

INTERFERENCE CONTROL IN LANGUAGE PROCESSING:
THE EFFECTS OF AGE AND WORKING MEMORY

BY

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DISSERTATION

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ABSTRACT

Language processing encompasses different levels of analysis, involving activation of semantic and perceptual features of concepts, binding of concepts, and understanding of the overall situation. Older adults or individuals with less working memory capacity have often been reported to have more difficulties in binding individual concepts in a sentence to form an integrated representation of ideas (e.g., thematic roles assignment). In contrast, situation understanding or simulation of language that draws on world knowledge and experience has been argued to be obligatory and relatively effortless, thus demonstrating relative resilience in the face of aging and working memory constraints. Recent models of language processing suggest that conceptual binding difficulties often observed in complex syntactic structures may be caused by semantic similarity of the to-be-integrated concepts and deficits in interference control in working memory. Furthermore, emerging evidence implies that situation construction/simulation can be compromised for individuals with less working memory resources or when binding concepts (that is the basis for enriched and refined situation simulation) is too resource-consuming. The study consisted of two experiments and was designed to 1) test whether similarity-based interference in working memory differentially impairs conceptual combination with age, and 2) whether such processes have downstream effects on situation simulation. In Experiment 1, the syntax (Object-relative clauses, ORC vs. Subject-relative clauses, SRC) and the semantic similarity between noun phrases (NPs) (same vs. different category) were manipulated (Gordon et al., 2006) to investigate their respective effect on conceptual binding among younger and older adults. In Experiment 2, the syntax and the similarity manipulations were crossed with match condition (match vs. mismatch between implied shape and actual shape) in a sentence-picture verification paradigm (Zwaan et al., 2002)

to investigate the effect of controlling interference during binding concepts on generating perceptual-level inferences. Results of Experiment 1 revealed that the combination of syntactic and semantic complexity differentially affected older adults' comprehension and there was evidence that older adults with less working memory resources showed poorer comprehension, particularly when the difficult syntax with similar NPs. Online eye-movement measures also showed that older adults with less working memory resources spent differentially more time at the critical relative clause region in this condition. Results of Experiment 2 demonstrated that there was a reliable mismatch effect in response latency for picture verification and that the effect did not vary as a function of syntax, similarity or age. Further analysis revealed that this mismatch effect was not associated with working memory for either age group across all the conditions, providing converging evidence that perceptual simulation was impermeable to syntactic complexity, semantic interference, and working memory constraint and might reflect distinctive and obligatory processes in language understanding beyond conceptual combination. Altogether, these results support a) a similarity-based interference control account of conceptual binding in working memory; b) a resource-independent and obligatory view of perceptual simulation that is immune to interference and working memory capacity; and c) a view of age differences in language understanding that processes requiring binding multiple concepts while controlling distractions in working memory is compromised, but that processes underlying situation-level inferences are preserved, even in face of interference and working memory constraint.

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CHAPTER 1

INTRODUCTION

Language comprehension is a multicomponent phenomenon (Kintsch & van Dijk, 1978; McNamara & Magliano, 2009). Readers or listeners have to make sense of visual or auditory stimuli, mapping shapes or sound to words (Marslen-Wilson, 1987), access semantic/perceptual/syntactic features of words (Dell, 1986), relate meanings of individual words with each other to form ideas (Kintsch & van Dijk, 1978; Kintsch, 1988; 1998), and represent an overall understanding of the discourse world (Barsalou, 1999; Gernsbacher, 1990; Gerrig, 1993; Graesser, Singer, & Trabasso, 1994; Zwaan, Langston, & Graesser, 1995; Zwaan, Magliano, & Graesser, 1995).

Although adults who have acquired literacy skills are efficient at coordinating this multilayered process, most of the time without much effort, some extant evidence implies that language processing is not completely effortless but rather consumes certain sorts of “resources” (Just & Carpenter, 1992; MacDonald, Pearlmutter, & Seidenberg, 1994; Seidenberg & MacDonald, 1999; Daneman & Carpenter, 1980; Lustig, Hasher, & Zacks, 2007; Gernsbacher, Varner, & Faust, 1990; Gernsbacher & Faust, 1991). However, the nature of the resources and their respective influences on different levels of language representation across the temporal time course remain to be specified (Caplan, DeDe, Waters, Michaud, & Tripodis, 2011). For example, Caplan and Waters (1999) have argued that working memory resources do not affect the early stages of sentence processing (i.e., syntactic parsing), whereas others (Just & Carpenter, 1992; Fedorenko, Gibson, & Rohde, 2006; Kemper & Herman, 2006) have suggested that early

processes, such as syntactic parsing, are subject to working memory constraints, such as those engendered by normal aging.

Recent debate surrounding a resource account of language processing has centered on the inhibitory function of working memory in ignoring distractions or controlling interference during online reading or listening (Gordon, Hendrick, & Johnson, 2001; Gordon, Hendrick, Johnson, & Lee, 2006; Van Dyke & Lewis, 2003; Van Dyke & McElree, 2006). One source of individual variability in inhibition is normal aging (Hasher & Zacks, 1988), and as a consequence, aging poses an interesting avenue to test an interference-based account of language representation at various levels of analyses.

The goal of this project was to examine the roles of interference control in age differences in language processing. I would start by reviewing theories of language processing more generally and then review what is known about how these processes change as a function of normal aging, demonstrating evidence for both age-related differences and invariance in conceptual activation/binding and situation simulation. I then reported results for two experiments and concluded by discussing the implications of a similarity-based interference control hypothesis in age differences in language understanding.

Overview of Language Processing:

Conceptual Activation, Combination, and Situation Simulation

All models of language processing take for granted that comprehension requires multiple components. Even understanding the simple sentence (1a) entails understanding the meaning and grammatical role of each individual word, combining words together to form ideas and inferring the situation implied by the sentence.

(1a) *The duck is in the nest.*

Specifically, the rudiments of language processing involve understanding the meanings of words or the conceptual representation of written or auditory word forms. For example, immediately upon hearing or reading the word *duck*, both semantic/associative features (e.g., chicken, animal, feather, Disney) and situational/perceptual features (e.g., lake, swim, quack) of the concept may be activated, depending on language context. Beyond the activation of such conceptual features, language comprehension requires binding multiple concepts together, a process through which concepts in the clause or sentence are bound to form the basic idea unit. For example, in sentence (1a), the concepts *duck* and *nest* are bound together in memory through the location preposition *in*. Relying upon the products of concept binding, further inferences or enriched situation simulation can be achieved and a more refined understanding of the meanings of the contextualized concepts can be reached. For example, beyond the information given by the text, *The duck is tired* can be inferred or *A resting/sleeping duck with folded wings and closed eyes* can be simulated. Yet, certain features associated with the concept *duck* may remain activated while others may become deactivated with more contextual support. For example, after reading/hearing sentence (1a), *lake, swim and quack* may become deactivated, whereas *quack* may stay activated after reading/hearing sentence (1b).

(1b). *The duck is very noisy.*

In the following three subsections, I will review empirical evidence for conceptual activation, conceptual binding and situated language processing, respectively.

Activation/Simulation of Concepts in Language Understanding

Early work of Meyer and Schvaneveldt (1971) demonstrated that semantic or associative features of concepts can be activated. In a classic priming paradigm, in which a target word (e.g., NURSE) was either preceded by a related word (e.g., DOCTOR) or an irrelevant control (e.g.,

WAITER), it was found that processing time to the target word was shorter following the related word in relation to the control. Subsequent studies suggest that recognizing a word in context necessitates the activations of all possible features and semantic associates of the contextually constrained concepts (Swinney, 1979; Simpson, 1984), probably in an anticipatory and predictive fashion (Federmeier, McLennan, De Ochoa, & Kutas, 2002; DeLong, Urbach, & Kutas, 2005; van Berkum, Brown, Zwitterlood, Kooijman, & Hagoort, 2005); however, a richer sentential or discourse context specifies the appropriate semantic/associative features to remain activated, and engenders activation of richer mental models and a more refined simulation of certain features.

Till, Mross, and Kintsch (1988) studied the time course of textbase and situation model activation in a priming paradigm. After reading a context sentence as in (2), participants were required to make a lexical decision for a target word that was an unrelated control (e.g., *breath*), a context-appropriate semantic associate (e.g., *money*), a context-inappropriate associate (e.g., *candy*), or a context-appropriate inference (e.g., *earthquake*).

(2). *The townspeople were amazed to find that all the buildings had collapsed except the mint.*

The researchers found that both types of associates were equally activated in the early time window (~200ms - ~400ms), and then appropriate associates stayed more active than the inappropriate ones (see Swinney, 1979, for similar findings); however, the priming effect for the inference condition was only evident in the later time window (after 1000ms). These findings suggested that the initial activation of word meanings is non-selective and context-independent, followed by a top-down semantic retrieval process from long-term knowledge (i.e., a mint makes money) to suppress unlikely interpretations of ambiguous words. Subsequently, the

mental model gets activated as it requires elaborated inference based upon an overall evaluation of the discourse and employment of knowledge from long-term memory.

There is also literature suggesting that in addition to semantic/associative features, functional and perceptual features of concepts can be activated as well in language understanding. For example, Tabossi (1988) used the cross-modal priming paradigm, in which participants made a lexical decision to a visually presented word (e.g., sour) after an auditorily presented sentence (3a-3c).

(3a). *The little boy shuddered eating a slice of lemon.*

(3b). *The little boy was late because he went to buy a lemon.*

(3c). *The little boy was playing on the floor rolling a lemon.*

She found that the response latency to the target word after the appropriate context (sentence 3a) was facilitated (compared to the neutral sentence 3b), while the response latency to the target word after the inappropriate context (sentence 3c) was slowed down relative to the neutral condition, suggesting activation/deactivation of functional features for concepts embedded in different sentential contexts. These findings provide some initial evidence for context-modulated perceptual feature activation of concepts embedded in sentences, because relevant features (i.e., sour) of the object in the sentence (3a) were activated and contextually irrelevant ones (i.e., round) in sentence (3c) (i.e., a rolling lemon) was inhibited.

Zwaan, Stanfield, and Yaxley (2002) presented participants with a picture of an object that was either consistent or inconsistent with the shape implied by a sentence (e.g., a picture of an eagle with outstretched wings vs. a picture of an eagle with folded wings after sentences like (4a and 4b)) and instructed participants to judge whether or not the object was mentioned in the sentence.

(4a). *There was an eagle in the sky.*

(4b). *There was an eagle in the nest.*

The result revealed that participants took more time to recognize an object preceded by an inconsistent sentence than a consistent one, suggesting that the implied perceptual features of the concept “eagle” had been activated during sentence comprehension. Some evidence suggests that activation of perceptual features of the to-be-integrated concepts starts at a rather young age (grade 2) and remains relatively stable through early adolescence (grade 6) (Engelen, Bouwmeester, Bruin, & Zwaan, 2011) and seems to be impermeable to verbal abilities (Engelen et al., 2011) and spatial ability (Stanfield & Zwaan, 2001).

Some researchers have even argued that perceptual simulation of concepts might happen in situations lacking in contextual support. In a property-verification task (Pecher, Zeelenberg, Barsalou, 2003), participants were presented with word pairs (e.g., diamond-sparkle) and instructed to judge whether or not one word was a property of the other. Quite interestingly, researchers found that response time for the word pair *diamond-sparkle* was faster following a pair containing perceptual property from the same modality *apple-green* than following a different-modality pair *airplane-noisy*. The modality specific switch cost effect supported the idea that sensory modality of acquired verbal knowledge was obligatorily accessed in conceptual representation. These results indicated that perceptual (modal) simulation happened in parallel with semantic (amodal) processing as a result of conceptual representations of both sources of knowledge. They provided strong support that not only are semantic features preconsciously activated (cf. Barsalou, 1999), but also are those perceptual experiences associated with the concepts.

So far I have reviewed work on multiple-feature activation of the to-be-integrated concept with or without sentential context. At the early stage of lexical processing, all possible features of concepts are activated independently of the context. Certain features remain activated and are later fine-tuned by the context over time. The implication is that initially concepts may activate too much information in working memory so that comprehension requires a suppression process to sculpt conceptual representation into a set of features that are contextually appropriate. Without such suppression, interference can impair comprehension during conceptual integration processes.

Gernsbacher et al. (1990) presented participants varying in comprehension abilities with homographs (i.e., words with multiple meanings, e.g., SPADE, which could mean a spade-shaped digging instrument or a figure on playing cards) or unambiguous words in sentences (5a-5b).

(5a). *He dug with the spade. (ambiguous word)*

(5b). *He dug with the shovel. (unambiguous word)*

After reading the sentence, with different intervals of delay (short 100ms vs. long 850ms), participants were instructed to decide whether or not a target word (e.g., ACE) matched the meaning of the sentence. At the short interval, participants regardless of comprehension abilities took longer to reject the target if it was preceded by the sentence with a homograph relative to one with an unambiguous word. This is because, initially, the context-inappropriate meaning of the ambiguous homograph that was related to the target was non-selectively activated. However, differences in response latencies disappeared with longer intervals (850ms) for the good comprehenders only; for poor comprehenders, there were no differences in response latencies for short and long intervals. These results imply that all semantic features of words are initially

activated but readers with good comprehension abilities are able to inhibit the contextually irrelevant ones with more processing time available. Poor comprehenders, however, confused the two meanings of a homograph and showed enduring difficulties of selecting/specifying word meanings in context.

In a word, initially semantic and perceptual features of concepts are activated independent of context, however, the tuning of feature activation/deactivation hinges upon the extra and probably richer sentential/discourse context and readers' abilities of inhibiting irrelevant information later in the time course of language understanding.

Conceptual Combination

Besides conceptual activation, language understanding involves binding multiple concepts to form a proposition, the basic idea unit in sentences, serving as the basis for higher-order linguistic analyses (e.g., situation model creation) (Kintsch, 1988). Concepts are bound through predicates (e.g., verbs, prepositional phrase), which define the relations of concepts, and concepts that are connected by predicates are called arguments (e.g., nouns, adverbs and adjectives). The predicate-argument structure (Harley, 2001, pp. 351; Kintsch, 2001) defines a proposition (Kintsch & van Dijk, 1978; Kintsch, 1988; 1998), for example, the sentence (1a) can be represented as one proposition: (LOC: IN, DUCK, NEST). A predicate not only specifies the relationship between arguments, but also constrains the appropriate meanings of the arguments that can be selected, for example, the sentence (1a) not only implies that the duck is in the nest and *not* that the nest is in the duck, but also disambiguates duck as a noun *not* a verb (Kintsch, 2001).

Empirical data have supported the idea that readers or listeners bind concepts through verb predicates during language processing. For example, Ratcliff and McKoon (1978) found

that in a primed recognition task after learning a set of sentences like sentence (6), participants responded equally fast to the target words “truck” and “clutch” when they were preceded by the prime “chauffeur,” relative to when they were preceded by an irrelevant control, even though the surface-form item distance between prime and target was different.

(6). *The chauffeur jammed the clutch when he parked the truck.*

However, no inter-item priming was observed from “clutch” to “truck” even though the physical distance was shorter for the clutch-truck pair than the chauffeur-truck pair. This is because the arguments (i.e., CLUTCH and TRUCK) were each linked to the concept CHAUFFEUR in the propositional representation (i.e., 1-(V: JAM, CHAUFFEUR, CLUTCH) and 2-(V: PARK, CHAUFFEUR, TRUCK)). On the other hand, CLUTCH and TRUCK belong to different propositions and are therefore less tightly linked in the memory representation. These findings were taken as evidence for proposition-based text representation, as the within-proposition priming was found to be greater than the between-proposition priming controlling for surface-form distance.

The predicate defines the thematic roles (e.g., agent and patient) that arguments can take (i.e., thematic role assignment), and two nouns connected by a verb to indicate subject and object (V: S-O) in a sentence. Certain characteristics of the predicate, such as subcategorization of verbs (i.e., the ability of verbs to allow certain types of arguments; Chomsky, 1965) and verb biases (i.e., the probabilistic likelihood of verbs to allow certain types of syntactic structures; Trueswell, Tanenhaus, & Kello, 1993; Ferreira, 1994), determine the difficulty of conceptual binding. Consider the examples in 7a and 7b.

(7a) *John likes swimming.*

(7b) *John disappears from school.*

In sentence (7b), the verb *disappear* subcategorizes for a single argument *John* while in sentence (7a) the verb *like* subcategorizes for two arguments *John* and *swimming*. According to Kintsch's (1988) model, sentence (7b) can be decomposed into two propositions, 1-(V: DISAPPEAR, JOHN); 2- (LOC: FROM, 1, SCHOOL) while sentence (7a) has one proposition, (V: LIKE, JOHN, SWIMMING). It is noteworthy that sentence (7b) also has two arguments, but the subcategorization differences between the two verbs would be expected to impact the nature of conceptual binding and make the two arguments in sentence (7b) harder to bind than the two in sentence (7a).

Recent evidence supports this idea that verb subcategorization can determine the associative strength of the Noun-Noun combination. McKoon and Ratcliff (2008) took advantage of the fact that different verbs in English can have different subcategorization abilities (i.e., lay out different templates for binding noun arguments) that affect propositional structure. Specifically, verbs that indicate manner of motion (MOM), such as *drift* as in sentence (8), do not take objects, but verbs that indicate change of location (COL), such as *escape* as in sentence (9), do.

(8). *The refugees drifted into the camp.*

(9). *The hostage escaped from the cell.*

According to Kintsch's (1988; Kintsch & Keenan, 1973) model, *refugee* and *camp* belong to two different propositions (1 - (V: DRIFT, REFUGEES); 2 - (LOC: INTO, 1, CAMP)) while *hostage* and *cell* belong to the same proposition (V: ESCAPE, HOSTAGE, CELL) joined by the COL verb *escape*. After studying such sentences, participants responded to the target (e.g., *cell* vs. *camp*) after a preceding prime (e.g., *hostage* vs. *refugee*) in a primed recognition task, in which participants had to indicate whether or not each word in the list was mentioned in the previous

sentences. The authors found that the priming effect was stronger for concepts within the same proposition (i.e., hostage-cell) than for those in different propositions (i.e., refugee-camp). This is consistent with the idea that sentence understanding entails the representation of bound concepts through verbs and verb subcategorization determines how closely or strongly two concepts are bound together.

Verb biases may also change the difficulty of binding arguments. Consider examples 10 and 11.

(10a) *John reads the newspaper.*

(10b) *John reads that it is true.*

(11a) *John believes that it is true.*

(11b) *John believes the newspaper.*

The verb *read* is often followed by direct objects as in sentence (10a) while the verb *believe* is often followed by a sentence complement as in sentence (11a). The verb *read* followed by a sentence complement as in sentence (10b) or the verb *believe* followed by a direct object as in sentence (11b) is also grammatical but less plausible, which creates initial bias towards their respective dominant interpretation during parsing. Such verb bias makes it easier to bind the same pair of arguments *John* and *newspaper* in (10a) than in (11b). Evidence for this comes from a study by Trueswell, Tanenhaus, and Kello (1993), who found that critical region (underlined) reading times for more plausible sentence endings following the verbs as in sentence (12a) were shorter than those for sentences finishing with less plausible endings as in sentence (12b).

