ARE THERE AGE DIFFERENCES IN SHALLOW PROCESSING OF TEXT?

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Abstract

There is growing evidence that young adult readers frequently fail to create exhaustive text-based representations as they read. Although there has been a significant amount of research devoted to age-related effects on text processing, there has been little research concerning this so-called shallow processing by older readers. This dissertation uses eye tracking to explore age-related effects in shallow processing across different levels of text representations. Experiment 1 investigated shallow processing by older readers at the textbase level by inserting semantic anomalies into passages read by participants. Older readers frequently failed to report the anomalies, but no more frequently than did younger readers. The eye-fixation behaviour revealed that older readers detected some of the anomalies sooner than did younger readers, but had to allocate disproportionately more processing resources to looking back to the anomalies to achieve comparable levels of detection success as their younger counterparts. Experiment 2 examined age-related effects of shallow processing at the surface form by inserting syntactic anomalies into passages read by older and younger adults. Older readers were less likely to detect syntactic anomalies when first encountering them relative to younger readers and engaged in increased regressive fixations to the anomalies. However, older readers with high
reading comprehension skill were able to use their familiarity with text content to increase their likelihood of syntactic anomaly detection. Experiment 3 investigated the role of aging on shallow processing of the temporal dimension of the situation model. No age-related differences reporting the anomalies were found. The eye-fixation behaviour revealed that older readers with high working memory capacity detected some anomalies sooner than did younger readers; however, they had to allocate increased processing resources looking back to the anomalies to achieve comparable levels of detection as younger readers. Together, the results demonstrate that older readers are susceptible to shallow processing, but no more so than younger readers when they can rely on their linguistic skill or their existing knowledge to help reduce processing demands. However, older readers appear to require additional processing time to achieve comparable levels of anomaly detection as younger readers.
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Chapter 1

Introduction

Most people are not surprised to hear that readers frequently fail to detect errors in a text as they read. In fact, most people can recount a personal experience in which they sent an important email to a superior, mailed a resumé, or submitted a manuscript for publication containing an error that should have been glaringly obvious, in spite of reading the text numerous times. Despite readers’ subjective experience, researchers have only recently begun to investigate this so-called shallow processing of text. Traditional theories of reading comprehension assume that readers process each word as thoroughly as possible upon first encountering it and integrate it with prior text before progressing to the following word (e.g. Just & Carpenter, 1980; Kintsch & van Dijk, 1978). However, there is now growing evidence that readers do not process incoming text as thoroughly as was once believed (e.g. Barton & Sanford, 1993; Christianson, Hollingsworth, Halliwell, & Ferreira, 2001; Daneman, Lennertz, & Hannon, 2007; Ferreira, 2003; Hannon & Daneman, 2001, 2004; Patson, Darowski, Moon, & Ferreira, 2009). This series of experiments used eye-tracking technology to investigate whether susceptibility to shallow processing is influenced by reader and text variables. Specifically, I explored the likelihood of shallow processing in older and younger readers across different levels of text representation using an incidental anomaly detection task. If readers fully process each word as it is encountered, they would be expected to detect information that is inconsistent with the previously-encountered text. Conversely, if readers are prone to shallow processing of text, they may be less likely to spontaneously detect anomalous information within a text. If readers provided evidence of spontaneous error detection, a second goal was to examine the time course of error detection and recovery in both age groups.
Evidence for shallow processing of text

One of the earliest demonstrations of shallow processing became known as the Moses illusion. Erickson and Mattson (1981) demonstrated that comprehenders frequently, and incorrectly, answer “two” when presented with the question “How many animals of each kind did Moses take on the ark?”, even though they know it was Noah, not Moses, who took the animals on the ark. The frequency of the illusion appears to depend, at least in part, on the degree of semantic relatedness between the lure word and the correct item in memory; indeed, readers are more likely to fall for the illusion if the word posing for Noah is Moses than if it is Adam, and they never fall for the illusion if the word posing for Noah is Nixon (Erickson & Mattson, 1981; Hannon & Daneman, 2001; van Oosterdorp & de Mul, 1990). Barton and Sanford (1993) extended the findings of the Moses illusion to more naturalistic texts and demonstrated that readers engage in shallow processing when the imposter word provides a good fit with the context of the rest of a passage. For example, they reported that readers frequently failed to notice a problem in a sentence such as “Authorities were trying to decide where to bury the survivors.” when it was presented in the context of a plane crash. However, readers were more than twice as likely to detect the problem when the same sentence was about a bicycle crash. Readers failed to construct a complete representation of the text when the imposter word provided a sufficient fit with the sentence context.

Ferreira and colleagues (Ferreira, Bailey, & Ferraro, 2002; Ferreira & Patson, 2007) have suggested that comprehenders frequently construct incomplete representations of discourse when they are confronted with difficult or complex material that correspond to plausible events in the real world. Because the linguistic representation is not robust, it needs to be reinforced by communicative context or by existing schema-related knowledge in long-term memory. When the linguistic signal cannot be reinforced, the reader will settle on a “good enough”
interpretation that allows the comprehension system to operate quickly while reducing cognitive demands. For example, support for the role of schema-related knowledge in “good enough” processing comes from the observation that listeners are less accurate when making decisions about the agent of implausible passive sentences compared to plausible passive sentences (Ferreira, 2003). Participants incorrectly reported the identity of the agent more often for the implausible sentence “The dog was bitten by the man.” compared to the more plausible sentence “The man was bitten by the dog.” Ferreira suggested these results provided evidence that comprehenders use a heuristic whereby they assume the first noun phrase they encounter is the agent and the next is the object (see also Townsend & Bever, 2001). Readers rely on such heuristics because they are accessed quickly and easily and conform to everyday knowledge. Experience tells us that dogs are more likely to bite men than men are to bite dogs; thus, readers appeared to use this knowledge to construct a “good enough,” but incorrect, interpretation of the implausible sentence, resulting in the incorrect identification of the agent.

Existing literature therefore suggests that readers frequently fail to fully process an incoming signal, provided an (potentially incorrect) interpretation can be supported by the semantic content of the previously encountered discourse or heuristics derived from schema-related prior knowledge. However, the construction of meaning from text does not only require that readers access the semantic content of words. It is generally accepted that text comprehension requires the integration of processes that represent the surface form, textbase, and situation model (Kintsch, 1988, 1998). The surface form is a representation of the specific words and syntax used in a text. The textbase represents the content of the text itself. This level of representation consists of propositions that describe the meaning and interrelationships between concepts in the text. The situation model is a global representation of the events described in a text, rather than a representation of the text itself (Johnson-Laird, 1983; van Dijk
& Kintsch, 1983). The situation model thus consists of information given in the text itself as well as that based on the reader’s background knowledge and prior experience. At present, shallow processing has been investigated at a level that most closely resembles the textbase – readers frequently create an incomplete representation of the information given in the text if it can be integrated with preceding propositions. The current investigation examines the likelihood of shallow processing at the level of the surface form, textbase, and situation model.

**Age differences in text comprehension**

Aging research has demonstrated that older readers show differential impairment in their representations of the surface form, textbase, and situation models. Older readers typically show deficits in their memory for the content of the textbase (Gupta & Srivastava, 2000; Johnson, 2003; Zelinski & Gilewski, 1988). Furthermore, age-related declines in text memory are exaggerated when text is syntactically complex (Kemper, 1987, 1988) or propositionally dense (Stine & Wingfield, 1990), suggesting the declines are related to reductions in availability of processing resources. However, frequently little or no difference in the construction of situation models in younger and older readers is reported (Miller, Stine-Morrow, Kirkorian, & Conroy, 2004; Radvansky, Copeland, Berish, & Dijkstra, 2003; Radvansky, Copeland, & Zwaan, 2003; Radvansky & Curiel, 1998; Radvansky, Zwaan, Curiel, & Copeland, 2001; Stine-Morrow, Gagné, Morrow & DeWall, 2004; Stine-Morrow, Loveless, & Soederberg, 1996; Stine-Morrow, Miller, Gagné, & Hertzog, 2008). For example, Radvansky et al. (2001) tested older and younger readers’ memory for probe sentences from historical texts. After reading texts about historical events, readers were given a recognition test in which they had to indicate whether they had previously read probe sentences that tapped different levels of text representation. Memory probes at the surface level were verbatim sentences from the actual text. Probes of the textbase were paraphrases of the text that changed individual words or word order, but
maintained the propositional content of the text. Finally, situation model probes consisted of inferences that were important to the description in the text, but were not actually stated. Older readers’ memory was impaired for surface form and textbase probes relative to that of younger readers; however, older readers’ memory was nominally better for situation model probes.

Radvansky et al. suggested that older readers use surface and textbase representations as a temporary scaffolding to create situation models and, as such, surface and textbase representations fade quickly but situation models remain stable. Furthermore, a growing number of studies indicate that older readers allocate more resources to situation model construction relative to younger readers (Radvansky et al., 2001; Stine-Morrow et al., 1996, 2004; 2008). For example, Stine-Morrow et al. (2004) measured the time older and younger adults spent reading and rereading scientific texts as a function of the level of text representation. Their results showed that older readers spent more time reading and rereading information that was judged to be most important to the text as a whole (a measure related to the situation model) compared to younger readers who engaged in the most time reading and rereading portions of the text that were the most propositionally dense (a measure related to the textbase).

Stine-Morrow, Miller & Hertzog (2006) have suggested that age-related reductions in processing capacity coupled with a shift from information-seeking goals toward socioemotional goals may lead older adults to strategically allocate their limited resources toward achieving an overall good understanding of the situation being described in the text at the expense of textbase fidelity. In light of the differential allocation of resources by older and younger readers at the three levels of text representation, the current experiments investigated whether any age-related differences in the likelihood of shallow processing varied between surface form, textbase, and situation model representations. If older readers allocate fewer processing resources to surface or textbase representations relative to situation model representations, it is possible that they
will display a greater likelihood to engage in shallow processing of surface and textbase representations than will younger readers, but will not be any more susceptible to shallow processing of the situation model.

According to Stine-Morrow and colleagues (Stine-Morrow et al., 2006, 2008), one reason why age-related declines in text processing have not been equally observed at all levels of text representation is that older readers’ superior vocabulary and world knowledge provide an alternative route for constructing language representations. At the word level, semantic priming and instantiation of word meaning show few age-related declines (Balota & Duchek, 1988; Light, Valencia-Laver, & Zavis, 1991), which may be a result of older adults’ reliance on their lexical expertise to improve their lexical efficiency. For example, Spieler and Balota (2000) reported that older readers showed a greater effect of word frequency on naming speed relative to younger readers; however, the effect of orthographic neighbourhood density on naming speed was reduced in older adults relative to their younger counterparts. This suggested to Spieler and Balota that older readers were using their reading experience to guide lexical access rather than allocating resources to the sublexical features of the word (e.g. similarity of letters).

