referred to the item (e.g. "He was sorry it didn't list the prices,") were faster when the item was described as close to the protagonist, and therefore in the foreground of the scene, relative to when it was described as farther away, and in the background. The authors interpreted the results as evidence that information about items in the foreground was more available than information about those in the background, suggesting that readers have fairly detailed situation models that include a representation of the proximity of the protagonist to objects mentioned in the text.

3. Cognitive Resources Underlying Situation Model Updating

While many reading researchers have tested the veracity of readers' situation models (e.g. Kintsch & Welsch, 1991; Myers & O'Brien, 1998; Zwaan, Langston & Graesser, 1995), there has been less investigation into the resources required to construct these models, and to update them in response to new information from the text. An underlying assumption in the text comprehension literature is that when presented with the same language input, different people have access to and use the same cognitive resources for comprehension. In large part, this assumption is what makes language research possible. Like most scientists studying human processing, language

researchers rely on commonalities between participants. However, skill for comprehension of language lies on a continuum. Neurotypical adults exhibit a wide scope of skill for reading as is shown by the range of scores on the verbal SAT (Gathercole & Baddeley, 1993). This should not be surprising considering that individuals vary in other human cognitive abilities as well, such as spatial and mathematical ability (Hegarty & Waller, 2005; Jarrold & Townse, 2006).

One important locus of individual differences is in working memory capacity. Working memory is commonly defined as the dynamic control and coordination of processing and storage that takes place during the performance of complex cognitive activities, such as language processing and visuo-spatial thinking (Miyake & Shah, 1999). On Baddeley's (2000) model, working memory is comprised of a number of separate components: the central executive, which is responsible for control of attention and coordination between subservient components, including the phonological loop, the visuo-spatial sketch pad, and the episodic buffer. The phonological loop represents material in phonological form, and consists of a short-term store subject to rapid decay. The visuo-spatial sketchpad is specialized for the maintenance of visual and spatial material, including mental imagery. The episodic buffer, a more recent addition to Baddeley's model, is used for integrating incoming verbal and visuo-spatial information with information in long-term memory.

3.1 Verbal Working Memory

The cognitive factor that has perhaps received the most attention in the literature on text comprehension is verbal working memory. In such investigations, differences between individuals' ability to simultaneously store and process verbal information are often assessed using either the Reading or Listening Span Test developed by Daneman and Carpenter (1980). This task requires participants to read a small set of sentences while simultaneously keeping track of to-be-remembered information, namely the last word of each sentence. Unlike other storage-oriented measures (e.g. digit span), this measure includes both a processing component (i.e. reading the sentences) and a storage component (i.e. remembering the last word of each sentence). Verbal working memory span has been found to correlate reliably with standardized verbal tests, such as the SAT and students' grade point average (GPA) (Shah & Miyake, 1996) as well as readers' abilities to resolve linguistic ambiguities (MacDonald, Just, & Carpenter, 1992; Miyake, Just, & Carpenter, 1994), and draw inferences from text (Masson &Miller, 1983; Singer, Andrusiak, Reisdorf, &Black, 1992; Singer & Richot, 1996). These results suggest there is a strong relation between performance on tasks that tap working memory (i.e. those tasks that require the simultaneous storage and processing of verbal information) and successful reading comprehension.

3.2 Visuo-Spatial Working Memory

Aside from a few exceptions, most researchers have not addressed the possible contribution of visuo-spatial working memory in language comprehension. However, these resources may be particularly important for understanding texts that require readers to make inferences about spatial relationships between elements mentioned in the text. In a study that tested the predictability of verbal and spatial working memory spans for spatial language processing, Friedman and Miyake (2000) asked participants to study the spatial layout of a museum, then read short narratives that described the curator solving a problem (e.g. stopping vandalism in the animal exhibits and deciding to mount hidden cameras). The texts varied in spatial and causal inferential demands (explicit / implicit). During reading, participants were interrupted with probes to assess causal or spatial processing. The causal probes were inferences that were verified or rejected ("He would have the tapes to prove the vandal's crime,"). The spatial probes were unlabeled maps of the museum with one of the rooms highlighted. The task was to indicate whether that room was referred to in the text ("He would put a camera in quail room,"). Spatial working memory span scores correlated significantly with reaction times to spatial probes. Causal probe accuracy correlated with verbal working memory span score.

Friedman and Miyake (2000) interpreted their results as showing that the spatial and causal dimensions of text were processed using different components of working memory, with verbal working memory span being more related to the causal dimension and the spatial span being more related to the spatial dimension. They further suggest that spatial and causal dimensions of situation models are maintained and elaborated independently in different working memory systems. Results from this experiment suggest that verbal and visuo-spatial working memories are separate pools of resources that may both be used to process text.

4. Representational Format of the Situation Model

Despite the importance of situation models in text comprehension, there has been little investigation into the exact nature of these representations. The traditional theoretical approach has been that situation models are sets of propositions and therefore amodal, symbolic systems (Kintsch, 1998; van Dijk & Kintsch, 1983). Amodal representations are descriptive, and not grounded in the perceptual systems that function during interaction with the environment. For example, the propositional representation of, “The ranger saw the eagle in the sky,” and “The ranger saw the eagle in the nest,” would be largely identical,

except for the final noun specifying a location: [[SAW[RANGER,EAGLE]], [IN[EAGLE,SKY]]] and [[SAW[RANGER, EAGLE]], [IN[EAGLE,NEST]]].

An alternative proposal is the embodied or grounded approach to language comprehension, which posits some modal content to the situation model as conceptual representations recruit brain areas involved in perceptual and motoric experience with their referents. According to the perceptual symbol systems framework (Barsalou, 1999), simulations are constructed by reactivating the perceptual memory traces that were originally laid down in memory during previous experiences with the described situation (Barsalou, 1999; Barsalou, Simmons, Barbey, & Wilson, 2003). For example, the concept *cat* triggers visual information from previously seeing a cat, tactile information from touching a cat, and so on. In this view, the meaning of a word is the product of many stored instances of our experience with its referent, as well as our linguistically cued experience with the word (Barsalou, 2010).

The perceptual symbol systems framework suggests that in order to account for discourse comprehension at the level of the situation model, readers establish analogue relationships between a text and the reader's background knowledge (Glenberg & Robertson, 1999). Barsalou (1999) argues that this background knowledge may take the form of perceptual experiences. Results from a study by Stanfield and Zwaan (2001) supports this hypothesis. They presented participants with sentences like the ones about the eagle, "the

eagle in the sky," or "the eagle in the nest," followed by a picture. Participants were asked to verify that the pictured object was present in the previous sentence. Response times to the picture probes were faster when the pictured object was in the implied configuration (e.g. outstretched wings for "in the sky," relative to wings tucked by its side). The researchers suggest that the situation models elicited by the two sentences about the eagle differed based on real world knowledge and previous perceptual experience.

Traditional accounts of language comprehension may presume that updating a situation model involves the management of propositional input, and thus predicts that verbal working memory is sufficient for constructing and updating the situation model. In contrast, embodiment theorists such as Zwaan and his colleagues, view situation models as dynamic representations, comprised of experiential event simulations that exploit representations derived from the perceptual systems. Such perceptually-based theories of comprehension suggest a relationship between visuo-spatial mechanisms and comprehension.

Consistent with this prediction, research by Wallentin et al. (2006; 2008) suggests that meaning from language relies on activation of other "nonlinguistic" cognitive systems, such as perception and memory. Using fMRI methodology, Wallentin et al. (2008) had participants read sentences that described two characters in a spatial relation, (e.g. "Next to each other stand a blushing

female student and an oldster with a beard," translation provided by the authors). Participants were then asked a question about the spatial relation (e.g. "Was he turned to her?") or a question that did not highlight the spatial relation (e.g. "Was he older than her?"). The investigators found that recalling the spatial content of the sentence resulted in higher BOLD signal in dorsoposterior regions of the brain, more specifically in a region that has previously been found to be involved in the recall of spatial relations from pictures (Walletin et al., 2006). Thus, thinking about spatial relations activated similar brain regions as actually performing spatial processing. By contrast, non-spatial information activated more ventral regions, primarily in the temporal lobe, known to be involved in semantic processing (Price, 2000). Wallentin et al. (2006) surmised that participants used visual imagery to respond to questions about the spatial relation of the two characters presented in the sentence. Therefore, visual imagery used for spatial language may be calling upon brain regions responsible for spatial processing. These results are in accordance with an "overlapping systems" model of language, where the meaning of language comes from an interaction between relevant cognitive systems that are not strictly linguistic (Talmy, 2000).

5. Spatial Situation Models

The extent to which readers encode spatial relationships in their situation models has been a contentious issue in the text comprehension literature. One commonly used paradigm is to present participants with a spatial layout of a scene and then test understanding of the spatial relationships using probe word recognition or target sentence reading time. In a study by Morrow, Greenspan, and Bower (1987), participants memorized the floor plan of a building and the locations of several objects before they read experimental narratives. Each narrative described the actions of a main character moving through the previously studied building. The narratives were interrupted periodically by test words that named two objects. Participants judged whether the objects were located in the same room or in different rooms of the building. Results from this study suggested that reaction times were fastest when the main character was currently occupying the same room as the mentioned objects, relative to objects from a previously occupied room. This finding suggests that readers kept track of the character's location during comprehension. Moreover, objects were identified more slowly as the distance between the character's location and the objects increased. That is, consistent with the predictions of an analogue situation model, the greater the distance between the protagonist and the object, the more difficult it was to retrieve information about the object.

Miller and McNamara (1992) partially replicated these results using target

sentence reading time as the dependent measure. They observed longer reading times for sentences that described objects as far away from the protagonist relative to sentences that described objects as close. However, in contrast to the results found by Morrow et al. (1987), the relative distance between the object and the character was not reflected in the reading time data, indicating that the character's movement was encoded discontinuously. Additionally, they found that when target objects were primed by either close or far objects, word recognition latencies did not indicate a distance effect, suggesting that text information is represented in a spatial format during *encoding*, but not at the time of *retrieval* from a situation model.

Some researchers argue that spatial information is only inferred in narrative comprehension when the task characteristics or stringent instructions encourage subjects to do so (McKoon & Ratcliff, 1992). Perrig and Kintsch (1985), for example, suggest that whether or not a spatial mental model is created depends on the perspective taken in the narrative. These researchers presented participants with descriptions of a town that were based in an allocentric (e.g. "North of the highway, just east of the river is a gas station,") or egocentric view-point (e.g. "On your left just after you cross the river you see a gas station,"). Results suggested that participants who read the allocentric text found it easier to draw a map of the town, but more difficult to remember the text itself. Participants who read the egocentric text remembered the text but had

difficulty drawing a map of the town. Perrig and Kintsch argued that these differences arose because allocentric texts facilitate the construction of a spatial situation model, while egocentric texts facilitate construction of a coherent propositional text base.

Other researchers have suggested that reader goals play a primary role in the construction of detailed spatial situation models. For example, Zwaan and Oostendorp (1993) asked participants to read part of a real, but edited, mystery novel describing the details of a murder scene, including the locations of the body and various clues. Participants had difficulty verifying spatial inferences when they were asked to read the text normally. However, when task instructions emphasized the construction of a spatial representation, participants' performance improved – but at the cost of a considerable increase in reading time. These results led Zwaan and Oostendorp to conclude that constructing and updating a spatial situation model may not necessarily be a priority during normal text comprehension of naturally occurring narratives.

Many previous studies have utilized problematic methodologies for the investigation of naturally-occurring spatial mental models from text. For example, participants may be interrupted during the experimental task (Friedman & Miyake, 2000; Morrow, et al., 1987), or be aware of the experiment's goal through the use of explicitly spatial texts (Perrig & Kintsch, 1985), explicitly spatial instructions (Zwaan & Oostendorp, 1993), or the use of

a map or spatial layout (Friedman & Miyake, 2000; Morrow, et al., 1987; Miller & McNamara, 1992). These methods thus may not reflect normal text comprehension mechanisms (Bestgen & Dupont, 2003). In sum, previous research on this topic leaves a number of issues unresolved regarding whether and when readers construct analogue situation models, and the extent to which they utilize visuo-spatial working memory to dynamically represent the spatial relationships between entities in the situation model.

6. The Present Study

The present studies investigate the representational format of the situation model by examining the cognitive resources that readers exploit when updating their situation models. Replication of Glenberg et al.'s (1987) experiment was chosen for this investigation, first, because it is a classic index of situation model updating, and, second, because the narratives involve subtle shifts in spatial relations, but are quite unlike the explicitly spatial texts utilized in some previous research (Friedman & Miyake, 2000; Morrow, et al., 1987; Perrig & Kintsch, 1985). As noted above, these texts describe a protagonist in a naturalistic setting whose activities naturally result in her getting closer to (associated condition), or father away from (dissociated condition), an item mentioned in the text. In chapters 2 and 3, we leverage individual differences between readers, and explore whether either verbal or visuo-spatial skills are

correlated with sensitivity to the difference between the associated and dissociated conditions, heretofore referred to as “the association effect.” In chapters 4, 5 and 7, we tax the verbal and visuo-spatial working memory systems separately to more directly test the relative import of verbal and visuo-spatial working memory for the updating processes indexed by the association effect. Chapter 6 compares the relative difficulty of the secondary tasks used in chapters 4, 5, and 7. Finally, chapter 8 is a general discussion of the previous chapters.

Chapter 2

Experiment 1: Individual differences in situation model updating (probe words)

Introduction

Text comprehension requires the reader to continuously update her situation model to reflect the changes described in the text. For example, when a reader is presented with a passage that describes a protagonist being handed a menu at a restaurant, the menu is in the foreground of the scene due to its proximity to the protagonist. It is thus in the foreground of the situation model. If instead, the text describes the menu being taken from the protagonist, the menu becomes less relevant and falls to the background. Because updating situation models involves the active manipulation of information, it may be a mental activity that falls under the rubric of working memory.

In a classic study by Glenberg et al. (1987), participants read short narratives that varied in the described distance between the protagonist and a critical item (e.g. the menu in the example above). The researchers were interested in the relative availability of the critical item when it was described as close (associated) or far away (dissociated) from the protagonist. In one experiment, they found that people were more likely to remember the target item (e.g. the menu) in a probe recall task when it was in the associated than in the dissociated condition. In a separate study, the dependent measure was reading time for a target sentence that anaphorically referred to the critical item

(e.g. the menu in “He was upset because *it* did not list the prices,”). Reading time results for the target sentence suggested that people took longer to read the target sentence when the item was described as farther away from the protagonist, or was left behind (e.g. “the menu was taken away,”) relative to when the item was close (e.g. “he was handed the menu,”) (Glenberg, et al., 1987). This was the first study to show that readers update their situation model during text comprehension. It was also the first to empirically demonstrate that readers are sensitive to subtle spatial shifts described in text and that the relative activation of a described item reflects spatial position in the situation model.

To determine the cognitive factors responsible for situation model updating, Radvansky and Copeland (2001) examined individual differences in reading times for the narratives used by Glenberg et al. (1987), along with participants’ performance on recognition probes for the target items (“Did the word ‘it’ in the previous sentence refer to the menu?”). Radvansky & Copeland (2001) found small, but statistically significant association effects on both reading times and probe accuracies. Radvansky and Copeland (2001) also had participants do several individual difference measures, including modified versions of Daneman & Carpenter’s reading span task, Shah & Miayke’s visuo-spatial span task, a word span task and an operation span task. Combining scores on these four measures into a composite measure, Radvansky &

Copeland (2001) failed to find significant correlations between working memory capacity and the association effect.

Radvansky & Copeland (2001) thus argued against an important role for working memory in situation model updating, suggesting instead that their own original assessment, the *situation identification test*, was better suited for measuring participants' capacity for this aspect of text comprehension. On the situation identification test, participants were given single-sentence narratives, followed by a six-alternative forced choice recognition test. The task was to select the sentence that most closely matched the 'gist' of the narrative. Radvansky and Copeland (2001) found a correlation between scores on the situation identification test and accuracies on target item recognition.

However, Radvansky & Copeland's (2001) findings are compromised by a number of factors. First, there were differences between their methodology and that used by Glenberg et al. (1987) that might have encouraged their participants to adopt unnatural reading strategies. For example, unlike Glenberg et al.'s (1987) study, Radvansky & Copeland (2001) did not include filler trials. Consequently, all anaphoric sentences referred to a critical item that was either physically associated or dissociated from the protagonist. Additionally, each story was followed by a question that specifically referred to the anaphor in the last sentence of the narrative, "Did the word 'it' in the previous sentence refer to the menu?" Moreover, whereas Glenberg et al. (1987) required participants to

answer comprehension questions after the narratives, Radvansky and Copeland (2001) did not. These factors presumably encouraged participants to attend to the small, movable objects in the texts, while providing little incentive to construct situation models of the stories.

In addition, there were a number of irregularities in Radvansky & Copeland's (2001) assessments of working memory. First, their modified version of the reading span task did not include comprehension questions to ensure that participants were reading sentences for comprehension, rather than simply attending to the last word in each sentence. Second, their modified version of the spatial span task presented participants with experimental materials (rotated letters) on index cards rather than on a computer monitor, possibly resulting in less reliable scoring. Third, Radvansky and Copeland (2001) scored the verbal and spatial working memory span tasks differently from the way they are typically scored. Rather than scoring performance based on the highest set size for which the participant correctly recalled the sentence-final word, Radvansky and Copeland (2001) summed the total number of words correctly remembered across all sets. This measure differs from span because it does not adequately represent the number of intervening sentences that might interfere with participants' memory of sentence-final words.

Perhaps most problematically, Radvansky and Copeland (2001) found that scores on all four of their working memory measures were correlated with

one another – including scores on verbal and spatial working memory. This outcome conflicts with psychometric testing that suggests verbal and spatial working memory are completely uncorrelated (Shah &Miyake, 1996; Friedman & Miyake, 2000). These factors undermine the validity of the findings reported by Radvansky & Copeland (2001), especially their claim that working memory is unrelated to situation model updating.

Present Study

In the present study, we re-examine the relationship between working memory capacity and the updating processes that underlie the association effect originally described by Glenberg et al. (1987). As in Radvansky & Copeland (2001), we examined the relationship between individual differences in the association effect and various measures of working memory capacity. As in Glenberg et al.'s (1987) study, we presented participants both with experimental narratives and with filler trials. This, along with the inclusion of comprehension questions, was intended to encourage participants to read the narratives for comprehension, and therefore should be a more valid index of situation model updating.

Accordingly, participants in the present study read the passages by Glenberg et al. (1987), responded to recognition probes about the critical items,

and answered comprehension questions about the stories. To help identify cognitive resources that underlie the association effect, participants also underwent a small battery of tests assessing their verbal and visuo-spatial working memory spans, imagery ability, and general reading ability. These tests included a verbal working memory task (Daneman & Carpenter, 1980), spatial rotation and spatial working memory task (Shah & Miyake, 1996), Nelson-Denny reading test (Brown, J., Fishco, V. & Hanna, G., 1993), and the Vividness of Visual Imagery Questionnaire (Marks, 1973).

If verbal working memory is important for updating the situation model (Daneman & Merikle, 1996), verbal working memory span would be expected to predict the size of the association effect. If spatial working memory is an important factor in this process (Friedman & Miyake, 2000), spatial working memory span would be expected to predict the size of the association effect. If mental imagery is important for situation model updating, we might expect the size of that effect to be predicted by measures of spatial rotation or vivid imagery. Finally, if the association effect is related to people's successful final comprehension of a text, we would expect the size of the effect to be predicted by scores on the Nelson-Denny reading comprehension test.

Method

Participants. Forty-four volunteers (31 women, 13 men) received course credit for their participation. All participants were native English speakers at the

University of California, San Diego (mean age = 19.2, SD = 1.4).

Materials. Materials were identical to those employed by Glenberg, et al. (1987), kindly provided by Art Glenberg. Materials were comprised of 48 experimental paragraphs such as the one in Table 2.1. Each paragraph begins with a sentence that sets the scene and introduces a main character. The second sentence is the critical sentence that describes an event in which the main character and the critical object are spatially close (associated condition) or farther away (dissociated condition). Importantly, both versions of the critical sentence (associated and dissociated) had the same number of words and almost identical wording. A filler sentence either did (long condition), or, did not (short condition), intervene between the critical sentence and the target sentence. Filler sentences were designed to keep the protagonist in the foreground by referring to him/her with a pronoun, and did not refer to the critical item. Target sentences all referred anaphorically to the critical object with the pronoun “it”. The target sentence was followed by the presentation of a recognition probe word, the critical object in the experimental paragraphs (e.g. “sweatshirt,” in the example in Table 2.1). Each trial ended with the presentation of a yes/no comprehension question intended to encourage participants to carefully read the paragraphs.

Table 2.1 Sample of narrative text stimuli

Setting sentence	George jogged home from work.
Critical (associated)	He put on his faded *sweatshirt* and decided to walk over to his girlfriend's.
Critical (dissociated)	He took off his faded *sweatshirt* and decided to walk over to his girlfriend's.
Optional filler	He loved to drop by unannounced.
Target sentence	He was sorry it was torn.
Recognition probe	Sweatshirt
Comprehension question	Was George going to church?

In addition to the 48 experimental stories, materials included 64 non-experimental stories of similar length and construction as the experimental paragraphs. These were included in order to prevent participants from focusing on the nouns introduced in the paragraphs and to ensure that half of the recognition probes required a "no" response. Non-experimental narratives differed in that some of the probe recognition words were not nouns (e.g. verbs and conjunctions). Additionally, whereas all of the experimental items required a "yes," response to the recognition probe, recognition probes for non-experimental trials usually included items that had not occurred in the preceding paragraph (viz. 56 of the 64 fillers required a "no" response to the recognition probe).