(12a). *The senator regretted the decision immediately.*

(12b). *The senator regretted the decision had ever been made public.*

Finally, semantic constraints afforded by the arguments can further determine the ease of binding concepts. Researchers (Garnsey, Pearlmutter, Myers, & Lotocky, 1997) found that temporary sentence ambiguity caused by verb biases as in sentences (12a and 12b) could be reduced by the semantic constraint offered by the arguments/noun phrases to be bound. Using sentences as (13), Garnsey and colleagues (1997) revealed that the previously reported verb bias effect (Trueswell et al., 1993) (sentence 12b is harder than sentence 12a) for the direct object bias verb “regret” was significantly mitigated if the second noun phrase (reporter vs. decision) was anomalous as the direct object of the verb (sentence 13), as measured by the reading times at the disambiguating region (underlined).

(13). *The senator regretted the reporter had ever seen the report.*

Syntactic Effects on Conceptual Combination

Not only do verb subcategorizations/biases and semantic constraints afforded by noun phrases define the linguistic computational processes of conceptual binding, but the very ways in which words are ordered and the sentence is structured in language (i.e., syntax) impact the difficulty of combining concepts in sentence. It is known certain sentence structures are harder than others to process in language. One of the most well-established findings on syntactic processing is that center-embedded object relative clauses (ORC), as in sentence (14a), are harder to process and understand than subject relative clauses (SRC), as in sentence (14b).

(14a). *The dog that the cat chased was fast.*

(14b). *The cat that chased the dog was fast.*

For example, participants read ORC slower than SRC (King & Just, 1991; Miyake, Carpenter, & Just, 1994, 1995). Caplan, Baker and Dehaut (1985) systematically summarized the factors contributing to the difficulties of processing ORC over SRC: compared to a SRC, an ORC

follows a non-canonical order of thematic role assignment (OSV vs. SVO as in SRC); the first noun phrases (NP, the dog) in an ORC is assigned two different thematic roles (i.e., object in the relative clause and subject in the main clause). There is some evidence suggesting that conceptual combination consumes working memory resources. For example, in relative clause processing, King and Just (1991) found that younger adults with lower working memory spans spent more time processing the ORC region (as measured by reading time per word) yet their comprehension was disproportionately worse than young adults with high working memory spans.

Semantic Effects on Conceptual Combination

Much of the research on semantic effects in sentence processing has focused on semantic priming/constraint (Foss, 1982; Rosenberg & Jarvella, 1970), and lexical ambiguity resolution in reading (MacDonald et al., 1994). For example, as argued earlier, lexical ambiguity (e.g., ambiguous homographs with multiple meanings vs. unambiguous words with a single meaning) affects the difficulty of instantiating word meanings in context (Gernsbacher et al., 1990) and semantic constraints afforded by lexical relatedness influence the difficulties of combining concepts with and without sentential context (Foss, 1982).

For example, Rosenberg and Jarvella (1970) found that even though recall of spoken sentences with strong vs. weak semantic constraints, as in sentences (15) and (16) respectively, were comparable under normal listening condition (quiet), recall was better for sentences with strong semantic constraint than for sentences with weak constraint in a noisy condition, implying that overlapping semantic features had facilitated integration during encoding so as to produce robust semantic representation.

(15). *The doctor cured the patient.*

(16). *The child fixed the sword.*

Perhaps counterintuitively, researchers (Gordon et al., 2001; van Dyke & McElree, 2006) have found evidence that when the syntactic structure is complex, semantic similarity of the to-be-integrated concepts can create difficulties for combining them in the sentence. It has been long argued that sentences with complicated syntactic structures are considered more acceptable when constituent nouns or noun phrases (NPs) are distinct from each other (e.g., doctor, I and John as in sentence 17a) relative to the case when constituent nouns or NPs are similar (e.g., doctor, nurse and dean as in sentence 17b) (Bever, 1974).

(17a). *The doctor everyone I met likes said John won't resign.*

(17b). *The doctor everyone the nurse met likes said the dean won't resign.*

The second (i.e., *nurse*) and the third (i.e., *dean*) common nouns in sentence (17b) (Lewis, 1996) were harder to integrate with prior content compared to pronoun (i.e., *I*) and proper name (i.e., *John*) in sentence (17a), respectively, as evidenced by acceptability judgments. Probably this is because proper names/pronouns referred to a certain entity more directly, while common nouns might be preliminarily unspecified and need to be further specified by the determiner or a void determiner (e.g., lawyers, the lawyers, the lawyer or a lawyer) to refer to a generic kind, a set of entities, a given or a new entity (Gordon, Hendrick, & Johnson, 2004), which takes extra time to interpret the specific meaning of a particular common noun. Furthermore and probably most importantly, Gordon suggested that the need to temporarily maintain a common noun (the first NP) in working memory before it can be interpreted as the object of the verb, as in ORC (cf. 14a & 14b), creates a condition where encoding of another similar NP can interfere with retrieving and/or integrating the previous one (Gordon et al., 2006). In contrast the NP-type effect would be minimized when the need of maintaining a previously

introduced NP was low, as in SRC in which the first NP is immediately and locally interpreted as the subject of the RC even before another similar NP is encountered.

In a series of experiments, Gordon and colleagues (2001; 2004; 2006) varied the confusability of two noun phrases embedded in the relative clauses as in sentences (18a-19b): *banker* and *barber* as in sentences (18a and 18b) belonged to the same grammatical class of common nouns while *banker* and *Steven* as in sentences (19a and 19b) belonged to different grammatical classes of common nouns and proper names, respectively.

(18a). *The banker that praised the barber climbed the mountain just outside of town.*
(similar-SRC)

(18b). *The banker that the barber praised climbed the mountain just outside of town.*
(similar-ORC)

(19a). *The banker that praised Steven climbed the mountain just outside of town.*
(dissimilar-SRC)

(19b). *The banker that Steven praised climbed the mountain just outside of town.*
(dissimilar-ORC)

They found in both self-paced reading and eye-tracking that the typical processing difficulty for ORC in relation to that for the SRC was greatly diminished (if not eliminated) when two NPs belonged to different semantic categories.

In the same vein, Gordon, Hendrick, and Levine, (2002) asked participants to read sentences varying in syntactic complexity (Object-extracted cleft or OC, as in sentence 20a vs. Subject-extracted cleft or SC, as in sentence 20b) in a moving window paradigm for comprehension while simultaneously maintaining/storing a three-word list (e.g., nurse-witness-pilot or James-Paul-Don) in memory.

(20a). *It was the banker that the barber praised after the conversation. (OC-common noun)*

(20b). *It was the banker that praised the barber after the conversation. (SC-common noun)*

(20c). *It was Kenneth that Robert praised after the conversation. (OC-proper name)*

(20d). *It was Kenneth that praised Robert after the conversation. (SC-proper name)*

They manipulated the semantic similarity between the memory load and the two-noun phrases embedded in the sentence, with noun phrases in the memory load and the sentence coming from the same (e.g., “nurse-witness-pilot” and “bank-barber”; “James-Paul-Don” and “Kenneth and Robert”) or different (e.g., “nurse-witness-pilot” and “Kenneth and Robert”; “James-Paul-Don” and “bank-barber”) semantic categories. Results revealed that the critical region (underlined) of the OC construction was read differentially longer than that of the SC construction when the semantic category of the load matched that of the noun phrases in the sentence (see Fedorenko Gibson, & Rohde, 2006, for similar findings), suggesting controlling interference in working memory could be a potential contributor to the “SC over OC,” or “SRC over ORC,” advantage in syntactic parsing.

Gordon et al. (2004, 2006) concluded that the ubiquitously reported ORC over SRC processing difficulty in English language could be mitigated (if not eliminated) by reducing the similarities between two to-be-integrated NPs (both common nouns vs. a mixture of common noun and proper name or a mixture of common noun and pronoun) (Gordon et al., 2001). When two similar NPs were embedded in SRC, the second NP could be immediately integrated with the first one through the verb because of the canonical SVO linear structure of SRC, while two similar NPs embedded in ORC structure consumed extra working memory to store and/or

retrieve before they would be interpreted as object or subject of the verb, respectively. Gordon also demonstrated nicely that it was the similarity between two NPs not the specific characteristics of the NPs (e.g., common nouns vs. proper names or definite vs. indefinite NPs) per se that was causing the interference in working memory (Gordon, 2001; 2004).

Moreover, the grammatical class similarity effect on conceptual combination is not just evident for noun-noun combinations (as in the case of ORCs/SRCs) but between verb-noun phrases. Van Dyke and McElree (2006) instructed participants to read sentences as in (21a-21b) region by region (as marked by slashes) in a self-paced moving window paradigm while simultaneously maintaining a three-word list (i.e., table-sink-truck).

(21a) *It was the boat/that the guy/who lived/by the sea/sailed/in two sunny days.*

(21b) *It was the boat/that the guy/who lived/by the sea/fixed/in two sunny days.*

The critical region (underlined) was the main verb (*sailed* vs. *fixed*) which served as a cue for the verb phrase attachment (*sailed-boat* vs. *fixed-boat*) during sentence processing. The memory load (table-sink-truck) could potentially interfere with the VP attachment in the second sentence because they all could be plausible arguments for the verb (*fixed*). Consistent with this prediction, it was found that reading time was significantly longer for the target word in the second sentence than in the first one, suggesting retrieving arguments for verbs in sentence comprehension was subject to controlling interference in working memory.

One question is whether similarity-based interference is specific to thematic role assignment in reading or reflects a more general memory principle. There are data to support the latter. Similarity-based interference was manifested in list memory paradigm such that easy-to-associate or similar concepts (as introduced by experimental manipulations, overlapping semantic/perceptual features or belonging to the same semantic/grammatical class) could cause

“false” memory during word list learning. In a word learning paradigm, Reinitz and Demb (1994) presented participants with compound words (e.g., *blackmail* and *jailbird*) and found that later during the test session participants made more recognition errors when a lure was recombined from component features of studied words (e.g., *blackbird*) and this type of recognition error (or memory illusion) decreased as feature interference decreased (e.g., *blackbird* vs. *blackboard* vs. *whiteboard*). *Blackbird* was most interfering not just because both sublexical features (black- and -bird) appeared during the study session, but because both features were connectable to form a plausible lure during recognition. *Blackboard* was moderately interfering because it shared partial semantic feature overlapping with the target *blackmail* (see also Reinitz, Lammers, & Cochran, 1992; Lampinen, Odegard, & Neuschartz, 2004; Chalfonte & Johnson, 1996). These findings suggested that association-based interference during encoding of a word list might penetrate into the retrieval stage of semantic feature combination.

At first glance, a similarity-based account of difficulty in binding concepts that share overlapping semantic features may seem at odds with the broader literature on semantic priming and semantic facilitation in conceptual integration. As discussed earlier, semantic facilitation in reading comprehension has been often observed in canonical SVO syntactic structures (Rosenberg & Jarvella, 1970; Foss, 1982); however, in these studies the first NP was immediately interpreted as the subject and second NP was immediately interpreted as the object with or without minimal reliance on working memory resources to retain the temporarily unbound concepts. In more complex syntactic structures such as ORCs, the thematic roles of the first and second NPs are under-determined to the point of the disambiguating relative clause verb, leaving both of them unbound. It is this temporary “unboundedness,” or lack of thematic

role specification, in ORCs that make concepts with overlapping semantic features confusable in working memory. ORC structure makes it necessary to maintain both concepts in working memory before encountering the clause verb, and semantic similarity between concepts makes them less distinct from and more liable to interfere with each other, competing to be the (specious) subject or object of the clause once encountering the clause verb during thematic role assignment (Gordon et al., 2004). On the contrary, concepts that are relatively distinct will cause little interference during thematic role assignment even if they are temporarily unbound as in the ORC construction. In addition, most previous studies with SRCs/ORCs (King & Just, 1991) controlled for the semantic constraints afforded by the clause verbs (e.g., *The patient that the doctor called/cured ...*), reducing or completely eliminating the facilitating effects of both expectancy and plausibility on integrating incoming concepts (Federmeier, 2007; Kutas & Hillyard, 1984) and making similar concepts especially hard to integrate/bind in difficult syntactic structures.

In short, rules of conceptual binding are defined by verb predicates and further constrained by the semantics of the noun phrases, generating the basic unit of meanings in sentence. Varying the surface word order of language (i.e., syntax) changes the processing difficulty of conceptual combination, which can be moderated by the semantic similarities of the to-be-integrated concepts embedded in sentence. Cross-paradigmatic comparison of language and memory literature revealed that similarity-based interference in combining concepts happened at both lexical and sublexical levels.

Situation Simulation and Embodied Language Processing

The representation of ideas directly from the text is often referred to as a “textbase” process (Kintsch & van Dijk, 1978). This process is often contrasted with a process in which

readers/listeners infer information that is text-driven but never explicitly mentioned (i.e., Situation Model processing). Representation of ideas and situation simulation, although independently regulated (Kintsch, 1994; Stine-Morrow et al., 2006; Shake et al., 2008), can be computed simultaneously (Zwaan et al., 1995a; 1995b) and interactively in normal reading (Stine-Morrow, Miller, & Hertzog, 2006; Stine-Morrow, Miller, Gagne, & Hertzog, 2008). Depending on specific reading goals (Graesser, Millis, & Zwaan, 1997; van den Broek, Lorch, Linderholm, & Gustafson, 2001), situation-level understanding is often desirable in language processing and learning, and demonstrates most resilience and least declines in face of cognitive constraints (Radvansky & Dijkstra, 2007).

While some theorists (Kintsch, 1998; Gernsbacher, 1990) argue that the situation model is strictly linguistically based (amodal), more recent models of language processing (Barsalou, 1999; Zwaan et al., 2002) have suggested that in addition to linguistically based semantic features, functional and perceptual features of to-be-integrated concepts can be activated. This latter view of language processing can be regarded as part of a general embodied cognition framework (Barsalou, 1999; 2008a; 2008b; 2009), in which the format of mental representation is modal. The form of experience-based representation is argued to be the consequence of perceptual simulation, or the mental and bodily “reenactment of perceptual, motor, and introspective states acquired during experience with the world, body, and mind” (Barsalou, 1999, p. 617). This distinction can be illustrated with an example. According to a proposition-based view of the situation model (e.g. Till et al., 1988), readers encountering a sentence as (4a) activate semantic associates such as *cloud*, as well as proposition-based inferences such as *the eagle is flying high*, based on pre-existing knowledge activated by the text-based propositions (Ericsson & Kintsch, 1995). However, according to an embodiment view of situation model

processing, readers may also mentally simulate the event described in the text (Bower & Morrow, 1990; Morrow, Bower, & Greenspan, 1989; Zwaan, et al., 2002; Barsalou, 1999), thereby enriching the situation model construction with perceptual features.

There is evidence that embodiment of language not only involves *mental* simulation of perceptual features (Zwaan et al., 2002) but also *bodily* simulation of motor experiences implied by text. Zwaan and Taylor (2006) demonstrated that comprehension of action verbs activates motor simulation. They took advantage of the fact that many verbs or verb phrases in English imply the direction of motor responses (Glenberg & Kaschak, 2002). For example, in sentences (22a and 23a), the verbs imply a counterclockwise manual movement, while in sentences (22b and 23b), the verbs imply a clockwise manual response.

(22a). Mark turned left at the intersection. (*counterclockwise*)

(22b). Mark turned right at the intersection. (*clockwise*)

(23a). Bob opened the gas tank. (*counterclockwise*)

(23b). Bob closed the gas tank. (*clockwise*)

Participants read such sentences segment by segment, self-pacing the text by rotating a knob either clockwise or counterclockwise. This way the researchers manipulated the compatibility between manual response required by the reading task and the simulated response implied by the verb phrase. Interestingly, readers spent more time on the verb region if the manual response was incompatible with the perceptually simulated response of the sentence. Zwaan and Taylor (2006) concluded that their data supported a simulationist view of language comprehension, which involves the immediate and localized activation of perceptual and motor experience rather than the activation of abstract modules (Fodor, 1983).

According to the embodiment view, meaning is constructed by grounding abstract linguistic symbols in specific perceptual-motor experiences in the external environment (Glenberg & Robertson, 2000) and language processing involves fast mental/bodily simulation of past motor, functional and perceptual experiences associated with concepts, conceptual relationships, situations, events or scenarios conveyed by the symbolic linguistic inputs (Barsalou, 2009; Zwaan & Taylor, 2006).

Recap

In sum, in language comprehension, features of individual concepts are first activated in a context-independent fashion. In the face of complicated syntactic structures that require the retention of unbound concepts, overlapping features of similar concepts could potentially cause confusions for the readers/listeners during thematic role assignment. On the other hand, binding multiple concepts together in the sentence provides the basis for generating inferences about the overall situation, which in turn contributes to selective conceptual feature activation. Initially both semantic features and perceptual features can be activated and evidence has shown that successful later selective activation of context-appropriate features depends on inhibitory function or resistance to interference of the individuals.

Age-Related Change and Invariance in Language Processing

Aging is associated with increments in crystallized abilities such as verbal knowledge and declines in fluid abilities such as working memory resources (Park, Smith, Lautenschlager, Earles, Frieske, Zwahr, & Gaines, 1996). Many theorists of language processing have argued that conceptual combination as in complex syntactic parsing consumes memory resources (Miller & Kintsch, 1980; Ericsson & Kintsch, 1995; King & Just, 1991; Gordon et al., 2002; Chen, Gibson & Wolf, 2005), and therefore, age-related deficits in text memory could be attributed in part to

age-related impairment in binding concepts (Johnson, 2003; Shake, Noh, & Stine-Morrow, 2008; Stine-Morrow et al., 2006). In contrast, conceptual activation (Laver & Burke, 1993), and modal, unconscious and obligatory situation simulation (Zwaan & Taylor, 2006; Barsalou, 1999, 2008a; 2008b; 2009; Solomon & Barsalou, 2001; 2004) in language understanding show relative age invariance (Radvansky, Zwaan, Curiel, & Copeland, 2001; Radvansky & Dijkstra, 2007; Radvansky & Copeland, 2004), probably because of their greater reliance on knowledge which tends to increase or at least be preserved with aging.

However, it is not clear a) what the underlying mechanisms contributing to conceptual binding difficulties that older adults face in sentence processing are, and b) to what extent processing resources allocated to binding might impair situation model construction. In the next subsections, I will review literature on age differences in conceptual activation/binding and situated language processing and on working memory capacity-constrained view of age differences in language understanding, concluding by providing a similarity-based interference control account of working memory in age differences in different levels of language processing.

Age Differences in Conceptual Activation in Language Processing

Although initial conceptual feature activation seems to be obligatory and thus demonstrates least age-related deficits, empirical results are not conclusive with regards to whether there are age-related changes in selective activation of context-appropriate features. It has been systematically documented that semantic priming is preserved (if not enhanced) with aging (Laver & Burke, 1993), possibly as a result of increased automaticity after years of using the language. Light, Valencia-Laver, and Zavis,(1991) argued that older adults are capable of activating situationally appropriate semantic associates (e.g., specific exemplars of a superordinate) according to event scenarios. For both age groups, response times in a lexical

decision task were faster to the typical exemplar “bee” than the atypical exemplar “termite” after reading the sentence 24a, while this pattern was eliminated after reading the sentence 24b, because readers suppressed the activation of more typical exemplar “bee” (the typicality effect) by taking the specific situation into consideration.