Furthermore, older readers appear to be able to compensate for a poor linguistic signal by relying on context. For example, despite reduced performance relative to young adults on a visual word recognition task in which words were presented in visual noise, age differences were eliminated when the same words were embedded in a predictive semantic context (Speranza, Daneman, & Schneider, 2000).

Similar knowledge-related compensatory strategies by older readers have been reported for discourse-level processing (Miller, 2001, 2003; Miller, et al., 2004; Miller & Stine-Morrow, 1998). Miller and Stine-Morrow (1998) asked older and younger participants to read vague and ambiguous passages similar to the frequently cited Bransford and Johnson (1972) “washing
clothes” passage. While older readers read ambiguous passages slower overall than did younger readers, the presentation of a disambiguating passage title resulted in a disproportionate increase in reading speed by older readers accompanied by text recall levels equivalent to that of younger readers. This suggests that in order to achieve adequate text recall, older readers take disproportionate advantage of their existing knowledge structures. In an investigation concerning newly acquired knowledge, Miller et al. (2004) presented half of a younger group and half of an older group of readers with information about the heart. Later, following a passage reading task, older readers who had read the training passage about the heart displayed equivalent comprehension scores to younger readers with the same background knowledge, but spent more time engaging in organization and integration processing. The evidence therefore seems to indicate that when older readers are able to use their increased vocabulary and background knowledge during reading, their text comprehension remains at least as good as that of younger readers.

Currently, little is known about age-related effects of knowledge on the likelihood of shallow processing. Given the importance of knowledge for older readers’ text comprehension, it is reasonable to predict that knowledge will have different effects on the quality of text representations by older and younger readers. If older readers rely on knowledge to compensate for reduced resources, we may expect them to use their knowledge-base to support a representation of text that matches their expectations at the expense of thorough, resource-demanding processing. Because younger readers do not rely as heavily on prior knowledge for text comprehension as do older readers, we may predict younger readers to construct such shallow representations less frequently. Alternatively, with age comes an increase in crystallized knowledge (Baltes, 1997; Baltes, Stauding, & Lindenberger, 1999; Salthouse, 1988), and older readers may be able to rely on their superior linguistic and world knowledge for efficient lexical
access and integration. In situations where older readers can take advantage of prior knowledge, we may, therefore, expect older readers to be less likely to construct “good enough” representations.

**Overview of experiments**

To examine any age-related differences in shallow processing, an incidental inconsistency detection paradigm was used. In each of three experiments, participants read text into which information that was inconsistent with the rest of the text was inserted; however, participants were not made aware of the existence of these errors prior to reading. The rationale behind such a procedure is that readers should spontaneously detect inconsistent information if they create a thorough and complete representation of the text. According to traditional models of reading comprehension, readers process each word as thoroughly as possible upon first encountering it and integrate it with prior text before progressing to the following word (e.g. Just & Carpenter, 1980; Kintsch & van Dijk, 1978). As such, inconsistent information would necessarily be detected by the reader because it cannot be integrated with previously read information (Just & Carpenter, 1980). If, however, readers fail to create a complete representation of the text, covertly inserted inconsistent information may go unnoticed.

To determine whether readers detected the inconsistent information presented in the text, their eye movements were monitored and recorded. An eye-tracking methodology allows for the observation of whether inconsistent information is detected spontaneously during natural reading. Previous research has shown that readers pause longer on words and phrases that are inconsistent with previously read information, and frequently make regressive fixation as they attempt to resolve the inconsistency (Braze, Shankweiler, Ni, & Palumbo, 2002; Daneman, Reingold, & Davidson, 1995; Frazier & Rayner, 1982; Ni, et. al., 1998; Rayner, Chace, Slattery, & Ashby, 2006). Any additional time spent fixating inconsistent information would indicate that
the inconsistency was detected during online reading. Eye tracking, therefore, allows for the investigation of inconsistency detection without the need to inform participants of the inconsistent information in advance, thereby allowing a more naturalistic investigation of spontaneous error detection. An additional benefit of monitoring eye movements is that it allows the researcher to differentiate between initial fixations and later regressions to review previously processed words. If inconsistent information is detected online, eye tracking allows the researcher to determine whether detection was immediate or delayed, as well as the ease and speed of error recovery and integration with previous text. In this way, a second goal to explore the time course of error detection and recovery was accomplished.

**Experiment 1**

Experiment 1 investigated age differences in shallow semantic processing of text. Early demonstrations of shallow processing in younger adults concentrated on whether readers failed to fully access the semantic content of words (e.g. Erickson & Mattson, 1981) and this has continued to be an active area of research (Barton & Sanford, 1993; Bredart & Modolo, 1988; Daneman, et al., 2007; Hannon & Daneman, 2001, 2004; Reder & Kusbit, 1991; Sturt, Sanford, Stewart, & Dawydiak, 2004; van Oostendorp & de Mul, 1990; van Oostendorp & Kok, 1990). As such, an investigation of shallow semantic processing is a logical first step in the exploration of age-related differences in shallow processing of text.

Experiment 1 presented readers with semantically anomalous words in short passages, similar to those used by Barton and Sanford (1993). Barton and Sanford demonstrated shallow semantic processing in young adults by asking participants to read a short passage that described a plane crash at the border of France and Spain. In the critical manipulation, one of four anomalous terms was presented in the final sentence of the passage (The authorities were trying to decide where to bury the survivors/ injured/ surviving injured/ surviving dead). The young
adults in their investigation frequently failed to detect the anomalous term, although detection rates differed across the four anomalous terms (59% for *survivors*, 7% for *injured*, 65% for *surviving injured*, and 23% for *surviving dead*). Semantic anomalies such as these occur at a level of representation that most closely resembles the textbase. Although shallow processing results when the reader fails to fully access the semantic content at the word level, the information is only anomalous in relation to the surrounding text. Thus, readers incorrectly integrate the incoming information with preceding propositions provided there is sufficient supporting context. Consequently, predictions concerning age-related differences in shallow semantic processing are informed by known age-related differences in textbase representations and by older readers’ use of knowledge-based processing.

Research regarding older readers’ textbase representations and memory for text content suggests that older readers may be more likely to engage in shallow semantic processing. With fewer processing resources available relative to younger readers, older readers allocate fewer resources to textbase processing (Radvansky et al., 2001; Stine-Morrow et al., 1996, 2006, 2008) and display reduced memory for the content of what they read (Gupta & Srivastava, 2000; Johnson, 2003; Zelinski & Gilewski, 1988). This reduced resource allocation to text content accompanied by older readers’ reliance on context and knowledge-based processing (Miller, 2001, 2003; Miller & Stine-Morrow, 1998; Miller, Stine-Morrow, et. al., 2004), may make older readers particularly susceptible to shallow semantic processing errors when the context provides a good fit for the anomalous phrase. A caution against the prediction that older readers will be more likely to engage in shallow semantic processing than their younger counterparts, however, comes from the observation that older readers are able to use their knowledge to compensate for their limited processing resources to maintain word recognition (Light, et al., 1991; Spieler & Balota, 2000) and comprehension (Miller, et al., 2004; Stine-
Morrow, et al., 2004, 2008). Older readers may be able to use their superior vocabulary and lifetime experience reading for efficient lexical access, thereby leading older readers to be similar to younger readers in shallow semantic processing.

**Experiment 2**

Experiment 2 investigated age-related effects on shallow processing at the surface level of text representation. In addition, this experiment further explored the role of knowledge in shallow processing by measuring readers’ comprehension skill and by manipulating domain knowledge. Older and younger skilled and less-skilled readers were asked to read two texts about diseases adapted from Kaakinen, Hyönä, and Keenan (2003). One text presented information about familiar diseases, such as the flu and diarrhea, and the other text presented information about rare, or unfamiliar, diseases, such as typhus and trigeminal neuralgia. In this way, readers’ domain knowledge regarding the content of the texts was manipulated. Syntactic anomalies were created by either adding or deleting the letter *s* to the end of words (e.g., “During diarrhea the body loses a lot of liquids and there is a dangers of dehydration.; The flu is a viral infection that tend to affect the very young and very old most severely.”) Syntactic anomalies such as these occur at a level of representation that most closely resembles the surface form. The addition or deletion of the letter *s* resulted in article-noun or noun-verb number violations that were anomalous with respect to the syntax used in the text, but did not alter the meaning of the text.

Because readers could not rely on the semantic content of the text for syntactic anomaly detection, older readers were not expected to benefit from their increased crystallized intelligence. Moreover, older readers’ reduced allocation of processing resources away from word-level processing toward global comprehension (Stine-Morrow et al., 1996, 2004, 2006, 2008) may make them particularly susceptible to the type of shallow syntactic processing
studied here. Offline measures of syntactic processing have frequently demonstrated that older adults are impaired relative to younger adults (Davis & Ball, 1989; Kemper, 1986, 1987; Kemtes & Kemper, 1997; Obler, Fein, Nicholas, & Albert, 1991; Waters & Caplan, 2001). For example, both Obler et al. (1991) and Kemtes and Kempler (1997) found that older readers were less accurate answering questions about syntactically complex ambiguous sentences relative to younger readers. More recent research using eye tracking to monitor readers’ online syntactic processing has supported the observation that processing syntactically complex sentences is more difficult for older readers (Kemper, et al., 2004; Kemper & Liu, 2007). These investigations demonstrated that while older and younger readers spent more time initially fixating syntactically ambiguous sentences compared to unambiguous ones, older readers engaged in many more regressive fixations than did younger readers, indicating that older readers require increased processing time to achieve comparable syntactic analysis. If older readers require more time to achieve comparable syntactic analysis to younger readers, and are more concerned with achieving an adequate understanding of the situation described in a text at the expense of syntactic processing (Stine-Morrow et al., 1996, 2004, 2006, 2008), it is likely they will be more susceptible to shallow syntactic processing.

Alternatively, if older readers are able to use their reading expertise to guide lexical access (Spieler & Balota, 2000), they may be as likely to detect syntactic anomalies as younger readers. This prediction may be particularly true for those readers with high reading skill. Reading skill is associated with automatic/efficient lexical processing, such that skilled readers are those who can quickly and efficiently decode a word and retrieve knowledge of word forms and meanings (Braze, Tabor, Shankweiler, & Mencl, 2007; Perfetti, 1985, 1992, 2007; Perfetti & Hart, 2002). Therefore, one can predict that the skilled older readers in this experiment may be able to take advantage of their lexical processing efficiency to increase their likelihood of
syntactic anomaly detection relative to less-skilled older readers. In addition, although older readers cannot rely on their knowledge base for syntactic anomaly detection, they may be able to take advantage of their knowledge of familiar diseases to free resources to be used for syntactic anomaly detection. As such, older readers could use their knowledge of the familiar diseases to compensate for reductions in cognitive resources, thereby increasing the likelihood they will detect the syntactic anomalies in the familiar diseases text.