As in Glenberg et al. (1987), we employed a counterbalanced within-participants 2x2 design with factors of association (associated / dissociated) and passage length (zero / one filler sentence). Four lists were employed such that each participant read 12 items per experimental condition, and no individual participant read more than a single variant of each paragraph. Participants read five practice stories followed by a series of 48 experimental stories and 64 non-experimental stories randomly intermixed. Materials were divided into four blocks of 28.

Procedure. Participants were encouraged to read the materials carefully for comprehension. The presentation and timing of all events was controlled by a Dell computer using E-Prime software program (Psychology Software Tools, Pittsburgh). Paragraphs were presented one sentence at a time in a self-paced manner. Subsequent sentences appeared by pressing the spacebar. Reading times were recorded for each sentence. Additionally, accuracy was recorded for recognition probes as well as for comprehension questions. Participants pressed "1" for "yes" or "2" for "no" to indicate whether that word had been in the previous narrative. Similarly, participants indicated their responses to comprehension questions by pressing, "1," or "2."

Individual differences measures. After completing the reading time task, participants were given four tests to determine their cognitive abilities, as described below.

Verbal working memory span was determined with the listening span task (Daneman & Carpenter, 1980). In this test, participants were presented with a series of unrelated sentences in increasing sets of two to five. The sentences were presented auditorily through speakers. The participants' task was to listen for comprehension while also remembering the last word of each sentence. At the end of each set of sentences, participants wrote down the last word of each sentence in the set. Occasional comprehension questions were also included to ensure attention to the content of the sentences. Verbal working memory span scores were defined as the highest set size for which the participant recalled all of the words in at least two of the three sets. An additional half-point was added to the final score for remembering all of the words in one of the three sets above the participant's base score. The maximum possible score on this task was 5.0, and the minimum possible score was 1.

Spatial working memory was assessed with a spatial span task (Shah & Miyake, 1996). Here, participants were presented with a series of rotated letters (e.g. F, J, L, P and R) in increasing items per set. After the presentation of each letter, participants indicated whether the letter was correctly oriented ("R") or mirror-reversed ("Я") by pressing "1" or "2". This task assessed participants' aptitude at mental rotation. Following each set of letters, participants used a mouse to indicate the location of the top of each letter

(among eight equally spaced locations laid out in a circle) in the most recent set. Set size increased from two to five letters. Responses were recorded on a computer. Spatial rotation ability was calculated as percent of correct responses. Spatial working memory span scores were defined as the highest set size for which the participant recalled the placement of all of the letters in at least two of the three sets. An additional half-point was added to the final score for identifying the placement of one of the three sets above the participant's base score. The maximum possible score on this task was 5.0, and the minimum possible score was 1.0.

The Nelson-Denny Reading Test (Brown, Fishco, & Hanna, G., 1993) was administered to assess participants' text comprehension ability. Participants were required to read seven passages and respond to questions about their content. They were given 20 minutes to answer 38 multiple-choice questions. Score on this task was the sum of the total correct answers. The maximum possible score on this task was 38, and the minimum possible score was 0.

The Vividness of Visual Imagery Questionnaire (Marks, 1973) consists of 4 scenarios (e.g. "visualize the rising sun,") in which the participant is invited to consider the image formed by thinking about four specific aspects of the scene (e.g. "The sun is rising above the horizon into a hazy sky,"). Participants rate the vividness of each suggested aspect of the scene on a 5-point scale. On this scale, "1" indicates, "No image at all, you only 'know' that you're thinking of the

object," and "5" indicates, "Perfectly clear and as vivid as normal vision." Vivid imagery is quantified as the sum total of the ratings. The maximum possible score on this task was 80, and the minimum possible score was 16.

Design & Analysis. In this experiment we employed a 2x2 within-participants design. Dependent measures included accuracy on comprehension questions and probe word recognition, as well as reading times for target sentences. The latter was considered the primary measure of interest.

Only trials for which the critical item was correctly recognized were included in the reading time analyses. Target sentence reading times were filtered for outliers. These were defined as being 2 or more standard deviations above or below the mean reading time per condition. Repeated measures ANOVAs were conducted with factors of Association (associated / dissociated) and Passage Length (short / long) on comprehension question accuracy, probe word recognition accuracy, and target sentence reading time. Significant factors in the ANOVA were further analyzed with multiple regression using scores on individual difference measures.

Results

Individual Differences. We report participants' range of scores on the 5 individual difference measures (verbal working memory, spatial working memory, spatial rotation, text comprehension, and vivid imagery), as well as

Pearson's correlations between these measures after Bonferroni correction. Scores on these tasks are presented in Table 2.2. It is worth mentioning that participants in the current experiment obtained higher scores than average on spatial and verbal working memory span tasks (Shah & Miyake, 1996), and text comprehension (Wood, 2011). Table 2.3 demonstrates a general absence of correlation between the individual difference measurements. Verbal and spatial working memories were, however, negatively correlated, $r(42) = -0.27$, $p < 0.05$.

Table 2.2 Individual difference scores

Measure	Mean	St. deviation	Minimum	Maximum	Possible Range
Verbal WM Span	3.4	1	1.5	5	1-5
Spatial WM Span	3.4	1.2	1.5	4.5	1-5
Spatial Rotation	84	17	66	99	1-100
Text Comprehension	33	4	17	37	1-38
Vivid Imagery	32	11	19	67	16-80

Table 2.3 Pearson correlations between individual difference tasks, with Bonferroni correction

	Verbal Span	Spatial Span	Spatial Rotation	Text comprehension	Vivid Imagery
Verbal WM Span	x				
Spatial WM Span	-0.27*	x			
Spatial Rotation	0.12	-0.18	x		
Text comprehension	0.14	-0.05	0.05	x	
Vivid Imagery	0.08	-0.01	-0.01	0.21	x

* = $p<0.05$

Comprehension Question Accuracy. Participants had little trouble comprehending the experimental narratives regardless of passage length or association. The average accuracy rate for the comprehension questions was 88.5%. No effect of association or passage length was found, $F(1,43) = 2.00$, $p = 0.164$; $F(1,43) = 0.657$, $p = 0.422$, respectively. There was also no interaction between these two factors, $F(1,43) = 0.006$, $p = 0.939$.

Probe Word Recognition Accuracy. Immediately following the narrative text, a single word was presented on the screen. Participants' task was to indicate whether the word had been seen in the preceding paragraph. Average probe recognition accuracy was 90.2% across all conditions. No effect of association or passage length was found, $F(1,43) = 1.186$, $p = 0.282$; $F(1,43) = 0.028$, $p = 0.867$, respectively. There was also no interaction between these two factors, $F(1,43) = 1.452$, $p = 0.235$.

Reading Time for Target Sentences. Overall, people read the anaphoric target sentence more slowly when it referred to a dissociated object than when it referred to an associated object. Analysis revealed a main effect of association due to longer reaction times in the dissociated (2273 ms) than associated (2160 ms) condition, an effect of 113 ms, $F(1,43) = 7.15$, $p = 0.011$. Neither the Passage Length factor, nor the Association x Passage Length interaction reached significance, $F's < 1$. Table 2.4 shows the mean reading times (ms) per condition as well as the difference between conditions.

Table 2.4 Mean reading times (ms) for target sentences, with standard deviations in parentheses

	Associated	Dissociated	Difference
Short (0)	2124 (671)	2267 (694)	143
Long (1)	2197 (517)	2280 (568)	83
Difference	73	13	

Target Sentence RT and Individual Differences. A multiple regression analysis was carried out in order to model the contribution of each individual difference measure to the association effect. Here, the difference between reading times for target sentences that followed paragraphs in the associated condition were subtracted from reading times for those that followed the dissociated condition. The association effect was the dependent variable and the individual difference scores (verbal working memory span, spatial working memory span, spatial rotation, text comprehension and vivid imagery) were the independent variables. Together, individual difference measure data explained a significant proportion of the variance in association effect for reading times, $R^2 = 0.3$, $F(5, 38)= 3.5$, $p < 0.01$. In this analysis, verbal working memory span [B=0.49, t(38) =3.55, p = 0.001] and spatial rotation ability [B=0.37, t(38) = 2.44, p = 0.02] explained a significant portion of the variance for the association effect in reading time for the target sentence. Spatial working memory [B=0.07, t(38) =0.54, p = 0.59], text comprehension [B= -0.11, t(38) = -0.76, p = 0.45], and vivid imagery [B= 0.24, t(38) = 1.8, p = 0.079] were not significant predictors of

the association effect.

To explore how verbal working memory capacity and spatial rotation ability affected reading times, we conducted post hoc analyses of reading time data in participants with high and low verbal working memory, defined via a median split on scores on the listening span task, and in participants with high and low spatial rotation ability, defined via a median split on accuracy scores on the spatial rotation task. Tables 2.5 and 2.6 show the effect of association based on median splits for verbal working memory and spatial rotation, respectively. The positive relationship between verbal working memory and association effect, and spatial rotation and association effect are illustrated in Graphs 2.1 and 2.2, respectively.

Table 2.5 Target sentence reading times (ms) in participants with high and low verbal working memory spans

Verbal WM Span	Associated	Dissociated	Association effect
High Span Group	2006	2220.5	214.5
Low Span Group	2315.5	2327	11.5
Span Effect	309.5	106.5	

Graph 2.1 Scatterplot depicting the relationship between verbal working memory and association effect.

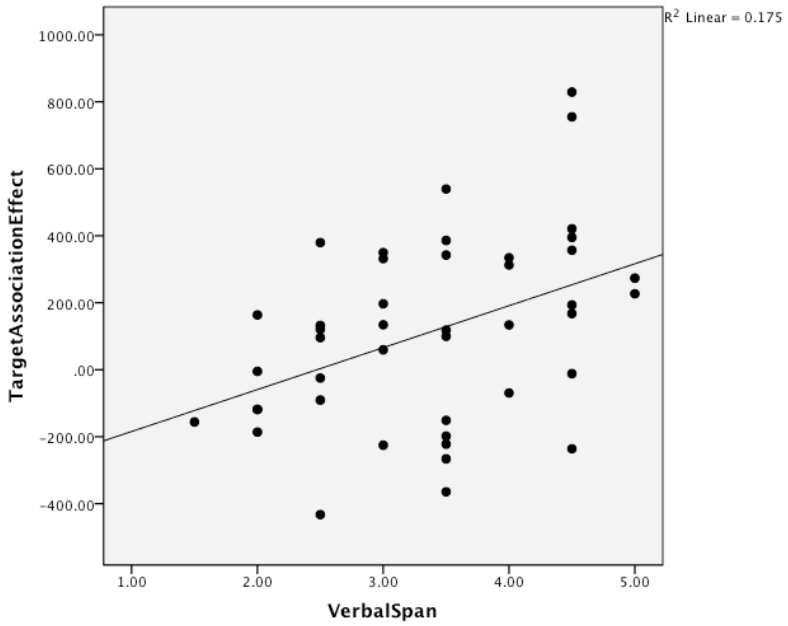
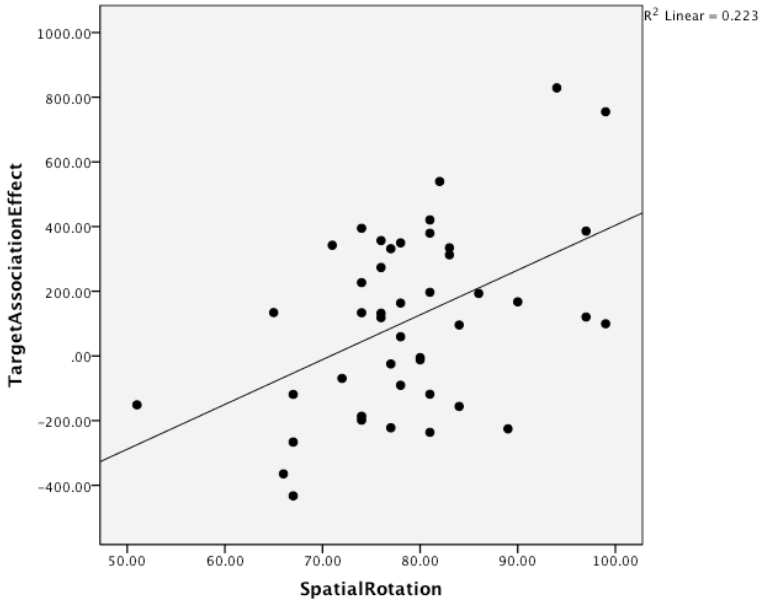


Table 2.5 suggests the association effect derives from the performance of the high verbal working memory span participants. This was confirmed by separate post hoc analyses of each group. Repeated measures ANOVA for target sentence reading times of high span participants revealed a main effect of association, $F(1,21) = 4.3$, $p = 0.05$, a non-significant effect of passage length, $F(1,21) = 1.15$, $p = 0.23$ and a non-significant interaction between the factors, $F(1,21) = 0.00$, $p = 0.99$. Analysis of data from low span participants failed to reveal any reliable effects, association, $F(1,21) = 2.88$, $p = 0.10$, passage length, $F(1,21) = 0.09$, $p = 0.77$, association x passage length, $F(1,21) = 0.67$, $p = 0.42$.

Table 2.6 Target sentence reading times (ms) in participants with high and low spatial rotation scores

Spatial Rotation	Associated	Dissociated	Association effect
High Acc. Group	2211	2332.5	121.5
Low Acc. Group	2110.5	2215.5	105
Rotation Effect	-100.5	-117	

Graph 2.2. Scatterplot depicting the relationship between spatial rotation ability and association effect.



Consistent with the regression analysis, Table 2.6 suggests the association effect was slightly larger in the group that performed better on our assessment of spatial rotation ability. Post hoc analyses of reading times from the high accuracy rotation group revealed only a marginal association effect $F(1,21) = 4.05$, $p = 0.06$, (passage length, $F(1,21) = 0.12$, $p = 0.73$; association x passage length, $F(1,21) = 0.06$, $p = 0.82$. Similarly, analysis of the low accuracy rotation group revealed only a marginal association effect, $F(1,21) =$

3.27, p = 0.09, and no significant effect of passage length, *F(1,21)* = 2.56, p = 0.12, or the interaction of these variables, *F(1,21)* = 1.22, p = 0.28.

Discussion

The present study replicated prior research suggesting that information about items that are described as physically close, or associated, to a story's protagonist is more readily available than information about items that are physically far, or dissociated, from the protagonist (Glenberg et al., 1987; Radvansky & Copeland, 2001). The regression analysis indicates that individuals with greater verbal working memory and spatial rotation ability had larger association effects. Beta weights suggest that the verbal working memory score was the most predictive of sensitivity to association, though spatial rotation also accounted for a significant portion of the variance.

Probe Recognition

In contrast to Glenberg et al.'s (1987) finding, we did not observe an association effect on probe recognition. That is, participants were equally likely to recognize probe words in the associated and dissociated conditions. This likely reflects the fact that we combined the two paradigms employed by Glenberg and colleagues into a single paradigm that included both a target

sentence and a probe task. Observed differences in the accessibility of critical items in the target sentences (evinced in reading times) may have dissipated by the time participants encountered the probes.

Text Comprehension Ability

Text comprehension ability did not predict the effect of association on target sentence reading time. This may be because the Nelson-Denny reading test is not a test of updating ability, but instead of final comprehension. Radvansky and Copeland's (2001) situation identification test is also a test of final comprehension and was not found to be predictive of reading times – only probe recognition.

Verbal Working Memory

In contrast to Radvansky & Copeland's null findings, the present study revealed a strong positive relationship between the association effect and verbal working memory span. This difference in findings may have been due to a difference in sample populations, a difference in scoring and treatment of the individual difference measures, a difference in overall size of the association effect between the two experiments, or a combination of these factors. Methodological choices such as the use of filler items and comprehension

questions may have impacted the size of the association effect between the two experiments. Additionally, analyses and treatment of the individual difference measures differed between the two experiments. Whereas Radvansky and Copeland (2001) applied correlations between the individual differences measures and the association effect, the present experiment examined the relative import of each individual difference measure by running a multiple regression analysis.

Median split analyses based on verbal working memory span suggest that the association effect was driven by the high span group whose effect size was 214.5 ms relative to the 11.5 ms difference in the low span group. This finding strongly suggests a role for verbal working memory in updating, as the association effect was not evident in participants who lacked sufficient verbal working memory resources. However, this result requires replication given that verbal working memory scores in our sample were negatively correlated (albeit weakly) with spatial working memory scores.

Spatial Working Memory and Mental Imagery

One somewhat surprising result was that the association effect was not predicted by spatial working memory span, and thus does not support the idea that spatial working memory is involved in updating of the situation model. One

reason for this may be that the spatial span task assesses people's ability to maintain multiple spatial entities in mind, rather than manipulate the information. A more reflective measure of this ability may be the spatial rotation task. This task requires the participant to mentally manipulate spatial relations. Scores on this task may thus be more representative of a reader's ability to manipulate subtle shifts in spatial relations, just as is required for situation model updating in Glenberg et al.'s (1987) narratives.

In fact, our multiple regression analysis suggested a positive relationship between the association effect and spatial rotation ability. Although the impact of spatial rotation ability was smaller than that of verbal working memory, it nonetheless made an independent contribution to the size of the association effect. The median split based on spatial rotation scores shows that both high and low spatial rotation groups exhibited a trend for the association effect, but that differences were slightly larger in the group that showed a greater facility manipulating mental images. Although imagery ability is not as relevant as verbal working memory, these data suggest a systematic relationship between the ability to mentally manipulate spatial relations and the proximity-based accessibility of objects in the situation model. This finding, in turn, supports the idea that situation model updating involves simulation with analog representational format, as suggested by Zwaan and colleagues (Zwaan et al., 1995; 1998).

It is interesting to note, however, that score for vivid imagery was not predictive of the association effect. This may be because the imagery assessment requires participants to report the subjective vividness of static mental images. By contrast, the spatial rotation task is an objective test of participants' ability to dynamically manipulate visual imagery.

Conclusion

The current study replicated previous findings suggesting that information about objects in the foreground of a story is more available than those in the background. A multiple regression analysis on the association effect for target sentences suggests that greater ability to dynamically manipulate verbal and spatial information, seen with verbal working memory span and spatial rotation ability, was associated with larger association effects. This analysis further suggested that ability to form an integrated representation of written materials did not predict the variance of the association effect, after independent contributions of verbal working memory and spatial rotation were factored out.

Participants in the current study earned higher than average scores on the individual difference measures. The largest association effects were found in individuals with higher verbal working memory span scores. Therefore it is possible that Radvansky and Copeland's (2001) null finding resulted from an

inability to observe the variance contributed by participants in the upper-most part of the distribution on the verbal working memory span task. In chapter 3, I describe an experiment intended to replicate the current findings while also extending the investigation into the representational format of the situation model.

Chapter 3

Experiment 2: Individual differences in situation model updating (picture probes)

Introduction

Situation models are nonlinguistic representations. Their components are not linguistic propositions, but mental representations of entities and their properties. Some text processing researchers suggest that comprehenders construct mental simulations of the state of affairs described in a text (Glenberg & Robertson, 2000; Stanfield & Zwaan, 2001). These simulations may be based on the reactivation of a perceptual, real-world experience (Zwaan et al., 2000). Accordingly, the 'modal' theory of language comprehension predicts that processing linguistic input is partially a result of the individual's tacit and automatic mental re-enactment of the situation described in a text, whether motorically or perceptually. Embodied cognitive psychology has highlighted the importance of low-level perceptual and motor processes in language and other higher-level phenomena (Barsalou, 1999; Glenberg & Robertson, 2000).

In line with this view, research has suggested that language comprehension involves the automatic activation of mental imagery (Barsalou, 1999; Bergen, Chang & Narayan, 2004; Nyberg et al., 2001; Bergen, Narayan & Feldman, 2003). Embodied theorists suggest these mental images are

unconscious and correspond with the content of the input (Bergen, Lindsay; Matlock, Narayan, 2007). Such imagery has the potential to interfere with (Kaschak et al., 2005; Richardson et al., 2003) or facilitate (Glenberg & Kaschak, 2002; Zwaan et al., 2002) participants' performance on tasks sensitive to language comprehension.

In an experiment by Stanfield & Zwaan, (2001), participants read sentences such as, (1) "John hammered the nail into the wall," or (2) "John hammered the nail into the floor." Shortly thereafter, participants saw a picture of a nail and verified that the object was present in the sentence. Response times were faster when the pictured object was in the implied orientation (horizontal for sentence 1, vertical for sentence 2) relative to when it was not (vertical for sentence 1, horizontal for sentence 2).

Similarly, using both picture verification and naming tasks, Zwaan et al. (2002) showed that participants responded faster to pictures that matched the implied shape of an object than to pictures that did not. For example, when a picture of an egg with its yolk exposed was preceded by, "There is an egg in the skillet," participants were faster to identify or name the object than they were when the picture that did not match the shape implied by the sentence (in this case, a whole egg). Although the task itself did not require participants to attend to the contextually relevant shape of the objects, these data suggest that participants nonetheless represented the visuo-spatial attributes of objects

implied by the sentence context. Given that the sentences did not explicitly state anything about the objects' orientation or shape, these findings are surprising in light of traditional assumptions about the abstract symbolic character of the situation model (as in Kintsch, 1988). In contrast, Zwaan and his colleagues suggest that when processing language, people activate perceptual information and thus naturally make inferences about object orientation, shape and spatial relations (Zwaan, Stanfield & Yaxley, 2002; Stanfield & Zwaan, 2001).