(24a). *The insect in the clover stung the professor.*

(24b). *The insect in the woodwork concerned the professor.*

However, other studies have suggested that older adults have difficulties selecting the appropriate meanings of ambiguous words in sentences. Faust, Balota, Duchek, Gernsbacher, and Smith (1997) adopted a paradigm (see sentences 5a-5b) originally developed by Gernsbacher, Varner, and Faust (1990) and extended it to older adults. Similar to younger adults, older adults showed inflated response latencies for the target after a homograph compared to after an unambiguous control with a short interval, suggesting that immediate activation of inappropriate meaning was age-invariant. However, in contrast to younger adults (Gernsbacher et al., 1990), healthy older adults did not show decay in the activation of inappropriate meanings at the longer delay (1000ms vs. 100ms), providing provocative evidence of age declines in coordinating and selecting between two competing and interfering meanings in working memory.

Recently age deficits in conceptual activation have been observed in assigning new meanings to ambiguous concepts in episodic memory. Rawson and Touron (2009) embedded novel concepts (e.g., monkey thieves) in narrative passages to investigate how readers learn the meanings of new concepts with training and repetition. Reading times on the disambiguating region after the novel concepts were collected, with either dominant or subordinate interpretation of the noun-noun phrase (e.g., the novel term monkey thieves might plausibly refer to *activists*

who stole the monkeys or to monkeys who stole the food). Reading times were shorter for later blocks than earlier ones and were shorter for dominant interpretations than subordinate interpretations, suggesting that the dominant interpretation is easier to remember. Regardless of age, readers benefited from repetition as they learned the conceptual referents and were able to automatically retrieve the mental representations of the novel combinations. However, the effect of dominance on processing time disappeared later in the practice blocks for the older adults than for the young, indicating older adults might have required more exposure to learn the infrequent subordinate meanings of new concepts. Rather, they appeared to persist in relying on an effortful recalculation strategy rather than switching to an automatic retrieval strategy to instantiate meanings in text (Rawson & Middleton, 2009). Interestingly, age differences were completely eliminated when the interpretations of combinations were pre-trained to ceiling-level. These findings provided strong evidence that older adults are slower in learning the associations between novel concepts and their text-derived meanings. Similar to older adults in Faust et al.'s (1997) study, older adults in this study failed to retrieve the proper meanings of ambiguous concepts from episodic or semantic memory and thus had to resort to a computation-based approach so as to guide their immediate online interpretation of novel concepts. It is noteworthy that both studies implied that coordinating two interfering meanings of concepts declines with normal aging despite prior contextual support or training, probably due to age-related impairment in inhibitory function.

This literature suggests that conceptual activation is preserved with aging, but empirical evidence concerning age differences in inhibiting irrelevant conceptual features is not conclusive. Discrepancies in results across experiments could potentially have been introduced by different computational demands imposed by the tasks. For example, in both studies (Faust et

al., 1997; Rawson & Touron, 2009) where age-related declines were identified, participants either had to immediately inhibit the irrelevant interpretation or instantiate novel concepts in discourse while reading, whereas in the Light et al. study (1991), participants (particularly the older ones) might have taken advantage of the extra time allowed (2500ms sentence presentation time plus 350ms delay before a relatedness judgment) to inhibit the activated irrelevant typical exemplar after sentence (23b), as timing has been shown to be critical in determining the contextual effect in selective meaning/feature activation (Miller & Kintsch, 1980; Gernsbacher et al., 1990; Swinney, 1979).

Age-Related Declines in Conceptual Combination

Assuming that syntactic structure “instructs” readers about how to bind concepts into a conceptual representation (e.g., Ericsson & Kintsch, 1995, p. 230), it is perhaps not surprising that, thematic role assignment in the face of complex syntax declines with age (Kemper, 2006). However, conceptual binding and integration can take many different forms beyond thematic role assignment. In previous sections, I discussed proposition extraction (Ratcliff & McKoon, 1978; McKoon & Ratcliff, 2008; Kintsch, 1988) as basic principles of conceptual integration in language processing and there has been ample evidence suggesting that proposition-based recall is also subject to age-related declines. In a comprehensive review of age differences in text memory, Johnson (2003) found that age differences were most pronounced for when the scoring unit for text was the word or proposition, whereas such differences were attenuated when the whole sentence or each phrase/clause was the basic consisting scoring unit, consistent with the idea that older adults paid more attention to the global situations than the details (Radvansky et al., 2001; Radvansky & Dijkstra, 2007; Stine-Morrow et al., 2006; 2008). Hartley and colleagues (1994) argued that age-related deficits in propositional recall could be attributed to deficits

during encoding as reflected in prolonged reading time for each proposition correctly recalled for this age group. Similarly, Stine and Hindman (1994) found that as a reading efficiency measure, reading time per proposition was differentially longer for those older adults with less working memory resources, supporting a resources-dependent view of conceptual binding during reading.

It is possible that age-related degradation in binding concepts in language processing, especially in the case of complex sentence processing, is ultimately due in part to more general associative binding deficits in memory (Naveh-Benjamin, 2000). For example, Naveh-Benjamin and his colleagues (2000; 2003; 2005; 2008a; 2008b) instructed participants to remember word pairs (i.e., paying attention to both members and their associations in a pair) and tested their recognition memory for either the pair as a whole or its constituent individual words. They showed that age-related declines in working memory selectively impaired older adults' associative memory for the word pairs but not respective members of the pairs, even if they were explicitly instructed to pay attention to both members as a whole and their associations. Furthermore, Naveh-Benjamin et al. (2003, Experiment 1) showed that older adults in a normal encoding condition or younger adults in a divided attention condition made more false alarms than the young in a full attention (normal) conditions even when the two to-be-learned words were not semantically related. Relevant to the similarity effect in complex sentence processing (e.g., Gordon et al., 2002), they also found (Naveh-Benjamin et al. (2003, Experiment 2) that false alarms increased with greater semantic relatedness for all three age groups, suggesting similarity-based interference during encoding and retrieval made it harder to distinguish old associated concepts from rearranged semantically-related new pairs.

Altogether, these findings suggest that a) there are age differences in binding concepts in sentence and binding words in a pair in associative learning; and that b) one mechanism of

explaining these age differences could be older adults' deficits in maintaining two similar entities and binding them together to form a unified meaning representation in working memory.

Age Differences in Situated and Embodied Language Processing

While considerable evidence supports the conclusion that situation model encoding and comprehension are preserved if not enhanced with aging (Radvansky et al., 2001; Radvansky & Dijkstra, 2007; Stine-Morrow et al., 2006), some data have suggested that it is not always the case (Copeland & Radvansky, 2007; Madden & Dijkstra, 2010; Friedman & Miyake, 2000).

Particularly strong support for an age advantage in situation model processing comes from Radvansky et al. (2001), who used the Kintsch, Welch, Schmalhofer, and Zimny (1990) paradigm to investigate how age differences in levels of representation during encoding might impact retrieval processes from long-term memory. After reading discourse passages, participants were presented with probes to which they responded to indicate whether or not they had read the sentence before. Four types of recognition memory probes were created as in sentences (25a-25d).

(25a). *The plot bitterly intensified Protestant suspicions of Catholics. (Verbatim)*

(25b). *The plot greatly heightened Protestant distrust of Catholics. (Paraphrase)*

(25c). *The plot led to increased acts of persecution of Catholics. (Inference)*

(25d). *After the plot, donations to Protestant churches rose dramatically. (Irrelevant Control)*

It was found that younger adults showed superior memory for verbatim and paraphrase information, whereas older adults showed better memory for the situation model information of

the text. Further study from this group (Radvansky & Copeland, 2004) adopting this paradigm with a larger sample of younger adults revealed that working memory span was not correlated with situation-level understanding but sparsely correlated with textbase processing (conceptual binding).

In another example, Dijkstra and her colleagues (2004) used the Zwaan et al. (2002, e.g., sentences (4a) and (4b)), demonstrating that both younger and older adults took more time to judge an object with shape inconsistent with that implied from the sentence. Older adults, however, demonstrated a stronger mismatch effect, suggesting that situational and perceptual simulation of the situation was preserved, or even enhanced, among the old.

Some exceptions have been demonstrated by Copeland and Radvansky (2007) and Madden and Dijkstra (2010), both of whom suggested that situation model encoding might in fact be constrained by working memory capacity. In a slightly modified perceptual simulation paradigm (Zwaan et al., 2002; Dijkstra et al., 2004, see sentences 4a and 4b), this same group of researchers (Madden & Dijkstra, 2010) found that situation simulation was only preserved for those elders with higher working memory capacities. In other words, situation simulation was impaired in those elders demonstrating relative cognitive declines, implying that more resilient situation model construction might (as well) be subject to constraints placed by available cognitive resources (Madden & Zwaan, 2006).

Copeland and Radvansky (2007, Experiment 1) presented participants with successive sentences depicting the arbitrary spatial relationships among objects as in sentences 26a-27c and then probed them by multiple choice questions concerning those relationships (e.g., "The rose is to the right of the orchid?"). Sentences as 26a-26c describes indeterminant spatial relationships among concepts because of lack of overlapping concepts in three successive sentences while

sentences as 27a-27c describes determinant spatial relationships because of overlapping concepts in consecutive sentences (Johnson-Laird, 1983).

(26a). *The rose is above the lily.*

(26b). *The tulip is below the orchid.*

(26c). *The lily is to the left of the orchid.*

(27a). *The rose is above the lily.*

(27b). *The lily is to the left of the orchid.*

(27c). *The tulip is below the orchid.*

Despite comparable performance in the determinant condition, older adults' identification accuracy in the indeterminant condition was just a little above chance performance and worse than that of the young. Regression analysis revealed that working memory partially explained this age difference in the indeterminant condition. Interestingly, the age difference in comprehension in the indeterminant condition was reduced by using a visual diagram (Experiment 3) explicitly conveying the spatial relationship implied by each sentence, suggesting that older adults might have failed to visualize and simulate the spatial relationships of objects that are hard to integrate in the discourse. These findings provided some support that binding conceptual relationships that could not be easily scaffolded by existing knowledge (Radvansky & Dijkstra, 2007) is so demanding on working memory resources that it constrained spatial situation model construction with unknown or at least underspecified mechanisms (Friedman & Miyake, 2000). Nevertheless, both studies (Copeland & Radvansky, 2007; Madden & Dijkstra, 2010) provided preliminary evidence that situation-level simulation under certain occasions can be constrained by working memory resources.

Consistent with those findings demonstrating age differences in conceptual combination/binding in sentence processing, there are some examples in discourse-level language processing suggesting that age deficits in situation model construction can be pronounced when the unfolding discourse calls for interference control (Lustig, Hasher & Zacks, 2007), which might serve as a candidate mechanism to explain age differences in situation simulation. Hasher and Zacks' classic findings (1988) revealed age differences in controlling interferences from a previously established situation model. In the original study, discourse context that either initially biased one interpretation and then shifted toward another interpretation (unexpected condition) (e.g., in the passage "The artist," the text first implied that the artist had three months to *finish* the art work and subsequent text indicated clearly that such an inference was wrong, requiring readers to update a more accurate one – the artist had three months to *live*) or consistently supported the initial interpretation (expected condition) (e.g., the initial and subsequent context always supported the inference that the artist had three months to *live*.) was adopted. Compared to the young, older readers' responses to probe questions (e.g., The artist had three months to do what?) following the passages were differentially impaired by shifting in topics to unexpected outcomes, suggesting that suppressing a previously established situation level inference was particularly hard for the old, which in turn compromised their text comprehension. They interpreted these results to mean that aging was associated with declines in revising previous established inference in discourse comprehension and forming new inference that was context-appropriate and further argued that the ability of successful inhibiting information that was no longer relevant was central to language understanding and could explain many age differences in language/cognitive tasks.

In sum, situation-level simulation of the text is mostly preserved, sometimes enhanced and rarely impaired with aging. The inconsistencies regarding age differences in situation simulation can be understood from a constrained resource perspective, according to which one of the mechanisms of working memory resources in language processing is controlling interference and resisting to distractors while staying on task. When the conditions call for interference control in working memory, situation-level construction/simulation of the meanings/events/scenarios might become compromised as well, beyond conceptual representations.

Basic Memory Mechanisms to Understand Age Differences in Language Processing

So far I have reviewed age differences in conceptual activation, combination and situation simulation in language processing and how the abilities of controlling interference in working memory might serve as a viable mechanism to understand such differences. For the remaining part of this section, I will argue that age-related deficits in controlling interference among similar concepts might reflect a regulatory failure that derives from more general memory mechanisms that can even be demonstrable in other memory tasks that are not language processing per se (Braver & West, 2008; Unsworth & Engle, 2007). Researchers (Lustig, May, & Hasher, 2001) further revealed that the oft-observed age differences in reading span (Daneman & Carpenter, 1980) can be significantly reduced by merely reversing the order of presentation, starting from the largest sentence set instead of the smallest one. They explained presumably this procedure decreases the proactive interference from previous smaller set(s) on the current one during word retrieval, which otherwise might have prevented participants from advancing to larger sets and systematically underestimated their performance potentials. By reversing the presentation order and starting with the bigger chunks, the task is adjusted for vulnerable

participants with their highest-possible memory level evaluated first that is uncontaminated or minimally contaminated by proactive interference. May, Hasher and Kane (1999) attempted to release the proactive interferences in span task by both reversing the order of presentation and inserting filler task between trials (i.e., participants were required to complete a visual discrimination task after each sentence set before starting a new one). They found that either order reversal or filler task eliminated the age differences in word recall observed in traditional working memory span task, indicating that tasks that minimized proactive inference had made newly presented items more distinct in working memory during encoding/retaining and thus easier to retrieve (Bunting, 2006; Nairne, 2002).

Similarly, the modulating role of interference on age differences in working memory has been reported in a visuospatial working memory task (Rowe, Hasher, & Turcotte, 2010), in which participants had to remember the spatial location of the target square (black) among many other irrelevant distracting squares (gray or black/white abstract pattern) on each screen. Analogous to complex reading span, screens containing squares were presented consecutively with the number of screens varied from 4-7 in a trial, taxing the visuospatial working memory by requiring 4-7 locations to be simultaneously maintained in a given trial. Critical to the manipulation was the pattern of the distracting squares, in a visually similar block distracting squares were filled with gray color that only differs in contrast level from black on the grayscale while in a visually distinct block, distracting squares were filled with abstract black and white patterns. The result revealed that making the target/distractors distinct from each other reduced the age differences in this complex visuospatial working memory task, probably because it decreased the interferences from the distractors during the encoding and retrieving of the spatial information of the target. Moreover, all the aforementioned paradigms targeting at reducing the

proactive inference in complex memory span tasks capitalized on making the to-be-remembered items distinct in working memory, a proposition echoing well with Gordon, Hendrick, and Johnson (2004)'s argument concerning the noun type effect on complex sentence processing.

CHAPTER 2

CURRENT STUDIES

The goals of this project are to test an interference control account of adult age differences in conceptual binding and to explore whether there are any residual effects of interference control during conceptual integration on perceptual simulation in language understanding. Previous studies on age differences in conceptual activation have shown that under some circumstances, such as complex syntax, speeded response, learning novel concepts, older adults have relative difficulty in selecting the most relevant features according to the sentential context. Older adults' failures in inhibiting irrelevant features of concepts or over-activation of conceptual features (Gernsbacher, 1991) may lead to less distinct representations of related concepts. When the syntax requires simultaneous maintenance of similar concepts in working memory, the compromised representations that are less distinguishable in working memory may eventually cause confusion for the older reader in assigning thematic roles to concepts with feature overlap, thus hampering binding. While considerable literature supports a resource-dependent and age deficits view of conceptual integration in reading, few studies have investigated the effects of working memory resources on situation or perceptual simulation. Given the inconsistencies regarding this issue in the existing literature, I situate the resource-dependent hypothesis of perceptual simulation under a stringent testing condition where conceptual binding and integration in sentence reading is subject to similarity-induced interference in working memory. Binding concepts is resource-consuming and it is particularly the case when the to-be-integrated concepts would cause confusability in the working memory. Under these circumstances (when concepts are hard to bind in the clause), subsequent sentence

processing, which calls for situation simulation, may suffer the downstream effect(s) of binding two confusable concepts. In other words, challenges of binding similar concepts can penetrate into situation simulation, leading to impoverished or incomplete situation-level inference or mental/bodily enactment that lacks in fidelity or perceptual richness. Understanding the exact roles of interference control in reading can help elucidate the underlying mechanisms of age-related changes in binding concepts and simulating situations.

Experiment 1

Although it is relatively clear that aging brings about deficits in binding concepts in language and memory in offline tasks (Johnson, 2003; Kemper, 2006), what is lacking is direct evidence of age differences in binding as it happens during reading to understand its underlying mechanisms. The goal of the current experiment was to test a similarity-based account of complex sentence processing (Gordon et al., 2006). The difficulty of conceptual integration was directly manipulated by simultaneously varying syntactic complexity and semantic similarity of embedded NPs and an individual difference approach was adopted. Fedorenko et al. (2006) found that among college-age students, high working load condition (three words in the list vs. one word in the list) was associated with greater syntactic effects particularly when the to-be-integrated NPs were similar (i.e., three-way load by syntax by similarity interaction), consistent with interference control theory of sentence processing. Based on this theory, it was predicted that older adults as a group would be differentially affected by complex syntax and semantic similarity compared to the young, and that these effects would be exacerbated among those with fewer working memory resources.

Kemper and Herman (2006) extended Gordon et al.'s paradigm (2002) in which participants had to maintain an interfering vs. non-interfering word list while processing object-

relative vs. subject-relative clefts to older adults. Replicating previous findings with young college students (Gordon et al., 2002; Fedorenko et al., 2006), the researchers found that there was a reliable interaction between syntax and similarity among the younger adults, who read the critical region of Object Cleft (OC) sentences disproportionately slower than that of Subject Cleft (SC) sentences when the memory load was semantically similar to the noun phrases in sentence (cf. sentences 18a vs. 18b). Surprisingly, this effect was not observed for the old, who only showed a main effect of the syntactic manipulation. In other words, based on the online measure, the older adults did not allocate disproportionately more time to process the harder cleft (OC) than the easy one (SC) while maintaining similar words in working memory. Similarly, sentence comprehension showed additive effects of age and syntax without any effect of memory load.