Experiment 3

Experiment 3 examined age-related differences in shallow processing of the situation model. A situation model represents a reader’s understanding of the events taking place in the discourse. As readers build their understanding of a text, they create representations of the goals and actions of protagonists that unfold in time and space (Zwaan, Langston, & Graesser, 1995; Zwaan & Radvansky, 1998). Zwaan et al. (1995) have proposed an event-indexing model to describe how readers construct their situation models in which events and characters’ actions are the focal points of situation models. Readers construct their situation models around these focal points and organize the events along five dimensions: space, time, characters, causality, and intentionality. According to the event-indexing model, readers actively monitor whether incoming information requires that any of the five dimensions be updated. For example, if the text indicates a time shift relative to the previous clause, the reader would update the temporal dimension.

Experiment 3 investigated susceptibility to shallow processing of the temporal dimension of readers’ situation models. Specifically, this experiment investigated whether readers would detect inconsistencies in event durations. Readers were asked to read short passages adapted from Therriault and Raney (2007) in which protagonists engaged in activities with durations that were inconsistent with the activity described. For example, while reading a
passage that described the character, Richard, waiting for his wife, Angel, to change their baby, participants were presented with temporally inconsistent information such as “Richard had listened to an entire talk show when Angel brought the baby out.” This example represents temporal information that exceeds the typical duration of the event described; it should not take the entire length of a talk show to change a diaper. If readers actively monitor events described in a text along the temporal dimension, they should be able to detect when incoming temporal information is inconsistent with the preceding information. If readers do not fully process incoming temporal information, they may fail to detect this type of inconsistency.

In contrast to the previous two experiments, there is reason to believe that older readers will be no more likely than younger readers to fail to detect errors at the level of the situation model. Research indicates that older readers represent situation models equivalently to younger readers (Miller, et al., 2004; Radvansky, et al., 2003; Radvansky, et al., 2001; Radvansky & Curiel, 1998; Stine-Morrow, et al., 2004) and that when performance is scored for text comprehension or for the understanding of a situation represented in the text rather than for recall, older readers’ performance is often equivalent to that of younger readers (Hultch & Dixon, 1984; Kemper & Liu, 2007; Miller, et al., 2004; Radvansky, et al., 2001; Stine-Morrow et al., 2004; Stine-Morrow, Morrow, & Leno, 2002). Furthermore, if older readers selectively allocate their processing resources to the situation model to gain a good understanding of the situation described in the text (Radvansky et al., 2001; Stine-Morrow et al., 1996, 2006; 2008), we might expect them to be particularly likely to detect inconsistencies that interfere with the construction of a coherent situation model.

Because situation model processing involves processing across relatively large spans of discourse, more processing resources are required in order to establish coherent situation models relative to textbase or surface form representations. Age-related declines in cognitive resources
are well-established, including reductions in working memory capacity, declines in speed of processing, and difficulty inhibiting irrelevant information (Brébion, 2003; Carpenter, Miyake, & Just, 1994; DeDe, Caplan, Kemptes, & Waters, 2004; Hartley, 2006; Hasher & Zacks, 1988; Salthouse, 1991, 2006; Salthouse & Babcock, 1991; Stine & Wingfield, 1990; Van der Linden, Bredart, & Beerten, 1994). Accordingly, Experiment 3 included a measure of working memory capacity in order to investigate whether working memory capacity influences shallow discourse processing independently of age.
Chapter 2

Experiment 1: Age differences in shallow semantic processing

As a teaching assistant, I have read numerous undergraduate essays and lab reports that contain spelling errors, poor grammar, and a wide variety of typing errors. Recently, in an effort to try to reduce the number of these needless errors, I sent an online announcement to students in my undergraduate class reminding them to reread their papers before submission. You can imagine my embarrassment when students pointed out the irony in my message that instructed them to “make sure you forget to proofread your papers before submitting them.”

Recent studies in the laboratory have well supported such anecdotal accounts of shallow semantic processing. One source of evidence for shallow semantic processing comes from the so-called Moses illusion. When asked questions such as, “How many animals of each kind did Moses take on the ark?” participants frequently respond “two,” even though they know it was Noah, not Moses, who took animals on the ark (e.g., Bredart & Modolo, 1988; Erickson & Mattson, 1981; Hannon & Daneman, 2001; van Oostendorp & de Mul, 1990; van Oostendorp & Kok, 1990). Failure to notice the anomaly appears to be influenced by the semantic relatedness of the impostor word to the correct item in memory; indeed, participants are much more likely to fall for the illusion if the word posing for Noah is Moses than if it is Adam, and they never fall for the illusion if the word posing for Noah is Nixon (Erickson & Mattson, 1981; Hannon & Daneman, 2001; van Oostendorp & de Mul, 1990). Some researchers have considered susceptibility to the Moses illusion as a failure of the memory retrieval processes or the memory match processes (see e.g., Reder & Kusbit, 1991), rather than as a failure of the comprehension processes (although see Hannon & Daneman, 2001; van Oostendorp & Kok, 1990), presumably

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because the task requires participants to process only a simple question or assertion (i.e., a single sentence) and to match it explicitly against facts stored in long-term memory. However, evidence is found for shallow semantic processing from more naturalistic anomaly detection tasks as well (Barton & Sanford, 1993; Daneman et al., 2007; Hannon & Daneman, 2004). Using an incidental anomaly detection task, Barton and Sanford (1993) showed that young adult readers often fail to detect a semantic anomaly (e.g., “The authorities were trying to decide where to bury the survivors”) embedded in a paragraph of text. In the current study, Barton and Sanford’s incidental anomaly detection paradigm was used to investigate whether the aging process influences a reader’s susceptibility to shallow semantic processing of text.

Barton and Sanford (1993) demonstrated the prevalence of shallow semantic processing by giving young adult readers the following short text that ended with one of four anomalous terms:

There was a tourist flight traveling from Vienna to Barcelona. On the last leg of the journey, it developed engine trouble. Over the Pyrenees, the pilot started to lose control. The plane eventually crashed right on the border. Wreckage was equally strewn in France and Spain. The authorities were trying to decide where to bury the survivors / injured / surviving injured / surviving dead. (p. 479)

Then they analyzed how their readers responded to the question, “What should the authorities do?” Whereas a response such as, “People who are not dead should not be buried,” indicated that the reader had detected the anomaly, a response such as, “Let the relatives decide,” was taken as evidence that the reader had failed to detect the anomaly, presumably because his or her semantic analysis of the anomalous term was shallow or incomplete. Barton and Sanford’s results showed high levels of detection failure among young adult readers, although detection
rates differed across the four anomalous terms (59% for the baseline *survivors*, 7% for *injured*, 65% for *surviving injured*, and 23% for *surviving dead*).

Barton and Sanford (1993) used their findings to argue that the proclivity toward shallow semantic processing is particularly evident when a word or phrase has a good semantic fit with the preceding theme of the passage. Because the term *survivors* fits well with the global plane crash theme, readers may have failed to include the *is alive* feature into their representation of *survivors*, and consequently failed to notice the anomaly between *survivors* and *bury*. Barton and Sanford’s results also showed that this tendency toward partial processing (and hence anomaly detection failure) was greater as the goodness of global fit increased. Although the term *survivors* has a good general fit with the plane crash theme, it has a poorer fit with expectations of dead victims than does the term *injured* because the crucial contradictory feature *is alive* is central to the meaning of *survivors*, but it is only presupposed by *injured*. As predicted by the goodness of global fit hypothesis, the detection rate for *injured* was significantly lower than the detection rate for *survivors*. Barton and Sanford found that the detection rate for *injured* could be substantially improved by increasing the salience of the *is alive* feature with the adjectivally qualified noun phrase (NP), *surviving injured*. However, the introduction of the same adjectival qualifier *surviving* before *dead* in the phrase *surviving dead* did not have the same facilitative effect on detection.

Indeed, one of the most provocative of Barton and Sanford’s (1993) findings was the very low detection rate for the internally incoherent NP, *surviving dead*. Traditional models of reading comprehension (e.g., Just & Carpenter, 1980; Kintsch & van Dijk, 1978; Mitchell & Green, 1978) assume that the local meaning of a NP is computed prior to incorporating it into the more global representation of a text. However, if this were the case, then the locally anomalous *surviving dead* should have been detected early and easily. Barton and Sanford’s
finding that detection rates for surviving dead were very low, and significantly lower than
detection rates for the adjectivally qualified but internally coherent surviving injured, is more
consistent with the view that local semantic coherence is not always established prior to
incorporation into the global text representation. Rather, Barton and Sanford’s findings suggest
that the perfect fit of the noun dead preempts further processing of the adjectival qualifier
surviving. In other words, readers are not particularly punctilious about processing and
integrating every word into their mental representation of a text, proceeding in a strict left-to-
right fashion and processing each word as deeply as possible before proceeding to the next word
as conventional models of reading comprehension tend to assume (Carpenter & Daneman, 1981;
Gernsbacher, 1990; Just & Carpenter, 1980; Kintsch & van Dijk, 1978; see Hannon &
Daneman, 2004, for a review). In fact, readers have a bias toward partial or incomplete semantic
processing of words and phrases, as long as a satisfactory level of global coherence has been
established (see also Glenberg, Wilkinson, & Epstein, 1982; Sanford, Barton, Moxey, &
Paterson, 1995; Sanford & Sturt, 2002; see Ferreira, et al, 2002, for a discussion of incomplete
syntactic processing).