Accordingly, research on mental models in narrative comprehension has emphasized the role of detailed perceptual and motor knowledge in the construction of mental representations of scenes from verbal input (Zwaan, 1999). The mental simulation process has been argued to be useful in the production of detailed inferences on the basis of language input to build a situation model of the described scene (Zwaan, 1999). Embodied approaches to language processing and to comprehension predict that understanding verbal input about events that can be perceived or performed, will result in an individuals' tacit and automatic mental enactment of corresponding perceptual imagery (Bergen et al., 2007).

In line with this view, embodied cognitive psychologists may predict that the association effect described by Glenberg et al. (1987) arises because the critical item, such as the menu in the story about a man at a restaurant, are

close to the focus of attention in the situation model in the associated condition, and outside of it in the dissociated condition. Moreover, if the situation model has a perceptual, and specifically visual, component, they might predict that the availability of information in the situation model would be indexed by participants' response to pictures of activated items (as in Stanfield & Zwaan, 1999 ; Zwaan et al., 2001).

Present Study.

In the present study we tested whether participants' responses on a picture probe recognition task would differ as a function of the described distance between a protagonist and an object mentioned in the text. As in experiment 1, participants read the vignettes used by Glenberg et al. (1987) and reading times were recorded for a sentence that anaphorically referred to the critical item. As in experiment 1, after the narrative, participants responded to a recognition probe corresponding to the critical item. Unlike experiment 1, however, the probe was not a word, but rather a photograph of the critical item. If the association effect reported by Glenberg et al. (1987) results because of tacit visual imagery in the situation model, responses to probes should be more accurate for pictures of associated than dissociated items.

Moreover, just as in the previous experiment, participants were required to

undergo the same small battery of individual difference assessments, so that we could examine cognitive abilities related to the association effect. Given that results from experiment 1 differed from those of a similar study done by Radvansky & Copeland (2001), experiment 2 was intended to address the replicability of our findings that verbal working memory span and spatial rotation ability were positively correlated with the association effect observed on reading times for target sentences in the narratives. If results of experiment 1 were robust, verbal working memory and spatial rotation should be predictive of the association effect, driven by the high span and high accuracy participants. If results were an artifact of an unrepresentative sample, we would expect to replicate the null results reported by Radvansky & Copeland (2001).

Method

Participants. Forty-four volunteers (28 women, 16 men) received course credit for their participation. All participants were native English speakers at the University of California, San Diego (mean age = 19.7, SD = 1.3).

Materials. The texts were identical to those employed in the previous experiment, and those used by Glenberg et al. (1987). The main difference between the previous experiment and the present study is in the format of the probe that follows each short narrative. The current study presents a pictorial

depiction of the probe that was presented as a written word in the previous experiment.

Picture probes were normed by forty-two UCSD undergraduate students on a 5-point scale. Ratings were based on how closely the pictures depicted the probe word and the adjective that described it, e.g. 'torn sweatshirt'. Pictures in the experimental and the non-experimental (filler) materials received high scores (*M*=4.2, *S.D.*=0.5; *M*=3.9, *S.D.*=0.7, respectively), where 5 indicated, "perfect match."

Procedure. The procedure for the present study is identical to that of the previous experiment, except that the recognition probes were pictures rather than words. In the recognition probe task, participants pressed "1" for "yes" or "2" for "no" to indicate whether the depicted object had been described in the previous narrative. Similarly, participants indicated their responses to comprehension questions by pressing, "1," or "2." After completing the task, participants took part in the same 5 individual differences tasks described in Chapter 2.

Design & Analysis. A 2x2 within-subjects experimental design was employed. Dependent measures in this experiment included accuracy on comprehension questions and picture probe recognition, as well as reading times for target sentences. Only trials for which the critical item was correctly recognized were included in the analyses of reading times. Target sentence

reading times were filtered for outliers. These were defined as being 2 or more standard deviations above or below the mean reading time per condition.

Repeated measures ANOVAs were conducted with factors of Association (associated / dissociated) and Passage Length (short / long) on comprehension question accuracy, picture probe recognition accuracy, and target sentence reading time. Significant factors in the ANOVA were further analyzed with multiple regression using scores on individual difference measures as predictors.

Results

Individual Differences. We report participants' range of scores on the 5 individual difference measures (verbal working memory, spatial working memory, spatial rotation, text comprehension, and vivid imagery), as well as Pearson's correlations between these measures after Bonferroni correction. Participants' scores on these tasks are presented in Table 3.1. As in our previous study with this participant pool, participants in the current experiment obtained higher scores than average on spatial working memory span tasks (c.f. Shah & Miyake, 1996), vivid imagery (c.f. Cui et al., 2007), and text comprehension (c.f. Wood, 2011). Table 3.2 demonstrates an absence of correlation between individual difference measurements.

Table 3.1 Individual differences scores

Measure	Mean	St. deviation	Minimum	Maximum	Possible Range
Verbal WM Span	3	1	1.5	5	1-5
Spatial WM Span	2.6	1.2	1	4	1-5
Spatial Rotation	87	10	60	100	1-100
Text Comprehensio	33	4	15	35	1-38
Vivid Imagery	35	10	20	60	16-80

Table 3.2 Pearson correlations between individual difference tasks, with Bonferroni correction

	Verbal Span	Spatial Span	Spatial Rotation	Text comprehension	Vivid Imagery
Verbal WM Span	x				
Spatial WM Span	-0.19	x			
Spatial Rotation	-0.06	0.25	x		
Text Comprehension	0.17	0.21	0.21	x	
Vivid Imagery	-0.21	-0.06	0.13	0.14	x

Comprehension Question Accuracy. Participants had little trouble comprehending the experimental narratives regardless of passage length or association. The average accuracy rate for the comprehension questions was 87%. No effect of association or passage length was found, $F(1,43) = 0.77$, $p = 0.38$; $F(1,43) = 1.23$, $p = 0.273$, respectively. There was also no interaction between these two factors, $F(1,43) = 0.98$, $p = 0.33$.

Picture Probe Recognition Accuracy. Immediately following the narrative text, a picture was presented on the screen. Participants' task was to indicate whether the item had been present in the immediately preceding text. The

analysis revealed a main effect of association, *F(1, 43)* = 7.3, p = .01, as well as a main effect of passage length, *F(1, 43)* = 5.87, p = .02. No interaction between these factors was observed, *F(1,43)* = 0.16, p = 0.67. Table 3.3 illustrates mean accuracy per condition as well as the difference between conditions.

Table 3.3 Picture probe recognition accuracy (%) and difference between conditions. Standard deviations are in parentheses.

	Associated	Dissociated	Difference
Short (0)	95.9 (5.8)	93.7 (7.3)	2.2
Long (1)	94.2 (5.8)	91.3 (8.1)	2.4
Difference	1.7	2.4	

We further considered these picture probe accuracy data by running a multiple regression analysis on the association effect. Here, the difference between recognition accuracy for pictures that followed paragraphs in the associated condition was subtracted from recognition accuracy for pictures that followed paragraphs in the dissociated condition. The association effect was the dependent variable and the individual difference scores (verbal working memory span, spatial working memory span, spatial rotation, text comprehension and vivid imagery) were the independent variables. Analysis revealed that individual difference measures accounted for a significant portion of the variance, R^2 = 0.57, F(5, 38)= 3.7, p < 0.008. Text comprehension [B=

0.34, t(38) = 2.38, p = 0.02] and spatial rotation ability [B= 0.31, t(38) = 2.18 p = 0.036] were reliable predictors of the association effect. Verbal working memory span [B= 0.09, t(38) = 0.62, p = 0.54], spatial working memory span [B= -0.10, t(38) = -0.72, p = 0.47], and vivid imagery [B= 0.20, t(38) = 1.44, p = 0.15] were not.

A separate multiple regression analysis was run to determine the impact of the individual difference measures on the effect of passage length. Here, the difference between recognition accuracy for pictures that followed paragraphs in the short condition (no filler) was subtracted from recognition accuracy for pictures that followed paragraphs in the long condition (1 filler sentence). This model did not reliably account for the effect of passage length, R^2 = 0.14, F(5, 38)= 1.3, $p < 0.28$.

To further explore the relationship between text comprehension and the association effect, we divided participants into two groups based on a median split of their scores on the Nelson-Denny comprehension test and conducted separate post hoc analyses of their accuracy rates on the probe recognition task. As in the overall analysis, this involved a 2x2 repeated measures ANOVA with factors of association and passage length. Among the good text comprehenders, high accuracy rates were observed (94.5%), and no experimental effects were found (all Fs < 1). The poor text comprehenders however, exhibited a main effect of association, due to greater accuracy in the

associated condition (95%) relative to the dissociated condition (91%), *F(1, 21) = 7.42, p = .013.* The effect of passage length only approached significance, *F(1, 21) = 2.91, p = 0.10.*

Analogously, participants were divided into two groups based on a median split of their spatial rotation scores and post hoc analyses of recognition probe accuracy rates were conducted as above. The good spatial rotation ability group exhibited a main effect of association, *F(1, 21) = 5.8, p = .025*, but no effect of passage length, *F(1, 21) = 1.9, p = 0.19*. The poor spatial rotation ability group exhibited a main effect of passage length, *F(1, 21) = 4.3, p = .05,* but no effect of association, *F(1, 21) = 1.8, p = 0.19.*

Reading Time for Target Sentences. Overall, people read the anaphoric target sentence more slowly when it referred to a dissociated object than when it referred to an associated object. As in Chapter 2, analysis revealed a main effect of association due to longer reaction times in the dissociated (2172 ms) than associated (2077ms) condition, *F (1, 43) = 6.68, p = 0.013.* Neither the Passage Length factor, nor the Association x Passage Length interaction were statistically significant, *F's < 1.* Table 3.4 shows the mean reaction time (ms) per condition as well as the difference between conditions.

Table 3.4 Mean reading times for target sentences (ms), with standard deviations in parentheses.

	Associated	Dissociated	Difference
Short (0)	2053 (466)	2146 (493)	93
Long (1)	2101 (440)	2197 (554)	96
Difference	48	51	

Target Sentence Reading Time and Individual Differences. A multiple regression analysis was carried out in order to model the relationship between the individual difference measures and the association effect, quantified as the difference between reading times for target sentences that followed paragraphs in the associated condition and reading times for those that followed the dissociated condition (viz. dissociated minus associated). The association effect was the dependent variable and the individual difference scores (verbal working memory span, spatial working memory span, spatial rotation, text comprehension and vivid imagery) were the independent variables. Together, these results explained a marginal proportion of the variance in association effect reading times, $R^2 = 0.21$, $F(5, 38)= 2.1$, $p<0.09$. In this model, only verbal working memory span [B=0.32, t(38)= 2.1, p= 0.045] and spatial rotation ability [B=0.33, t(38) = 2.19, p = 0.035] were significant predictors of the association effect. Spatial working memory [B=0.11, t(38) =0.69, p = 0.49], text comprehension [B= -0.59, t(38) = -0.09, p = 0.55], and vivid imagery [B= -0.09, t(38) = -0.56, p = 0.58] were not significant predictors. Individuals with greater

verbal working memory spans and spatial rotation ability were more sensitive to the described proximity of the critical item to the protagonist. Tables 3.5 and 3.6 show the effect of association based on median splits for verbal working memory and spatial rotation, respectively. The positive relationship between the association effect, verbal working memory and spatial rotation score can be seen in the scatter plots below (Graphs 3.1 and 3.2, respectively).

Table 3.5 Target sentence reading times (ms) based on a median split of verbal working memory span

Verbal WM Span	Associated	Dissociated	Association effect
High Span Group	1897	2019	122
Low Span Group	2257	2271	20
Span Effect	360	252	

Graph 3.1 Scatterplot depicting the relationship between verbal working memory and association effect.

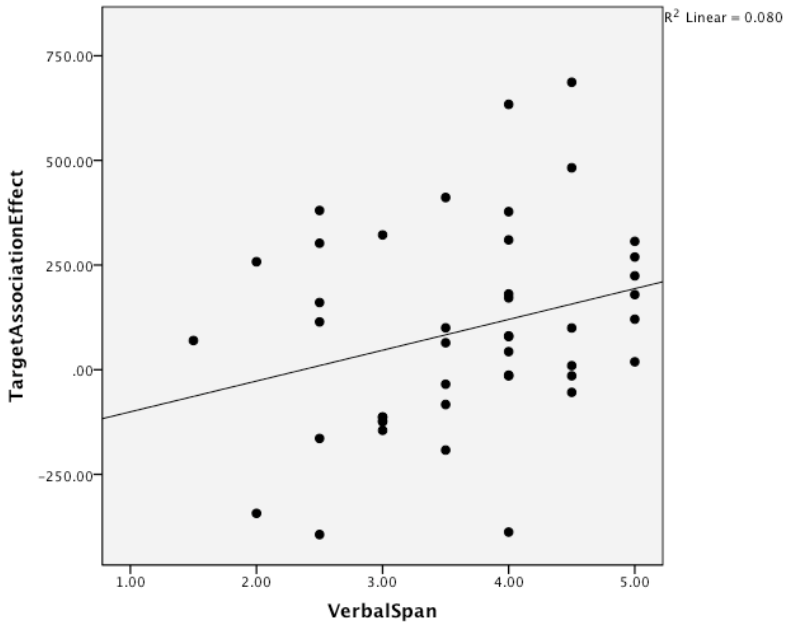
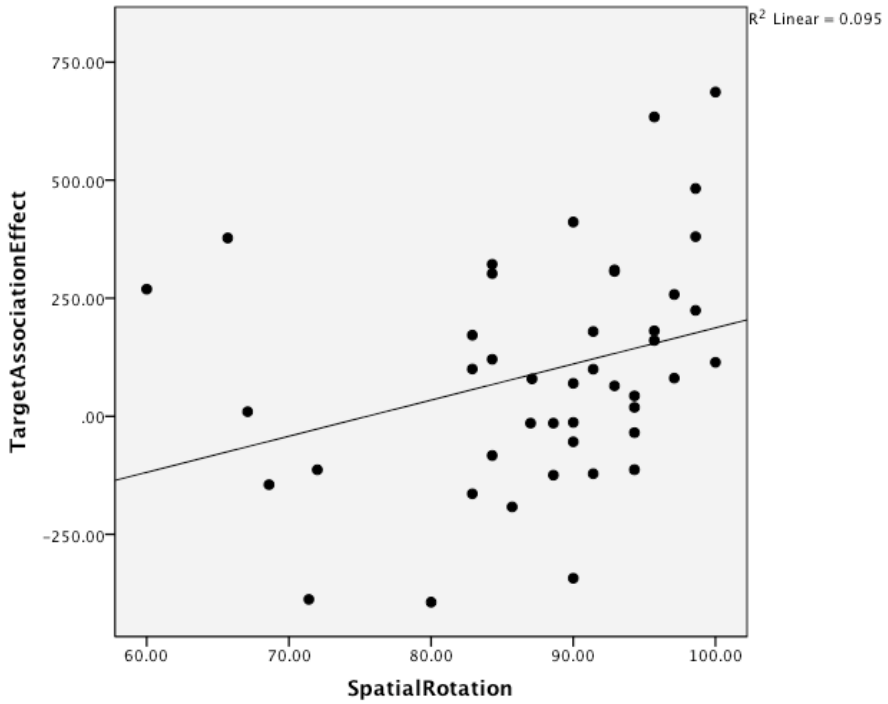


Table 3.6 Target sentence reading times (ms) based on a median split of spatial rotation ability

Spatial Rotation	Associated	Dissociated	Association effect
High Acc. Group	1987	2164	177
Low Acc. Group	2166	2178	12
Rotation Effect	179	14	

Graph 3.2. Scatterplot depicting the relationship between spatial rotation ability and association effect.



Median split analyses based on verbal working memory span suggest that the association effect was driven by the high span group, whose effect size was

122 ms relative to the 20 ms difference in the low span group. A 2x2 repeated measures ANOVA with factors of association and passage length for target sentence reading times in the high verbal working memory span participants revealed a statistically significant effect of association, $F(1,22) = 19.2$, $p = 0.000$, as well as a main effect of passage length, $F(1,22) = 10.6$, $p = 0.004$. No interaction between the two factors was found. In contrast, for the low verbal working memory group, no significant effects were observed, $F<1$. Inspection of the means in Table 3.5 suggests differences between high and low verbal span participants are more evident for the associated than the dissociated condition.

Separate analysis of the target sentence reading times in the high spatial rotation group revealed a statistically significant effect of association, $F(1,22) = 14.0$, $p = 0.001$, but no effect of passage length or interaction. The same analysis was conducted for the low spatial rotation group but no statistically significant effects were observed, $F<1$. Inspection of Table 3.6 suggests that differences between participants with high and low accuracy on the spatial rotation task were most evident in reading times for the associated condition.

Combined Analyses of Target Sentence RTs.

To increase the power of our data, reading times from the present study were combined with those collected in the previous study, which was identical

except for the inclusion of word probes rather pictures. Table 3.7 demonstrates the absence of statistically reliable correlations between individual difference measures in the combined dataset.

Table 3.7 Pearson correlations (with Bonferroni correction) between individual difference tasks for participants in Experiments 1 and 2

	Verbal Span	Spatial Span	Spatial Rotation	Text comprehension	Vivid Imagery
Verbal WM Span	x				
Spatial WM Span	-0.17	X			
Spatial Rotation	0.08	0.12	X		
Text comprehension	0.16	0.19	0.15	x	
Vivid Imagery	-0.04	0.03	0.12	0.19	x

With 88 participants, a 2x2 repeated measures ANOVA with factors of association and passage length revealed a significant main effect of association, $F\ (1, 87)$ = 13.9, p = 0.000, a non-significant main effect of passage length, $F\ (1, 87)$ = 2.34, p = 0.13, and a non-significant interaction between the two factors, $F\ (1, 87)$ = 0.16, p = 0.69. A regression model revealed that individual difference measures reliably predicted the effect of association, R^2 = 0.24, F(5, 38)= 5.3, p<0.000. Significant predictors included verbal working memory span, [B=0.36, t(82) = 3.6, p = 0.001], and spatial rotation ability, [B=0.31, t(82) = 3.2, p = 0.02]. Vivid imagery, [B=0.07, t(82) = 0.70, p = 0.48], text comprehension, [B=-1.16, t(82) = -0.11, p = 0.25], and spatial working memory, [B=0.12, t(82) = 1.19, p = 0.24] were not found to be predictive of the variance on the association effect for target sentence reading time.

Discussion

The present study was intended to replicate and extend the experiment described in chapter 2. To that end, we measured recognition accuracy rates for pictures of critical objects mentioned in the texts, and reading times for target sentences in the narrative texts used by Glenberg et al. (1987). Results for each of these tasks are discussed in turn.

Probe Recognition Performance

Unlike the non-significant results found for probe recognition accuracy in Experiment 1, the present study, which presented pictures, revealed a small, but statistically reliable difference in accuracy due to the association manipulation. Participants made more errors identifying the picture probe when it was a dissociated object (92.5%) relative to associated object (95%), suggesting information about the pictured object was more available in memory when the object was described as being physically close to the protagonist than when it was described as being farther away. Similarly, recognition accuracy was worse after long passages than short ones that contained less intervening material between the presentation of the critical item and the probe. But whereas the passage length effect was similar in all participants, the association effect differed as a function of participants' cognitive abilities.

Accuracy on probe recognition was worst among participants who scored poorly on a general test of text comprehension, and improved systematically as reading comprehension scores increased. This result is consistent with the report by Radvansky & Copeland (2001) that performance on probe recognition correlated with scores on their situation identification test. The situation identification test, like our measure of text comprehension, is an instrument intended to assess participants' ability to accurately represent the situation described in a text. While it is perhaps unsurprising that sensitivity to the association factor was related to participants' overall ability to understand texts, it is interesting that performance on probe recognition was indexed by this measure of language ability rather than verbal working memory span. In this respect our results resemble those of Radvansky & Copeland (2001), who also failed to find a relationship between working memory capacity and probe recognition.

Besides text comprehension scores, the multiple regression analysis also revealed that spatial rotation ability was a significant predictor of the association effect. This result is in keeping with the suggestion that the situation model results, at least in part, from the automatic activation of mental imagery (Bergen, Chang, & Narayan, 2004; Bergen, Narayan & Feldman, 2003; Bergen, Lindsay, Matlock, Narayan, 2007). On this account, probe recognition depends on inspecting an unconscious mental image constructed to represent the text.

Participants with less facility manipulating mental images might construct situation models that lack visual detail needed for sensitivity to the association factor.

Overall, probe recognition results of the present study are consistent with the original findings reported by Glenberg et al. (1987), and the replication by Radvansky and Copeland (2001). They differ, however, from probe recognition results in Experiment 1 in which word probes were equally likely to be accurately recognized, irrespective of their proximity to the protagonist. One potential explanation for this result is that the representational format of the picture probes was more compatible with the analog format of the situation model, as proposed by Zwaan (1998). This fits with our finding that variance on the association effect was predicted by spatial rotation ability. Perhaps individuals with good spatial rotation ability show an association effect on probes because they more easily relate the probes to the imagistic component of their situation models.

Reading Times for Target Sentences

Results for target sentence reading times generally replicate those found in the previous Experiment 1 (chapter 2). Reading times were reliably faster when the anaphor “it” referred to an object that was described as being spatially

close (associated) to the protagonist relative to when it was described as far (dissociated). As in Experiment 1, the present study revealed a main effect of association that was predicted by verbal working memory span and spatial rotation. Individuals with higher scores on these tasks exhibited larger reaction time differences between association conditions than those with lower scores.

Verbal Working Memory. The size of the association effect in the high span group in the present experiment is 92 ms smaller than that found in the high span group in the previous experiment. This may have been due to the previous experiment's sample having higher verbal working span (3.4) relative to the current sample (3.0). A closer look at the distributions between samples reveals that the difference between high and low groups was not equivalent across experiments. The high span group in Experiment 1 obtained an average score of 4.1, whereas the same group in the present study had an average score of 3.5.