These data are not consistent with an interference control account of age differences in language processing. However, older adults' recall for words in the memory load was not differentially impaired among the old by more complex syntax, leaving open the possibility that older adults might have re-allocated their resources to understanding the most complex sentences, depleting resources that would otherwise be available for the memory load. This possibility for differential trade-offs between memory load and sentence understanding with age leaves open the possibility this paradigm may provide a relatively insensitive test of the critical age by syntax by similarity interaction. Furthermore, the age effect in list recall that older adults made more recalling errors suggested that older adults might have forgotten the presumably interfering words while processing the clefts, and consequently the load manipulation failed to exact its effect on complex syntax processing. In order to further test an interference-based account of age differences in sentence processing and the modulating role of working memory in simultaneously maintaining and integrating two highly confusable concepts, I directly

manipulated the semantic similarity of the noun concepts within the sentence (without introducing a secondary task; cf. Gordon et al., 2006), and examined comprehension among younger and older adults with varying levels of working memory capacity.

Methods

Participants

Thirty-six community-dwelling older adults ($M=70$ yrs, aged 61-83) and 36 college students ($M=23$ yrs, aged 19-37) participated in this experiment. The age groups did not differ in education ($M_o=16.4$, $SD=3.4$; $M_y=15.4$, $SD=2.4$) or vocabulary ($M_o=45.0$, $SD=8.1$; $M_y=46.9$, $SD=6.1$; Wechsler, 1981), all $t < 1$, but younger adults had a larger verbal working memory span (Stine & Hindman, 1994) than the old ($M_o=4.1$, $SD=1.2$; $M_y=6.4$, $SD=1.3$), $t(70)=7.62$, $p<.001$.

Materials & Design

Forty-eight sentences were adapted from Gordon et al. (2001; 2002; 2006) and previously published papers (King & Just, 1991; Frazier & Clifton, 1986), varying in syntactic complexity and conceptual similarity between the to-be-integrated noun phrases (Table 1; the critical region is underlined, and post-critical region is italicized). There were also 48 filler passages, none of which involved any syntactic or similarity manipulation. Four stimulus lists were created in which materials were counterbalanced across conditions. Passages were presented in a single pseudorandomized order for all subjects.

Procedure

Passages in white font were presented on black background on a 19-in. ViewSonic P225f monitor set to a resolution of 1024 x 768 pixels and a refresh rate of 120Hz. Eye movements were monitored by an SR Research EyeLink II head-mounted eye-tracker with a sampling rate of

500 Hz. Participants were instructed to place their heads on a chin rest and to keep their heads as still as possible during the experiment. The distance from monitor to chin rest was 96.5cm and the visual angle was 1/3 degree per letter with 30-point Times New Roman font.

Materials were positioned on the screen such that target words never appeared at the beginning or end of a line of text. Participants read passages with both eyes, however, only the data of the dominant eye was collected and analyzed for every participant after initial calibration and validation. A randomly selected one-third of the passages were followed by a Yes/No comprehension question to assure that participants read for comprehension.

Results

Comprehension Accuracy

Comprehension accuracy was analyzed with hierarchical linear modeling (HLM, Baayen, Davidson & Bates, 2008) using a logit model for binary dependent variables, with age, syntax and similarity entered as predictors in the full model (all the main effects plus all the possible interactions). Figure 1 showed that younger adult had better comprehension than older adults, $M_{\text{Young}}=90.9\%$ vs. $M_{\text{Old}}=77.2\%$, $z=5.11$, $p<.001$, and it was also more difficult for readers to understand sentences with more difficult syntactic structure, $M_{\text{ORC}}=80.2\%$ vs. $M_{\text{SRC}}=87.8\%$, $z=8.12$, $p<.001$, or sentences containing two noun phrases from the same semantic category, $M_{\text{Same}}=82.1\%$ vs. $M_{\text{Different}}=85.9\%$, $z=3.90$, $p<.001$. Most importantly, the three-way age by syntax by similarity interaction plotted in Figure 1 was significant, $z=4.76$, $p<.001$, demonstrating the two age groups were differentially affected by syntax and similarity. The three-way interaction was decomposed by analyzing young and old data separately, revealing that older adults' comprehension was differentially impaired by complex syntax when the two noun phrases belonged to the same category, $z=4.07$, $p<.001$, for the two-way interaction; while

younger adults were equally affected by syntax regardless of the linguistic similarity manipulation, $z < 1$.

Previous research (Fedorenko et al., 2006) has indicated the effects of syntax and similarity on sentence comprehension could be modulated by working memory load among younger adults, and thus a separate four-way full model was implemented in HLM with individuals' working memory span entered as a potential moderator. Figure 2 showed that individuals with higher working memory span had better comprehension performance, for estimates of performance at the mean-level and at the 1SD above/below the mean-level of working memory, $M_{\text{Mean}-1\text{SD}}=89.4\%$, $M_{\text{Mean}}=93.0\%$, $M_{\text{Mean}+1\text{SD}}=95.5\%$, $z=2.25$, $p < .05$; and the span effect was stronger when both noun phrases belonged to the same category, $z=3.55$, $p < .001$, for the two-way interaction. Interestingly, the four-way age by syntax by similarity by span interaction was also significant, $z=2.99$, $p < .01$, suggesting that working memory interacted with syntax and similarity to affect younger and older adults differently. Decomposing this four-way interaction revealed that this four-way interaction was driven by the significant three-way syntax by similarity by working memory interaction for the old (left panel of Figure 2), $z=4.34$, $p < .001$, but not for the young (right panel of Figure 2), $z < 1$. Within the older adults, the three-way interaction showed that there was a reliable syntax by working memory interaction when the two NPs were similar, $z=4.29$, $p < .001$; but not when they were dissimilar, $z < 1$. Thus comprehension was disproportionately worse among the old when they were low in span and the complex syntax instructed thematic role assignment for similar noun concepts, supporting the role of working memory in controlling interference during conceptual integration.

In contrast, within the younger group, neither working memory alone nor its interactions with other independent variables predicted comprehension performance, $ps > .23$. The null effects

of working memory were somewhat surprising given findings from Fedorenko et al. (2006) who manipulated working memory load and found a three-way load by syntax by similarity interaction. However, this result difference could have been introduced by the paradigmatic differences between two experiments. First, as mentioned earlier, the reading with memory load paradigm (see Gordon et al., 2002; Kemper & Herman, 2006 as well) might have shifted readers' attention between remembering the words in the list and reading for comprehension, as evidenced by an overall lack of syntax effect on list recall in Fedorenko et al.'s study. Secondly, as pointed out by these authors (Fedorenko et al., 2006), participants had to recall the words before answering the comprehension questions and this procedure might have contaminated participants' comprehension, and further (implicitly) biased their attention towards the load manipulation.

Eye-tracking data

Four dependent variables that were derived from eye-tracking data were gaze duration (GD, the first-pass fixation times in a given region before any regressive or progressive eye-movements), regression path duration (RPD, the fixation times in a given region plus time spent on regressive eye-movements before any progressive eye-movements), rereading time (total time spent in a given region minus first-pass fixation times), and trial dwell time (total time spent in a given region) (Rayner, 1998; 2009). GD was taken as a measure of early lexical access in language understanding; while RPD, rereading time, and trial dwell time were considered measures of later semantic/conceptual integration processes (Rayner, 1998; 2009). It was expected that the syntax effect would be exaggerated for similar condition, the syntax by similarity interaction would be further exaggerated by aging and/or working memory and these effects would generally show up in the three later measures of processing.

These four variables are reported for each of the four regions of interest whenever appropriate¹ (see Appendices A and B). These measures of reading times were trimmed within each participant within each region of interest, with reading times more than 2.5SD above the mean of the corresponding region and measure deleted. This procedure only trimmed 4.5% of the data and all the following analyses were based on the trimmed data. Firstly, in order to understand how the linguistic manipulations would affect two age groups differently, a series of hierarchical linear models were conducted with age, syntax and similarity entered into the full models for each dependent measure within the corresponding region (see Appendix A). Generally speaking, GD and RPD at all four regions and Total Trial Time showed effects of age, and the linguistic manipulations, while rereading time only showed these effects for the initial region and the relative clause region. We now detail these effects more specifically (cf. Appendix A).

We first focused our analyses on the critical relative clause region where similarity and syntax were directly manipulated. Rows 1 to 3 of Table 2 and rows 1, 5 and 10 of Appendix A summarized the means and test statistics for this region, respectively. The main effects of age and linguistic manipulations for this region were mostly reliable for later measures of processing (i.e., RPD and Rereading), but not the early measures (i.e., GD). Similarly, the critical syntax by similarity interaction was reliable for RPD and Rereading, not for the GD. RPD and rereading time at the relative clause were differentially increased by complex syntax in the similar condition, providing clear evidence that difficulty in processing the ORC constructions was exacerbated by semantic similarity of the noun phrases bound by these constructions. This argument was further substantiated by the syntax by similarity interactions for RPD at wrap-up (Appendix A row 8), for similar condition, $Mean_{ORC}=2611ms$, $se=213ms$, $Mean_{SRC}=2437ms$,

se=195ms; for dissimilar condition, *Mean_{ORC}=2442ms*, *se=186ms*, *Mean_{SRC}=2564ms*, *se=193ms*; rereading time at the initial region (Appendix A row 9), for similar condition, *Mean_{ORC}=818ms*, *se=77ms*, *Mean_{SRC}=698ms*, *se=67ms*; for dissimilar condition, *Mean_{ORC}=674ms*, *se=64ms*, *Mean_{SRC}=717ms*, *se=65ms*; and total trial time (Appendix A row 13, last row of Table 2). These patterns of results suggested that the moderating role of noun phrase similarity on ORC/SRC syntactic processing happened later (instead of earlier) during encoding (Gordon et al., 2006) and this effect could be localized to syntactic resolution difficulties at the early part of the sentence (beginning region and relative clause) and sentence wrap-up, with little evidence of spillover onto the matrix verb and spillover region. There was also no evidence that this moderating effect of similarity on syntactic processing varied as a function of age.

For regions other than the relative clause, in general older adults were slower on all measures in almost all of the rest of the regions (first data column of Appendix A). As might be expected, the main effects of relative clause complexity and semantic similarity (second and third data columns of Appendix A) were minimal for GD, but were more robust for later measures of processing (i.e., RPD, Rereading and Trial Time), which reflected integration processes in reading.

Next, to further test the modulating role of working memory in age differences in sentence reading, building upon the first set of models (Appendix A), a separate set of analyses for all measures across different regions of the sentence was conducted in HLM with working memory entered as a moderator (Appendix B). First, working memory reduced GDs across all four target regions (rows 1 to 4 of Table 3 for cell means; rows 1 to 4 of the first column of Appendix B for test statistics) and reduced RPD for the relative clause region (row 5 of Table 3

and row 5 of the first column of Appendix B), suggesting that working memory supports early lexical encoding throughout sentence reading (Stine-Morrow et al., 2008) and conceptual integration at the intra-sentence boundaries (i.e., relative clause, Calvo, 2001). However, rereading time at the spillover region (row 12 of Table 3 and row 12 of the first column of Appendix B) was longer for individuals with larger working memory capacities, probably reflecting the attentional regulatory strategy employed by those readers of chunking greater amount of information at the later segment of sentence (Stine-Morrow et al., 2010).

There was evidence from different measures and regions (Appendix B) indicating that working memory interacted with age to affect online sentence reading times, but the direction of the age by span interaction was different for early and later eye-tracking measures. For early GDs at the spillover and wrap-up region (rows 3 and 4 of Table 3, and rows 3 and 4 of the second column of Appendix B), higher working memory span was associated with faster speed at lexical access and this effect was stronger for the old than for the young. However, RPD at the RC and spillover region (rows 5 and 7 of Table 3 and rows 5 and 7 of the second column of Appendix B) and total dwell time (row 13 of Table 3 and row 13 of column 2 of Appendix B) were longer for younger adults with higher span but shorter for older adults with higher spans, suggesting that working memory span functions differently for the young and the old, allowing more resource allocation to parse the syntactic structures among the young but speeding up the parsing to permit more efficient integration among the old.

Working memory interacted with either syntax or similarity mainly at the critical relative clause region or the verb region immediately following the relative clause (third and fourth data columns of Appendix B). Overall, the aforementioned syntax and similarity effects on GD were exaggerated by low working memory span in the predicted direction. At the RC region, the span

effect on RPD was greater for more complicated syntax (row 5 of the third column) or for more confusing NPs (row 5 of the fourth column). For the span by syntax interaction, the span effect was stronger for the ORC, $t=3.22, p<.001$, ($M_{\text{Mean}-1\text{SD}}=855\text{ms}$, $M_{\text{Mean}}=759\text{ms}$, $M_{\text{Mean}+1\text{SD}}=663\text{ms}$), than for the SRC, $t=2.49, p<.01$ ($M_{\text{Mean}-1\text{SD}}=775\text{ms}$, $M_{\text{Mean}}=716\text{ms}$, $M_{\text{Mean}+1\text{SD}}=658\text{ms}$); for the span by similarity interaction, the span effect was stronger for similar category, $t=2.73, p<.001$, ($M_{\text{Mean}-1\text{SD}}=896\text{ms}$, $M_{\text{Mean}}=802\text{ms}$, $M_{\text{Mean}+1\text{SD}}=708\text{ms}$), than for dissimilar category, $t=2.93, p<.001$, ($M_{\text{Mean}-1\text{SD}}=734\text{ms}$, $M_{\text{Mean}}=673\text{ms}$, $M_{\text{Mean}+1\text{SD}}=612\text{ms}$). There were also syntax by working memory interactions for both the RC region for rereading time (row 10 of the third column) and at the verb region for RPD (row 6 of the third column). There was an exaggerated syntax effect in rereading the ORC for low span (Mean-1SD) individuals ($M_{\text{ORC}}=747\text{ms}$, $M_{\text{SRC}}=652\text{ms}$) compared to high span (Mean+1SD) individuals ($M_{\text{ORC}}=673\text{ms}$, $M_{\text{SRC}}=645\text{ms}$). However, the interaction for RPD at the verb region tended towards the opposite direction, with a greater span effect for SRC, $t=2.10, p<.05$, ($M_{\text{Mean}-1\text{SD}}=410\text{ms}$, $M_{\text{Mean}}=382\text{ms}$, $M_{\text{Mean}+1\text{SD}}=355\text{ms}$) than for ORC, $t=1.23, p=.18$ ($M_{\text{Mean}-1\text{SD}}=434\text{ms}$, $M_{\text{Mean}}=436\text{ms}$, $M_{\text{Mean}+1\text{SD}}=439\text{ms}$). This counterintuitive finding very likely reflected the between-region trade-off in reading time allocation: as described slightly earlier, low-span individuals were more likely to regress back and reread as soon as they encountered the objective-relative clause than the subject-relative clause and they might not have resumed reprocessing the subject-relative clause until the matrix verb region.

Table 4 presents the cell means for three significant three-way interactions (Columns five, six and seven of Appendix B). For trial dwell time (last row of column 5 of Appendix B), working memory interacted with syntax to affect older and younger adults differentially: within the old group, there were reliable effects of syntax and working memory without their

interaction, $t=6.11, p<.001$; $t=1.49, p<.05$, respectively, such that complex syntax and lower working memory capacity were related to longer trial dwell time; within the young group, there was a reliable effect of syntax, $t=7.18, p<.001$, which was exaggerated by low working memory, $t=3.91, p<.001$, for the two-way interaction.

The three-way age by similarity by working memory interaction for RPD (row 6 of column 6 of Appendix B) at the verb was due to a significant similarity by working memory interaction within the old group, $t=2.47, p<.001$, but not within the young group, $t<1$. Further analysis revealed that within the old working memory facilitated RPD at the verb region only when two NPs were dissimilar, $t=1.73, p=.06$, but not when they are similar to each other, $t<1$, reflecting persisting working memory advantage even after the critical clause region when the processing demand in the dissimilar condition was relatively low.

Finally, Table 4 shows the syntax by similarity by working memory interaction on RPD at the verb region (row 6 of column 7 of Appendix B), which was driven by the significant two-way similarity by working memory interaction when syntax was more complicated, $t=2.67, p<.01$, such that working memory continued benefiting the processing of the verb region when NPs embedded were dissimilar in face of difficult syntax, $t=2.03, p<.05$, but not when similar NPs caused confusion in working memory, $t<1$. However, when syntax was relatively easy, working memory facilitated verb region processing regardless of similarity, $t=2.12, p<.05$.

Figures 3 and 4 present the two four-way interactions, one involving GD at the verb and the other, RPD at the critical RC² (last column of Appendix B). For GD at the verb (Figure 3), the age by working memory by syntax by similarity interaction can be characterized as a three-way interaction among the young, $t=2.11, p<.05$, but not among the old. A further breakdown of the three-way interaction within the young by similarity showed that the working memory by

syntax interaction was not significant for different-category NPs, $t=1.34$, $p=.18$, or same-category NPs, $t=1.52$, $p=.15$. However, there were numerical trends for younger adults with less working memory to spend more time encoding the lexical information of the verb with increasing syntactic difficulty when the NPs were dissimilar and spent less time with increasing syntactic difficulty when the NPs were similar. Combined with result for this sub-group of younger adults in Figure 4, these counterintuitive trends might merely reflect the trade-off between resource allocation in RC and verb region, because in Figure 4 this subgroup did not show syntax effect when the NPs were dissimilar but showed obvious syntax effect when the NPs were similar. Given a lack of *any* theoretical predictions for GD at this region and my major interest in conceptual binding processes in language, the focus of further decomposition would be next moved onto RPD.

There was also an age by working memory by syntax by similarity interaction for RPD at the critical RC (Figure 4). Decomposing the four-way interaction by age groups revealed that there was a significant syntax by similarity by span interaction for the old, $t=2.18$, $p<.05$, but not for the young, $t=1.35$, $p=.19$. Within the old group, the three-way interaction was due to syntax by span interaction when NPs were similar to each other, $t=2.93$, $p<.01$, but not when they were dissimilar, $t<1$. Aligning quite well with comprehension accuracy plotted in Figure 2, RPD at the RC region shows that older adults with lower span were disproportionately slowed in processing the relative clause when it was both syntactically complex and required binding of similar NPs.

Discussion

Consistent with Gordon et al. (2006), we found that for both age groups, the oft-reported ORC vs. SRC processing/performance difficulty was exaggerated by semantic similarity during online encoding. Most critically, the syntactic complexity and semantic similarity interaction was

further exaggerated by individual differences in age and working memory as measured by both online sentence reading and offline probe questions. Specifically, reading times and comprehension were differentially impaired for the old with lower span when the ORC contained NPs from the same category, indicating greater performance cost of controlling interference in working memory for this sub-age group.

The four-way interactions involving age, working memory, syntax and category in both online and offline measures were illuminating in that it indicated clearly that working memory functioned differently for the old than for the young. One explanation could be complex reading span was measuring something qualitatively different of the old compared to the young. For example, researchers (Lustig, May, & Hasher, 2001) revealed that the oft-observed age differences in reading span measure was significantly reduced by merely reversing the order of presenting the sentence set, starting from the largest chunk instead of the smallest chunk. They explained presumably this procedure decreased the interferences from previous sets with smaller chunks, which originally prevented participants from advancing to sets with larger chunks and thus systematically underestimated their memory potentials. By reversing the order, participants were treated with more just evaluation of their highest-possible memory level that was uncontaminated or minimally contaminated by proactive inferences. Relevant to our results was that the prevalent and popular reading span measure might have tapped more into inhibitory and/or executive functions of the older adults in a relative sense compared to those of the young and therefore WM span showed pronounced effects with the combination of syntactic and semantic difficulty for our older group (left panels of Figures 2 and 4), a speculation that echoed (quite coincidentally and nicely) with the very similarity-based interference control hypothesis of working memory span in language.