Hannon and Daneman (2004) used Barton and Sanford’s (1993) incidental anomaly
detection task to investigate how reading comprehension skill impacted on shallow semantic
processing. They assessed reading comprehension skill with the widely used Nelson-Denny test
of reading comprehension (Form E; Brown, Bennett, & Hanna, 1981); participants who scored
at or above the 50th percentile were classified as skilled readers, whereas participants who
scored below the 50th percentile were classified as less-skilled readers. Hannon and Daneman’s
results revealed both quantitative and qualitative differences in the text-processing styles of
skilled versus less-skilled readers. Although they found that readers of all skill levels were
susceptible to anomaly detection failures, less-skilled readers were significantly more
susceptible. This finding suggested that many readers, particularly less-skilled readers, tend to engage in partial semantic processing, producing mental representations of the text that are underspecified and incomplete. In addition, Hannon and Daneman found that mainly the less-skilled readers had particular difficulty detecting locally anomalous NPs such as surviving dead. Their finding suggested that less-skilled readers often fail to establish the local meaning of a complex NP prior to integrating it into their more global representation of the text (see also Daneman et al., 2007, for a similar result). That less-skilled readers are particularly poor at noticing locally incoherent NPs is consistent with the claim that they tend to trade local processing of details for more extensive processing of global or thematic discourse information (Lee-Sammons & Whitney, 1991). Hannon and Daneman also showed that their individual-differences findings were not restricted to a single passage (the plane crash one) and a small family of anomalous terms (survivors, surviving injured, surviving dead). They developed a set of four new texts, each with four anomalous terms modeled after the survivor problem, and they showed that their individual-differences findings generalized to the new materials.

In addition to replicating Hannon and Daneman’s (2004) findings with respect to how reading comprehension skill impacts on shallow semantic processing, Daneman et al. (2007) showed how the time course of anomaly detection is revealed spontaneously in the moment-to-moment computational processes of natural reading. Previous studies (Barton & Sanford, 1993; Hannon & Daneman, 2004) relied on readers’ written responses to the question posed to them after reading the experimental passage(s), as well as their oral responses during a postreading structured debriefing procedure in which they were specifically asked if they had noticed anything odd in the passage. The debriefing was used to help identify participants who had detected the anomaly but had made a cooperative written response to the question because they assumed it had been an unintentional error in the text. Making inferences about anomaly
detection based on responses to the question and debriefing alone is problematic. Some readers who were classified as nondetectors might have actually noticed the anomaly but then failed to report it (despite explicit prompting) because they still assumed that the anomalous phrase was an unintentional error. Alternatively, a substantial proportion of readers who were classified as detectors might not have actually detected the anomaly while reading, but were alerted to it by the nature of the questioning, particularly during the structured debriefing. In other words, when prompted about whether they had noticed anything odd about the passage they had just read, readers may have been able to draw on their memory for the short passage and then been able to identify the anomaly after the fact. This was a particular concern for Hannon and Daneman’s new materials because a substantial proportion of the readers who were classified as detectors did not reveal evidence for having detected the inconsistency until prompted during the debriefing session.

Because postreading responses may not be valid or sensitive enough indices of anomaly detection and because they shed no light on the time course of anomaly detection, Daneman et al. supplemented the traditional question-asking procedures with an eye-tracking task in which they monitored readers’ eye movements for the presence or absence of disruptions when encountering the anomalous NP. The eye-fixation data revealed evidence for online, albeit delayed, detection of anomalies. Readers who later reported having detected the anomalous NP did not pause longer on the anomalous NP (e.g., surviving injured, surviving dead) relative to a nonanomalous control NP (e.g., unfortunate dead) when they first encountered it; however, they did spend longer looking back to it, suggesting that they recognized a problem after leaving the phrase and returned at some point during reading to revisit the phrase. Because there is ample evidence that readers are able to detect other kinds of errors and inconsistencies immediately on encountering them (e.g., Braze, et al., 2002; Carpenter & Daneman, 1981; Daneman, et al, 1995;
Frazier & Rayner, 1982; Ni, Fodor, Crain, & Shankweiler, 1998), Daneman et al. took the delayed detection for these particular anomalies as lending support to Barton and Sanford’s (1993) claim that they are not easily detected. Daneman et al.’s findings provided some validation for the postreading testing procedures Barton and Sanford (1993) and Hannon and Daneman (2004) used, and they had the additional advantage in that they revealed the time course of anomaly detection.

This study applied Daneman et al.’s (2007) eye-tracking and anomaly detection paradigm to investigate whether aging has an impact on a reader’s tendency toward engaging in shallow or incomplete semantic processing of text. As far as I am aware, no studies have been done that have used the incidental anomaly detection paradigm to investigate whether the aging process influences a reader’s susceptibility to shallow semantic processing of text. However, a relatively large body of literature exists on aging and discourse processing, and this literature can be used as the basis for several contradictory predictions concerning the impact of aging on a reader’s tendency to engage in the kind of shallow processing that results in failure to detect semantic anomalies such as surviving injured and surviving dead.

On the basis of existing literature on aging and context effects in discourse processing, one might be tempted to predict that older readers would engage in shallower semantic processing than younger readers, and hence be poorer at detecting semantic anomalies such as surviving injured and surviving dead. Whereas perceptual and cognitive processing resources are known to decline in normal aging (Baltes, 1997; Salthouse, 1991), linguistic knowledge and world knowledge appear to be well preserved or even grow with aging (Baltes, 1997; Kempler & Zelinski, 1994; Light, 1990; Salthouse, 1988). Hence, it is not surprising that older adults have been shown to benefit from the availability of linguistic context during prose processing (Kemper & Anagnostopoulous, 1993; Stine & Wingfield, 1990; Wingfield & Tun, 2001) and to rely
on context and knowledge-based processing even more so than younger adults do, presumably as a way of compensating for their deficits in processing capacity (Miller & Stine-Morrow, 1998; Miller, et al, 2004; Pichora-Fuller, Schneider, & Daneman, 1995; Rybash, Roodin, & Hoyer, 1995; Speranza, et al, 2000). If older readers engage in, or rely on, knowledge-driven or scenario-based processing more so than their younger counterparts, then one might expect older readers to be more susceptible to incomplete processing of phrases that have a good fit with the global theme of the text, and hence they may be more susceptible to missing good-fit anomalous phrases such as surviving injured and especially the trickier surviving dead. According to this prediction then, the profile of older adults might resemble that of less-skilled younger adult readers (see Hannon & Daneman, 2004).

Although this prediction seems reasonable enough, the literature on aging and discourse processing has produced other findings that caution us against assuming or predicting that older adults will behave like less-skilled readers. Older readers usually show deficits in their memory for text (see Johnson, 2003; Verhaeghen, Marcoen, & Goossens, 1993; Zelinski & Gilewski, 1988 for meta-analyses). Some researchers have attributed the memory deficit to a processing-depth deficit (Craik & Simon, 1980), that is, to the hypothesis that older adults remember less of the texts that they read because they have more difficulty initially encoding them at a semantically “deep” level (G. Cohen, 1979, 1981, 1988; G. Cohen & Faulkner, 1983, 1984). However, age differences in text memory are much smaller when reading is self-paced rather than experimenter paced (Johnson, 2003; Stine-Morrow, Milinder, Pullara, & Herman, 2001; Verhaeghen et al., 1993), and may even be absent when the memory load is not high (Johnson, 2003; Light & Albertson, 1988). Indeed, Light and Albertson have attempted to dissociate memory deficits from comprehension deficits in aging, and they claim to have found “no evidence for impoverished semantic analysis of words and sentences” (p. 150) with age. Given
findings such as these, it is reasonable to predict that older readers would be as good (or bad) as their younger counterparts with regard to detecting anomalous phrases such as *surviving injured* and *surviving dead* under the self-paced reading conditions of Barton and Sanford’s (1993) incidental anomaly detection task. However, equivalent detection success may come as a result of older readers spending disproportionally longer reading or rereading the anomalous phrase (Brébion, 2003). By monitoring our readers’ eye movements for spontaneous disruptions when encountering the anomalous NP, an investigation of whether older readers needed to allocate more online processing resources than their younger counterparts to achieve comparable outcomes with respect to detecting and reporting the semantic anomalies could be conducted. Two studies have previously monitored the eye movements of older readers during a comprehension task (see Kemper, Crow, & Kemtes, 2004; Kemper, McDowd, & Kramer, 2006). The Kemper et al. study is relevant here in that it showed that older adults made many more regressive fixations than did younger adults when reading sentences with temporary syntactic ambiguities such as, “The experienced soldiers warned about the dangers conducted the midnight raid” (Kemper et al., 2004, p. 157). If performance on this syntactic resolution task is related to performance on our semantic anomaly detection task, then one might expect that the older semantic anomaly detectors would achieve comparable levels of detection success as their younger counterparts by engaging in more regressive fixations to the anomalous NP, particularly in the case of the trickier-to-detect internally incoherent anomalous NPs (e.g., *surviving dead*).  

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2 Most studies have used the less natural moving window methodology to investigate online comprehension processes in older adults (e.g., Miller & Stine-Morrow, 1998; Miller et al., 2004; Stine-Morrow et al., 2001). This methodology is less natural than eye-tracking methodology because it does not allow readers to use parafoveal information to preview upcoming words or to make regressive fixations to review previously processed words. The sentence-by-sentence method (e.g., Hartley, Stojack, Mushaney, Annon, & Lee, 1994) allows for parafoveal preview and limited regressive fixations; however, it does not allow the researcher to differentiate between first-pass fixations (immediate processing) and regressive fixations (delayed processing) as eye-tracking methodology does.
Daneman et al.’s (2007) study with younger adult readers has two versions of the semantic anomaly detection task, one in which the semantically anomalous NP occurred in the first sentence of the passage and another in which it appeared in the last sentence of the passage. Daneman et al. found that the location of the anomalous NP did not influence anomaly reporting performance or online fixation behaviour, and so they presented their data collapsed across the two conditions. In the current study, all the older readers were given the last-sentence version of Daneman et al.’s task. The last-sentence condition was chosen because it allows the reader more opportunity to establish a global theme or scenario-based expectations prior to encountering the anomaly. Although location did not influence the anomaly or eye-fixation behaviour of the younger adult readers, the last-sentence version would maximize the conditions for older readers to engage in knowledge-driven or scenario-based processing. The anomaly detection data and the eye-fixation patterns of the older adults in this study were compared with the subset of younger adults who completed the last-sentence condition in Daneman et al.’s study.

**Method**

**Participants**

The participants were 35 older adults whose ages ranged from 65 to 83 years ($M = 73.48, SD = 4.80$). They were volunteers from the local community in Mississauga, Ontario. A questionnaire was used to screen participants for general health, hearing, vision, and cognitive status. Only participants who reported that they were in good health and had no history of serious pathology (e.g., stroke, head injury, neurological disease, seizures) were included in the study. All participants were fluent speakers of English and had normal or corrected-to-normal vision. Participants were tested individually in a session lasting approximately 1 hr. They were paid $10 per hr for their participation.
The anomaly detection data and eye-fixation patterns of the 35 older adults were compared with those of the 30 younger adults who completed the last-sentence condition in Daneman et al.’s (2007) study. These 30 younger adults were 18 to 21 years old ($M = 19.01$, $SD = 0.59$) and were undergraduates enrolled in an introductory psychology course at the University of Toronto at Mississauga who received course credit for participation.