The low span groups in both studies, however, were approximately equivalent. The low span group in the previous study had an average score of 2.6, while those in the current study had a score of 2.4. It is thus plausible that the high verbal working memory group in the previous experiment was more sensitive to the difference between association conditions due to their generally larger verbal working memory span. In both experiments however, the low span groups did not seem to be sensitive to the difference between association

conditions. Thus, comparison between median splits based on verbal working memory supports the idea that the high span group is driving the association effect. Additionally, in both experiments, the high spans group exhibited substantially shorter reading times than the low span groups. This pattern of reading rate results is in keeping with previous research suggesting speed of verbal processing is related to verbal working memory (Salthouse, 1992).

The finding that in both experiments the association effects on target sentence reading times was predicted by scores on verbal working memory span, contrasts with the null results reported by Radvansky and Copeland (2001), who conducted a similar study. One reason for the disparate results might be that Radvansky and Copeland (2001) tested a more representative sample than those of the present and previous experiments because they tested 160 participants in contrast to the 44 tested (in each experiment) here. This is unlikely, however, because (as noted in the previous chapter) scores of verbal and spatial working memory scores were positively correlated in Radvansky and Copeland's (2001) sample, in contrast with Shah and Miyake's (1996) normative report that these forms of working memory are uncorrelated in the college population. Unlike Radvansky and Copeland's (2001) results, data from the present experiment suggests that each individual difference assessment measures independent cognitive capacity.

The Structure Building Framework (Gernsbacher et al., 1990) suggests that individuals with higher verbal working memory capacity are skilled at suppressing or inhibiting irrelevant information, whereas individuals with lower verbal working memory are less successful with this. Gernsbacher's theory predicts that the high verbal working memory group would differ most from the low group at the dissociated condition.

Data from the present and previous experiment, however, suggest that the difference between the high and low verbal working memory groups on target sentence reading time was greatest in the associated condition. This pattern of results is more in line with the theory that individuals with high verbal working memory are able to actively attend to and maintain the most relevant information without distraction (Unsworth & Engle, 2007). Engle (2002) suggests that differences between people with high and low working memory spans are not due to a difference in ability to suppress irrelevant information (as suggested by Gernsbacher et al. (1990), but instead are due to an ability to maintain the relevant information in contexts that require mental manipulation.

Spatial Rotation Ability. In both the present and previous experiment, multiple regression analyses suggested that spatial rotation ability was also predictive of the association effect for target sentence reading time. However, unlike the previous experiment, which showed that high and low spatial rotation groups exhibited an effect of association, only the high spatial rotation group

exhibited the effect in the present study. Results of the present study thus suggest the ability to manipulate mental imagery is highly relevant for the updating processes indexed by the association effect. As for verbal working memory, participants who lack the ability to manipulate mental imagery were not sensitive to the proximity between the critical object and the protagonist.

Neither experiment 1 nor experiment 2 revealed a relationship between the size of the association effect and spatial working memory span. These results argue against our hypothesis that updating the situation model recruits visuo-spatial working memory systems. Similarly, the null finding for vivid imagery argues against a role for conscious imagery in the updating process indexed by the association effect. By contrast, the ability to manipulate mental images indexed by the spatial rotation test was positively correlated with the size of the association effect. Consistent with the idea that the association effect arises due to the salience of the target item in a visual situation model, the effect was larger for participants who showed greater facility manipulating mental images, and absent in participants who scored poorly on the spatial rotation task. Moreover, reading times for target sentences were quite similar for the dissociated condition, which would not be expected to differ because they are not activated in the situation model. Rather, differences between the two groups arose because reading times for the activated, associated condition were shorter in the group with greater ability to manipulate images.

Chapter 4

Experiment 3: Situation model updating with a concurrent verbal task

Introduction

A number of considerations suggest verbal working memory is important for updating the situation model. Updating a situation model requires that a large amount of information be kept available while the reader encounters subsequent text within a narrative. To form an accurate and coherent mental model the reader must integrate new, relevant information and discard irrelevant information. The larger one's verbal working memory capacity is, presumably, the easier this task should be. Indeed, research on verbal working memory has repeatedly indicated that individuals with greater verbal working memory capacity perform better on language comprehension tasks (Daneman & Merikle, 1996; Just & Carpenter, 1992). Moreover, Experiments 1 and 2 both revealed that individuals with greater verbal working memory capacity showed systematically larger association effects than those with lower capacity, suggesting a role for verbal working memory in the situation model updating processes that underlie the association effect.

As correlational evidence, however, it is unclear whether verbal working memory is in fact causally linked to the association effect, or is involved in

processes peripheral to those underlying the effect. It is possible that the impact of verbal working memory on situation model updating may more accurately be measured using dual-task methodology.

A dual-task paradigm requires that the participant perform a primary task such as reading a narrative text while simultaneously performing a secondary verbal task, such as the rehearsal of numerals (Farmer, Berman & Fletcher, 1986). If the two tasks compete for the same limited resources of working memory, then performance on one or both tasks should be diminished.

Present Study

In Experiment 3, we directly manipulate demands on verbal working memory in order to assess its impact on situation model updating. To do so, we asked participants to rehearse either 2 (light load) or 4 (heavy load) digits as they read the narratives used by Glenberg et al. (1987). If verbal working memory operations are independent of the processes that underlie the association effect, we should observe additive effects of memory load and association/dissociation. Alternatively, if verbal working memory is intimately involved in situation model updating, we predict interactive effects of these variables.

Method

Participants. Forty-four volunteers (26 women, 18 men) received course credit for their participation. All participants were native English speakers at the University of California, San Diego (mean age = 20.6, SD = 2.5).

Materials.

Narrative Texts. The texts were identical to those employed in the previous experiments, and those used by Glenberg et al. (1987). However, in this experiment, the sentence containing the critical item was always followed by a filler sentence. The long passage length was chosen because Glenberg et al. (1987) found this condition to be most sensitive to the association effect. This, in turn, was followed by a target sentence that referred anaphorically to the critical item.

Digit Recall (Verbal Load). Materials for the digit recall task were constructed by recording a woman reading each of the integers from 0 to 9. Sequences of 2, 3, or 4 numbers were created by combining individual sound files. Sequences were constructed using a random number generator. However, no single integer was repeated within a sequence. Half of the experimental trials were coupled with 2 auditory numbers (light load condition), while the other half were paired with 4 auditory numbers, (heavy load condition).

The non-experimental, filler trials were presented with sets of three auditory numbers.

Procedure. Each trial began with the auditory presentation of digits for the digit recall task via speakers (see Figure 4.1). Immediately thereafter, a narrative text was visually presented on the computer monitor. These were presented one sentence at a time, in a self-paced manner. Next, a visual array of numbers (0 to 9) in random order appeared on the monitor. Participants used a mouse to point to the numbers heard before reading the text. After completion of the verbal load task (i.e. digit recall) participants were presented with a Yes / No comprehension question based on the narrative. Feedback on text comprehension and digit recall was provided on a single screen. After completing this task, participants took part in the same individual difference measures described in Chapters 2 and 3 (verbal working memory, spatial working memory, spatial rotation, text comprehension and vivid imagery).

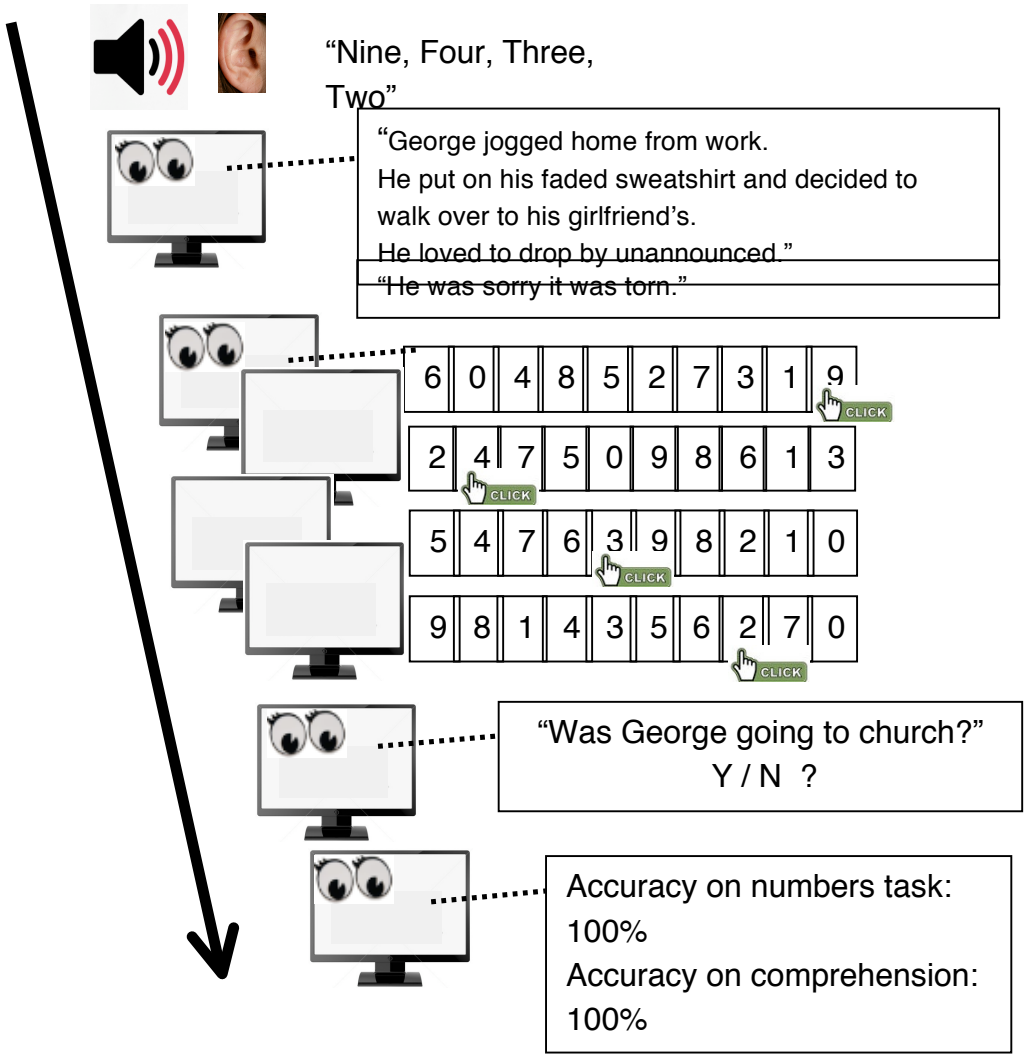


Figure 4.1 Example of a trial in the heavy digit recall condition.

Design & Analysis. This experiment employed a 2x2 within-participants design. Dependent measures included accuracy on comprehension questions, accuracy on the digit recall task, and reading times for the target sentences.

Target sentence reading times were filtered for outliers. These were defined as being 2 or more standard deviations above or below the mean reading time per condition. Approximately 3% of the data were excluded for this reason. Data were analyzed with repeated measures ANOVA with factors of Association (associated / dissociated) and Verbal Load (heavy / light). Significant factors in the ANOVA were further analyzed with multiple regression using scores on individual difference measures.

Results

Individual Differences. We report participants' range of scores on the 5 individual difference measures (verbal working memory, spatial working memory, spatial rotation, text comprehension, and vivid imagery), as well as Pearson's correlations between these measures after Bonferroni correction. Scores on these tasks are presented in Table 4.1. Table 4.2 demonstrates that the individual difference measures were not significantly correlated with one another.

Table 4.1. Performance on individual difference measures

Measure	Mean	St. deviation	Minimum	Maximum	Possible Range
Verbal WM Span	3.3	1	1	5	1-5
Spatial WM Span	3	0.9	1.5	5	1-5
Spatial Rotation	86	9	65	99	1-100
Text Comprehensio	33	4.3	16	38	1-38
Vivid Imagery	33	9	17	55	16-80

Table 4.2. Pearson correlations between scores on individual difference tasks, with Bonferroni correction

	Verbal Span	Spatial Span	Spatial Rotation	Text comprehension	Vivid Imagery
Verbal WM Span	x				
Spatial WM Span	0.19	x			
Spatial Rotation	0.09	0.05	x		
Text Comprehension	0.78	0.04	0.24	x	
Vivid Imagery	0.04	-0.2	-0.24	-0.09	x

Digit Recall (Verbal Load). After reading each narrative text, participants indicated the series of numbers they had heard at the beginning of the trial. Experimental stimuli consisted of 2 (light load) or 4 digits (heavy load). Overall accuracy on the digit recall task was 95.2%. Stimuli in the light load condition (96.5%) were recalled with greater accuracy than stimuli in the heavy load condition (93.9%). Analyses of participants' accuracy on this digit recall task revealed a significant main effect of load, $F(1,43) = 9.89, p = 0.003.$ There was no effect of association, nor interaction between load and association, $F<1.$

To determine which individual difference measures were predictive of success on the digit recall task, a multiple regression analysis was carried out. Total digit recall accuracy was the dependent variable and the individual difference scores (verbal working memory span, spatial working memory span, spatial rotation, text comprehension and vivid imagery) were the independent variables. The model explained a significant proportion of the variance on digit

recall accuracy, R^2 = 0.405, F(5, 38)= 5.18, p < 0.001. Verbal working memory was the only individual difference measure that accounted for a significant portion of the variance, [B=0.53, t(38) = 4.12, p = 0.000]. None of the other individual difference measures were significant predictors, all Fs<1. Participants with greater verbal working memory capacity exhibited greater accuracy at recalling the numbers presented at the beginning of each trial.

Comprehension Accuracy. Overall, participants had little trouble comprehending the experimental narratives. The average accuracy rate on the comprehension questions was 88%. A 2x2 ANOVA with factors of association and load revealed a statistically significant effect of load, *F(1,43)* = 4.53, p = 0.04. Questions in the heavy load condition were answered less accurately (87.5%) than those in the light load condition (90.2%). The effect of association did not reach significance, *F(1,43)* = 1.85, p = 0.18, and there was no interaction between the 2 factors, *F(1,43)* = 0.05, p = 0.83. To discern which cognitive abilities, if any, predicted the effect of load on comprehension question accuracy, a multiple regression analysis was conducted. The dependent variable was the effect of load (heavy-light load accuracy) and scores on the individual difference measures were the independent variables. This model did not account for a significant proportion of the variance on comprehension accuracy, R^2 = 0.12, F(5, 38)= 1.08, p < 0.38.

Reading Time for Target Sentences. Overall, people read the anaphoric

target sentences more slowly when the pronoun 'it' referred to an object that had shifted to the background of the situation model (dissociated condition), than when it referred to an object in the foreground (associated condition). As in experiments 1 and 2, analysis revealed a main effect of association due to longer reaction times in the dissociated (2359.5 ms) than associated (2225 ms) condition, $F\ (1, 43) = 14.1$, $p = 0.002$. Additionally, target sentences in the light verbal load condition were read faster (2217ms) than those in the heavy load condition (2367ms), $F\ (1, 43) = 4.12$, $p = 0.048$. There was no interaction between factors of association and verbal load, $F\ (1, 43) = 0.027$, $p = 0.87$. Table 4.4 shows the mean reaction times (ms) per condition as well as the difference between conditions.

Table 4.3. Mean reading times (ms) for target sentences, with standard deviations in parentheses.

Verbal Load	Associated	Dissociated	Difference
Light (2)	2153 (649)	2281 (808)	128
Heavy (4)	2296 (641)	2438 (704)	142
Difference	143	157	

Target Sentence Reading Time and Individual Differences. Separate multiple regression analyses were carried out in order to model the impact of individual difference measures on the effects of association and verbal load, respectively.

Verbal Load Effect for Target Sentences. To quantify the effect of verbal load, reading times for target sentences that followed paragraphs in the light load condition were subtracted from reading times for those that followed the heavy load condition. A multiple regression analysis was carried out to model the impact of individual difference measures on the effect of verbal load. The load effect was the dependent variable and the individual difference scores (verbal working memory span, spatial working memory span, spatial rotation, text comprehension and vivid imagery) were the independent variables. The model did not explain a significant proportion of the variance, R^2 = 0.1, F(5, 38)= 0.85, p < 0.52.

Association Effect for Target Sentences. In the regression analysis, the association effect (quantified by subtracting reading times for target sentences in the associated condition from those in the dissociated condition) was the dependent variable, and the individual difference scores (verbal working memory span, spatial working memory span, spatial rotation, text comprehension and imagery) were the independent variables. This model explained a significant proportion of the variance in the reading time association effect, R^2 = 0.27, F(5, 38)= 2.79, p < 0.03. Verbal working memory span [B=0.34, t(38) =2.4, p = 0.021] and spatial rotation ability [B=0.3, t(38) = 2.1, p = 0.045] were significant predictors of the association effect. Spatial working memory [B=0.08, t(38) =0.57, p = 0.57], text comprehension [B= 0.09, t(38) =

0.62, p = 0.54], and vivid imagery [B= -0.04, t(38) = -0.25, p = 0.81] were not significant predictors. Participants with greater verbal working memory capacity or high spatial rotation ability were most sensitive to the difference between the associated and dissociated conditions when reading the target sentence. Tables 4.4 and 4.5 show the effect of association based on median splits for verbal working memory and spatial rotation, respectively. Graphs 4.1 and 4.2 illustrate the positive relationship between scores on these tasks and the association effect.

Table 4.4 Target sentence reading times (ms) based on a median split for verbal working memory span

Verbal WM Span	Associated	Dissociated	Association effect
High Span Group	2224	2399	175
Low Span Group	2226	2320	94
Span Effect	2	-79	

Graph 4.1 Scatterplot depicting the relationship between verbal working memory and association effect.

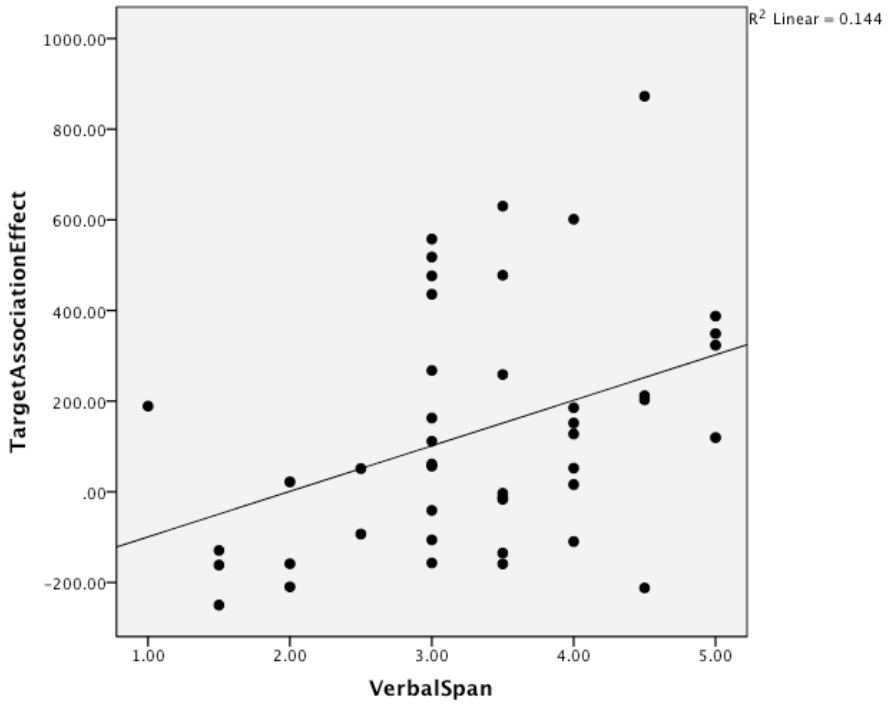
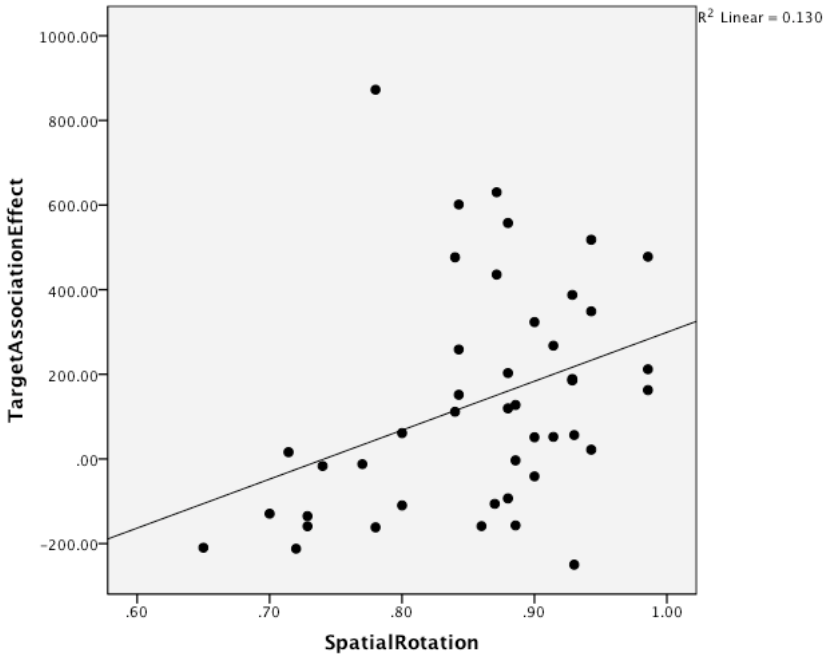


Table 4.5 Target sentence reading times (ms) based on a median split for spatial rotation ability

Spatial Rotation	Associated	Dissociated	Association effect
High Acc. Group	2067	2240	173
Low Acc. Group	2382	2478	96
Rotation Effect	315	238	

Graph 4.2 Scatterplot depicting the relationship between spatial rotation ability and association effect.