Last but not least, the presence of the four-way interaction could simply be caused by the distributions of participants' working memory level within each age group when this variable was entered as a single continuous variable in the modeling. Specifically, for the old, there was only 9 out of 32 participants having a working memory level higher five (the span test has a range of 2-8 with a median of 5), however, there was only 4 of 32 participant having a score lower than five for the young group. In other words, working memory functioning differently for the young and the old to interact with our linguistic manipulations might merely have been caused by that there were just very few younger adults having lower span as to demonstrate a span by similarity by syntax interaction for this age group. Future study should oversample younger adults with lower span and/or older adults with higher span in order to clarify whether working memory truly contributed differently to interference control with aging or the higher-order age by working memory interaction was actually due to sampling bias.

Nevertheless, across various dependent measures (eye-movement and comprehension), the greater processing and performance cost for the low-span older adults while comprehending sentences containing both syntactic and semantic complexities provided convergent support for a similarity-based interference view of controlling processes in working memory (Gordon et al., 2001; 2002; 2006; Fedorenko et al., 2006; Kemper & Herman, 2006). These results also extended the previous findings by revealing the mechanisms of age-related deficit in syntactic processing, i.e., inefficiency of regulating attentional resources in the face of similarity-based interference in working memory.

Experiment 2

Given that Experiment 1 demonstrated that interference control increased the resource requirements for binding concepts in sentence processing and this was more so for older adults

with less working memory span, the purpose of the next experiment was to determine whether the resource requirements for interference control would have downstream consequences for generating inferences and simulating the situation. Recently, Rawson (2007) in one of a series of nicely designed experiments, presented participants with short passages such as in (27) and then asked them to make lexical decisions about probe words that either reflected an inference from the passage or not (e.g., “STRIKE” vs. “SCREEN”).

(27). *Steve was organizing a group to make signs and to contact the press. The workers [who were] presented the last offer from management had been insulted.*

Temporary ambiguity was manipulated in the context by creating reduced relative clauses in which the clause verb (“presented”) could be temporarily interpreted as the matrix verb of the sentence, which introduced extra processing demand for the readers.

It was found that contextual facilitation for the target probes (control minus inference in lexical decision latency) was reduced by the reduced relative clause manipulation, supporting the idea that global inferencing processes shared the common resources that were used for syntactic parsing (Just & Carpenter, 1992). Except for Rawson (2007), as to the author’s knowledge, no one has explicitly extended the shared resources hypothesis to inferencing processes in sentence reading. Thus, in this experiment, I directly manipulated the difficulty of conceptual binding (through syntax and semantics) to examine their effects on a particular kind of inference in reading – generating the perceptual properties of the embedded concepts (i.e., perceptual simulation), a process that has empirically been evidenced to be immune to instructional and individual variations and has been argued to be obligatory and modal. By doing this, I am putting a similarity-based resource-dependent view of language processing to a strong test.

As literature is mixed with regards to the age effect (Dijkstra et al., 2004; Madden & Dijkstra, 2010) and modulating role of working memory (Copeland & Radvansky, 2004; Madden & Zwaan, 2006) in situation simulation, with slightly modified paradigm of Zwaan et al. (2002), Experiment 2 is designed to explore whether controlling interference during sentence-level conceptual binding would serve as a potential mechanism of understanding (occasionally) failed situation simulation for a subgroup of older adults with limited resources.

Methods

Participants

Thirty-two community-dwelling older adults (60+ years old) and 32 college students (18-30 years old) participated in this experiment. Three older adults and two younger adults were removed from all the following analyses either due to unexpected construction noise outside the lab or to computer/technical errors. The older adults had better education ($M_o=15.9$, $SD=3.3$; $M_y=14.4$, $SD=1.1$) and vocabulary ($M_o=10.3$, $SD=4.3$; $M_y=7.6$, $SD=2.6$; Ekstrom, French, Harman, & Derman, 1976), $t(56)=2.34$, $p<.05$; $t(57)=2.91$, $p<.01$, but younger adults had a better verbal working memory span (Stine & Hindman, 1994) than the old ($M_o=4.2$, $SD=1.4$; $M_y=5.3$, $SD=1.5$), $t(57)=2.93$, $p<.01$.

Materials and Design

40 target sentences were selected and modified from the previous experiment (Zwaan et al., 2002; see Table 5). Besides the critical similarity and syntax manipulation at the relative clause (as in Experiment 1), there was a picture depicting an object immediately after each sentence, which either matched or mismatched the shape of the object introduced in the prepositional phrase (PP) following the matrix verb in the sentence. After each picture, there was also a Yes/No comprehension question either probing the relative clause attachment (e.g., *The*

ranger talked to the hiker.) or the object location (e.g., *The eagle was in the nest.*). An additional 40 filler sentences of the same form as the target sentences and associated pictures of objects that were not mentioned in the sentence were created to balance the number of Yes and No responses. There are 48 more filler sentences, none of which involve SRC/ORC or similarity manipulation. Eight stimulus lists were created in which materials were counterbalanced across conditions. Passages were presented in a single fixed pseudo-randomized order for all subjects, with sentences from the same condition never presented together in three consecutive trials.

Procedure

Participants were seated in front of the computer at a constant distance. At the beginning of each trial, a “READY?” signal was presented at the center of the display, and replaced by a cross “+” as soon as the participant pressed the advance button (space bar). The cross remained on the screen for 1000ms, followed by a sentence presented in the center of the monitor, on which participant could spend as much time as he/she wanted. Participants indicated they had finished the sentence by pressing the advance button again, which caused the screen to go blank for 500ms, after which a picture depicting an object appeared in the center of the screen. Participants were required to make a speeded Yes/No judgment as to whether or not the object depicted in the picture was mentioned in the prior sentence. After another delay of 500ms, a short comprehension question regarding the preceding sentence appeared in the center of the screen, to which participant had to respond whether it was consistent with the meanings of the previous sentence by pressing Yes/No button again. Self-paced sentence reading times and response latencies/accuracies to both the picture and the comprehension questions were collected.

Results

Sentence Reading Times

Sentence reading times 3SD longer than the mean of all the trials of each individual participant were deleted, resulting in the deletion of 1.51% of the total data. Sentence reading time data were submitted to a three-way Age X Similarity X Syntax HLM (Figure 5). Each of the three main effects was significant. Sentences containing two similar NPs took longer to read than sentences containing dissimilar ones, $t=5.55, p<.001$; sentences with ORCs embedded took longer to process than sentences with SRCs, $t=4.34, p=.001$; and older adults read more slowly than younger adults, $t=3.86, p<.001$. None of the interactions reached statistical significance.

Even though the three-way interaction was age did not reach significance, $t<1$, data were analyzed separately for younger and older readers given the particular interest in understanding patterns of effects within each age group. For the young, there were reliable effects of similarity and syntax on sentence reading time, $t=2.75, p<.01$; $t=4.42, p<.001$, respectively, without significant interaction, $t<1$. For the old, there was reliable effect of similarity, $t=4.99, p<.001$, but the syntax effect was marginal, $t=1.86, p=.06$. The syntax by similarity interaction was not significant, $t<1$.

As measured by whole-sentence reading time, NP similarity and syntactic complexity impacted processing within each group. These effects were independent in affecting sentence processing without interactive effects, which were obtained in the first experiment. The discrepancy between findings across two experiments might have been due to the fact that previous studies used more sensitive online measures of language processing (e.g., region-by-region sentence reading and eye-tracking) (Fedorenko et al., 2006; Gordon et al., 2006; Experiment 1 of this paper).

Response Accuracy for Picture Verification

The key behavioral indicators of interest in the present study were those related to the picture verification task. Zwaan et al. (2002) found that in addition to impacting response latency, the mismatch condition reduced the picture verification accuracy. According to a resource-dependent view of perceptual simulation (Madden & Dijkstra, 2010), perceptual simulation would be differentially affected by syntactic complexity in the similar condition, and this would be particularly true for older adults, as reflected in the mismatch effect in both response latency and response accuracy. Therefore, picture verification accuracy was analyzed in a four-way Age X Match X Similarity X Syntax logistic HLM. As shown in Figure 6, neither age, match, nor the linguistic manipulations affected picture verification accuracy, $z < 1$ for all effects. Rather, scores were at ceiling. Verification accuracy approached perfect accuracy across participant groups and conditions, $Mean = 98\%$, $SD = 3\%$, $range = 89\% - 100\%$. These findings indicated that participants were highly accurate at identifying the object in the picture and seemed not to be bothered by the mismatch between the implied shape and the actual shape of the object.

Response Latency for Picture Verification

Response latency was more sensitive than accuracy to experimental manipulations based on previous research (Zwaan et al., 2002; Dijkstra et al., 2004). I examined both raw and standardized data of latency.

Raw Scores

Response latencies 3SD longer than the mean of all the trials of each individual participant were deleted, resulting in the deletion of 2.48% of the total data. Because the particular interest of this project was whether the mismatch effect obtained while reading short

simple sentences (Zwaan et al., 2002) is moderated by syntactic and semantic complexity as well as aging, a full model containing age, syntax, similarity and match as predictors was submitted to HLM. As shown in Figure 7, there were significant effects of age, $t=7.38, p<.001$, and match on response latency, $t=5.13, p<.001$, such that older adults responded slower and mismatched pictures took longer to respond to. There was also a marginal age by match interaction, $t=1.70, p=.09$, indicating that older adults showed a trend towards greater mismatch effect (Dijkstra et al., 2004), $Mean_{Mismatch}=1418ms, se=143ms; Mean_{Match}=1266ms, se=111ms$, than the young, $Mean_{Mismatch}=847ms, se=72ms; Mean_{Match}=754ms, se=53ms$. The age by syntax interaction, $t=1.74, p=.09$, was also marginal suggesting a trend toward older adults differentially slowing for complex syntactic structures, $Mean_{ORC}=1372ms, se=139ms; Mean_{SRC}=1310ms, se=118ms$, than the young, $Mean_{ORC}=787ms, se=59ms; Mean_{SRC}=813ms, se=68ms$.

Next, two separate HLMs were conducted within each age group. For the old, the only significant effect was match, $t=3.95, p<.001$. For the young, besides the main effect of match, $t=3.78, p<.001$, there was a reliable similarity by syntax interaction, $t=2.19, p<.05$, suggesting that the similarity effect was stronger when the syntax was more complicated, for the ORC, $Mean_{Similar}=813ms, se=59ms; Mean_{Dissimilar}=759ms, se=59ms$; for the SRC, $Mean_{Similar}=800ms, se=62ms; Mean_{Dissimilar}=827ms, se=73ms$. This finding within the younger adult group indicated that even though mismatch effect was neither moderated by syntax nor similarity for this age group, overall picture verification latency was slowed when the previous sentence was demanding on resources for conceptual binding. In other words, there appeared to be an overall spillover effect of syntax and similarity from the sentence reading onto picture verification. However, the critical match-related interactions were not evident in our analysis, suggesting that perceptual simulation per se was not impaired by our linguistic manipulations. Finally, I

correlated the mismatch effect (response latency in the mismatch condition minus response latency in the match condition) with individuals' working memory span (Table 6). There was no clear evidence that working memory constrained individuals' ability to make perceptual-level inferences about concepts embedded in sentence across four linguistic conditions.

Z-scores

In order to control for age-related slowing in response latency (Dijkstra et al., 2004), z-scores were computed within each participant by standardizing the raw scores against the mean and SD of that participant for all the trials. The patterns with z-scores replicated the major findings from raw scores (Figure 8). For the full four-way model, there was reliable effect of match, $t=5.75$, $p<.001$, however, the marginal age by match and age by syntax interactions were no longer evident, $p>.15$ for both, suggesting the marginal effects were both driven by age-related slowing. Further breakdown of the four-way model by age groups revealed that only the effect of match was significant for the old, $t=4.41$, $p<.001$; the effect of match, $t=3.83$, $p<.001$; and the Similarity X Syntax interaction, $t=2.08$, $p<.05$, were significant for the young, such that similarity effect was stronger when the syntax was more complicated, for the ORC, $Mean_{Similar}=0.076$, $se=0.19$; $Mean_{Dissimilar}=-0.12$, $se=0.17$; for the SRC, $Mean_{Similar}=-0.011$, $se=0.18$; $Mean_{Dissimilar}=0.055$, $se=0.18$. I further conducted four two-way age by match analyses under each of the four language conditions and none of the age by match interaction reached significance, $t<1$ for all.

In summary, across two sets of analyses with the response latency there was clear evidence that match effect was not influenced by age and the linguistic manipulations (i.e., similarity and syntax), as evidenced by the absence of any match-related interactions with both raw and standardized scores.

Comprehension Accuracy

Comprehension questions contained two types, one about relative clause attachment and the other about the location of the object, each tapping into different processes in language understanding (conceptual binding vs. situation simulation). Although it could be potentially interesting to test the residual effect of match on sentence comprehension, constrained by the small number of trials per condition (crossed over similarity, syntax and question type), comprehension data were collapsed across match conditions. To test how question type, linguistic manipulations (i.e., syntax and similarity) and aging affected reading comprehension, syntax, similarity, age and question type were entered into the full logistic HLM (Figure 9). Comprehension was worse when the question probed the relative clause compared to the object location, $z=4.16$, $p<.001$, and when the sentence contained two similar NPs, $z=2.26$, $p<.05$. Although there was no overall age difference in comprehension, the age by question type interaction was significant, $z=2.11$, $p<.05$: the age difference was bigger when the question was about the relative clause attachment, $Mean_{Old}=76\%$, $se=8\%$; $Mean_{Young}=81\%$, $se=7\%$; than when it was about the situation, $Mean_{Old}=95\%$, $se=4\%$; $Mean_{Young}=94\%$, $se=4\%$. Within each age group, older adults only demonstrated the effect of question type, $z=4.31$, $p<.001$. Younger adults showed the effect of question type $z=2.80$, $p<.01$, which interacted with and was reduced by similarity, $z=2.20$, $p<.05$: for similar condition, $Mean_{Location}=92\%$, $se=5\%$; $Mean_{RelativeClause}=83\%$, $se=7\%$; for dissimilar condition, $Mean_{Location}=96\%$, $se=4\%$; $Mean_{RelativeClause}=80\%$, $se=7\%$. Consistent with many previous results (Radvansky et al., 2001; Stine-Morrow et al., 2004), these findings suggested that age differences was exaggerated for processes requiring integrating and binding concepts in sentence while remained minimal (if not reversed) for situation construction in language understanding.

Discussion

In the second experiment, it was found the oft-obtained mismatch effect in verification latency was not moderated by age or any of our linguistic manipulation and further analysis revealed that this mismatch effect was not associated with memory span for either age group, neither. This provided converging evidence that perceptual simulation in language is resource-independent (Radvansky & Copeland, 2004; Zwaan et al., 2012) and not permeable by normal aging or semantic or syntactic complexities. Individual differences analysis revealed that mismatch effect was not correlated with working memory span, providing further evidence that inferring the perceptual features (i.e., physical shape) of the incoming concept was not constrained by processing resources that was otherwise used for conceptual binding (Experiment 1). Picture verification accuracy in general was high across conditions and did not demonstrate any age-related differences, suggesting relative age-related preservation in situation creation (Radvansky et al., 2001; Stine-Morrow et al., 2006). Although one could argue that participants could have biased their attention to the lexical item (i.e., the eagle) in order to accomplish the object verification task (without fully processing the information about the object location), given the overall lack of match effect in accuracy, this explanation could not explain why the mismatch effect was obtained in the latency data with both raw and standardized score.

There were main effects of similarity, syntax and age on whole sentence reading time without any obvious high-order interactions. Although there was clear evidence that age difference was reduced in the easier condition (i.e., the combination of SRC and dissimilar NPs) qualified by the two-way age by similarity interaction when the syntax was relatively easy, these results were different from our first experiment using more sensitive region-by-region eye-tracking and were somehow expected given most of the similarity by syntax interactions in

Experiment 1 were localized to the critical relative clause region without spilling over onto other regions of the sentence. There was no age difference in sentence comprehension, however, younger adults comprehended the questions probing the clause attachment (who did what (to whom)?) differentially better than the old but not for questions probing the situation creation (the location of the object?). This finding was nevertheless nontrivial, as it replicated many previous studies showing that age difference in language understanding was exaggerated for processes requiring conceptual binding but minimized or completely reduced for processes requiring situation generation (Stine-Morrow et al., 2004; Radvansky et al., 2001).

CHAPTER 3

GENERAL DISCUSSION

This research was designed to test a similarity-based interference theory of language processing adopting an individual differences approach. Across two experiments, distinct patterns of linguistic manipulations impacting conceptual binding and situation simulation were obtained. In Experiment 1, comprehension for sentences with object-relative clauses containing similar NPs, which require memory resources for conceptual binding, was differentially impaired for the old compared to the young. An examination of these effects as a function of individual differences in working memory span revealed that this interaction was stronger for older adults with fewer attentional resources (i.e., lower span scores). Concomitantly, one of our primary online eye-tracking measures (i.e., regression path duration, which has been argued to reflect online conceptual integration processes) showed that older adults with less working memory span spent more time on the critical relative clause region under the most difficult condition (i.e., the combination of ORC and similar NPs), supporting a resource-dependent (King & Just, 1991) and similarity-based interference control view (Gordon et al., 2001; 2002; 2006; van Dyke & McElree, 2006; Fedorenko et al., 2006). These findings are not consistent with a resource-independent view of language processing (Caplan & Waters, 1999), which predicts that conceptual binding during syntactic parsing should not be permeated by semantic factors, such as similarity of the to-be-bound concepts, or by individual differences in age and working memory. Both the online and offline results supported quite the opposite.

Many have argued that compared to textbase processes, such as semantic integration, situation construction and perceptual simulation processes in language understanding are

relatively less constrained by processing resources (Radvansky & Copeland 2004) and age-related working memory declines (Radvansky et al., 2001; Stine-Morrow et al., 2006), because of their obligatory and unconscious activation in language processing (Barsalou, 1999; Radvansky & Dijkstra, 2007). Consistent with this view of situation simulation, Experiment 2 demonstrated that the previously reported situation mismatch effect (Zwaan et al., 2002; 2012) was not moderated by aging, similarity, or syntax, as measured by response latency. Additionally, working memory span was not correlated with the mismatch effect for either age group, which is consistent with findings using other individual differences measures (i.e., spatial and verbal abilities and visual imagery) (Stanfield & Zwaan, 2001; Engelen et al., 2011; Zwaan et al., 2012). Findings of Experiment 2 contradicted the idea that situation construction would be impaired for older adults due to working memory constraints (Madden & Dijkstra, 2010). Overall, the results across two experiments indicate that difficulty in conceptual binding is subject to similarity-based interference, which has no downstream effect on situation simulation. These findings provide strong support for the ideas that a) conceptual integration and situation construction are distinguishably and independently regulated in language understanding (Kintsch, 1988; 1998; Miller & Kintsch, 1980; Stine-Morrow et al., 2006); b) binding concepts is impaired in later adulthood but situation simulation is preserved (Radvansky & Dijkstra, 2007; Stine-Morrow et al., 2006).