**Semantic Anomaly Detection Task**

**Overview and design.** Participants read seven passages and responded to a question after each of them. Three of the passages were experimental passages, two containing an anomalous NP and one containing a nonanomalous control NP. The other four passages were filler passages with no anomalies in them. Participants’ eye movements were monitored and recorded while reading the passages. The materials and procedure for the 35 older adults were identical to those for the 30 younger adults assigned to the last-sentence condition in Daneman et al.’s (2007) study.

**Materials.** The experimental materials consisted of three short passages adapted from Barton and Sanford (1993) and Hannon and Daneman (2004), each containing one of three possible target NPs in the last sentence of the passage: (a) an internally coherent anomalous NP (e.g., *surviving injured, tranquilizing sedatives*); (b) an internally incoherent anomalous NP (e.g., *surviving dead, tranquilizing stimulants*); and (c) a nonanomalous control NP (e.g., *unfortunate dead, potent stimulants*). Table 1 provides a sample passage and its three possible target NPs as well as the complete set of target NPs used in the study (see Appendix A for complete set of passages and anomalies). Note that these adaptations of the original Barton and Sanford and Hannon and Daneman passages included adding one or more words after the target NP (e.g., “The authorities were trying to decide where to bury the surviving injured from the plane crash”) so that the target NP did not occur in sentence-final position.
The three versions of a passage were assigned to one of three stimulus files with the constraint that one of each type of target NP (internally coherent anomalous NP, internally incoherent anomalous NP, nonanomalous control NP) be included in each file. In each stimulus file, the three experimental passages were randomly interspersed with four nonanomalous filler passages. Each participant read only one stimulus file.

Table 1

Sample Passage with Three Possible Target NPs and Complete Set of Target NPs

(a) Sample Passage and Question

Once again Amanda was studying all night for exams. She entered the school and picked up her third extra large coffee. After drinking her black coffee she went into the library. But when she sat down, she found that she could not focus. She was so hyperactive that she couldn’t even sit still. Amanda was bouncing all over because she’d had too many tranquilizing sedatives/tranquilizing stimulants/potent stimulants in one day.

What should Amanda do?

(b) Complete Set of Target NPs

<table>
<thead>
<tr>
<th>Internally Coherent NP</th>
<th>Internally Incoherent NP</th>
<th>Unambiguous control NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>tranquilizing sedatives</td>
<td>tranquilizing stimulants</td>
<td>potent stimulants</td>
</tr>
<tr>
<td>surviving injured</td>
<td>surviving dead</td>
<td>unfortunate dead</td>
</tr>
<tr>
<td>native resident</td>
<td>native foreigner</td>
<td>obvious foreigner</td>
</tr>
</tbody>
</table>

Procedure. Passages were presented in double-spaced Arial 24 font on a computer screen. Participants read the passages silently at their own pace. They were instructed to read for comprehension because they would be presented a question about the passage after reading it. Participants informed the experimenter when they had finished reading a passage. The experimenter then pressed a button and the question (e.g., “What should the authorities do?” “What should Amanda do?”) appeared on the screen. Participants wrote their response to the question on paper. Prior to seeing the first experimental passage, participants practiced the procedure by reading and answering a question for a passage that did not contain an anomaly.
Participants were given no warning about potential anomalies prior to reading any of the passages.

While reading, participants’ eye movements were recorded using an eye-tracker system (EyeLink II, which SR Research Ltd. developed). Each participant wore the EyeLink headband, which contains three small cameras that allow simultaneous tracking of both eyes and head position, making possible the computation of true gaze position with unrestrained head motion. The movements of both the right and left eyes were recorded, and data from the right eye were analyzed (see Shen, Reingold, & Pomplun, 2003, for a similar set-up). The online saccade detector of the eye tracker was set to detect saccades with an amplitude $0.5^\circ$ or greater, using an acceleration threshold of $9,500^\circ$/s$^2$ and a velocity threshold of $30^\circ$/s. The EyeLink system uses an Ethernet link between the eye tracker and the display computers so that real-time gaze position data can be displayed. Two computer monitors were used for the semantic anomaly detection task. One was used to display the passages to the participant, and the second was used to display real-time feedback about the participant’s eye movements to the experimenter; this allowed the experimenter to monitor performance and recalibrate the eye-tracking system as necessary.

On completion of the task, participants underwent a structured debriefing about the two experimental passages that contained anomalous NPs (see also Barton & Sanford, 1993; Daneman et al., 2007; Hannon & Daneman, 2004). The interview was to identify participants who had detected the anomaly, but who had made cooperative written responses because they assumed that the anomaly had been an unintentional error in the passage. Participants were first asked if they noticed anything odd about the passage. If they responded no, they were alerted to the anomalous phrase that had appeared in their version of the passage, and they were asked if they had noticed it and whether this NP made the passage odd in any way. Finally, they were
asked if they had ever encountered this problem or a similar problem before. Daneman et al. (2007) excluded participants who reported having encountered any form of the survivors problem in the past. None of the older participants needed to be excluded because none of them reported having encountered any form of the survivors problem in the past.

Results and Discussion

Evidence of Anomaly Detection from Postreading Responses

For each of the two experimental passages containing anomalous NPs, participants were classified as detectors or nondetectors based on their written responses to the question posed at the end of the passage (e.g., “What should the authorities do?” “What should Amanda do?”), as well as their answers during the structured debriefing. As in previous studies (Barton & Sanford, 1993; Hannon & Daneman, 2004), participants who explicitly mentioned the anomaly in their written responses and during the structured debriefing were classified as detectors; participants who failed to mention explicitly the anomaly in their written responses but pointed out the anomaly when asked during debriefing if they noticed anything odd about the passage were also classified as detectors; participants who explicitly failed to mention the anomaly in both their written responses and when asked about the oddness of the passage were classified as nondetectors. For example, if participants responded, “People who are not dead should not be buried,” to the question, “What should the authorities do?” they were classified as detectors of the plane crash anomaly. If they responded, “Their relatives should decide,” and still failed to report the anomaly during debriefing, they were classified as nondetectors of that anomaly. If they responded, “Their relatives should decide,” but reported the anomaly when prompted during debriefing, they were classified as detectors. Similarly, if participants responded “Tranquilizers don’t make you hyperactive,” to the question, “What should Amanda do?” (see Table 1), they were classified as detectors of the Amanda anomaly. If they responded, “Amanda
should stop drinking coffee because it is contributing to her hyperactivity,” and still failed to report the anomaly during debriefing, they were classified as nondetectors of that anomaly. If they responded, “Amanda should stop drinking coffee because it is contributing to her hyperactivity,” but reported the anomaly when prompted during debriefing, they were classified as detectors of that anomaly.

The postreading responses showed that older adults were susceptible to missing the anomalous NPs, but they were no more susceptible than were the younger readers. The overall anomaly detection rate for older adults was 44%; this was not significantly different from the 56% anomaly detection rate for the subset of younger adults who read the identical passages under the identical eye-tracking conditions in Daneman et al.’s (2007) study, χ²(1) = 1.98, p = .16, and it was exactly the same as the 44% detection rate for the young adults who read comparable NPs in Hannon and Daneman’s (2004) two experiments. Consistent with earlier findings with younger adults (Barton & Sanford, 1993; Hannon & Daneman, 2004), the older readers in the current study showed higher detection rates for internally coherent anomalous NPs than for internally incoherent anomalous NPs (57% vs. 31%), χ²(1) = 4.69, p < .05, but again, their detection rates for both types of anomalous NPs were not statistically different from the detection rates for the subset of younger adult readers in Daneman et al.’s study, χ²(1) = 1.85, p = .17, for the internally coherent anomalous NPs (e.g., surviving injured; tranquilizing sedatives), and χ²(1) = 0.52, p = .47, for the internally incoherent anomalous NPs (e.g., surviving dead, tranquilizing stimulants), respectively. These findings show that older adult readers frequently engage in shallow semantic processing of text, but no more so than their younger counterparts. But did older readers need to allocate more online processing resources than their younger counterparts to achieve comparable outcomes with respect to detecting and
reporting the semantic anomalies? And did older adults differ in the time course of anomaly detection? To answer these questions, we turn to the eye-fixation data.

**Evidence of Anomaly Detection from Eye-Fixation Data**

Two dependent measures were used to investigate whether age differences existed in the time course of anomaly detection and in the amount of time needed to detect the anomalous NPs: first-pass fixation time on the target NP, and look back time on the target NP. The first-pass fixation time on the target NP was simply the time spent fixating the target NP when first encountered and before the reader moved on to a subsequent word. First-pass fixation time was used to determine whether anomaly detection was immediate; that is, whether it occurred when the reader first encountered the anomaly rather than later on, for example, at the end of the sentence. Look back fixation time on the target NP was the time spent in regressive fixations to the target NP. Look back time was used to provide evidence for delayed detection of the anomaly because it included only refixations of the target NP, that is, regressive fixations that were initiated after the reader proceeded beyond the target NP.

The two dependent measures were subjected to two sets of analyses. In the first set, the eye-fixation data of the 35 older participants and Daneman et al.’s (2007) subset of 30 younger participants was analyzed as a function of the three types of target NPs (internally coherent anomalous NPs, internally incoherent anomalous NPs, and nonanomalous control NPs); Table 2 presents these results. In the second set of analyses, a contingency analysis was conducted on each dependent measure, in which we compared performance on each type of anomalous NP as a function of whether the older and younger participants had been classified as detectors or nondetectors based on their responses to the postreading questions and debriefing; Table 3

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3 The number of first-pass fixations and the number of look back fixations were also analysed. The pattern of results was identical to that of the fixation time measures; as such, only the results for the fixation time analyses are presented here.
presents these results. Because the preliminary analyses showed a different pattern of age effects for the two types of anomalous NPs, the results for the analysis of the two types of NPs are presented separately.

**Internally Coherent Anomalous Noun Phrases**

The eye-fixation data for the easier-to-detect internally coherent anomalous NPs (e.g., surviving injured, tranquilizing sedatives) produced two interesting age-related effects: first, older adults who reported the anomaly appeared to detect the anomalous NP earlier than did younger adults who reported the anomaly, and second, older adults spent a disproportionately longer time in regressive fixations to the anomalous NP than did their younger counterparts.