A post hoc 2x2 repeated measures ANOVA with factors of association and verbal load for target sentence reading times in the high verbal working memory span group revealed a statistically significant effect of association (see Table 4.5), $F(1,22) = 8.97$, $p = 0.007$. Neither the effect of verbal load, $F(1,22) = 0.71$, $p = 0.41$, nor interaction between the factors, $F(1,22) = 0.12$, $p = 0.91$, were significant. The same analysis of reading times exhibited by the low verbal working memory span group revealed marginal effects of association, $F(1,22) = 2.94$, $p = 0.10$, and verbal load, $F(1,22) = 3.61$, $p = 0.07$. These factors did not significantly interact, $F(1,22) = 0.02$, $p = 0.88$.

Based on a median split on spatial rotation accuracies, separate 2x2 repeated measures ANOVAs were carried out on target sentence reading times

for the two groups. For the high spatial rotation group, analysis revealed a statistically reliable effect of association (see Table 4.6), $F(1,22) = 15.3$, $p = 0.001$. The effect of load was not significant, $F(1,22) = 1.88$, $p = 0.18$, and the factors did not interact, $F(1,22) = 0.014$, $p = 0.91$. Analysis for the low spatial rotation group revealed that neither the effect of association, $F(1,22) = 2.05$, $p = 0.17$, nor load, $F(1,22) = 2.17$, $p = 0.15$, reached significance. These factors did not interact, $F(1,22) = 0.01$, $p = 0.91$.

Discussion

The present experiment directly examined the role of verbal working memory on situation model updating. This was done using a dual-task method where heavy or light verbal working memory loads were presented before a narrative text was read for comprehension. Target sentence reading times replicated the association effect found in the previous experiments in Chapters 2 and 3, suggesting that information about the critical item was more available when it was in the foreground (associated) than in the background (dissociated). Additionally, as in the two previous experiments, the size of the association effect on target sentence reading time was predicted by verbal working memory span and spatial rotation ability. These two individual difference measures predicted similar, but independent, amounts of variance on

the association effect found on target sentence reading times, suggesting that these abilities are relevant for narrative comprehension.

Digit Recall Task (Verbal Load)

The secondary, digit recall task was added to investigate the possibility that verbal working memory is actively engaged in situation model updating. As expected, accuracy on the digit recall task was greater in the light load condition relative to heavy, indicating it taxed our participants' cognitive resources. Further, accuracy on the digit recall task was positively, linearly related to verbal working memory span. This finding confirms our assumption that the digit recall task did indeed utilize verbal working memory resources, as those with the greatest verbal working memory capacity performed the best on it. Moreover, none of the other individual difference measures predicted performance on the digit recall task.

Target Sentence Reading Times

Given that the digit recall task taxed the verbal working memory system, we investigate its impact on performance of the primary task of narrative comprehension. Target sentences in the light load condition were read reliably faster than those paired with heavy loads. Also, responses to comprehension questions were more accurate in light than heavy load trials. Taken together, these data suggest that maintaining a greater amount of information in verbal

working memory made the construction of the situation model more difficult, and decreased its quality.

However, increasing the load on the verbal working memory system did not modulate the association effect, indicating these two effects were independent of one another, and arguing against a direct role for verbal working memory in situation model updating. Whereas results in the present study differ from those found by Radvansky and Copeland (2001), the conclusions are broadly consistent.

Individual Differences and Target Sentence Reading Times

As in Experiments 1 and 2, beta weights from the multiple regression analysis suggested that verbal working memory score and spatial rotation ability were about equally predictive of variance for the association effect on target sentence reading times. Median splits based on these measures reveal that in both cases, the effect is driven by the high ability group. It might be tempting to conclude that there is a great deal of overlap among participants with high verbal working memory spans and those good at spatial rotation. However, scores on the two measures were uncorrelated. Moreover, the pattern of results between high and low groups differs on verbal working memory and spatial rotation, suggestive of different mechanisms.

When considering verbal working memory, the greatest difference between high and low span groups emerges from the high verbal span group, which exhibits longer reading times for the dissociated condition, consistent with the idea that high span readers suppress the representation of the irrelevant, dissociated object (Gernsbacher, 1990). On the other hand, the greatest difference between high and low spatial rotation ability groups comes from the high accuracy group having faster reading times in the associated condition, in keeping with the idea that associated items are more active in a tacit visual representation of the situation model.

While target sentence reading time results from the current experiment replicated the association effect observed in experiments 1 and 2 (Chapters 2 and 3), median split analyses based on verbal working memory reveal different patterns between the first two experiments and the present study. In particular, the association effect in the present study seems to be driven by increased reading times in the dissociated condition, whereas the association effect in experiments 1 and 2 was largely due to decreased reading times in the associated condition. This discrepancy may be due to differences in task demands between experiments, namely the need to perform a digit recall task.

In the present study, individuals with higher verbal working memory span may have exhibited increased reading time in the dissociated condition because they had already suppressed the no-longer relevant critical item. It therefore,

took this group longer to reactivate those referents at the pronoun in the target sentences. In that respect, results from the present study are consistent with the Structure Building Framework, which suggests that highly skilled readers suppress irrelevant information more efficiently than less skilled readers (Gernsbacher et al., 1990).

According to the theory put forth by Gernsbacher et al., (1990), if the verbal working memory system had been crucial for eliciting the association effect, we would have expected that reducing the availability of that system would also have reduced the size of the association effect. If this had been the case, loading up the verbal working memory system with a secondary task should have made it more difficult to suppress dissociated items, resulting in a smaller association effect.

This pattern of results, however, was not observed in the present study. Among low verbal span participants, imposing an additional load on the verbal working memory system slowed target sentence reading times, but did not modulate the association effect. High verbal span participants exhibited larger association effects than those with lower spans. However, verbal load did not modulate the association effect in high verbal span participants, either. In fact, the verbal load manipulation did not even affect these participants' reading times for target sentences – in spite of the fact that it was the high verbal span participants who scored the best on the digit recall task. The present study

suggests that while verbal working memory is important for the initial construction of the situation model, and subsequent access to it, verbal working memory does not seem to be critical for updating the situation model.

Conclusion

The present study investigated the possibility that verbal working memory mediates situation model updating, as reflected by the association effect. Dual-task methodology was used to directly assess the contribution of verbal working memory to this process. As in Experiments 1 and 2, regression models in the present study suggested a relationship between verbal working memory and the target sentence association effect. However, reading times in this experiment revealed additive effects of association and verbal load, suggesting the two effects were driven by independent processes. Although verbal working memory may be important for the initial construction of situation models, these data suggest it does not mediate the updating processes indexed by the association effect.

Chapter 5

Experiment 4: Situation model updating with a concurrent spatial task

Introduction

Previous researchers have suggested that the construction of situation models for multi-modal stimuli involves visuo-spatial working memory. For example, Kruley et al. (1994) demonstrated that visuo-spatial working memory is utilized in the integration of texts and pictures. They found that performance on a concurrent spatial tapping task interfered with comprehension of texts that were accompanied by pictures. However, comprehension of these texts was not impaired when participants performed a concurrent verbal task, suggesting an important role for visuo-spatial working memory when processing texts with pictures.

Gyselinck et al. (2002) also investigated the role of verbal and spatial working memory on text comprehension using a dual-task paradigm. They presented participants with texts that either were or were not accompanied by illustrations in conjunction with a concurrent verbal or spatial task. Results suggested a selective interference effect for comprehension of texts that were accompanied by illustrations when participants were simultaneously engaged in a concurrent spatial task. However, unlike Kruley et el. (1994), these researchers found that a verbal concurrent task impaired comprehension both

for texts that were accompanied by illustrations and for texts that were not. They suggest that while verbal working memory is involved in the processing of all texts, visuo-spatial working memory is specifically involved in comprehension of illustrated texts.

Studies by Kruley et al. (1994) and Gyselinck et al. (2002) suggest that the integration of texts and pictures calls upon the visuo-spatial working memory system, in line with the hypothesis that the situation model involves perceptual symbols with analogue representational format (Barsalou, 1999). It is less clear, however, how important visuo-spatial working memory is for the construction and updating of situation models for narrative texts without pictures.

Present Study

Results from experiment 3 (Chapter 4) suggest that verbal working memory may be important for the construction of a situation model based on text, but may not integral to situation model updating. The previous three experiments have suggested a role for the mental manipulation of visuo-spatial information in situation model construction as observed by the systematic, positive relationship between spatial rotation and the size of the association effect. However, there has been no clear evidence that the association effect is

directly related to the visuo-spatial working memory system as indexed by spatial span.

To more directly assess the role of spatial working memory in situation model updating, we used a dual task paradigm to manipulate the load on the visuo-spatial working memory system as participants read the same passages used in experiment 3 (Chapter 4). If spatial working memory is independent of the processes underlying the association effect, we would expect to observe additive effects of spatial load and association/dissociation on target sentence reading times. Alternatively, if spatial working memory is integrally involved in the processes underlying the association effect, we would expect to observe an interaction between these two factors.

Method

Participants. Forty-four volunteers (14 women, 24 men) received course credit for their participation. All participants were native English speakers at the University of California, San Diego (mean age = 20.1, SD = 1.7).

Materials.

Narrative Texts. The texts were identical to those employed in the previous experiment in Chapter 4. Narrative texts were paired with a secondary spatial load task. Half of the associated trials occurred with a heavy spatial

load, while the other half occurred with a light spatial load. Non-experimental filler trials were paired with a medium load.

Dot Sequence Recall (Spatial Load). Materials for the spatial load task were comprised of jpeg picture files. Each file contained a 5x5 grid of 3cm black squares on a white background. A single red dot appeared on one of the black squares in each of the jpeg picture files. Sequences of 2, 3, or 4 dots were created by combining individual picture files. Sequences were constructed using a random number generator. However, no single dot placement was repeated within a sequence. Half of the experimental trials were coupled with 2 dots (light load condition), while the other half were paired with 4 dots (heavy load condition). Non-experimental trials were paired with sequences of 3 dots.

Procedure. Each trial began with the visual presentation of a 5x5 grid of squares with a red dot on one of the squares (see Figure 5.1). The number of screens with a red dot on the grid varied based on the load condition. Immediately thereafter, a narrative text was visually presented on the computer monitor. These were presented one sentence at a time, in a self-paced manner. Next, an empty 5x5 grid of black squares appeared on the monitor. Participants used a mouse to point to the placement of the dots they viewed before reading the text. After completing the spatial load task (i.e. dot sequence recall), participants were presented with a Yes / No comprehension question based on

the narrative. Feedback on text comprehension and dot sequence recall performance was provided on a single screen.

After completing this task, participants took part in the same individual differences measures described in previous chapters (verbal working memory, spatial rotation, spatial working memory, text comprehension and vivid imagery).

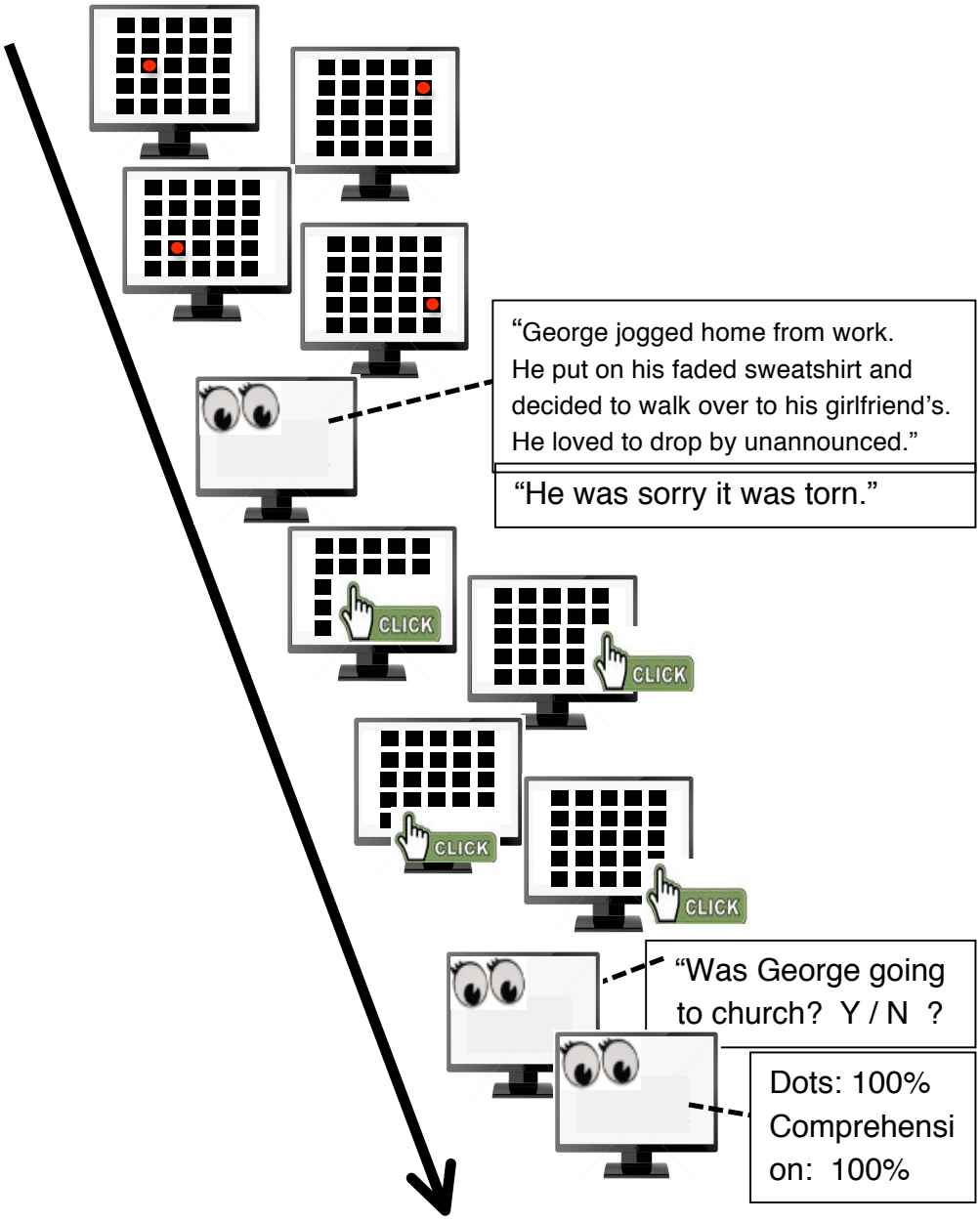


Figure 5.1 Example of the heavy spatial load condition.

Data & Analysis. In this experiment, we employed a within-participants 2x2 experimental design. Dependent measures included accuracy on dot

sequence recall, comprehension questions, and reading time for target sentences**.**

We conducted repeated measures ANOVA with factors of Association (associated / dissociated) and Spatial Load (heavy / light) on accuracy for dot sequences and comprehension questions, as well as target sentence reading times. Target sentence reading times were filtered for outliers. These were defined as being 2 or more standard deviations above or below the mean reading time per condition. Approximately 4% of the data were excluded for this reason.

Significant factors in the ANOVA were further analyzed with multiple regression using scores on individual difference measures.

Results

Individual Differences. We report participants' mean scores on the five individual difference measures in Table 5.1. Pearson's correlations between these measures after Bonferroni correction are presented in Table 5.2. None of the individual difference measures were significantly correlated.

Table 5.1 Individual difference scores

Measure	Mean	Standard deviation	Minimum	Maximum	Possible Range
Verbal WM Span	3.2	1	0	5	1-5
Spatial WM Span	2.8	1	1	5	1-5
Spatial Rotation	86	8	67	99	1-100
Text Comprehension	32	4.1	18	38	1-38
Vivid Imagery	33	10	16	65	16-80

Table 5.2. Pearson correlations between individual difference tasks, with Bonferroni correction

	Verbal WM Span	Spatial WM Span	Spatial Rotation	Text comprehension	Vivid Imagery
Verbal WM Span	x				
Spatial WM Span	-0.21	x			
Spatial Rotation	0.14	-0.12	x		
Text Comprehension	0.04	0.24	0.20	x	
Vivid Imagery	-0.05	-0.11	-0.09	0.21	x

Dot Sequence Recall Accuracy. After reading each narrative text, participants indicated the placement of the series of dots seen at the beginning of the trial. Experimental stimuli consisted of sequences of either 2 (light load) or 4 (heavy load) red dots. Overall accuracy on the dot sequence recall task was 92%. Stimuli in the light load condition were recalled with greater accuracy (96%) than stimuli in the heavy load condition (88%). A 2x2 repeated measures ANOVA with factors of association and load revealed a significant main effect of

load, *F(1,43)* = 5.96, p = 0.02. There was no effect of association, nor interaction between load and association, *Fs<1.*

To determine which individual difference measures were predictive of success on the dot sequence recall task, a multiple regression analysis was carried out. Total recall accuracy was the dependent variable, and the individual difference scores, (verbal working memory span, spatial working memory span, spatial rotation, text comprehension and vivid imagery), were the independent variables. This analysis revealed that individual difference measures reliably accounted for part of the variance R^2 = 0.39, F(5, 38)= 2.99, p < 0.001. Spatial working memory [B= 0.45, t(38) = 1.44, p = 0.01] and spatial rotation ability [B= 0.27, t(38) = 2.01, p = 0.05] were the only individual difference measures that accounted for a significant portion of the variance in the spatial load effect on dot sequence recall accuracy. Participants with higher spatial working memory spans (i.e. those in the upper half of our sample) exhibited greater accuracy (96.5%) than those with lower spatial spans (88.9%). Similarly, participants with higher spatial rotation ability accurately recalled the placement of the dots with greater accuracy (90%) than those with lower spatial rotation scores (88%).

Comprehension Accuracy. Overall, participants had little trouble comprehending the experimental narratives. The average accuracy rate on the comprehension questions was 86.3%. Questions in the associated condition

were answered more accurately (87%) than those in the dissociated condition (84%), *F(1,43)* = 10.5, p = 0.002. Questions in the heavy load condition were answered less accurately (83.3%) than those in the light load condition (89.1%), *F(1,43)* = 23.4, p = 0.000. The interaction was also significant, *F(1,43)* = 5.39, p = 0.025.

To further analyze the interaction between association and load on comprehension questions, separate ANOVAs were conducted in the heavy and light load conditions. The association effect was significant in the heavy load condition, *F(1,43)* = 2.02, p = 0.01, but not in the light load condition, *F(1,43)* = 0.31, p = 0.58.

The association effect in the heavy load condition was subjected to a multiple regression analysis. However, the model revealed that individual difference measures were not predictive of the effect, presumably due to high accuracy and low variance, R^2 = 0.09, F(5, 38)= 0.82, p < 0.54.

Reading Time for Target Sentences. As in our previous experiments, analysis revealed a main effect of association due to longer reaction times in the dissociated (2508 ms) than associated (2166 ms) condition, *F* (1, 43) = 61.2, p = 0.00. Additionally, target sentences in the light spatial load condition were read faster (2203 ms) than those in the heavy spatial load condition (2471 ms), *F* (1, 43) = 23.1, p = 0.00. There was also an interaction between factors of association and spatial load, *F* (1, 43) = 5.50, p = 0.024. Table 5.3 shows the

mean reading times (ms) per condition as well as the difference between conditions.

Table 5.3 Mean reading times (ms) for target sentences, with standard deviations in parentheses.

Spatial Load	Associated	Dissociated	Difference
Light (2)	2072 (571)	2235 (675)	163
Heavy (4)	2260 (705)	2682 (854)	422
Difference	188	477	

To further analyze the interaction between association and load on target sentence reading times, separate ANOVAs were conducted to test the effect in the heavy and light load conditions. Both analyses revealed a statistically significant effect of association, light load: $F(1,43) = 25.9$, $p = 0.000$; heavy load: $F(1,43) = 51.7$, $p = 0.000$. The interaction between association and load results because the association effect was more pronounced with heavy (422ms) than light (163ms) loads.

Association effects for target sentence reading times in the heavy and light load conditions were each subjected to a multiple regression analysis where the dependent measure was the association effect (dissociated – associated) and the independent variables were the individual difference measures. The model for the light load association effect was not significant, $R^2 = 0.19$, $F(5, 38) = 1.85$, $p < 0.12$. The model for the heavy load condition, however, did reliably

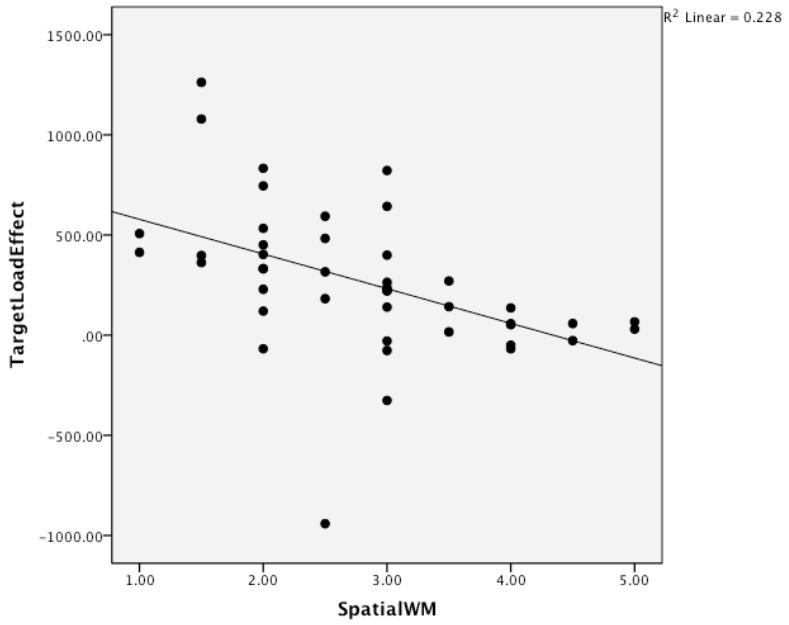
predict variance in the association effect, R^2 = 0.39, F(5, 38)= 5.05, p < 0.001. Spatial working memory span [B= 0.33, t(38) = 2.33, p = 0.025], verbal working memory span [B=0.32, t(38) = 2.4, p = 0.021], and spatial rotation ability [B=0.31, t(38) = 2.31, p = 0.03] were reliable predictors of the heavy load association effect on target sentence reading time. Vivid imagery [B= -0.11, t(38) = -0.79, p = 0.43] and text comprehension [B= 0.05, t(38) = 0.32, p = 0.75] were not.