Interference Control and Age Differences in Language Processing

In the first experiment, consistent with previous studies in age differences in conceptual binding (see Stine-Morrow et al., 2000; Kemper & Herman, 2006, for language; and Naveh-Benjamin, 2000, for memory), this study found reliable age differences in off-line comprehension such that lower-span older adults were disproportionately impaired with the

combination of syntactic and semantic complexity. Kemper and Herman (2006) found that the young showed an exaggerated syntactic effect in the same-category memory load condition, while the old showed no syntactic effect in the same-load condition. Aside from Kemper and Herman's "floor effect" explanation for the old in the same-category load condition, discrepancies between their findings and ours in reading time effects may be due to the paradigmatic differences between self-paced reading and eye-tracking: Eye-tracking permits regressive eye-movements thus rereading of prior text as in natural reading. There is some evidence (Stine-Morrow et al., 2004) that during rereading older adults tended to spend more time consolidating previously impoverished representation of conceptual relationships. While there has been general consensus that aging negatively affects offline complex syntax understanding (see Kemper, 2006 chapter for a review), there is still debate as to whether aging exacts its effects during online reading (Caplan & Waters, 1999; Caplan et al., 2011). A meta-analysis collapsing experiments across different paradigms (e.g., self-paced reading vs. eye-tracking vs. ERPs; word-by-word vs. segment-by-segment vs. sentence-by-sentence reading) is desirable in the future to define the boundary conditions(s) for these effects.

In the second experiment, the match effect obtained for both age groups substantiated that aging was associated with preserved perceptual simulation, a process that has been argued to be obligatory (Barsalou, 1999) and resource-independent (Zwaan, 2012; Radvansky & Copeland, 2004). The resource-independent view of perceptual simulation was subjected to a very strong test in this study by introducing both semantic similarity and syntactic complexity into the sentence evoking the perceptual simulation, yet there was no evidence that these processes were modulated by linguistic complexity or normal aging. This is consistent with the correlational/cross-sectional findings that perceptual simulation in a similar sentence-pictures

verification paradigm is not affected by verbal knowledge or spatial ability, and is intact in school age children as young as 7-8 years old (Stanfield & Zwaan, 2001; Engelen et al., 2011).

One could still argue that the null effects of similarity, syntax, and age could have been caused by participants' strategic shifting of their attention to the lexicalized items in order to fulfill the task requirement (i.e., verifying the previously mentioned *object* without explicit instruction about its *shape*) with only good-enough representation (Christianson et al., 2006) of the other parts of sentence (i.e., conceptual binding and object location). A closer look at the reading time and comprehension data does not support this argument. First, there was clear evidence that older adults were as sensitive as the young to semantic and syntactic manipulations in sentence reading time, suggesting that older adults did not lower their criterion for comprehension. In fact, there was even a trend for the old to show a similarity by syntax interaction such that sentence reading time for complex syntactic structures were differentially longer than simpler ones when similar NPs were embedded in the sentence. Also, there was no age difference in understanding the object-location related questions, suggesting that the old were allocating attention to remembering the "peripheral" details (i.e., location) of the object which was not imposed by the verification task per se. To this point, the safest conclusion to draw is that similarity-based interference in processing complex syntax does not *interfere* with the generation of perceptual inferences in the unfolding discourse, and that this is even true among older adults with lower working memory span. One limitation was that the factors impacting interference were not manipulated for the concepts directly involved in the simulation. So it may be that readers were able to effectively compartmentalize the binding of concepts not involved in the simulation. Further research should address this question.

The Effects of Working Memory on Binding and Simulation

Capitalizing on the participant differences in age and working memory, we found that a) there were minimal age differences (except for general slowing) in online syntactic processing; b) many of the effects of syntax or similarity showed up relatively late as measured by RPD, Rereading time and Trial Dwell Time, suggesting syntactic or semantic complexity affected online reading during conceptual integration stages rather than lexical encoding (Gordon et al., 2006); c) most interestingly, the critical syntax by similarity interaction as predicted by the interference-based control view of sentence processing was restricted to the relative clause or wrap-up region where processing difficulty was either first encountered or where local integration (relative clause processing) posed a challenge for global semantic integration at the sentence boundary (Just & Carpenter, 1980); and d) despite the absence of obvious age differences, which would otherwise be predicted by an interference account, working memory moderated all the aforementioned main effects of syntax and similarity (and age) and the critical two-way syntax by similarity interaction as measured by RPD at the critical relative clause region and the post-critical matrix verb region. Furthermore, as qualified by the four-way interaction in Figure 4, there was clear evidence for a moderating role of working memory for older and younger adults. These findings suggest that with advancing age working memory may become a more limiting factor for continued engagement in reading. The exaggerated syntax effect for the old with poor working memory when the to-be-integrated noun phrases came from the same category provides strong support for the interference-based account of sentence processing (Fedorenko et al., 2006). Noteworthy, categorical similarity may only be one of the many sources of interference for binding concepts in working memory. There is no reason to believe an interference-based account is only applied to relative clause processing. As long as

computational demands are high in sentence processing, integrating confusing concepts may be compromised (e.g., see van Dyke & McElree, 2006, for searching for verb argument in sentence understanding under memory load).

On the other hand, there was little evidence that working memory was associated with perceptual simulation even when conceptual binding elsewhere in the sentence was hard to achieve. Compared to Madden and Dijkstra (2010), who suggested that perceptual simulation was only reserved for those with more working memory resources, Experiment 2 directly manipulated the working memory demands in sentence processing with combinatory processing demands imposed by both difficult syntax and confusing NPs. However, the results showed clearly that the mismatch effect was unimpaired by both linguistic manipulations and was further unaffected by working memory span, providing converging evidence for an obligatory and automatic view of situation simulation (Zwaan et al., 2002; Zwaan & Pecher, 2012; Barsalou, 1999). There are two reasons for discrepancies between these results and those of Madden and Dijkstra (2010). First, they adopted a naming task in which participants had to name the object (regardless of the shape) immediately after the sentence, which has been shown to be less sensitive (i.e., smaller effect size, Rommers et al., 2013) to the match manipulation than object verification task (Zwaan et al., 2002; Stanfield & Zwaan, 2001) used in the current study. In addition, the age by working memory interaction could have been caused by the fact that phonological coding in speech planning was particularly resource-consuming for older adults (Burke et al., 1991; Burke & Shafto, 2004), differentially undermining the mismatch effect for the older adults with less working memory resources.

Interestingly, previous correlational studies (Copeland & Radvansky, 2007) found that working memory was correlated with the older adults' comprehension of spatial situation models, particularly when the concepts or the NPs were temporarily unbound in working memory. Consistent with this finding, across two experiments it was found that relative clause or whole sentence reading time was slowed by the combination of complex syntax and similarity, and that older adults' comprehension was differentially worse than the young when the sentence required holding unbound concepts in working memory. One critical difference between the spatial situation construction in Copeland and Radvansky's paradigm and the perceptual simulation paradigm in the second experiment was that successful conceptual integration was crucial to the understanding of the spatial situation model while participants in Experiment 2 did not have to successfully parse the relative clauses in order to perform the simulation, which led to the lack of association between memory span and mismatch effect. As noted above, this is a further boundary condition on the interference effect that remains to be explored.

The Interactions Between Levels of Processing In Language Processing

The differential effects of interference and aging/working memory on binding concepts and situation simulation are nevertheless consistent with the more general theoretical framework (Kintsch, 1988; 1998; McNamara & Magliano, 2009) in which textbase propositional extraction and knowledge-driven situation-level inference generation both underpin language processing. Some have argued that these two processes are independently monitored and regulated (Stine-Morrow et al., 2006), and can be experimentally isolated. For example, Stine-Morrow et al. (2004) adopted a rereading paradigm and used a resource allocation approach by regressing reading times onto discourse variables that operationalize conceptual integration and situation construction processes. These investigators (Experiment 2) found that in understanding

narratives, older adults spent differentially more time rereading than the young to consolidate the propositional representation, suggesting that the integration of concepts was particularly difficult for the older adults. However, older adults were more responsive than the young to the situational dimensions (e.g., time/location shift; tracking protagonists and figuring out the causal relationships) of the discourse initially; age differences did not persist in the second reading, indicating situation encoding was preserved if not enhanced with aging. Interestingly, younger adults tended to spend more time integrating concepts than creating the situation model in the first pass but vice versa during the second pass, suggesting that binding concepts might have provided a foundation for situation construction and that two different levels of linguistic analyses could interactively affect each other as well. In contrast, the results of the second experiment demonstrated unequivocally that demands on lower-level conceptual integration did not penetrate into higher-level perceptual simulation in sentence processing.

There are two reasons for these subtle differences. First, Stine-Morrow et al. (2004) and Experiment 2 of the current study operationalized situation model processing quite differently. Stine-Morrow et al. (2004) adopted the Zwaan et al. (1995a; 1995b) event-indexing framework in which situation creation involved constantly monitoring of the shifts in time, location, major characters and their emotions and goals, and updating the causal relationships as the discourse unfolded. In the current study, situation construction was operationalized with the Zwaan mismatch effect based on the conceptualization that readers generate inferences about the physical and perceptual properties of concepts. Although both approaches assume that readers infer information not mentioned by the textual description and traverse beyond words and their associations, perceptual simulation has been argued to be inevitable in understanding and more fundamental to human cognition in general (Barsalou, 1999). It is still debated as to whether the

event-indexing model effectively models perceptual simulation given the assumption that *all* dimensions are simultaneously monitored in routine language understanding (Graesser et al., 1994; 1997). Second, text coding based on the event-indexing model assumes that textbase and situation model processes are conducted in parallel (Stine-Morrow et al., 2006) so that each word is coded in terms of its simultaneous contribution to both conceptual integration and situation construction (for example, the concept “nest” in the sentence “The eagle descended from the sky and landed in his nest directly” was not only coded as a new noun argument to be integrated into the textbase, but also as changing in location. This correlational approach with naturalistic text does not unambiguously parse the variance between textbase and situation model processing. In contrast, the current paradigm used an experimental approach in which the processing demand of conceptual binding was directly manipulated to examine its spillover effect on perceptual simulation as the sentence unfolded. As noted above, future studies should manipulate the conceptual binding difficulties as perceptual simulation happens to further test the interactions between distinctive levels of linguistic computations.

CHAPTER 4

CONCLUSION

This project was designed to test a similarity-based interference control theory of language processing, examining the effects of interference on both conceptual binding and perceptual simulation, using an individual differences approach. Our data suggested that binding concepts together is never an easy task for older adults or individuals with limited processing resources and one of the mechanisms accounting for such difficulties is managing unbound concepts. This helped our understanding of the component processes underpinning the well-replicated finding of age-related declines in comprehending complicated sentence structures. There was converging evidence that controlling interference during binding concepts did not penetrate into perceptual simulation in language, which has been shown to be obligatory and resilient in cognitive development in children and older adults. Therefore, a similarity-based interference theory of language processing may only apply to conceptual binding in sentence processing, and still deserves further examination in future, particularly in the context of an ever growing literature on embodied perspectives of language processing and cognition.

FOOTNOTES

¹GD and RPD for the starting region (the first noun phrase plus the relativizer “that”) and rereading for the sentence-final word were omitted because measures on these regions are not meaningful or interpretable. Trial dwell time was reported for the whole trial independent of each region.

²The critical four-way interaction for the RPD at the RC was even significant, $t=2.12$, $p<.05$, after a further more stringent test of our hypothesis involved, by controlling the effects of vocabulary on reading time, allowing it to interact with important independent variables in HLM, i.e., age, syntax and category.

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TABLES

Table 1

Examples of Experiment 1 Materials and Regions of Analysis

Type	Region	Initial	Relative Clause	Matrix Verb	Spillover	-	Wrap-up
Similar/SRC		The banker that	praised the barber	climbed	the mountain	just outside of	town.
Similar/ORC		The banker that	the barber praised	climbed	the mountain	just outside of	town.
Dissimilar/SRC		The banker that	praised Sophie	climbed	the mountain	just outside of	town.
Dissimilar/ORC		The banker that	Sophie praised	climbed	the mountain	just outside of	town.

Table 2

Estimated Means of GD, RPD, Rereading Time for Relative Clause Region and Trial Dwell Time as a Function of Age, Similarity and Syntax (ms) in Experiment 1

Row #	Measure	Group		Old		Young		Overall					
		Similarity		Dissimilar		Dissimilar		Similar					
		SRC	ORC	SRC	ORC	SRC	ORC	SRC	ORC				
1	GD	541	537	561	570	528	497	556	562	535	517	558	566
2	RPD	808	789	850	1025	675	631	714	828	742	709	782	927
3	Rereading	758	741	825	1057	641	593	656	836	700	667	741	947
4	Trial Time	5216	5051	5238	5607	4593	4414	4516	4944	4908	4730	4877	5272

Table 3

Reading Time Estimates of all the Eye-movement Measures as a Function of Age, Working Memory and Region (ms) in Experiment 1

Row#	Measure	Region	Group		Old		Young		Overall			
			WM	Mean-1SD	Mean	Mean+1SD	Mean-1SD	Mean	Mean+1SD	Mean-1SD	Mean	Mean+1SD
1	GD	RC		565	532	499	594	559	524	580	546	512
2		Verb		342	304	267	310	300	289	326	302	278
3		spillover		467	383	299	388	378	367	428	380	333
4		wrap-up		734	627	519	630	615	601	682	621	560
5	RPD	RC		927	766	604	702	709	716	815	738	660
6		verb		465	432	400	379	386	394	422	409	397
7		spillover		594	513	432	466	486	505	530	499	469
8		wrap-up		2732	2701	2670	1802	2112	2422	2267	2406	2546
9	Rereading	IniReg		890	793	696	509	565	622	700	679	659
10		RC		864	817	769	440	588	736	652	702	753
11		verb		213	220	227	149	175	201	181	198	214
12		spillover		189	215	242	119	178	237	154	197	239
13	Trial Time	-		5464	4966	4469	4142	4436	4731	4803	4701	4600

Note: IniReg=Initial Region; RC=Relative Clause; Verb=Matrix Verb.

Table 4

Estimated Means for Significant Age by Syntax by Working Memory, Age by Similarity by Working Memory and Syntax by Similarity by Working Memory Interaction for Respective Measures at Pertinent Regions (ms) in Experiment 1

Measure and Region	WM	Group		Old		Young	
		Syntax	ORC	SRC	ORC	SRC	ORC
Trial Time	Mean-1SD		5383	5544	3953	4331	
	Mean		4851	5081	4311	4562	
	Mean+1SD		4320	4617	4669	4793	
RPD at verb	Group	Similarity	Old		Young		
			Dissimilar	Similar	Dissimilar	Similar	
	Mean-1SD		473	457	358	400	
	Mean		412	453	377	396	
	Mean+1SD		351	450	395	393	
RPD at verb	Syntax	Similarity	SRC		ORC		
			Dissimilar	Similar	Dissimilar	Similar	
	Mean-1SD		389	431	442	426	
	Mean		374	391	414	459	
	Mean+1SD		359	350	386	492	

Table 5

Sample Stimuli for Experiment 2









Type	Sentence	Possible Ending: ...in the sky. <i>Consistent Picture</i>	Possible Ending: ...in the nest. <i>Consistent Picture</i>
ORC-Similar	The <i>ranger</i> that the <i>hiker</i> talked to saw an eagle in the sky/nest.		
SRC-Similar	The <i>ranger</i> that talked to the <i>hiker</i> saw an eagle in the sky/nest.		
ORC-Dissimilar	The <i>ranger</i> that <i>Steve</i> talked to saw an eagle in the sky/nest.		
SRC-Dissimilar	The <i>ranger</i> that talked to <i>Steve</i> saw an eagle in the sky/nest.		

Table 6

Correlation between working memory span and mismatch effect under each condition for each age group and overall sample in Experiment 2

	OLD	YOUNG	ALL
Similar-ORC	0.11	0.09	0.05
Similar-SRC	0.30	- 0.16	0.05
Dissimilar-ORC	- 0.01	0.04	- 0.11
Dissimilar-SRC	0.26	0.11	0.17

FIGURES

Figure 1. Comprehension as a Function of Age, Syntax and Similarity in Experiment 1

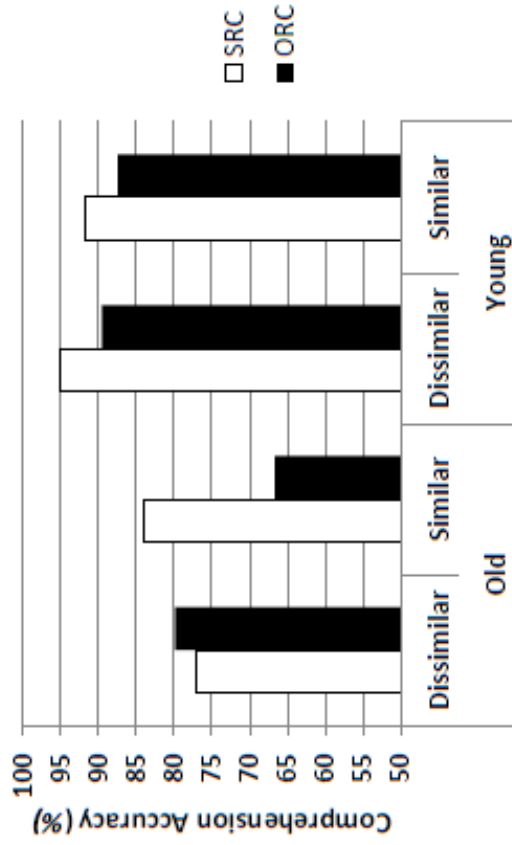


Figure 2. Comprehension as a Function of Age, Syntax, Similarity and Working Memory in Experiment 1