**Immediate effects.** Evidence for early detection of the internally coherent anomaly by older readers did not come from an analysis of the overall first-pass fixation times (see Table 2).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Internally Coherent Anomalous NP</th>
<th>Internally Incoherent Anomalous NP</th>
<th>Non-anomalous Control NP</th>
</tr>
</thead>
<tbody>
<tr>
<td>First-pass fixation time</td>
<td>Mean 547 SE 82</td>
<td>Mean 594 SE 60</td>
<td>Mean 586 SE 63</td>
</tr>
<tr>
<td>Older</td>
<td>499 46</td>
<td>512 65</td>
<td>563 56</td>
</tr>
<tr>
<td>Younger</td>
<td>2690 438</td>
<td>2121 669</td>
<td>993 103</td>
</tr>
<tr>
<td>Look back time</td>
<td>794 169</td>
<td>560 120</td>
<td>401 89</td>
</tr>
</tbody>
</table>

Indeed, an analysis of variance (ANOVA) on first-pass fixation times with age (older readers, younger readers) as a between-subjects variable and type of phrase (internally coherent anomalous NP, nonanomalous control NP) as a within-subject variable yielded no significant effect of age, type of phrase, or age X phrase interaction, all $F$s < 1. However, the null findings may have been a result of the fact that many readers did not detect the anomaly. Consequently, a contingency analysis was conducted that compared first-pass fixation times on the internally
coherent anomalous NP for readers who did versus did not report the anomaly later (see Table 3). The contingency analysis provided evidence for immediate detection of the internally coherent anomalous NP by the older detectors but not by the younger detectors. As Figure 1 shows, there was a significant age X detection interaction, $F(1, 61) = 6.30$, $MSE = 140,568$, $p < .02$. Older detectors spent on average 701 ms on the internally coherent anomalous NP when first encountering it, which was 361 ms longer than older nondetectors spent on the same NP, $t(33) = 2.32$, $p < .03$; on the other hand, younger detectors spent 461 ms on the anomalous NP, which was 144 ms less than young nondetectors spent on the same phrase, although this difference was not statistically significant, $t(28) = 1.40$, $p = .17$.

Table 3

<table>
<thead>
<tr>
<th>Measure</th>
<th>Internally Coherent Anomalous NP</th>
<th>Internally Incoherent Anomalous NP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Detectors</td>
<td>Non-detectors</td>
</tr>
<tr>
<td>First-pass fixation time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Older</td>
<td>701</td>
<td>125</td>
</tr>
<tr>
<td>Younger</td>
<td>461</td>
<td>51</td>
</tr>
<tr>
<td>Look back time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Older</td>
<td>3318</td>
<td>614</td>
</tr>
<tr>
<td>Younger</td>
<td>1013</td>
<td>212</td>
</tr>
</tbody>
</table>

This pattern of findings could not be attributed to the fact that the older detectors of the internally coherent anomalous NP happen to be readers who make longer first-pass fixations in general than do older nondetectors of the internally coherent anomalous NP. If this were the case, then older detectors of the internally coherent anomalous NP would also have longer first-pass fixation times on the internally incoherent anomalous NP than their nondetector counterparts. A contingency analysis on the internally incoherent anomalous NP with age and
detector status on the internally coherent anomalous NP as between-subject factors did not reveal any significant effects (all $Fs < 1$). This showed that detector status on the internally coherent anomalous NP was not related to first-pass fixation time on the internally incoherent anomalous NP. In other words, older detectors of the internally coherent anomalous NP only spent significantly longer in first-pass fixations to the particular anomaly that they reported. Together these results show that older readers who reported the internally coherent anomaly spent reliably longer processing that anomalous NP when first encountering it than did older readers who failed to report the same anomaly. Presumably, the additional first-pass time reflected the fact that these particular older readers had already noticed that something was amiss (see also Carpenter & Daneman, 1981; Daneman et al., 1995; Ni et al., 1998).

![First-pass fixation times of older and younger detectors and non-detectors on the internally coherent anomalous NPs](image)

**Figure 1.** *First-pass fixation times of older and younger detectors and non-detectors on the internally coherent anomalous NPs (e.g., surviving injured; tranquilizing sedatives).*

What might account for the finding that only the older detectors were able to detect the anomaly when first encountering it? One might be tempted to conclude that older readers adopt a slower and more cautious reading style than their younger counterparts and consequently are
more likely not to proceed to the next word until they have finished processing the one that they are currently fixating. Indeed, there is some evidence in the literature to suggest that older adults sometimes display a more cautious criterion in the speed–accuracy trade-off (Brébion, 2003; Smith & Brewer, 1995) and can achieve similar sentence comprehension accuracy scores to their younger counterparts by increasing their processing times (see Brébion, 2003). However, age difference in the speed–accuracy trade-off cannot account for the findings here because there was no hint of an age difference in first-pass fixation times on the anomalous NP or on the nonanomalous control NP in the current study (all age main effect $F_s < 1$). One plausible hypothesis is that the older detectors were linguistically more sophisticated than the younger readers (Baltes, 1997; Salthouse, 1988) and could draw on this knowledge to function more efficiently and effectively in the semantic anomaly detection task (see also Rybash et al., 1995).

**Delayed effects.** The main age-related finding of interest was that older readers invested a disproportionately greater amount of time in regressive fixations to the internally coherent anomalous NP relative to the nonanomalous control NP than did their younger counterparts. As Table 2 shows, both older and younger readers spent more time looking back to the internally coherent anomalous NP than to the nonanomalous control NP, $F(1, 63) = 15.27, MSE = 2,308,822, p < .001$. However, a significant age X phrase type interaction, $F(1, 63) = 5.95, MSE = 2,308,822, p < .02$, showed that older readers spent disproportionately longer in look back fixations to the internally coherent anomalous NP than did younger readers. This interaction showed that older readers spent 2,690 ms looking back to the internally coherent anomalous NP, and this was 1,697 ms in additional look back time to it relative to the nonanomalous NP, whereas younger readers spent 794 ms looking back to the internally coherent anomalous NP, and this was only 393 ms in additional look back time relative to the nonanomalous NP. This pattern of results suggests that older readers allocated more resources to
the processes involved in detecting the anomaly and attempting to resolve or repair it. However, based on the findings of the contingency analysis that compared detectors versus nondetectors of the internally coherent anomalous NP to be discussed next, this additional look back time may indicate, in part, that some of the older nondetectors did in fact detect the anomaly even though they failed to report it later.

The contingency analysis on look back time to the internally coherent anomalous NP showed a main effect of age, $F(1, 61) = 14.50, p < .001$, and a main effect of detector status, such that younger and older detectors spent more time looking back to the anomalous NP than did younger and older nondetectors (2,110 ms vs. 1,275 ms), $F(1, 61) = 4.82, MSE = 3,778,015, p < .05$. However, the additional processing time older detectors spent relative to older nondetectors (3,318 ms vs. 1,853 ms) was not significantly greater than the additional processing time younger detectors spent relative to younger nondetectors (1,013 ms vs. 192 ms; see Table 3), age X detector interaction, $F < 1$. This result should not be taken as showing that older detectors did not need to allocate more online processing resources than their younger counterparts to achieve comparable outcomes with respect to detecting and explicitly reporting the internally coherent semantically anomalous NP. Remember that older detectors showed elevated processing time when first fixating the internally coherent anomalous NP whereas younger detectors did not; consequently, some of the extra time allocated by older detectors to the anomaly detection process occurred during the original reading of the anomalous NP and not simply during the rereading.

Of course, not drawing attention to the fact that older nondetectors spent an appreciable time looking back to the internally coherent anomalous NP ($M =1,853$ ms; see Table 3) would be remiss; although this was significantly less than the time older detectors spent looking back to the same anomalous NP, it appears to be considerably longer than the average time that older
readers engaged in look back activity when there was no anomaly (for the nonambiguous control NPs, average look back time was 993 ms; see Table 2). This finding, coupled with the significant age X phrase interaction found for the noncontingency related look back times (Table 2), suggests that a substantial number of older readers must have detected something amiss, but that they failed to report explicitly the anomaly later. The same pattern was not evident for the younger nondetectors; they spent only 192 ms looking back to the internally coherent anomalous NP, and this was certainly not more than the younger readers’ baseline look back time for nonanomalous NPs ($M = 401$ ms; see Table 2). Why these older “nondetectors” failed to report the anomaly is not clear. Numerous possibilities exist. Perhaps they actually did notice the anomaly but failed to report it (despite explicit prompting) because they still assumed that the anomalous phrase was an unintentional error. Perhaps they were less confident that they had detected the anomaly and were more cautious about reporting it (Smith & Brewer, 1995). Perhaps they simply forgot. If a sufficient number of these individuals actually detected the anomaly when revisiting the anomalous NP, then caution needs to be taken about concluding that older readers show equivalent levels of shallow semantic processing as their younger counterparts, at least with respect to detecting semantically anomalous NPs of the internally coherent kind.

**Internally Incoherent Anomalous Noun Phrases**

The eye-fixation data for the harder-to-detect internally incoherent anomalous NPs (e.g., surviving dead, tranquilizing stimulants) showed only one interesting age-related effect: older adults spent a disproportionately longer time in look back fixations to the anomalous NP than did their younger counterparts.

**Immediate effects.** The first-pass fixation times provided no evidence that internally incoherent anomalous NPs were detected when first encountered, either by older or younger
readers (see Table 2). An ANOVA on first-pass fixation times with age (older readers, younger readers) as a between-subjects factor and type of phrase (internally incoherent anomalous NP, nonanomalous control NP) as a within-subject factor yielded no significant effect of age, type of phrase, or age X phrase interaction, all $F$s < 1. One could argue that the null findings were a result of the fact that many of the readers did not detect the internally incoherent anomalies (the detection rate for the older readers was only 31%). However, this was not the reason for the nonsignificant findings. The contingency analyses that compared first-pass fixation time on the incoherent anomalous NP as a function of whether readers had reported the anomaly also failed to provide evidence for early detection; neither older nor younger detectors showed a first-pass fixation time cost on the internally incoherent anomalous NP relative to their respective nondetector counterparts. As Table 3 shows, older detectors spent 620 ms on the NP, which was 37 ms longer than the 583 ms older nondetectors spent on it, and younger detectors spent 543 ms on the NP, which was 52 ms longer than the 491 ms younger nondetectors spent on it; however, neither the detector effect nor the age X detector interaction was significant, both $F$s < 1. Together these results show that older and younger readers did not spend reliably longer on the internally incoherent anomalous NP if they reported detecting it than if they did not report detecting it. Because there is ample evidence that readers are able to detect other kinds of errors and inconsistencies immediately on encountering them (e.g., Carpenter & Daneman, 1981; Daneman et al., 1995; Frazier & Rayner, 1982; Ni et al., 1998), these findings lend support to Barton and Sanford’s (1993) claim that internally incoherent anomalous NPs (e.g., *surviving dead, tranquilizing stimulants*) are not easily detected.