Tables 5.4, 5.5, and 5.6 show the effect of association in the heavy load condition based on median splits for spatial working memory span, verbal working memory span, and spatial rotation accuracy, respectively. Graphs 5.1, 5.2 and 5.3 illustrate the relationship between scores between scores on these measures and the association effect.

Table 5.4 Target sentence reading times (ms) in heavy load condition for participants with high versus low spatial working memory spans

Spatial WM	Associated	Dissociated	Association effect
High Span Group	2450	2976	524
Low Span Group	2071	2390	319
	-378	-586	

Graph 5.1 Scatterplot depicting the relationship between spatial working memory and the effect of spatial load on target sentence reaction time.



To explore the relationship between spatial working memory span and the association effect, participants were divided into high and low spatial span groups based on a median split for spatial working memory span, and separate follow-up analyses were done. Analysis involved 2x2 repeated measures ANOVA with factors of association and spatial load. Analysis of target sentence reading times in the high spatial span group revealed a statistically significant effect of association, $F(1,22) = 16.7$, $p = 0.001$, as well as a main effect of spatial load, $F(1,22) = 13.2$, $p = 0.002$. No interaction between the two factors was found, $F(1,22) = 0.74$, $p = 0.39$.

Analysis of reading times in the low spatial span group revealed

statistically significant effects of association, $F(1,22) = 11.1$, $p = 0.00$, spatial load, $F(1,22) = 10.4$, $p = 0.004$, and an interaction between these factors, $F(1,22) = 5.1$, $p = 0.035$. The interaction results because within the low spatial working memory group, the association effect was smaller in the heavy (319 ms) than the light (416 ms) load condition.

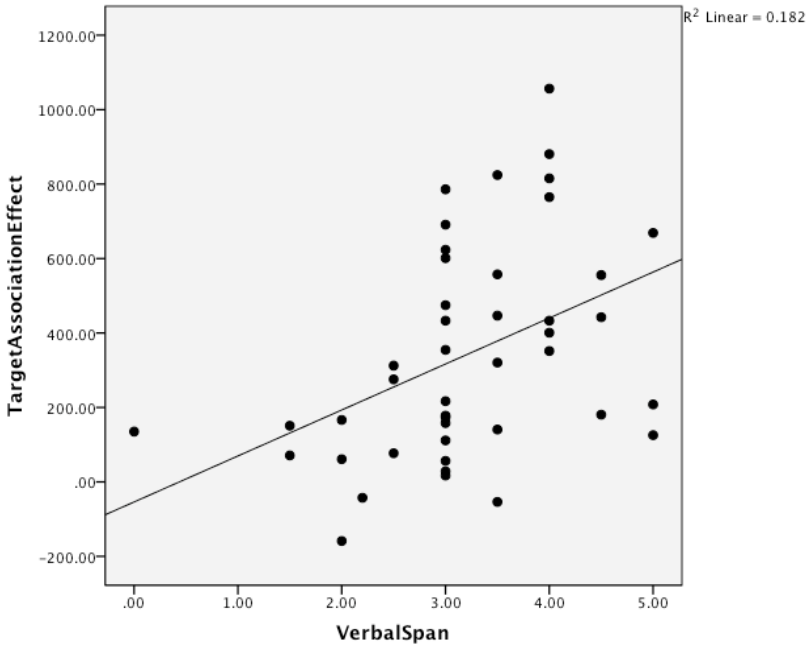
Differences between high and low spatial span participants were more apparent in reading times in the dissociated condition.

To explore performance differences in high and low verbal span readers, participants were divided into two groups based on a median split of their scores on the verbal working memory span task. Target sentence reading times in the heavy load condition were subjected to a post hoc ANOVA with a between participants factor of verbal working memory span (high / low) and within-participants factor association (associated / dissociated). This analysis revealed a non-significant effect of group, $F(1,21) = 1.61$, $p= 0.22$, a significant effect of association, $F(1,21) = 64.9$, $p= 0.000$, and a marginal interaction between factors, $F(1,21) = 6.4$, $p= 0.08$. Table 5.5 suggests the interaction reflects a larger association effect in participants with high verbal working memory spans (516 ms) relative to low verbal working memory span (328 ms). Group differences are more apparent in reading times in the dissociated condition.

Table 5.5 Target sentence reading times (ms) in the heavy load condition in high versus low verbal working memory span participants grouped via a median split of scores on the verbal working memory span task

Verbal WM	Associated	Dissociated	Association effect
High Span Group	2261	2777	516
Low Span Group	2171	2499	328
	-90	-278	

Graph 5.2 Scatterplot depicting the relationship between verbal working memory and association effect.



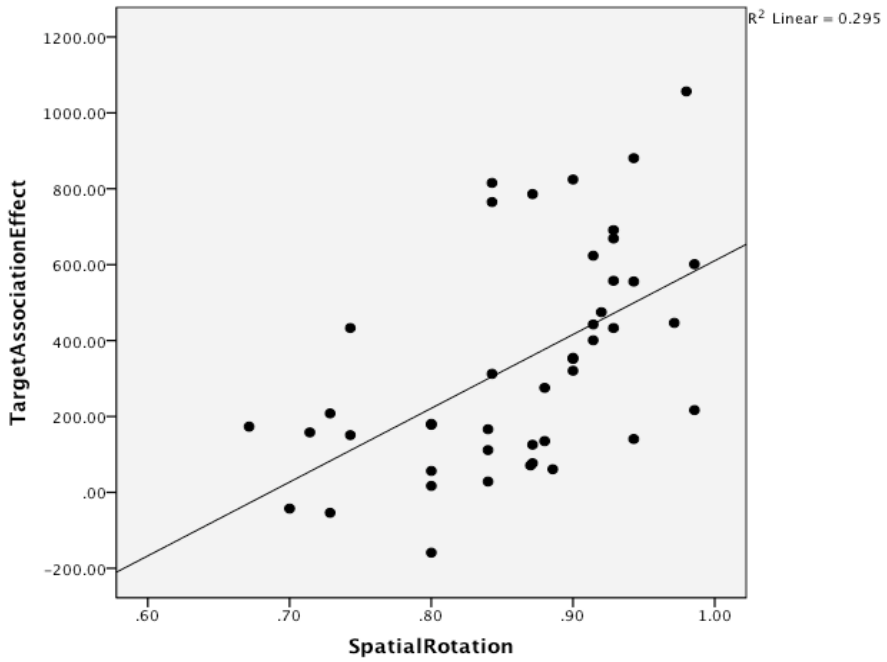
To explore the relationship between spatial rotation ability and the association effect, participants were divided into High and Low groups based on a median split of accuracy rates on our spatial rotation assessment (see Table 5.6). Separate post hoc ANOVAs investigated the association effect within the

heavy load condition. Both the high and low accuracy spatial rotation groups exhibited robust association effects, high group: $F(1,21) = 42.4$, $p = 0.000$; low group: $F(1,21) = 26.7$, $p = 0.000$. Group differences were most apparent in the dissociated condition, where the low accuracy spatial rotation group had reading times that were 222 ms faster than those in the high accuracy spatial rotation group.

Table 5.6 Target sentence reading times (ms) in the heavy load condition in participants with High versus Low Accuracy for spatial rotation

Spatial Rotation	Associated	Dissociated	Association effect
High Accuracy Group	2276	2825	549
Low Accuracy Group	2237	2603	366
	-39	-222	

Graph 5.3 Scatterplot depicting the relationship between spatial rotation ability and association effect.



Discussion

The present study directly examined the role of visuo-spatial working memory on situation model updating by requiring participants to maintain heavy and light loads of visuo-spatial information during narrative text comprehension. As in the previous four studies, participants exhibited shorter reading times for target sentences that referred to a critical item that was described as physically close to the protagonist, suggesting that information about the critical item was more available when it was in the foreground (associated) than in the background (dissociated). However, this difference was much larger under heavy than light load conditions, suggesting the demands of the secondary spatial task made it more difficult to access to the dissociated item. These data support an important role for visuo-spatial working memory in the dynamic construction and updating of the situation model.

Dot Sequence Recall Task (Spatial Load)

The secondary, dot sequence recall task was added to investigate the possibility that spatial working memory is integral to situation model updating. As expected, accuracy for recall of the dot sequence task was greater in the light load condition relative to heavy load. Accuracy on the dot sequence recall

task was positively, linearly related to participants' spatial working memory spans and their scores on the spatial rotation task. This finding confirms our assumption that the dot sequence recall task did indeed utilize spatial working memory resources, as participants with the greatest spatial working memory capacity performed the best on it. None of the other individual difference measures predicted performance on the dot sequence recall task.

Narrative Comprehension

Given that the dot sequence recall task taxed the visuo-spatial working memory system, we investigate its impact on performance of the primary task of narrative comprehension. Analysis of accuracy rates on the comprehension questions suggested the spatial load task interfered with narrative comprehension, as participants showed better comprehension under conditions of light load, consistent with the claim that visuo-spatial working memory plays a role in narrative comprehension.

Moreover, the load manipulation modulated the association effect, as participants' showed worse comprehension in the dissociated condition only for texts paired with the heavy spatial load. This pattern of results differs from that observed in experiment 3, in which the same materials were paired with a verbal load task. Whereas association and verbal load had additive effects on comprehension scores, association and spatial load did not, suggesting visuo-

spatial working memory plays a more important role in the updating processes indexed by the association effect.

Target Sentence Reading Time

Target sentence reading times also suggested visuo-spatial working memory plays an important role in situation model updating. First, target sentence reading times were faster in the light load relative to heavy load condition, indicating that processing under light spatial load was easier. Second, and most notably, the present study found that maintaining additional spatial load information modulated the association effect. In both the heavy and light load conditions, target sentences reading times were faster following narratives that described a foregrounded item relative to one in the background. This difference was greatest under heavy spatial load constraint, suggesting reactivation of the dissociated item was particularly difficult when visuo-spatial working memory resources were less available.

This proposal is supported by our analysis of individual differences in reading times. The multiple regression analysis on the association effect in the heavy load condition revealed that spatial working memory was the strongest predictor of the individual difference measures. Individuals with high spatial working memory exhibited a robust association effect regardless of the spatial load manipulation. By contrast, participants with lower spatial working memory

span were less sensitive to the difference between association conditions under heavy spatial load relative to light.

This modulation of effect size may be explained by the two tasks competing for a limited pool of visuo-spatial resources. For participants with higher spatial working memory capacity, heavy spatial load encouraged a strategy in which dissociated items were suppressed, leading to an especially large association effect. Among participants with lower spatial working memory spans, the demands of maintaining a heavy spatial load reduced the amount of visuo-spatial resources available for situation model updating, thus reducing the size of the association effect. These data support the hypothesis that visuo-spatial working memory is integrally involved in situation model updating.

It is interesting to note that evidence of situation model updating, the association effect, was reduced but not eliminated for the low spatial working memory group. It was reduced when there were demands on visuo-spatial resources, indicating interference, but even with those demands, these participants were sensitive enough to the spatial relations described in the text to exhibit an association effect in target sentence reading times. This may have been due to the recruitment of other cognitive resources such as verbal working memory and spatial rotation, which were also found to be reliable predictors of the association effect in the heavy spatial load condition.

Results from the Verbal Load experiment (Chapter 4) suggest that verbal working memory span and spatial rotation ability reliably predict sensitivity, or access to the situation model. It is thus possible that participants with low spatial working memory in the present experiment successfully constructed an accurate situation model, but were not as efficient at updating the situation model due to the secondary spatial task. Alternatively, it may be that maintaining a visual array does not completely deplete visuo-spatial resources and, therefore some resources are still available for situation model updating.

Verbal Working Memory. The present study found a similar pattern of results for target sentence reading times elicited by high and low verbal working memory groups as in experiment 3 (Chapter 4). In both studies, the greatest group differences between high and low verbal span groups were found to be due to longer reading times in the dissociated condition. This is pattern is in line with the Structure Building Framework which suggests that individuals with higher verbal working memory span may have required more time to re-activate the already suppressed irrelevant (dissociated) item (Gernsbacher et al.'s, 1990).

In both experiment 3 and the present study, spatial rotation ability was found to be a reliable predictor of association effect size. As in experiment 3, the present study revealed a larger association effect in participants with better

spatial rotation ability. However, in experiment 3, in which the concurrent task involved the verbal working memory system, the high spatial rotation group read target sentences *faster* than the low group; in the present study, which involved a concurrent visuo-spatial task, reading times were *slower* in the high spatial rotation group than the low group. Perhaps the larger association effects observed for participants with high spatial rotation ability in the present study reflect strategic suppression of the dissociated items from the situation model, due to the demands the dot sequence recall task placed on visuo-spatial working memory.

Conclusion

Whereas previous studies by Kruely et al. (1994) and Gyselinck et al. (2002) suggest that visuo-spatial working memory is involved in comprehension of texts accompanied by pictures, results from the present study suggest that visuo-spatial working memory is also involved in tracking changes of spatial relations during naturalistic narrative text comprehension that are not accompanied by pictures.

Results from target sentence reading times contrast with those found in experiment 3 in which participants read the same passages with a concurrent task that required verbal working memory resources. Whereas a concurrent

verbal task gave rise to additive effects of association and load, a concurrent spatial task led to larger association effects under heavy than light load. This finding suggests that visuo-spatial working memory is particularly important for the situation model updating processes indexed by the association effect.

Chapter 6

Experiment 5: Visual search task

Introduction

Experiments 1-4 (Chapters 2-5) all revealed a systematic relationship between the size of the association effect and verbal working memory span as well as spatial rotation ability, suggesting the potential involvement of verbal working memory and mental imagery systems in situation model updating. However, Experiment 3, which measured how verbal load affected situation model updating, revealed additive effects of verbal load and association, consistent with the proposal that independent processes mediate the two effects. By contrast, Experiment 4, which measured how visuo-spatial load affected situation model updating, revealed interactive effects of load and association, consistent with the proposal that situation model updating utilizes visuo-spatial working memory resources.

An alternative explanation of these results, however, might be that the two load tasks were not equivalently taxing. Perhaps our visuo-spatial load task placed more demands on the so-called central executive than did our verbal load task, and thus interfered more with the primary task of narrative comprehension. To evaluate this possibility, we compared the impact of the two load tasks on an unrelated task. In particular, we chose the visual search task,

as it has previously been used by a number of investigators to equate the difficulty of secondary tasks designed to engage verbal versus visuo-spatial working memory (Hermer-Vasquez, Spelke & Katsnelson, 1999; Lupyan, 2009).

Present Study. In the present study, participants performed a visual search task along with either the digit recall task used in chapter 4, or the dot sequence recall task used in chapter 5, under both light and heavy load conditions. Given that both of the concurrent tasks have proven to tap into targeted processing resources, we predict a main effect of load. If the visuo-spatial load task is more taxing than is the verbal load task, we should observe either a main effect of secondary task, or an interaction between secondary task and load.

Method

Participants. Eighteen volunteers (10 women, 8 men) received course credit for their participation. All participants were native English speakers at the University of California, San Diego (mean age = 21.2, SD = 2.1).

Materials

Search Task. Materials for the visual search task were similar to those used by Hermer-Vazquez et al. (1999). There were 96 total visual search trials.

Each trial presented a total of 3, 7, or 11 alphanumeric black characters on a white background. The alphanumeric characters consisted of capital “L”s and “T”s in Times font, size 24. Each letter was randomly presented in one of 8 possible angles of rotation: 0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°. In constructing the visual search stimuli, the white background screen was divided into a 16x16 grid. Each square in the grid was assigned a temporary number. A random number generator was used to determine the placement of each letter. Half of the trials contained a target, “L” while the other half of the trials did not.

Digit Recall. Forty-eight visual search task trials were coupled with a digit recall task known to tax verbal working memory. Stimuli were identical to those presented in chapter 4. Half of the experimental trials (i.e. 24) were coupled with 2 digits (light load condition), while the other half were paired with 4 digits, (heavy load condition).

Dot Sequence Recall. Forty-eight visual search task trials were coupled with a dot sequence recall task known to tax visuo-spatial working memory. Stimuli were identical to those presented in chapter 5. Half of the experimental trials were coupled with 2 dots (light load condition), while the other half were paired with 4 dots (heavy load condition).

Digit Recall (Verbal Load) Procedure. Each trial began with the auditory presentation of digits for the verbal load task via speakers (see Figure 7.1). Immediately thereafter, 3, 7, or 11 black alphanumeric characters were

presented on a white background. Participants were required to press “1” to indicate the target was present, or “2” to indicate the target was absent. This response terminated the trial. Next, a visual array of numbers (0 to 9) in random order appeared on the monitor. Participants used a mouse to point to the numbers heard before the visual search task. Feedback on the visual search task and digit recall was provided on a single screen. The display was presented on a PC with a 17-inch monitor and was controlled by E-Prime experimental software (Schneider, Eschman, & Zuccolotto, 2002). The viewing distance was approximately 22 inches.

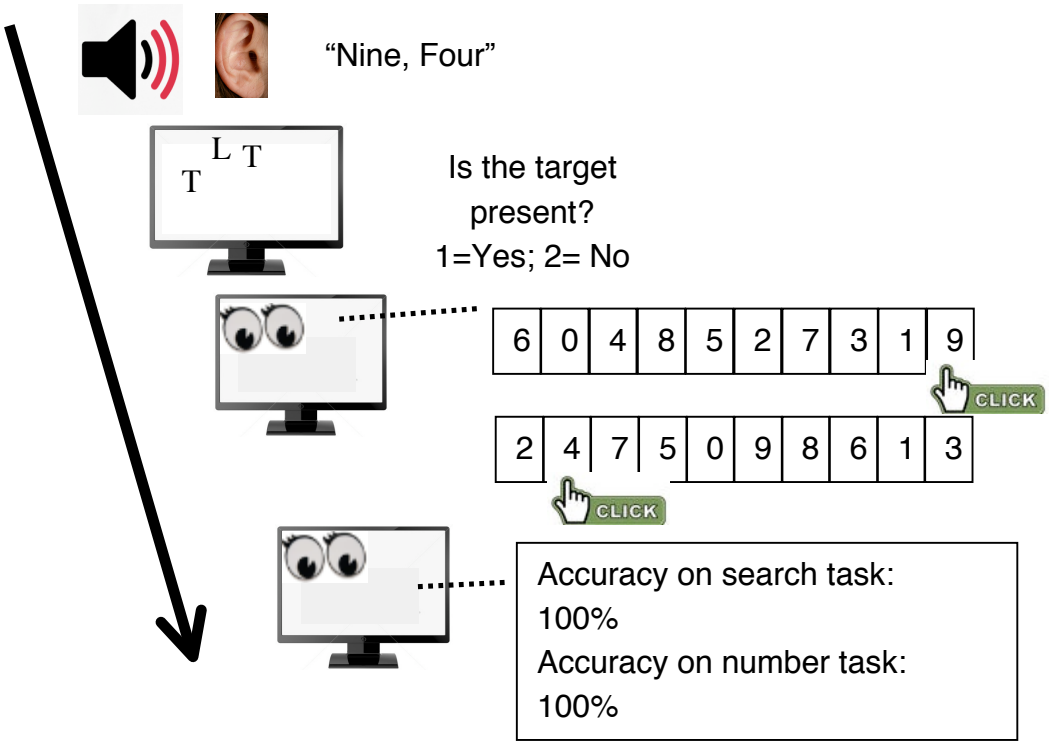


Figure 6.1 Example of digit recall (concurrent verbal task) with visual search

Dot Sequence (Spatial Load) Procedure. Each trial began with the visual presentation of a 5x5 grid of squares with a red dot on one of the squares (see Figure 7.2). The number of screens with a red dot on the grid varied based on the load condition. Immediately thereafter, 3, 7, or 11 black alphanumeric characters were presented on a white background. Participants were required to press “1” to indicate the target was present, or “2” to indicate the target was absent. This response terminated the trial. Next, an empty 5x5 grid of black squares appeared on the monitor. Participants used a mouse to point to the placement of the dots they viewed before reading the text. Feedback on the visual search task and spatial recall was provided on a single screen.