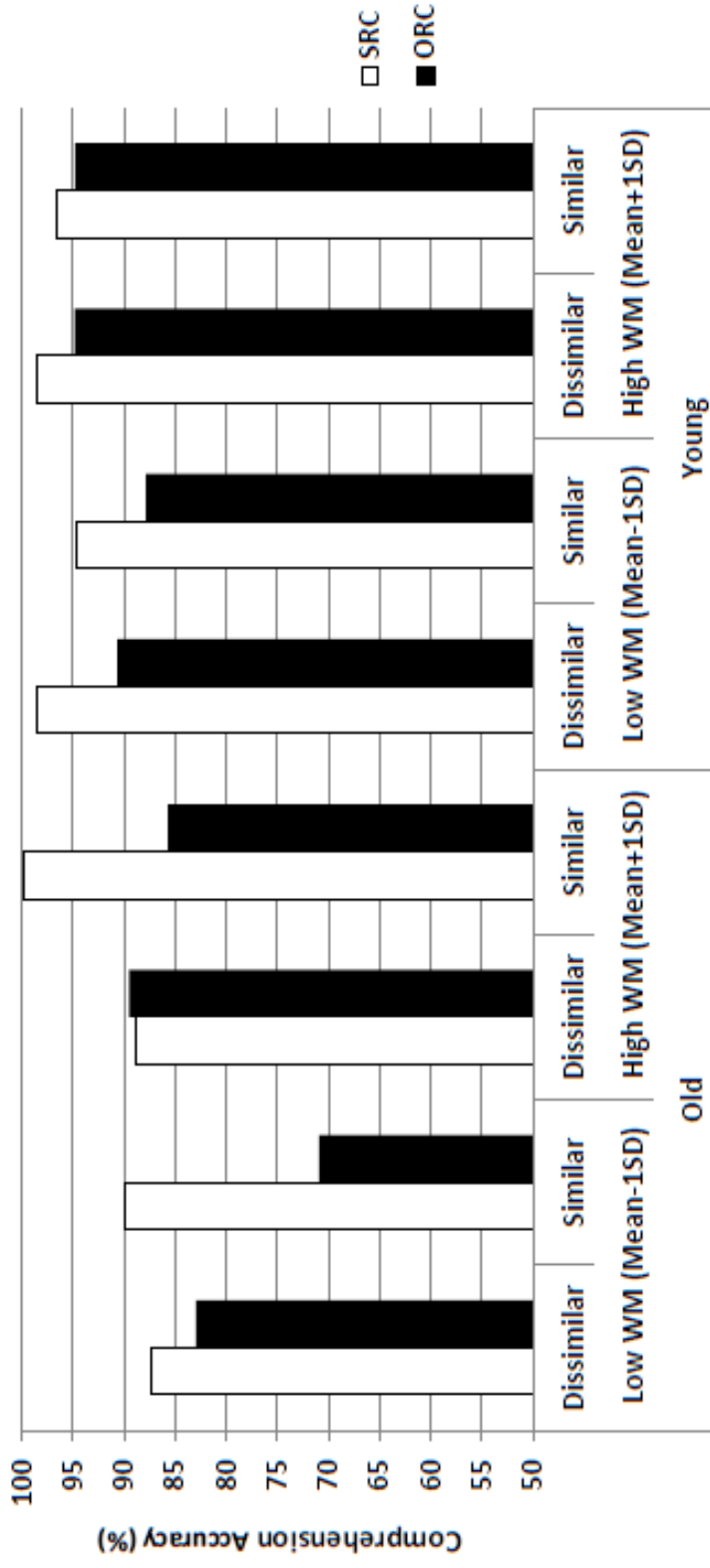


Figure 3. GD at the Verb Region as a Function of Age, Syntax and Similarity and Working Memory in Experiment 1

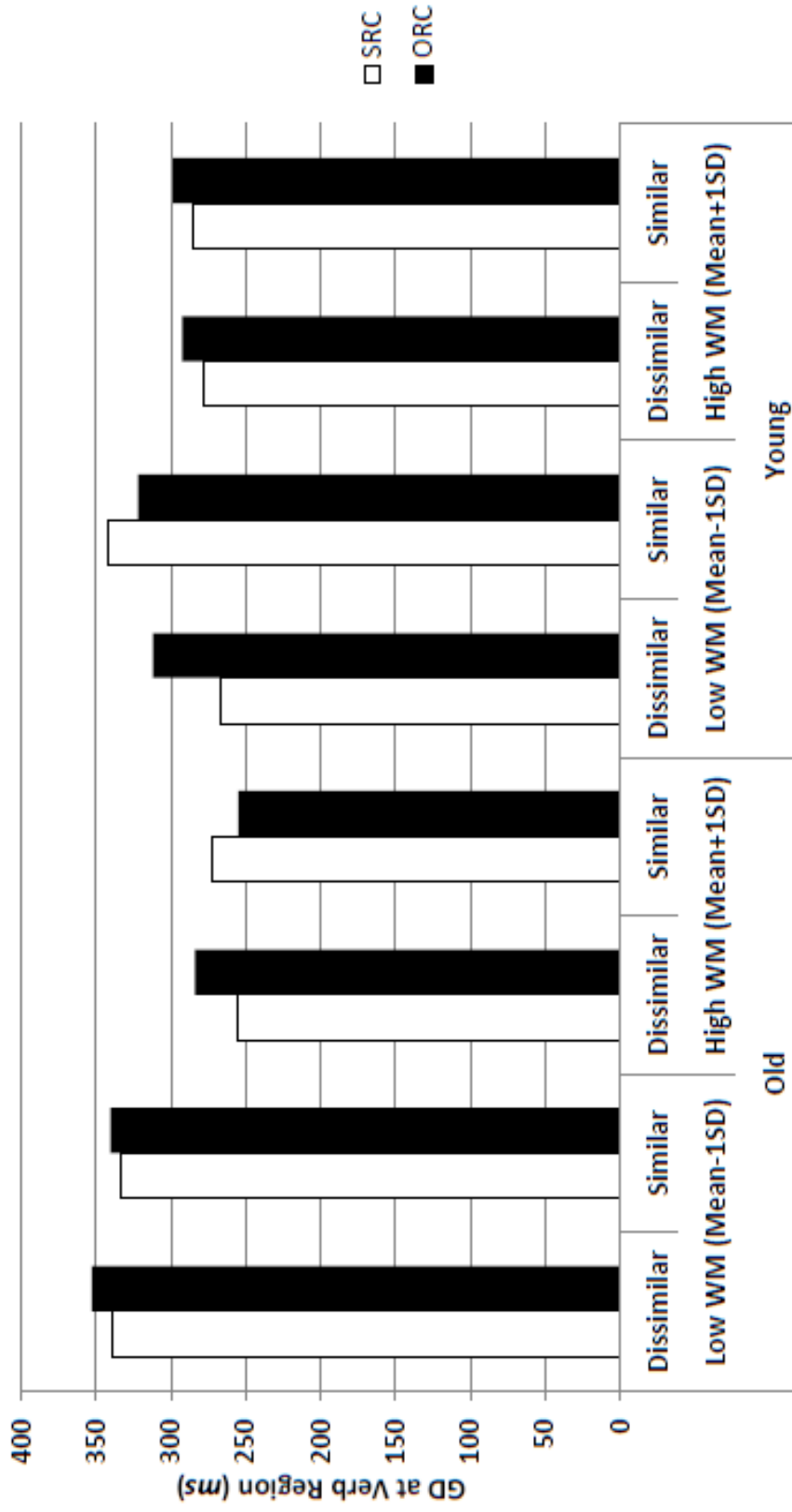


Figure 4. RPD at the Relative Clause Region as a Function of Age, Syntax and Similarity and Working Memory in Experiment 1

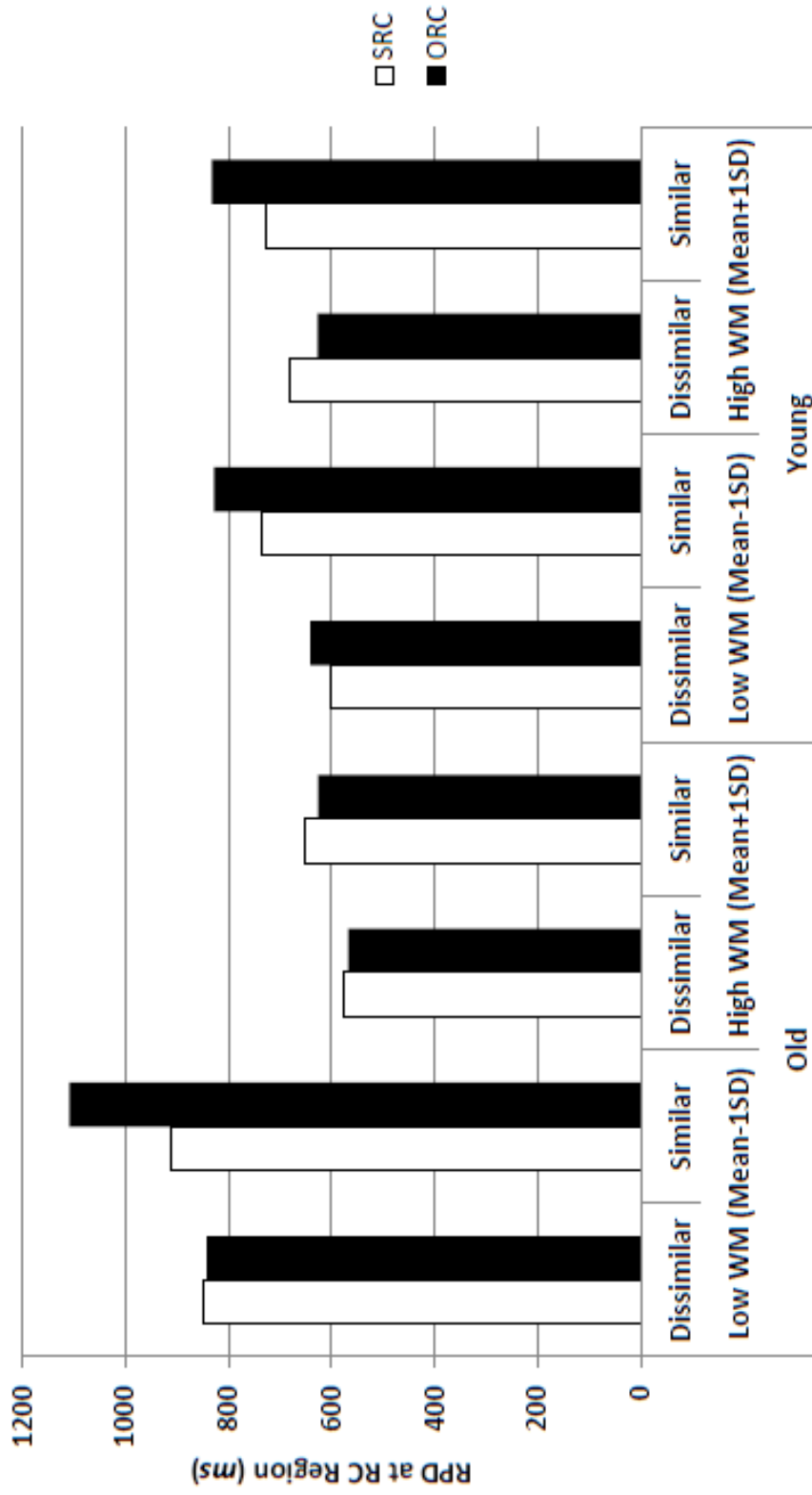


Figure 5. Sentence reading times as a function of age, similarity and syntax (in ms) in Experiment 2

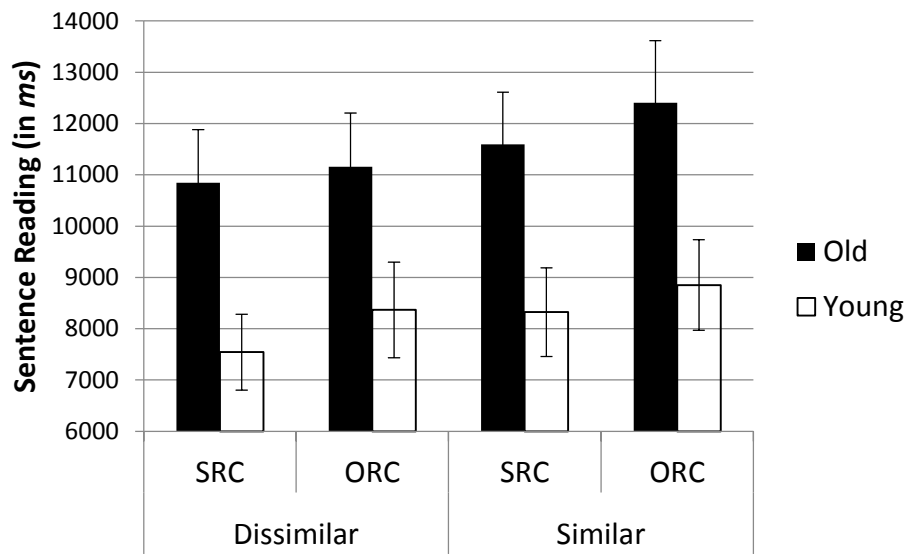


Figure 6. Verification accuracy (%) as a function of similarity, syntax and match separated by age (Top panel: Old; Bottom panel: Young) in Experiment 2

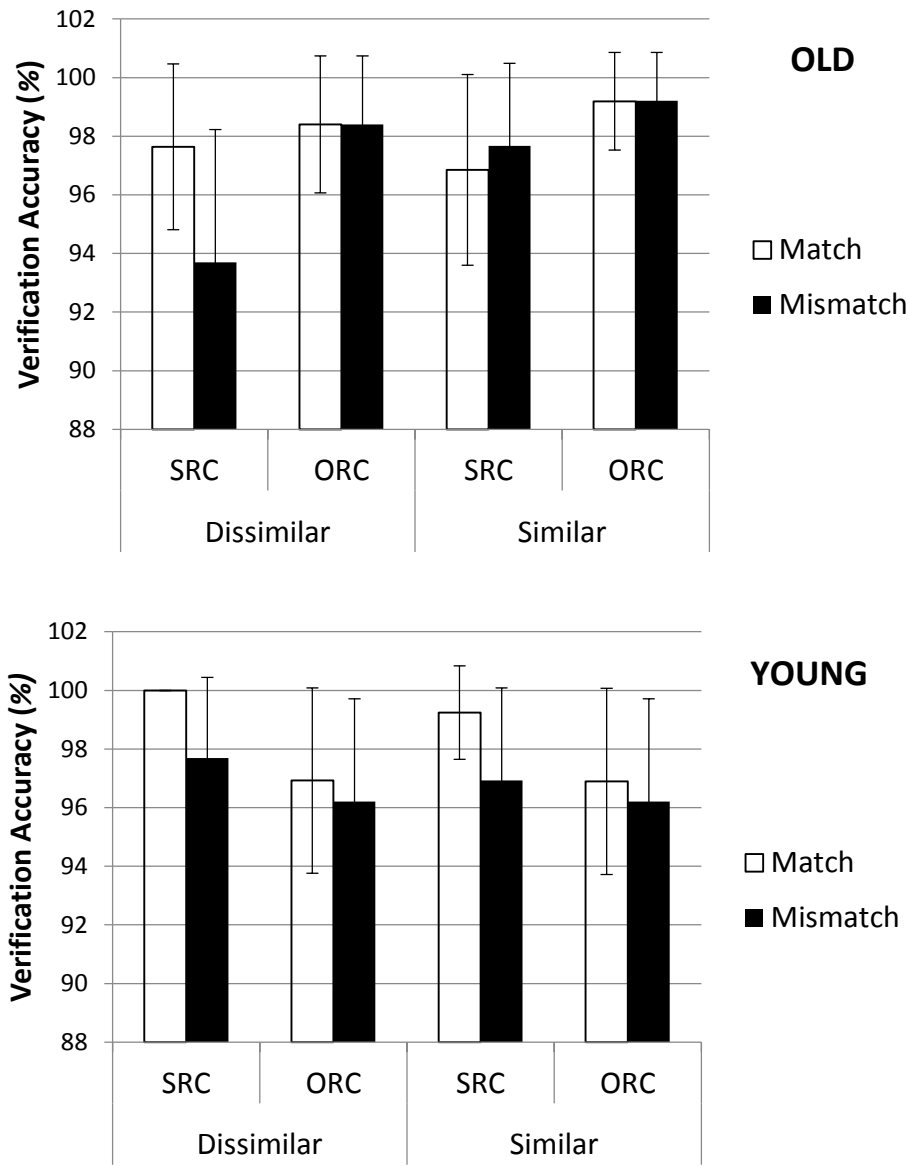


Figure 7. Mismatch effect as a function of age, similarity and syntax (in ms) (Top panel: Old; Bottom panel: Young) in Experiment 2

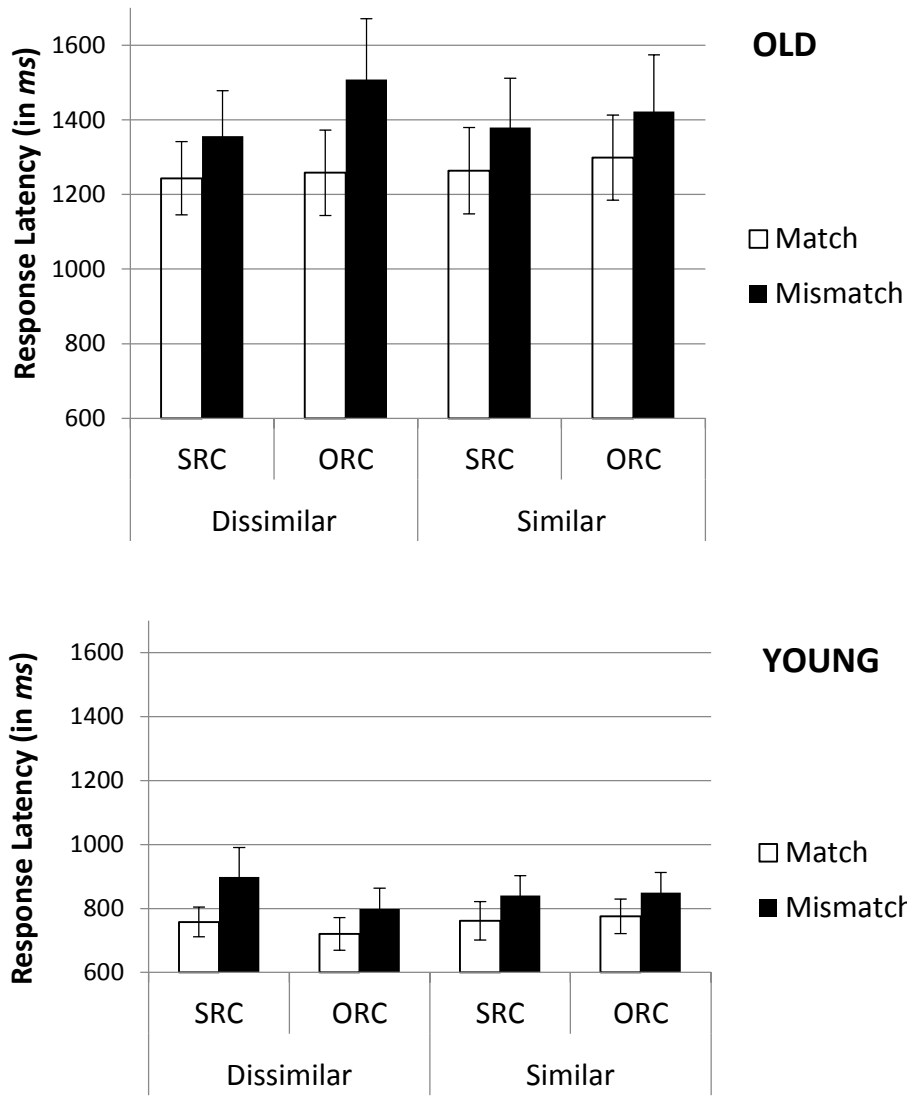


Figure 8. Mismatch effect as a function of age, similarity and syntax (z-score) (Top panel: Old; Bottom panel: Young) in Experiment 2