**Delayed effects.** Older and younger readers provided evidence for delayed anomaly detection when regressive fixations to the target NPs were analyzed. In addition, older detectors spent disproportionately longer looking back to the internally incoherent anomalous NP than did
younger detectors. However, the effects were significant only in the contingency analyses (see Table 3).

Although older readers spent longer looking back to the internally incoherent anomalous NP than to the nonanomalous control (2,121 ms vs. 993 ms), and younger readers spent longer looking back to the internally incoherent anomalous NP than to the nonanomalous control (560 ms vs. 401 ms; see Table 2), the effect of phrase type was not significant, $F(1, 63) = 2.69, MSE = 4,973,702, p = .11$, and the age × phrase type interaction was not significant either, $F(1, 63) = 1.53, MSE = 4,973,702, p = .22$. Only the main effect of age was significant, $F(1, 63) = 30.36, MSE = 4,419,918, p < .001$, and showed that older readers spent much more time rereading previously processed NPs than did younger readers. The lack of a significant difference in look back time on the internally incoherent anomalous NPs relative to the nonanomalous control NPs could be a function of the low detection rates for these anomalies. And indeed, the contingency analyses provided strong support for the fact that both older and younger readers who reported the anomaly later actually did detect it during reading and that older detectors spent a much longer time looking back to the internally incoherent anomalous NP than did younger detectors.

As Figure 2 shows, an older detector of the internally incoherent anomalous NP spent on average 4,678 ms refixating it, and this was 3,729 ms longer than an older nondetector spent on the same NP; a younger detector of the internally incoherent anomalous NP spent on average 736 ms refixating it, and this was 293 ms longer than a younger nondetector spent on the same NP. An ANOVA confirmed this description of the results insofar as a significant main effect of detector status was found, $F(1, 61) = 8.27, MSE = 7,204,439, p < .01$, and a significant age × detector interaction, $F(1, 61) = 6.04, MSE = 7,204,439, p < .02$. Together these results show that readers who reported the internally incoherent anomaly spent reliably longer reprocessing it than did readers who failed to report it, and older detectors devoted disproportionately more
time than did younger detectors to reprocessing it. Presumably, the additional time reflected the
time taken to detect the anomaly and any attempts initiated to resolve or repair it (see also
Carpenter & Daneman, 1981; Daneman et al., 1995; Ni et al., 1998). The processing cost to
older detectors was 3,446 ms more than the processing cost to younger detectors; this finding
suggests that older readers may have needed to allocate more online processing resources than
their younger counterparts to achieve comparable outcomes with respect to detecting and
explicitly reporting the semantic anomalies later (see also Stine-Morrow et al., 2001).

![Figure 2](image)

**Figure 2.** Look back fixation times of older and younger detectors and non-detectors on the
internally incoherent anomalous NPs (e.g., surviving dead; tranquilizing stimulants).

Of course, some of that additional processing time may have involved postdetection
reinspection of the anomalous NPs, reflecting older adults’ greater need or greater motivation to
attempt to repair or understand the source of the inconsistency.

Even though older and younger detectors looked back to the internally incoherent
anomalous NP significantly longer than did their nondetector counterparts, one might still ask
whether any evidence was found that some nondetectors actually had detected the anomaly but
failed to report explicitly the anomaly in their responses to the postreading question and
debriefing. This did not appear to be the case for either older or younger nondetectors. Older
nondetectors spent on average 949 ms looking back to the internally incoherent anomalous NP, but this was certainly not longer than the average time that older readers engaged in look back
fixations when no anomaly existed (for the nonanomalous control NPs, mean look back time
was 993 ms; see Table 2). Younger nondetectors spent 443 ms looking back to the internally
incoherent anomalous NP, which was similar to their baseline look back time for the
nonanomalous NPs ($M = 401$ ms; see Table 2). Thus, older and younger individuals who failed
to report the internally incoherent anomalous NP appear to have been oblivious to its presence.

**Summary and Conclusions**

Researchers increasingly acknowledge that readers frequently produce mental
representations of the linguistic input that are much less accurate, detailed, and coherent than
traditional theories of sentence and discourse processing have assumed. For example,
investigations of the misinterpretation of garden-path and passive sentences support the view
that readers (and listeners) often establish meanings that are simply “good enough” rather than
accurate or complete (Christianson, et al, 2001; Ferreira et al., 2002). Task instructions (such as
warnings of a subsequent test) can shift the individual’s criterion for what is deemed good
enough (e.g., van den Broek, Lorch, Linderholm, & Gustafson, 2001) and possibly
characteristics intrinsic to the individual reader can too (Hannon & Daneman, 2004; Sanford &
Garrod, 1994). Certainly less-skilled readers have been shown to demonstrate a greater
propensity toward shallow or partial semantic processing of text (Hannon & Daneman, 2004),
which could be a function of their lower “standards of coherence” (van den Broek et al., 2001)
or their inferior linguistic computational skills. This study used Daneman et al.’s (2007) eye-
tracking version of the incidental anomaly detection task (Barton & Sanford, 1993) to
investigate whether aging has an impact on a reader’s proneness toward shallow semantic processing.

Because “aging brings declines in mental mechanics but growth in crystallized knowledge” (Miller et al., 2004, p. 812; see also Baltes, 1997), making predictions about how older readers might perform on Barton and Sanford’s (1993) incidental anomaly detection task relative to their younger, college-aged counterparts was difficult. If older adults rely too much on their existing linguistic and schema-based knowledge to compensate for their deficiencies in mental mechanics (Miller & Stine-Morrow, 1998; Miller et al., 2004), we might expect them to be more susceptible to incomplete processing of phrases that have a good fit with the global theme of the text, and hence to be even more susceptible than their younger counterparts to missing good-fit anomalous NPs (e.g., surviving injured, surviving dead). In other words, older readers might have been even more prone to shallow semantic processing than their younger counterparts. On the other hand, the superior linguistic and world knowledge of older readers could also be put to advantage in anomaly detection, especially if the reading conditions allow older adults to compensate for declines in mental mechanics by reading at a slower pace (see Johnson, 2003) and adopting a more cautious criterion (Brébion, 2003) with respect to processing and integrating every word into their mental representation of the text. In other words, older readers may be no worse (and could possibly be even better) at detecting and reporting semantically anomalous NPs than their younger counterparts, and their compensatory mechanisms should be evident in their online eye-fixation behaviour. By comparing the performance of a group of older adults with that of the subset of younger adults who read the identical passages in Daneman et al.’s (2007) study, the current study provided evidence more consistent with the second set of predictions.
The postreading responses showed that older adults were susceptible to shallow or incomplete semantic processing, but no more so than their younger college-aged counterparts. Older adults reported the internally coherent anomalous NPs (e.g., *surviving injured, tranquilizing sedatives*) 57% of the time, and they reported the internally incoherent anomalous NPs (e.g., *surviving dead, tranquilizing stimulants*) 31% of time. These detection rates were comparable to those of the subset of younger adults who read the same passages in Daneman et al.’s (2007) study. However, the postreading responses alone do not tell the whole story. The online eye-fixation data revealed some interesting age-related differences in the anomaly detection processes. For the easier-to-detect internally coherent anomalous NPs, older detectors showed an advantage over their younger counterparts in that they appeared to detect the anomaly sooner than did the younger detectors; the analyses of first-pass fixation time versus look back time revealed that older detectors achieved their detection when first encountering the internally coherent anomaly, whereas younger detectors did not. This early detection could not be attributed to slower overall first-pass times on the part of older readers, and a plausible hypothesis is that the older detectors could draw on their superior linguistic knowledge to function more efficiently and effectively in detecting the internally coherent anomalous NPs. Older detectors did not show the same temporal advantage over younger detectors in the case of the trickier-to-detect internally incoherent anomalous NPs in that the eye-fixation behaviour revealed that both age groups showed evidence of delayed rather than immediate detection. In addition, older detectors spent disproportionately longer looking back to the internally incoherent anomalous NP than did their younger counterparts, a finding that suggests that they allocated significantly more processing resources to anomaly detection and recovery. These additional resources may have been necessary to achieve comparable levels of detection success.
as their younger counterparts, or they may have reflected older readers’ greater needs with respect to resolving the detected anomalies.

Experiment 1 thus demonstrated that older readers engage in shallow processing of the textbase. When an anomaly was present that altered the content of the text, older readers frequently failed to detect it; however, older readers were not more likely to engage in shallow semantic processing than were younger readers. In fact, older readers detected internally coherent semantic anomalies earlier than did younger readers. Although linguistic knowledge was not manipulated in this investigation, it is possible that older readers were able to take advantage of their superior linguistic knowledge to aid anomaly detection. Experiment 2 extends upon the current findings by investigating whether similar age-related effects on shallow processing are observed at surface level representations. In addition, prior knowledge was manipulated and measures of reading comprehension were collected in order to further explore the role of knowledge in shallow processing.
Chapter 3

Experiment 2: Age differences in shallow syntactic processing

Consider reading the following passage:

Many rare diseases are treatable or at least their symptoms can be somewhat relieved. Typhus is nearly extinct because there is an efficient treatment for it. Strong antibiotics can be used to treats the disease. Tetracyclic antibiotics are very effective. Treatment of trigeminal neuralgia is a lot more difficult. Over-the-counter pain reducing drugs hardly help at all. Combinations of drug used to treat depression and epilepsy are the most frequently used treatment. In addition, it is possible to treat the pain with surgery of the many tactile nerves in the face. Either the nerve can be cut or it can be injected with glycerol or alcohol. The problem is that one side of the face goes numb, which could be uncomfortable.

Did you notice the errors in the preceding text? The passage contains two syntactic errors created by either adding or deleting the letter $s$ to the end of a word. The first error is a noun-verb number violation created by adding the letter $s$ to the word *treats* in the sentence “Strong antibiotics can be used to *treats* the disease.” The second error is a noun-noun number violation created by deleting the letter $s$ from the word *drug*, and can be found in the sentence “Combinations of *drug* used to treat depression and epilepsy are the most frequently used treatment.” The above passage was an excerpt from a 1500-word text about rare diseases that are unfamiliar to most readers. Do you think you would have been more likely to notice the syntactic errors if the passage had been about more familiar diseases, such as the flu or diarrhea? What would have happened if you had been warned that you would later be asked questions about typhus? Would that have led you to be more likely to detect the error in the sentence about typhus? The question for the current investigation was whether reader and text variables
influence the likelihood of shallow processing at the surface level of text processing. Specifically, readers’ eye movements were monitored to investigate whether there were differences in the time course of spontaneous syntactic anomaly detection as a function of the age and reading comprehension skill of the reader. In addition, I investigated the effect of two text variables – domain familiarity and content relevance – on the likelihood of syntactic anomaly detection. First, I briefly review the evidence for shallow semantic processing of text and the task that has been used to demonstrate incidental semantic anomaly detection by readers covered in Chapter 2. I then review the current evidence for shallow syntactic processing and show how I used the incidental anomaly detection task to investigate reader and text characteristics that influence the likelihood of spontaneous syntactic anomaly detection.