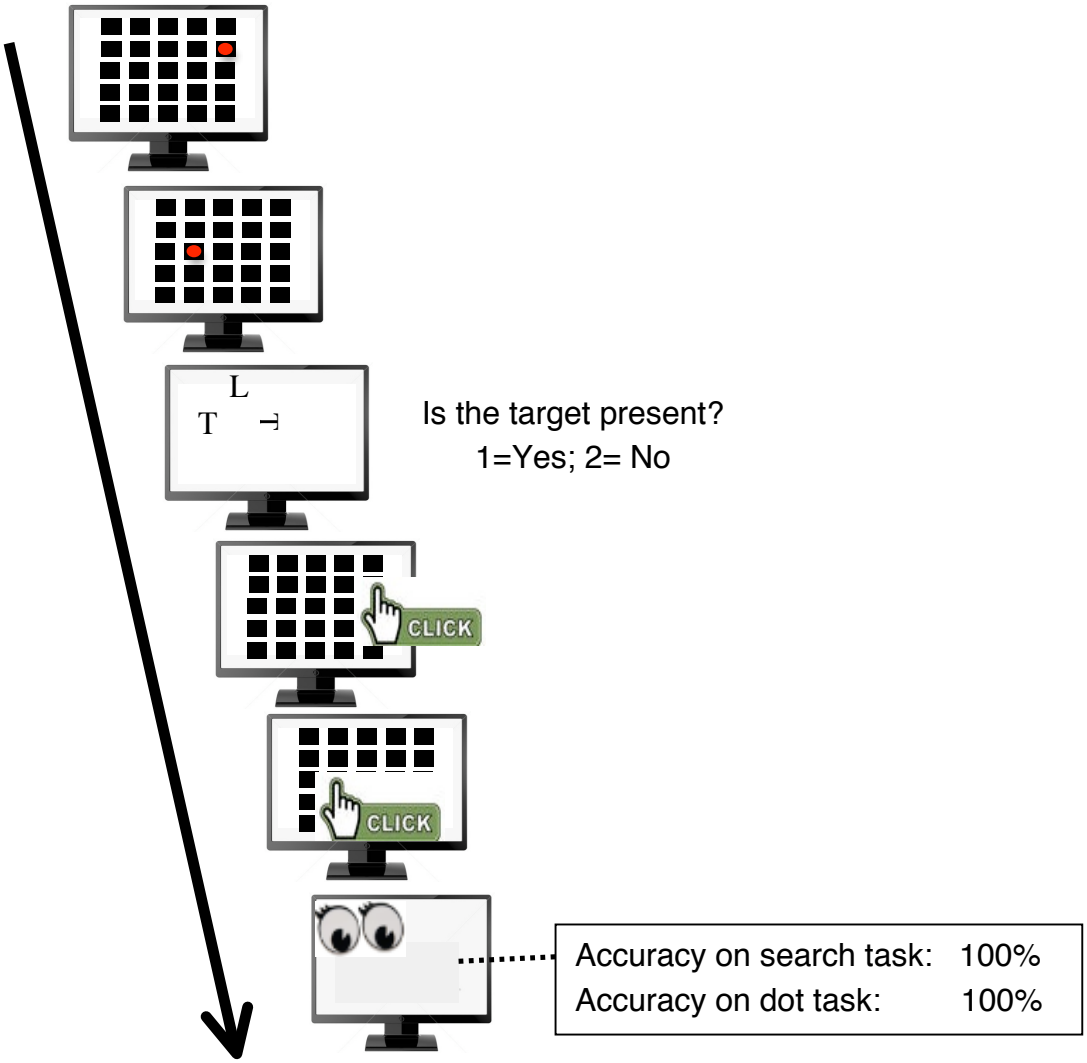


Figure 6.2 Example of dot sequence recall (concurrent spatial task) with visual search

Design & Analysis. We employed a within-subject 2x2 experimental design. Dependent measures in this experiment included reaction time and accuracy on the visual search task. We conducted a repeated measures ANOVA with factors of Concurrent Task (verbal / spatial) and Load (heavy / light) on reaction time and accuracy in the visual search task. Only correct trials were analyzed. Reaction times were filtered for outliers. These were defined

as being 2 or more standard deviations above or below the mean per condition. Approximately 7% of the data were excluded for this reason. Participants also completed verbal and spatial working memory span assessments.

Results

Individual Differences. Scores on individual difference measures and correlations between these measures may be seen in Tables 7.1 and 7.2, respectively. The range and distribution of scores on these tasks are similar to those observed by participants in the previous experiments.

Table 6.1 Table of scores on individual difference tasks

Measure	Mean	St. deviation	Minimum	Maximum	Possible Range
Verbal WM Span	3.4	1	2	5	1-5
Spatial WM Span	3.1	1	2	4.5	1-5
Spatial Rotation	78	8	54	98	1-100

Table 6.2 Pearson correlations between individual difference tasks, with Bonferroni correction

	Verbal Span	Spatial Span	Spatial Rotation
Verbal WM Span	X		
Spatial WM Span	0.27	x	
Spatial Rotation	-0.26	0.27	x

Visual Search Task. Overall, participants took longer to determine the presence or absence of the target in the heavy load conditions (2557ms) relative to the light load conditions (2262ms). This was found with both verbal and spatial tasks. Analysis revealed a main effect of load, $F\ (1, 17) = 5.1$, $p = 0.04$. There was no effect of task, $F\ (1, 17) = 0.12$, $p = 0.73$, nor interaction between the two factors, $F\ (1, 17) = 0.01$, $p = 0.9$. Table 7.3 shows mean reaction times (ms) per condition.

Table 6.3 Visual Search Task Reaction Times in ms (sd)

Visual Search	Verbal Load	Spatial Load	Task Effect
Light (2)	2279 (424)	2245 (386)	34
Heavy (4)	2577 (482)	2537 (642)	40
Load Effect	298	292	

Participants were highly accurate at detecting the presence or absence of the target letter. Analysis did not reveal main effects of task, $F\ (1, 17) = 1.5$, $p = 0.24$, or load, $F\ (1, 17) = 0.17$, $p = 0.69$. There was no interaction between the two factors, $F\ (1, 17) = 3.8$, $p = 0.07$. Table 7.4 shows mean accuracy (%) per condition.

Table 6.4 Visual Search Task Accuracy in Percent Correct (sd)

Visual Search	Verbal Load	Spatial Load	Task Effect
Light (2)	97 (3)	98 (4)	-1
Heavy (4)	98 (2)	94 (9)	4
Load Effect	1	-4	

Discussion

Reaction times and accuracy rates for the visual search task were similar when it was paired with the concurrent verbal and visuo-spatial load tasks. Although participants' performance on the primary (visual search) task was faster and more accurate under conditions of light than heavy load, load effects were similar in size for the two concurrent tasks. The current study thus suggests the secondary tasks used to engage the verbal working memory system in Chapter 4 versus the visuo-spatial working memory system in Chapter 5 were approximately equal in difficulty. Therefore, differences found in the data for the spatial and verbal tasks in previous chapters are unlikely to be related to the difficulty of the secondary tasks. Instead, these differences reflect varying degrees to which participants utilize their verbal versus visuo-spatial working memory when updating the situation model of a narrative. However, perhaps the best way to examine the relative import of these working memory systems would be to directly compare the extent to which they interfere with the updating processes indexed by the association effect. I address this issue in the next chapter.

Chapter 7

Experiment 6: Situation model updating with verbal versus spatial concurrent task

Introduction

The present study was designed to confirm and clarify the roles of verbal and visuo-spatial working memory in the updating of situation models. Results from the study with a concurrent verbal task (experiment 3; Chapter 4) revealed additive effects of verbal load and the association factor on target sentence reading times, suggesting the processes indexed by the association effect are independent of those needed to maintain information in a verbal format. By contrast, results from the study with a concurrent spatial task (experiment 4; Chapter 5) revealed interactive effects of spatial load and the association factor, and suggest visuo-spatial working memory is recruited when readers update their situation model.

An alternative explanation of these findings, however, is that the secondary verbal and spatial tasks used in experiments 3 and 4 differ in overall difficulty. This possibility was addressed in experiment 5 in which we compared participants' performance on an unrelated task paired with light and heavy load versions of our two secondary tasks. Experiment 5 revealed that our verbal and spatial tasks were equally detrimental to performance on a visual search task, and that the load effect was similar for each. While this undermines the

possibility that our secondary tasks differed in difficulty, it leaves open the question of whether verbal or visuo-spatial working memory are differentially important for updating the situation model.

Present Study

In view of the degree to which the association effect varies as a function of individual differences in verbal working memory span and spatial rotation ability, the relative import of verbal versus visuo-spatial working memory is best addressed in a within-participants comparison. To this end, participants in the present study read the narratives used in experiments 3 and 4 while they performed either the concurrent verbal task used in experiment 3, or the concurrent spatial task used in experiment 4.

Method

Participants. Forty-four volunteers (26 women, 18 men) received course credit for their participation. All participants were native English speakers at the University of California, San Diego (mean age = 21.1, SD = 2.7).

Materials

Narrative Texts. The texts were identical to those employed in experiment 3 (Chapter 4) and experiment 4 (Chapter 5), and included both

experimental and non-experimental scenarios. Half of the experimental narratives (24) were paired with the digit recall task used in experiment 3 (Chapter 4) and experiment 5 (chapter 6), while the other half were paired with the dot sequence recall task used in experiments 4 and 5 (chapters 5 and 6, respectively). Unlike the previous experiments, which presented both light and heavy loads, the present study exclusively presented the heavy load of each. This choice was motivated by the results of the previous studies, which suggested the heavy load conditions yielded the most informative data.

Each of the dual-task paradigms were presented in blocks of 6, and were interleaved.

Digit Recall (Verbal Load). Materials and procedure for the digit recall task were identical to those used in experiment 3, except that all trials involved 4 digits.

Dot Sequence Recall (Spatial Load). Materials and procedure for the dot sequence recall task were identical to those used in experiment 4, except that all trials involved a sequence of 4 dots.

Design & Analysis. This experiment employed a 2x2 within-participants design. Dependent measures included accuracy on comprehension questions, accuracy on digit recall, accuracy on dot sequence recall, and reading times for

the target sentences**.** Analysis involved repeated measures ANOVA with factors of Association (associated / dissociated) and Secondary Task (verbal / spatial).

Target sentence reading times were filtered for outliers. These were defined as being 2 or more standard deviations above or below the mean reading time per condition. Approximately 4% of the data were excluded for this reason.

Significant factors in the ANOVA were further analyzed with multiple regression using scores on individual difference measures.

Results

Individual Differences. Participants' scores on the 5 individual difference measures (verbal working memory, spatial working memory, spatial rotation, text comprehension, and vivid imagery) are presented in Table 7.1. Pearson's correlations between these measures after Bonferroni correction are presented in Table 7.2. The individual difference measures were not significantly correlated with one another.

Table 7.1. Performance on individual difference measures

Measure	Mean	St. deviation	Minimum	Maximum	Possible Range
Verbal WM Span	3.3	0.9	1.5	5	1-5
Spatial WM Span	3.1	1	1	5	1-5
Spatial Rotation	86	7	70	99	1-100
Text Comprehension	32	4.1	18	38	1-38
Vivid Imagery	33	10	16	65	16-80

Table 7.2. Pearson's correlations of scores on individual difference measures, after Bonferroni correction

	Verbal Span	Spatial Span	Spatial Rotation	Text comprehension	Vivid Imagery
Verbal WM Span	x				
Spatial WM Span	0.1	x			
Spatial Rotation	0.27	0.19	x		
Text comprehension	0.14	0.10	0.18	x	
Vivid Imagery	0.18	-0.28	-0.20	0.24	x

Digit Recall (Verbal Load). Overall accuracy on the digit recall task was 92.5%. No difference was observed was between digit recall accuracy that followed the associated condition (92.6%) relative to the dissociated condition (92.4%), $F(1,43) = 0.03$, $p = 0.86$.

Dot Sequence Recall (Spatial Load). Overall accuracy on the dot sequence recall task was 91.2%. No difference was observed between dot sequence recall accuracy that followed the associated condition (91.6%) relative to the dissociated condition (90.8%), $F(1,43) = 1.0$, $p = 0.52$.

To directly compare performance on the secondary tasks, accuracy rates were subjected to repeated measures ANOVA with factors of Secondary Task (digit/dot recall) and Association (associated/dissociated). None of the effects were significant: secondary task, $F(1, 43) = 0.23$, $p = 0.63$, association, $F(1, 43) = 0.89$, $p = 0.35$, secondary task x association, $F(1, 43) = 0.64$, $p = 0.21$.

Comprehension Accuracy. Overall, participants had little trouble comprehending the experimental narratives. The average accuracy rate on the comprehension questions was 87%. A 2x2 repeated measures ANOVA with factors of task and association revealed a significant main effect of task, $F(1, 43) = 12.3$, $p = 0.001$. This effect was due to higher comprehension accuracy following narratives that were paired with a digit recall task (89%) relative to those that were paired with a dot recall task (84.3%). There was no effect of association, $F(1, 43) = 1.95$, $p = 0.17$, nor interaction between these two factors, $F(1, 43) = 0.43$, $p = 0.51$.

Subsequently, a multiple regression analysis was carried out to discern the most predictive individual difference measures for the effect of task. Here, the dependent variable was the effect of task (accuracy on comprehension questions that followed the dot sequence recall task was subtracted from accuracy on comprehension questions that followed the digit recall task). This analysis revealed that the individual difference measures were not significantly

predictive of the difference in comprehension accuracy by task, R^2 = 0.34, F(5,38)= 1.00, p< 0.439.

Reading Time for Target Sentences. Overall, people read the anaphoric target sentences more slowly when they referred to dissociated objects than when they referred to associated objects. As in the previous experiments, analysis revealed a main effect of association due to longer reaction times in the dissociated (2604ms) than associated (2283.5 ms) condition, F (1, 43) = 48.2, p = 0.00. Additionally, target sentences in the digit recall condition (2327.5 ms) were read marginally faster than those in the dot recall condition (2560 ms), F (1, 43) = 3.77, p = 0.06. A statistically reliable interaction between factors of association and task was found, F (1, 43) = 9.49, p = 0.004. Table 7.3 shows mean reading times (ms) per condition as well as the difference between conditions.

Table 7.3. Mean reading times (ms) for target sentences, with standard deviations in parentheses.

	Associated	Dissociated	Difference
Verbal Load	2207 (669)	2448 (709)	241
Spatial Load	2360 (480)	2760 (651)	400
Difference	153	312	

To further analyze the interaction between association and task on target sentence reading times, separate ANOVAs were conducted to test the effect in

the digit recall (verbal load) and dot recall (spatial load) conditions. Both analyses revealed a statistically significant effect of association, digit recall: *F(1,43)* = 30.4, p = 0.000; dot recall: *F(1,43)* = 43.5, p = 0.000. The interaction between association and task results because the association effect was more pronounced with dot sequence recall (400ms) than digit (241ms) loads.

Target Sentence Reading Times and Individual Differences. Association effects for the digit and dot sequence recall conditions were each subjected to a multiple regression analysis where the dependent measure was the association effect (dissociated – associated) and the independent variables were the individual difference measures.

Digit Recall (Verbal Load). The model for the association effect in the digit recall task (verbal load) condition reliably predict variance in the association effect, R^2 = 0.54, F(5, 38)= 18.85, p < 0.00. Verbal working memory span [B=0.47, t(38) =13.98, p = 0.007] and spatial rotation ability [B=0.44, t(38) = 13.60, p = 0.011] were significant predictors of the association effect. Spatial working memory [B=0.02, t(38) = 0.18, p = 0.85], text comprehension [B= -0.02, t(38) = -0.16, p = 0.87], and imagery ability [B= 0.03, t(38) = 0.22, p = 0.83] were not significant predictors of the association effect. Tables 7.4 and 7.5 show the effect of association in the digit recall task condition based on median splits for verbal working memory and spatial rotation, respectively. Graphs 7.1 and 7.2 illustrate the relationships between verbal working memory, spatial

rotation and the association effect on target sentence reading times.

Table 7.4 Target sentence reading times (ms) with verbal load in high and low verbal span participants

Verbal WM Span	Associated	Dissociated	Association effect
High Span Group	2261	2706	445
Low Span Group	2344	2536	192
Span Effect	83	-170	

Graph 7.1 Scatterplot depicting the relationship between verbal working memory and association effect for the digit recall task.

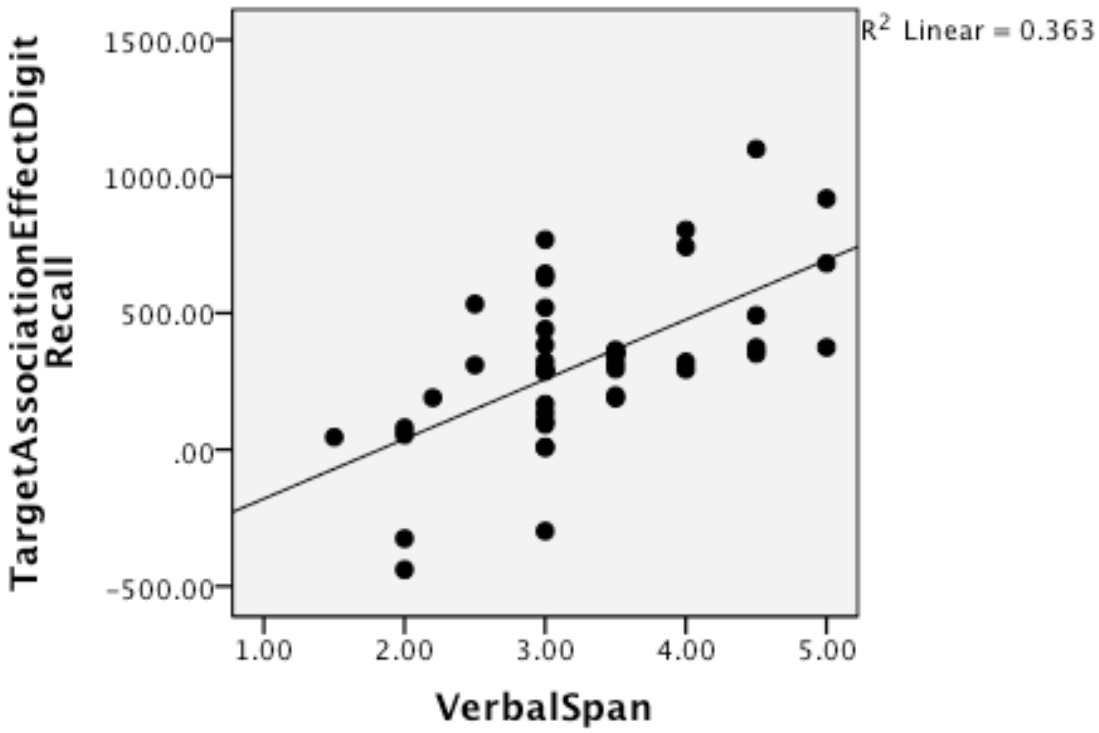
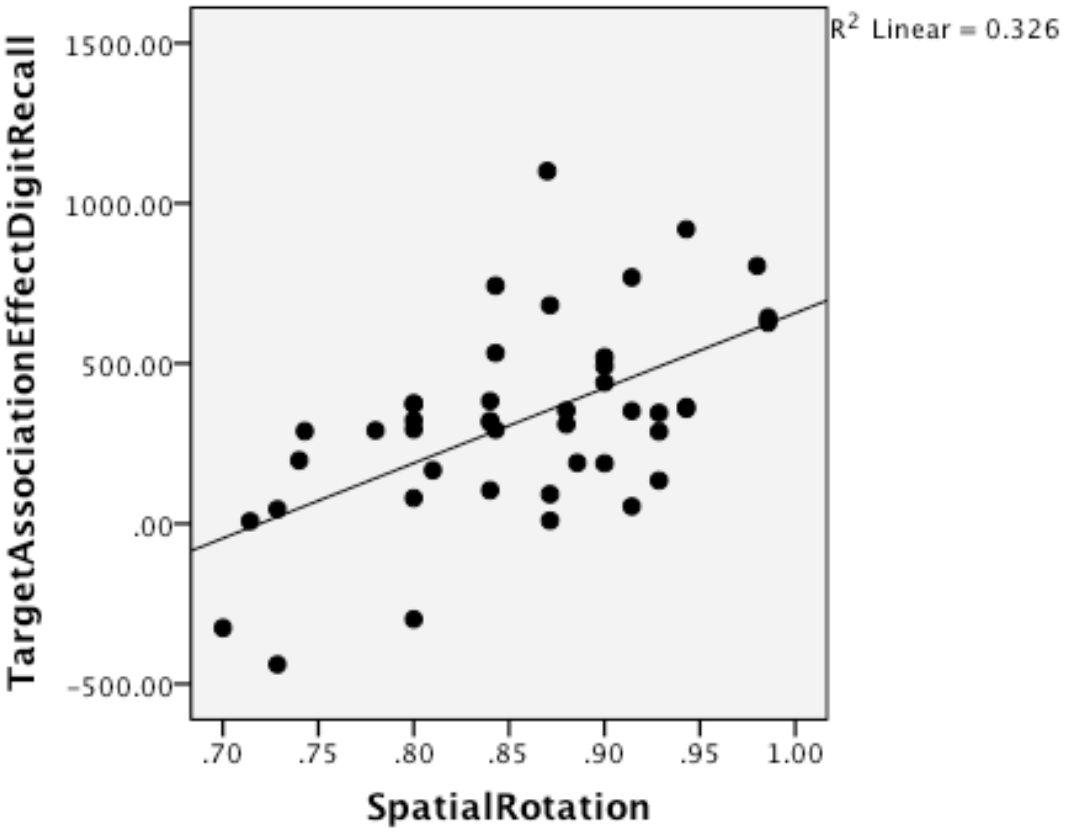


Table 7.5 Target sentence reading times (ms) with verbal load in participants with high and low accuracy on spatial rotation

Spatial Rotation	Associated	Dissociated	Association effect
High Acc. Group	2219	2562	343
Low Acc. Group	2194	2335	141
Rotation Effect	-25	-227	

Graph 7.2 Scatterplot depicting the relationship between spatial rotation score and association effect for the digit recall task.