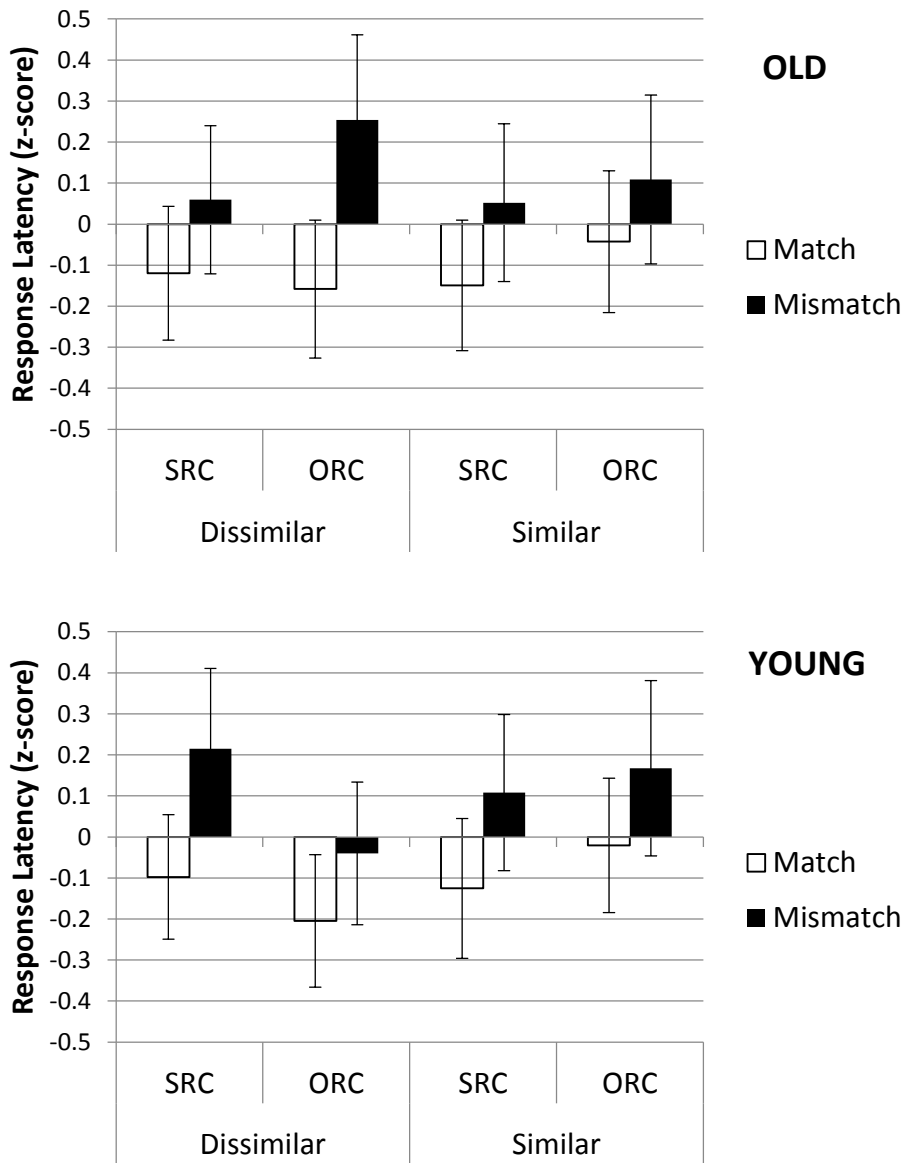
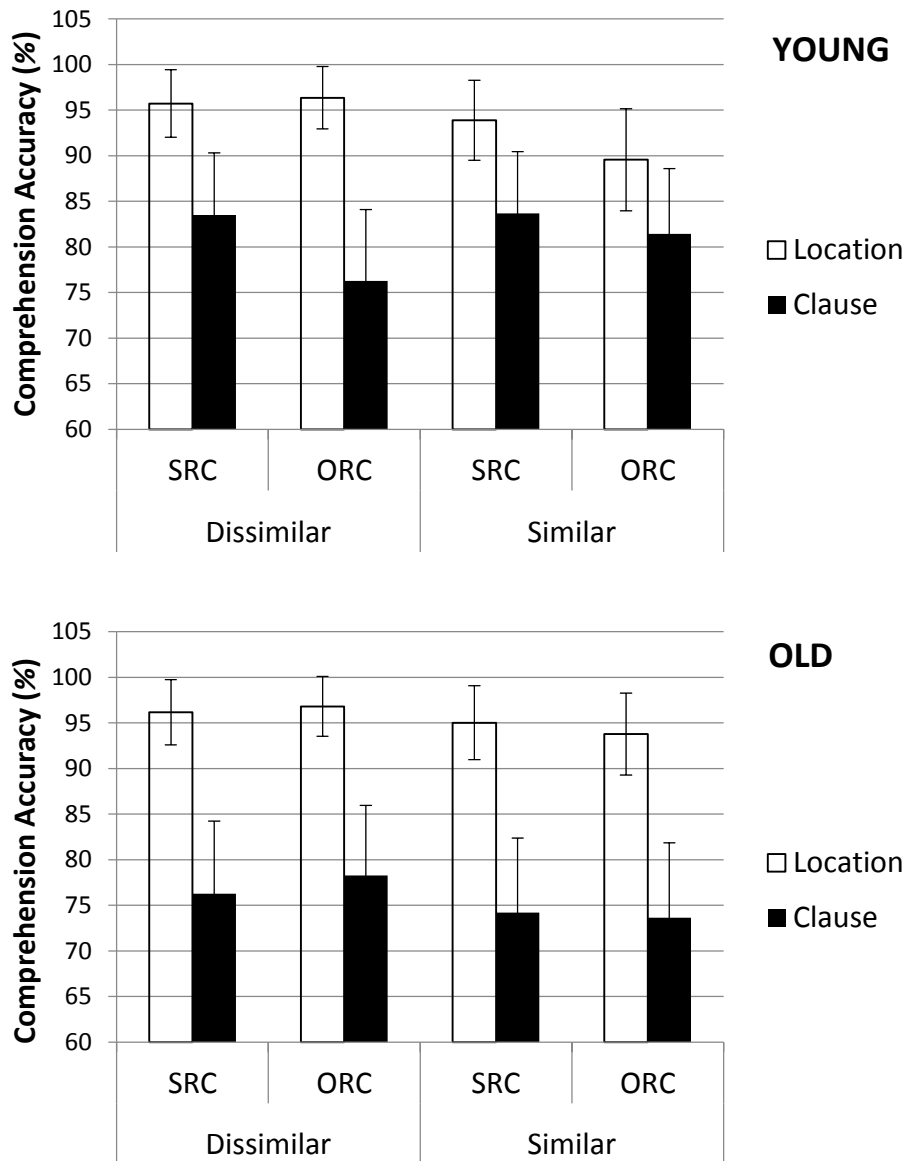


Figure 9. Comprehension accuracy (%) as a function of similarity, syntax and question type separated by age (Top panel: Old; Bottom panel: Young) in Experiment 2



APPENDIX A

SUMMARY OF TEST STATISTICS FOR THE THREE-WAY FULL

MODEL IN EXPERIMENT 1

Row#	Measure	Region	Effects							
			Age	Syn	Sim	Age x Syn	Age X Sim	Syn x Sim	Age x Syn x Sim	
1	GD	RC	0.62	-1.12	4.35 ***	0.72	-1.06	1.02	-0.63	
2		Verb	2.49 **	2.34 *	0.57	-0.47	-2.43 *	-1.30	0.00	
3		Spillover	2.96 ***	-2.51 *	0.99	0.39	1.10	0.07	-1.50	
4		Wrap-up	2.43 **	-0.63	-1.56	-0.14	-1.19	-0.16	0.02	
5	RPD	RC	2.69 ***	4.37 ***	11.49 ***	1.87	0.67	6.23 ***	0.50	
6		Verb	2.16 *	5.00 ***	0.34	1.04	-0.08	0.07	-1.88	
7		Spillover	2.08 *	-1.08	3.01 **	-0.22	-1.32	0.27	-0.50	
8		Wrap-up	1.75 *	1.06	1.26	0.60	0.59	2.08 *	-0.24	
9	Rereading	IniReg	3.49 ***	3.25 **	3.10 **	2.69 **	0.78	4.47 ***	1.23	
10		RC	1.74 *	4.81 ***	7.76 ***	1.15	1.21	4.30 ***	0.03	
11		Verb	0.79	1.62	0.61	0.04	1.16	1.31	-0.82	
12		Spillover	-0.55	-0.53	0.63	0.81	1.42	0.36	0.20	
13	Trial Time	-	2.13 **	7.48 ***	13.39 ***	0.38	1.56	7.90 ***	-0.58	

Note: The values represented the t-values from the HLM, with $p < .05$, *; $p < .01$, **; $p < .001$, ***. Syn=Syntax; Sim=Similarity; IniReg=Initial Region; RC=Relative Clause; Verb=Matrix Verb.

APPENDIX B

SUMMARY OF TEST STATISTICS FOR THE FOUR-WAY FULL

MODEL IN EXPERIMENT 1

Row#	Measure	Region	Effects							
			WM	Age X WM	Syn X WM	Sim X WM	Age x Syn X WM	Age X Sim X WM	Syn x Sim X WM	Age x Syn x Sim X WM
GD										
1		RC	-1.91 *	0.06	1.18	0.28	1.62	1.84	-0.30	-1.00
2		Verb	-2.65 **	-1.45	-0.14	-1.31	-0.23	1.63	0.45	-2.18 *
3		Spillover	-3.52 ***	-2.75 **	1.16	-0.62	-1.28	-1.61	0.04	-0.77
4		Wrap-up	-2.61 **	-1.99 *	1.00	1.04	0.73	-1.60	0.29	0.64
RPD										
5		RC	-2.09 *	-2.28 **	-2.42 *	-2.16 *	-1.21	-1.01	-0.93	-2.68 **
6		Verb	-0.66	-1.04	2.31 *	1.36	0.07	3.03 **	3.28 **	1.63
7		Spillover	-1.49	-2.46 *	0.69	-0.85	0.01	-0.37	-0.78	-1.55
8		Wrap-up	0.90	-1.10	-0.51	-0.42	1.18	0.28	1.21	1.08
Rereading										
9		IniReg	-0.42	-1.60	-1.55	-0.67	0.47	-1.58	0.46	0.79
10		RC	0.82	-1.58	-2.07 *	-0.15	0.05	-0.11	1.23	-0.52
11		Verb	0.82	-0.48	0.49	-0.10	0.88	1.66	1.71	0.39
12		Spillover	2.11 *	-0.82	-1.37	-0.86	1.80	1.17	1.31	1.20
Trial Time										
13		-	-0.50	-1.95 **	-1.01	-1.28	3.36 ***	-0.76	1.24	0.10

Note: The values represented the t-values from the HLM, with $p < .05$; *, $p < .01$; **, $p < .001$; ***, $p < .0001$. WM=Working Memory; Syn=Syntax; Sim=Similarity; IniReg=Initial Region; RC=Relative Clause; Verb=Matrix Verb

APPENDIX C

MATERIALS USED IN EXPERIMENT 1

- 1 The governor that the comedian/Kathryn admired answered the telephone in the restaurant.
- 2 The coach that the referee/Evelyn criticized talked publicly about the incident.
- 3 The plumber that the electrician/Joanne called drove a grey truck everyday to work.
- 4 The dancer that the reporter/Angela phoned cooked the pork chops in their own juices.
- 5 The detective that the secretary/Trevor disliked clipped the coupons out with scissors.
- 6 The chef that the cashier/Justin distrusted called for help after the restaurant closed.
- 7 The burglar that the policeman/Thomas scared carried a pistol in his pocket.
- 8 The quarterback that the linebacker/Calvin hated signed a new contract after the season.
- 9 The landlord that the tenant/Leslie annoyed took a short vacation on a Caribbean island.
- 10 The baby that the housewife/Katie chased squealed with delight at the game.
- 11 The sailor that the captain/Joanne saved retired after twenty years on the job.
- 12 The sculptor that the designer/Antonio greeted impressed everyone at the exhibition.
- 13 The auditor that the bookkeeper/Audrey defied bought a house downtown Chicago.
- 14 The aunt that the child/Kristen amused made paper dolls out of the newspaper.
- 15 The poet that the painter/Philip inspired wrote a biography after they became friends.
- 16 The psychologist that the patient/Denise confronted apologized for her behavior.
- 17 The freshman that the lecturer/Herbert embarrassed passed by the hallway after the debate.
- 18 The singer that the stagehand/Emily irritated played tennis every Saturday.
- 19 The fisherman that the hiker/Richard passed carried lots of heavy gear over his shoulder.
- 20 The hunter that the ranger/Albert saw disappeared into the forest all of a sudden.
- 21 The virologist that the biologist/Julia invited arrived late for the panel meeting.

- 22 The professor that the chair/Michelle introduced got an emergency call from the court.
- 23 The waiter that the broker/Janice despised drove the sports car home from work that evening.
- 24 The soldier that the civilian/Nathan assisted showed up in the local TV news.
- 25 The defendant that the plaintiff/Angelina terrified requested an adjournment from the jury.
- 26 The surgeon that the nurse/Sasha disappointed decided to quit the job at last.
- 27 The cowboy that the sheriff/Edward stabbed wore a red vest and traditional tan hat.
- 28 The salesman that the accountant/Jonathon contacted spoke very quickly on the phone.
- 29 The clerk that the traveler/Landon helped worked in a large investment bank in Britain.
- 30 The admiral that the general/Jeremy advised reminisced nostalgically before the trip.
- 31 The prisoner that the guard/Arnold attacked walked past the door during the lunch.
- 32 The tailor that the customer/Pamela described worked in a building near the bus station.
- 33 The banker that the priest/Sophie praised climbed the mountain just outside of town.
- 34 The photographer that the publisher/Kevin hired traveled around the world every year.
- 35 The manager that the columnist/Maggie angered blamed the entire staff at the meeting.
- 36 The pilot that the attendant/Teresa flattered feared flying before this job.
- 37 The gardener that the homeowner/Elizabeth envied had a coffee in the backyard.
- 38 The musician that the producer/Howard applauded made a new record in his studio.
- 39 The judge that the doctor/Daniel ignored watched the special on the nightly news.
- 40 The architect that the fireman/Wesley liked dominated the conversation during the game.
- 41 The janitor that the mechanic/Andrew tripped cheated at cards very frequently.
- 42 The clown that the magician/Margaret entertained became a star overnight after his debut.
- 43 The teacher that the student/Robert questioned wrote a long novel during the summer.
- 44 The actor that the director/Faith thanked worked in many hit movies before 1990.
- 45 The servant that the mailman/Stephen insulted read the newspaper article about the fire.
- 46 The editor that the author/Jennifer recommended changed jobs after a new merger.

- 47 The lawyer that the client/Kenneth interviewed took a long walk through the park.
- 48 The violinist that the conductor/Michael complimented performed at Carnegie Hall Friday.

APPENDIX D

MATERIALS USED IN EXPERIMENT 2

Sentences

- 1 After the show, the clown that the acrobat/Jonathan envied left a balloon in the pack/air.
- 2 At the end of the expedition, the tourist that the guide/Samanthan ignored found a bat in the air/cave.
- 3 Before the meeting, the librarian that the curator greeted put a book on the shelf/on the photocopier.
- 4 In the control room, the engineer that the mechanic/Emma liked inspected an airplane in the sky/hangar.
- 5 After preparing the meal, the host that the guest/Joel trusted placed an apple in the bag/salad.
- 6 At the bakery, the waiter that the cashier/Natalie annoyed took the bread out of the toaster/window.
- 7 At the crime scene, the police that the detective/Mike defied neglected the cheese left on the mousetrap/sandwich.
- 8 After arriving, the rancher that the farmer/Alexa talked with took a picture of the lemon in a tree/drink.
- 9 After entering, the customer that the owner/Jacob noticed picked up a lime on the Corona bottle/in the produce section.
- 10 After the discussion, the fisherman that the peasant/Amy invited put the lobster in the sea/salad.
- 11 During the picnic, the child that the parent/Thomas shouted at found a mushroom in the forest/soup.
- 12 Before entering the office, the patient that the doctor/Katherine called saw a newspaper on the driveway/rack.
- 13 After the argument, the worker that the employer disliked removed a pineapple from the skewer/tree.
- 14 After the debate, the shopper that the storekeeper/Emily misunderstood put the onion in the basket/batter.
- 15 During the visit, the inspector that the owner/David negotiated with checked a chicken in the oven/coop.
- 16 After a long night, the writer that the editor/Tiffany admired left a cigarette in the box/ashtray.
- 17 Before opening the store, the salesman that the manager/Martin respected put a fish in the oven/pond.
- 18 In the middle of the game, the judge that the coach/Samuel disagreed with irritated a hockey player on the bench/ice.
- 19 Before the dusk, the ranger that the hiker/Brenna passed saw an eagle in the nest/air.
- 20 After the moving-out, the landlord that the tenant/Jason hated found an egg in the refrigerator/skillet.

- 21 After the harvest, the farmer that the visitor/Crystal contacted pointed to the corn in the field/pot.
- 22 Before the dawn, the navigator that the captain/David called spotted a sailboat on the trailer/lake.
- 23 While packing up, the son that the mom complained about forgot a shirt on the hanger/shelf.
- 24 In the bathroom, the janitor that the plumber/Michael despised noticed a tissue in the box/trashcan.
- 25 At the corner, the child that the parent/Margaret chased found a tomato on the vine/pizza.
- 26 After the shower, the worker that the manager/Samuel phoned placed a towel on the rack/floor.
- 27 After the class, the student that the teacher/Susan helped held up the watermelon in the garden.
- 28 After the training, the athlete that the instructor/Matthew visited finished up the spaghetti in the box/bowl.
- 29 On a rainy day, the lawyer that the judge/Bill hated folded/opened the umbrella after arriving/before leaving.
- 30 At the end of the hallway, the secretary that the owner/Amanda worked with saw a computer in the box/on display.
- 31 Overly excited, the man that the usher/Bruno praised lost his hat at the game/ball.
- 32 Kicking too hard, the goalkeeper that the player provoked discovered the ball floating/deflated on the water.
- 33 Overwhelmed by the work, the carpenter that the blacksmith/Elena sympathized with left a dollar in the ATM/jar.
- 34 During the experiment, the assistant that the professor/Thompson questioned took peas from the garden/freezer.
- 35 Early next morning, the writer that the editor/Freddy chose left a paper in the trash/on the table.
- 36 After searching for hours, the boy that the mother/Audrey loved found the sock on his foot/in the drawer.
- 37 After waiting for days, the director that the producer/Finnegan complained about was excited about the crescent/full moon in the sky.
- 38 After hunting for many days, the poacher that the police spotted caught the leopard resting in the tree/running in the desert.
- 39 While shopping, the mayor that the secretary/Earnest adored liked the necktie on the model/in the box.
- 40 After the storm, the gardener that the cleaner/Gelsey disappointed saw a butterfly on the flower/in the air.