Analysis of reading times (with verbal load) in the high verbal working memory span group revealed a robust 445ms association effect, $F(1,21) = 19.3$, $p= 0.00$. The 192ms association effect in the low verbal working memory did not reach significance, $F(1,21) = 3.32$, $p= 0.08$. Table 7.4 suggests group differences were most apparent in the dissociated condition.

Analysis of reading times in the high spatial rotation group revealed a significant 343ms association effect, $F(1,21) = 40.0$, $p= 0.000$. Analysis of reading times in the low spatial rotation group also revealed a significant association effect, $F(1,21) = 14.9$, $p= 0.04$, though it was smaller in magnitude (141ms) than that of the high spatial rotation group. Table 7.5 suggests group differences arise primarily from long reading times for the dissociated condition by the high spatial rotation group.

Dot Sequence Recall (Spatial Load). The multiple regression model for reading times paired with the dot recall task (spatial load) reliably predicts variance in the association effect, $R^2 = 0.35$, $F(5, 38)= 4.11$, $p < 0.004$. Spatial working memory [$B=0.41$, $t(38) = 2.93$, $p = 0.006$], verbal working memory span [$B=0.33$, $t(38) = 2.3$, $p = 0.03$], and spatial rotation ability [$B=0.28$, $t(38) = 1.9$, $p = 0.05$] were significant predictors of the association effect. Vivid imagery [$B= 0.03$, $t(38) = 0.22$, $p = 0.83$] and text comprehension [$B= -0.12$, $t(38) = -0.89$, $p = 0.37$] were not reliable predictors of the association effect.

To explore differences as a function of spatial working memory capacity, participants were divided into two groups based on a median split of their scores on the spatial working memory span test. Reading times in the spatial load condition are presented in Table 7.6. Analysis of reading times in the high spatial span group revealed a significant 517 ms association effect, $F(1,21) = 40.0$, $p = 0.000$. Analysis of reading times in the low spatial span group revealed a smaller (280ms), though still significant, effect of association, $F(1,21) = 14.9$, $p = 0.04$ Group differences are more apparent in reading times in the dissociated condition for the high spatial working memory group. Graphs 7.3, 7.4 and 7.5 illustrate the relationships between spatial working memory, verbal working memory, spatial rotation, and the association effect for target sentence reading times.

Table 7.6 Target sentence reading times (ms) with spatial load in participants with high and low spatial working memory spans

Spatial WM	Associated	Dissociated	Association effect
High Spatial Span	2271	2788	517
Low Spatial Span	2296	2576	280
Span Effect	25	-212	

Graph 7.3 Scatterplot depicting the relationship between spatial working memory span and the association for the dot recall task.

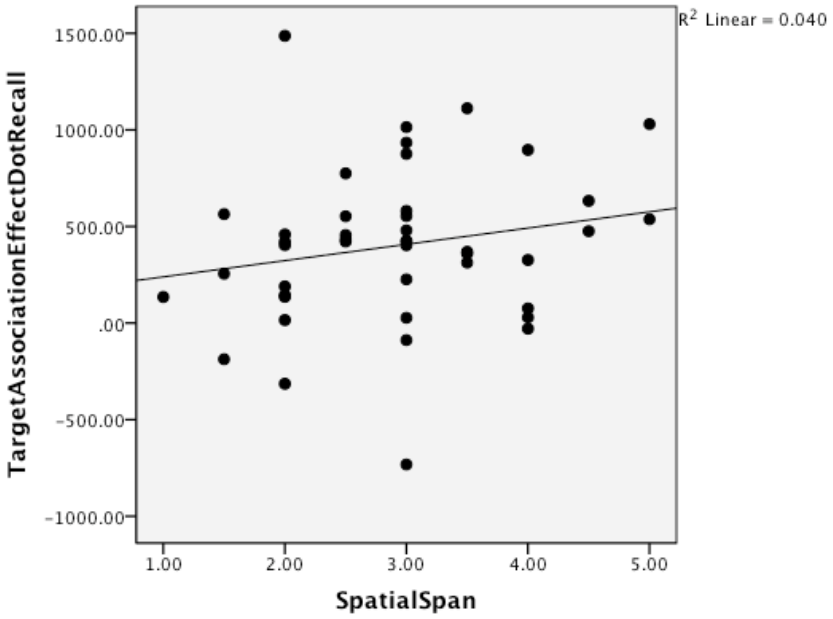
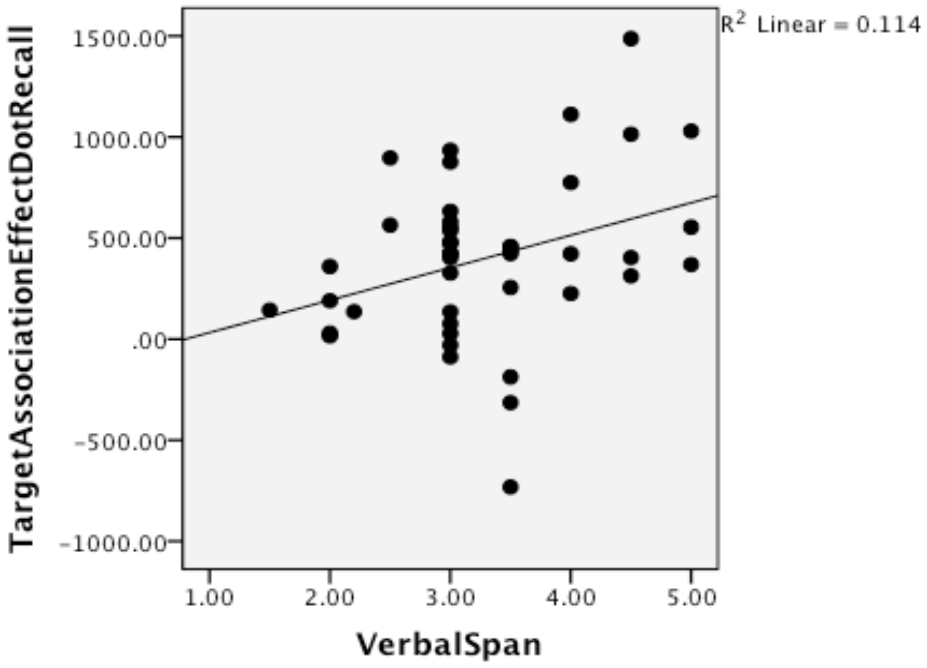


Table 7.7 Target sentence reading times (ms) with spatial load in participants with high and low verbal working memory spans

Verbal WM	Associated	Dissociated	Association effect
High Verbal Span	2338	2899	561
Low Verbal Span	2483	2623	140
Span Effect	145	-276	

Graph 7.4 Scatterplot depicting the relationship between verbal working memory and the association effect for the dot recall task.



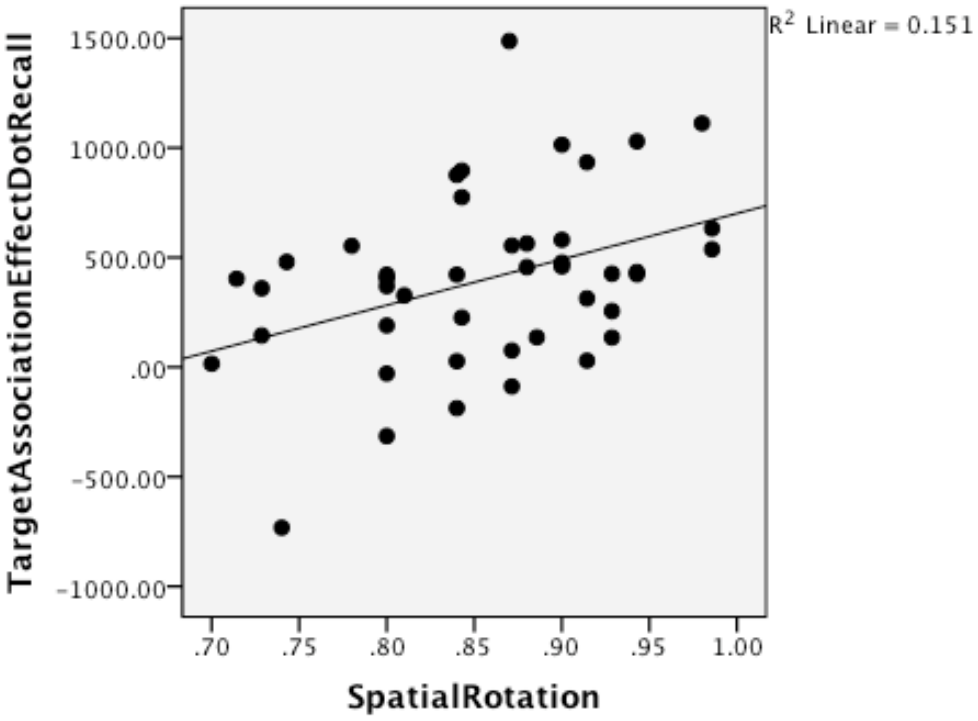
To explore the relationship between verbal working memory span and the association effect, participants were divided into high and low groups based on a median split of verbal working memory span scores (see Table 7.7). Separate post hoc ANOVAs investigated the association effect within the high and low verbal working memory groups. In the high accuracy verbal working memory span group, the 561 ms association effect was significant, $F(1,21) = 64.2$, $p= 0.000$. In the low verbal working memory group, the 140 ms association effect was also significant, $F(1,21) = 7.43$, $p= 0.01$. Group differences were most apparent in the dissociated condition, where the high verbal working memory group had reading times that were 276 ms slower than those in the low verbal

working memory group.

Table 7.8 Target sentence reading times (ms) with spatial load in participants with high and low spatial rotation ability

Spatial Rotation	Associated	Dissociated	Association effect
High Acc. Group	2529	2998	469
Low Acc. Group	2192	2523	331
Rotation Effect	-337	-477	

Graph 7.5 Scatterplot depicting the relationship between spatial rotation score and the association effect for the dot recall task.



To explore the relationship between spatial rotation ability and the association effect, participants were divided into High and Low groups based on

a median split of accuracy rates on spatial rotation ability (see Table 7.8). Separate post hoc ANOVAs investigated the association effect within the high and low spatial rotation ability groups. In the high accuracy spatial rotation group, the 469 ms association effect was significant $F(1,21) = 41.1$, $p= 0.000$. In the low spatial rotation group, the 331 ms association effect was also significant, $F(1,21) = 11.8$, $p= 0.002$. Group differences were most apparent in the dissociated condition, where the high spatial rotation ability group had reading times that were 477 ms slower than those in the low spatial rotation group.

Discussion

Results from the present experiment broadly replicate results seen in the heavy load conditions of the Verbal Load experiment (chapter 4) and Spatial Load experiment (chapter 5).

Digit Recall (Verbal Load) and Dot Sequence Recall (Spatial Load).

Accuracy on the digit and dot sequence recall tasks in the present study were similar to those found in the heavy conditions of the previous Verbal and Spatial Load studies (Chapters 4 and 5). Moreover, performance on the two secondary tasks was similar, consistent with our findings in experiment 5 that

suggest the two tasks do not differ in their overall level of difficulty. Additionally, accuracy on these tasks was predicted by the same individual difference measures as those found to be predictive in the previous studies. Digit recall performance was predicted by verbal working memory span and dot sequence recall was predicted by spatial working memory span. In sum, the digit recall task taxed the verbal working memory system, while the dot sequence recall task taxed the visuo-spatial working memory system.

Target Sentence Reading Times in the Digit Recall (Verbal Load) Condition

The present study found a greater association effect size of 241ms in the heavy digit recall condition, than the association effect size of 142ms found in experiment 3 under the same conditions. This slight difference might be attributable to the added demands of task switching in the present study, that were absent in experiment 3. Similar to results in chapter 4, however, the multiple regression analysis on the association effect revealed that verbal working memory span and spatial rotation ability were the only individual difference measures that were predictive of the association effect.

In both studies, the high verbal working memory group and the high spatial rotation group drove the size of the association effect. In both cases, this was due to longer reading times for the dissociated condition. In line with Gernsbacher et al.'s (1990) Strucutre Building Framework, the pattern of results

suggests that individuals with high verbal working memory are more efficient at suppressing irrelevant information (the critical item in the dissociated condition) than those with lower verbal working memory. Suppression of the irrelevant information may be the reason that information about dissociated items is less accessible to the high verbal working memory group.

Target Sentence Reading Times in Dot Sequence Recall (Spatial Load) Condition

The size of the association effect in the dot sequence recall condition in the present study was almost identical to that found in chapter 5. The present study found an association effect of 400ms, while results from the spatial load experiment revealed an effect size of 422ms. Just as in the previous spatial load study, the multiple regression analysis on this effect revealed that spatial working memory span, verbal working memory span, and spatial rotation ability were predictive of the association effect. Similar to results found in Chapter 5, the present study found that individuals with lower spatial working memory were not as sensitive to the condition of association when they were required to simultaneously maintain external visuo-spatial information. In both experiments however, the low spatial working memory group did exhibit some sensitivity to the manipulation of association. As in chapter 5, we hypothesize that this may have been due to recruitment of other cognitive abilities, specifically verbal

working memory and spatial rotation ability, which were also reliable predictors of the size of the association effect.

Conclusion

Results from the present study replicate those found in experiment 3 and experiment 4 (Chapters 4 and 5). Moreover, the within-participants comparison here indicated that the addition of a secondary spatial task was more disruptive to situation model updating processes, indexed by reading times, than was the imposition of a verbal task. Taken together, these results suggest that while verbal working memory is important for the construction of the situation model, the visuo-spatial working memory system plays a critical role in updating the model to reflect changes in the spatial relationship between entities in the text.

Chapter 8

General discussion

The typical approach for investigating how readers represent real world information, such as spatial information, has been to provide participants with texts that explicitly elicit a visual representation analogous to a three-dimensional space of our real experience, or to give texts that are accompanied by a photograph (Glenberg & Langston, 1992; Glenberg & Robertson, 1999) or map (Morrow et al., 1987; Rinck & Bower, 1995). These studies, which purport to demonstrate the topographic nature of situation models may not reflect natural text comprehension mechanisms (see Bestgen & Dupont, 2003 for a review).

Unlike previous studies of its kind, Glenberg et al. (1987) presented participants with short narratives that did not call unnatural attention to the spatial relationships described in the text. Participants were asked to read the texts for comprehension, without instruction to prioritize the spatial aspect of the scenarios. The texts described familiar situations (e.g. going to a restaurant) in which a protagonist interacted with easily perceptible, concrete nouns. Results from this study suggested that participants took longer to read target sentences whose anaphoric pronoun referred to an object that was no longer in the foreground of the situation model (dissociated) relative to those that referred to

objects that were still in the foreground of the situation model (associated). These researchers interpreted the difference in reading times by condition (the association effect) to mean that readers actively updated their situation models of scenarios described in texts.

The studies described in Chapters 2-5 and 7 replicate Glenberg et al.'s association effect and add to it a better understanding of the cognitive abilities that underlie the effect. Rather than assume homogeneity between comprehenders, we exploited the differences between readers to explore whether the construction and updating of situation models is attributable to different, specific cognitive abilities. Specifically, we considered whether successful construction and updating of situation models is mediated by vividness of imagery, verbal working memory, spatial working memory, mental rotation ability, or simply text comprehension skill. Additionally, the pattern of reading time results exhibited by high and low groups of these abilities was further considered.

Accounts of Working Memory

Working memory capacity is a dimension along which people are known to vary and that influences situation model construction and updating. One line of thought about the application of working memory to text comprehension is that individual differences are due to differences in the ability to actively maintain relevant information (Engle 2002; Unsworth and Engle, 2007; Conway

et al., 2003; Kane and Engle, 2001). Engle and colleagues suggest that differences in working memory are related to an executive attention ability, which supports the active maintenance of relevant information. Using a Stroop paradigm, Kane & Engle (2001) found that participants with low working memory made more errors than participants with high working memory. This difference was most pronounced in conditions with more distractors, suggesting that individuals with high working memory were more easily able to focus on the relevant information. A good text comprehender may then be better capable of activating relevant information from the context (Garner, 1987; Palladino et al., 2001).

An alternative account, proposed by Gernsbacher et al. (1990), suggests that skilled comprehenders are more efficient at suppressing or inhibiting irrelevant information. In contrast, poor comprehenders may be relatively insensitive to contextual information because they have difficulty suppressing irrelevant information (Gernsbacher, 1993). Gernsbacher et al. (1990) base their theory on behavioral experiments using sentence-final homographs. These researchers found that while both skilled and unskilled readers (grouped by an original comprehension task) activated both meanings of the homograph, only less-skilled readers still had the inappropriate meaning activated 850ms after the end of the sentence.

Experiments 1 and 2 (Chapters 2 and 3) found that the greatest association effect emerged in the associated condition, where participants were faster to read target sentences that referred to foregrounded objects. Beta weights from multiple regression analyses revealed that for both experiments, this pattern of results was driven by participants with high verbal working memory (based on a median split of scores on the verbal working memory task for our sample of 44 in each study). In fact, the low verbal working memory group did not demonstrate reliable sensitivity to the associated/dissociated manipulation in either experiment. This pattern of results is inline with Engle's (2002) hypothesis, which suggests that individuals with higher working memory capacity exhibit greater sensitivity to relevant information. For the higher working memory group, objects in the associated condition may be more accessible because these participants are better able to actively attend to and maintain relevant information from text.

When narrative text comprehension was paired with a concurrent verbal load task (Chapter 4) the largest differences in the size of the association effect also emerged from the high verbal working memory span group. In this case, however, the effect was due to longer reading times of target sentences that referred to the now-irrelevant, dissociated item. This pattern suggests that the high verbal working memory group had already successfully suppressed the irrelevant item, causing them to take longer to re-activate the dissociated item.

The difference in patterns seen between experiments may have been due to an alternative processing mechanism adopted to manage the additional information presented by the concurrent load task. With a greater amount of potential interference to manage, the high verbal working memory participants were more efficient at actively suppressing the irrelevant textual information. Taken together, these data suggest that Engle's Active Maintenance Theory and Gernsbacher's Active Suppression Hypothesis are not mutually exclusive. Individuals with high verbal working memory capacity may employ different processing strategies for information management depending on the requirements of the task. These individuals exhibited robust association effects in all experiments. Most notably, however, the size of the association effect was not modulated by the concurrent verbal load task in either the high or low verbal working memory groups. This suggests that although verbal working memory is clearly related to sensitivity to the difference between association conditions (as shown by multiple regression analyses in Chapters 2-5, 7), verbal working memory is independent of the cognitive mechanisms that underlie situation model updating.

Visuo-Spatial Working Memory and Text Comprehension

Cognitive theorists have claimed that situation models may not be propositional as are their complementary representations, the surface structure

and the text-base, but instead may be image-like and have perceptual components (Ericson & Kintsch, 1995; Glenberg, Meyer, & Lindem, 1987; Johnson-Laird, 1983, Fincher-Kiefer, 2001). While scores on our vivid imagery assessment proved to not be predictive of the association effect, experiments 1-4, 6 (Chapters 2-5, 7) all revealed a systematic, positive relationship between the size of the association effect and spatial rotation ability, suggesting the potential involvement of imagery-based, visuo-spatial systems in situation model updating.

To my knowledge, only one other researcher who has investigated the possibility that perceptual and visuo-spatial processing are involved in comprehension of texts that are not explicitly spatial. Fincher-Kiefer (2001) used dual task methodology in 2 separate studies. In one study, she had participants hold a high-imagery or low-imagery sentence in memory (high: “A star of David has six points,” low: “.“The shortest month of the year is February,”) while reading passages (approximately 16 sentences) that introduced a character’s personality traits or likes and dislikes (e.g. “Mary is a vegetarian…” or “Mary enjoys going to McDonald’s...”). The passage was then followed by a critical sentence that matched or mismatched global coherence of the scenario, (“Mary ordered a salad / hamburger,”). The dependent measure was reading time of the final sentence. Reading times for sentences that were inconsistent with global coherence were expected to be longer than reading times for sentences

that were consistent ("the contradiction effect"). In a second study, she had participants hold a light or heavy verbal or visuo-spatial load in memory while reading the same passages. Results from these studies suggested that holding a high-imagery sentence or high spatial load while reading the passages reduced the size of "the contradiction effect," relative to holding a low-imagery sentence or low spatial load. The "contradiction effect" was not found to be modulated by verbal load. She hypothesized that the reduced difference in reading time following in/consistent passage endings was due to reduced availability of visuo-spatial resources.

While Fincher-Kiefer's (2001) results are suggestive, it is possible that the long, descriptive passages she used as experimental materials encouraged greater imagistic processing. Additionally, the load tasks used in Fincher-Kiefer's (2001) studies may not have been equivocal, whereas experiment 5 (Chapter 6) demonstrated equivalent difficulty of our concurrent tasks.

Experiment 4 (Chapter 5), which measured how visuo-spatial load affected situation model updating, supports Fincher-Kiefer's hypothesis. Analysis revealed interactive effects of load and association, consistent with the proposal that situation model updating utilizes the limited pool of visuo-spatial working memory resources. Our individual difference measures lend further support to this claim by revealing that the interactive effect of visuo-spatial load

on the association effect was greatest in participants with fewer visuo-spatial resources (low spatial working memory span group).

Considering individual differences to the investigation of situation model processing added to the identification of mechanisms underlying situation model updating, as indexed by the association effect. Whereas Glenberg et al. (1987) showed that readers are sensitive to subtle spatial shifts in narrative texts, the experiments described in the previous chapters revealed that several independent factors are related to the size of the association effect. These experiments revealed that while verbal working memory and spatial rotation ability are related to situation model updating, visuo-spatial working memory seems to be responsible for the effect. This, and the association effect found for picture probe recognition accuracy in experiment 2 (Chapter 3) lends support to the idea that situation models have visually-based analogue components, as suggested by Zwaan (1999).

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