**Evidence for Shallow Semantic Processing**

One of the earliest demonstrations of shallow processing comes from the Moses Illusion (Erickson & Mattson, 1981). Erickson and Mattson demonstrated that when asked “How many animals of each kind did Moses take on the Ark?” readers frequently, but incorrectly, answered “two,” despite having the knowledge that it was Noah, not Moses, who was on the Ark. The illusion remains even when readers are given the information needed to answer the questions correctly, and warned to monitor for such errors beforehand (Reder & Kusbit, 1991). The illusion appears to be related to the strength of the semantic relatedness of the foil word to the rest of the statement. For example, although readers frequently failed to detect the incorrect statement that Moses brought animals on the Ark, few readers made the same oversight if asked “How many animals of each kind did *Nixon* take on the Ark?” (Erickson & Mattson, 1981; van Oostendorp & de Mul, 1990; van Oostendorp & Kok, 1990).

The classic Moses Illusion was established in simple sentences; however, more recently, Barton and Sanford (1993) demonstrated that shallow processing occurs across larger, more
naturalistic prose passages. They gave readers a short passage that described a plane crash over
the Pyrenees mountains, and contained one of four anomalous phrases, such as “The authorities
were trying to decide where to bury the survivors/injured/surviving injured/surviving dead.”
Next, they analyzed how readers responded to the question “What should the authorities do?” in
order to look for evidence that their readers had detected the anomaly. An answer such as “let
the relative decide where they want the bodies to be buried” was taken as evidence that the
anomaly was not detected. Barton and Sanford found that the detection rate of semantic
anomalies was related to the overall goodness-of-fit of the inconsistent information with the rest
of the passage, with detection rates differing across the four anomalous terms (59% for
survivors, 7% for injured, 65% for surviving injured, and 23% for surviving dead). Importantly,
readers were surprisingly poor at detecting the locally incoherent anomaly surviving dead,
reporting the anomaly on only 23% of the trials. If, as predicted by traditional theories of
reading comprehension (e.g. Just & Carpenter, 1980; Kintsch & van Dijk, 1978), readers were
processing each word as they encountered it, this anomaly should be identified easily given the
local inconsistency between surviving and dead. The fact that this inconsistency was missed
77% of the time suggests that if a word fits well with the global theme of a passage, a thorough
analysis is not executed locally before it is integrated into the global representation.

Further investigations extended Barton and Sanford’s (1993) findings by reporting
quantitative and qualitative differences in the processing styles of skilled and less-skilled adult
readers. For example, Hannon and Daneman (2004) found that while readers of all skill levels
frequently failed to engage in a rigorous analysis of each word they read, readers who scored
below average on a standardized test of reading comprehension called the Nelson-Denny were
particularly susceptible to partial analysis, suggesting they form a less coherent text
representation than do more skilled readers. Furthermore, these less-skilled readers had
particular difficulty noticing the anomalies that had the best fit with the global theme of the text. Hannon and Daneman’s (2004) findings were replicated and extended by Daneman, et al (2007) who investigated the time course of semantic anomaly detection in skilled and less-skilled readers. This was accomplished by monitoring readers’ eye movements as they read passages based on Barton and Sanford (1993), containing one of three target phrases (e.g. surviving injured/surviving dead/unfortunate dead). Any additional time spent reading an anomalous phrase (e.g. surviving injured/surviving dead) relative to a nonanomalous control phrase (e.g. unfortunate dead) was taken to indicate spontaneous online anomaly detection. Detection rates based on readers’ responses to probe questions (e.g. “What should the authorities do?”) replicated Hannon and Daneman’s findings of differences in processing styles by skilled and less-skilled readers. On the other hand, no differences in the time course of anomaly detection as a function of reading skill were revealed by the eye movement data. Readers who reported the anomaly spent more time processing the anomaly relative to a nonanomalous control phrase. However, readers who later reported the anomaly did not spend longer processing the anomaly when first encountering it. Instead, readers provided evidence of delayed detection, as indicated by increased time spent refixating the anomalies.

Daneman, et al.’s (2007) semantic anomaly detection paradigm was used in Experiment 1 to investigate age-related changes in shallow semantic processing. This experiment on age-related differences in shallow semantic processing found that readers of all ages engage in shallow processing of text and that semantic anomaly detection rates are not reduced in older readers. However, age-related processing differences were found in the pattern of eye movements reflecting online anomaly detection. For easier-to-detect internally coherent anomalies (e.g. surviving injured), older readers provided evidence of earlier detection than younger readers. On the other hand, a similar age-related advantage was not found when
readers’ encountered the more difficult-to-detect internally incoherent anomalies (e.g. surviving dead). Furthermore, the older readers who reported detecting the anomaly spent more time regressing to the anomalous phrase compared to younger readers, suggesting that older readers allocated more processing resources to anomaly detection and recovery than did younger readers.

In summary, the findings to date indicate that readers frequently fail to compute the local meaning of words before proceeding in a text if there is sufficient semantic and contextual information to support a partial analysis. Although readers have been shown to frequently engage in such shallow semantic processing, the likelihood that readers perform a partial analysis of text, and thereby fail to detect semantically anomalous information, varies as a function of reading comprehension skill and age. Among younger readers, those with lower reading comprehension skill are more likely to engage in shallow semantic processing than their higher skilled counterparts, particularly if they encounter anomalous information that has a good fit with the global theme of the text. Older readers, on the other hand, are no more likely to engage in shallow processing than are younger readers; in fact, older readers are able to detect easier-to-detect semantic earlier than younger readers. Among older readers, however, detection and recovery from semantic anomalies requires increased processing resources relative to younger readers. Using a paradigm similar to Daneman et al. (2007), the current study examined whether analogous skill- and age-related differences are found during syntactic processing by investigating the likelihood that readers detect syntactically anomalous information in text.

**Evidence for Shallow Syntactic Processing**

There is evidence that readers fail to construct complete syntactic representations when they read; instead, readers create representations that are merely “good enough” to satisfy their goals of comprehension (see Ferreira & Patson, 2007 for a review). However, this research
regarding readers’ “good enough” syntactic representations has focused on the processing of complex syntactic structures, rather than on readers’ detection of anomalous syntactic information, per se. On the other hand, research that directly explores syntactic anomaly detection in discourse indicates that readers are quite good at detecting syntactically anomalous information in text (Braze, et al., 2002; De Vincenzi, et al., 2003; Fodor, Ni, Crain, Shankweiler, 1996; Ni, et al., 1998), suggesting that readers may not engage in shallow syntactic processing to the same degree that they engage in shallow semantic processing. In the following section, I first review the evidence that readers engage in shallow syntactic processing. Next, I describe evidence for quick and thorough detection of syntactic anomalies by readers before highlighting how the current investigation aimed to reconcile these equivocal findings.

In a series of experiments, Christianson, et al., (2001) provided evidence that readers create a representation of text that is merely “good enough” to satisfy the comprehender. They presented readers with garden-path sentences such as “While Anna dressed the baby played in the crib.” Readers are lead down the garden path, so to speak, because they initially interpret the baby to be the object of dressed, and only later must reinterpret the sentence to comprehend the correct interpretation that the baby is the subject of the main clause (e.g. “The baby played in the crib”). Christianson et al. asked their participants questions such as “Did Anna dress the baby?” and “Did the baby play in the crib?” to assess the final syntactic interpretation of the sentence held by readers. Although most readers correctly answered that the baby played in the crib, more than half of the readers incorrectly believed that Anna also dressed the baby. In other words, the incorrect interpretation of the garden-path sentence remains even when readers correctly reinterpret the sentence. The authors conclude that this partial reanalysis is consistent
with the notion that comprehenders construct representations that are sufficient for understanding, but not necessarily exhaustive (see also Patson, et al, 2009).

Evidence for incomplete syntactic processing has also been observed for standard passive sentences. For example, Ferreira (2003) asked participants to identify the agent of aurally presented plausible and implausible active and passive sentences. Participants were less accurate in identifying the agent in passive sentences relative to active sentences, but they were particularly likely to misjudge the agent in implausible passive sentences. For instance, participants were likely to correctly identify the dog as the agent in the plausible sentence “The man was bitten by the dog.” but less likely to identify the man as the agent in the implausible sentence “The dog was bitten by the man.” In other words, listeners tended to interpret both sentences to indicate the more likely event that the dog bit the man, rather than fully parsing each sentence in order to identify their different meanings. Ferreira and colleagues (e.g. Ferreira, et al, 2002) have used their results in combination with those of Barton and Sanford’s (1993) semantic anomaly detection paradigm to argue for a linguistic system that is designed to enable the comprehender to obtain the meaning of discourse that is intended by the speaker. If a linguistic representation is not sufficiently robust readers may rely on context and knowledge to accept an interpretation that is merely “good enough.”

Nevertheless, research concerning syntactic anomaly detection in discourse indicates that readers can easily detect syntactic anomalies online (Boland, 1997; Braze, et al., 2002; Coulson, King, & Kutas, 1998; De Vincenzi et al., 2003; Fodor, et al., 1996; Friederici, Pfeifer, Hahne, 1993; Kutas & Hillyard, 1983; Martín-Loeches, Nigbur, Casado, Hohlfeld, & Sommer, 2006; McElree & Griffith, 1995; Ni, et al, 1998; Osterhout & Holcomb, 1992), suggesting that rather than engaging in a partial analysis of syntactic information, readers fully process syntactic information as they encounter it. Fodor, et al. (1996) conducted one of the first investigations
that directly compared the time course of syntactic and semantic anomaly detection and recovery in written text. These authors monitored the eye movements of readers as they encountered syntactic and semantic anomalies such as the following:

It seems that the cats from across the road…

<table>
<thead>
<tr>
<th>Type of Anomaly</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syntactic anomaly</td>
<td>won’t eating</td>
</tr>
<tr>
<td>Semantic anomaly</td>
<td>won’t bake</td>
</tr>
<tr>
<td>Baseline (no anomaly)</td>
<td>won’t eat</td>
</tr>
</tbody>
</table>

…the food that Mary puts out on the porch every morning as soon as she gets up.

Upon encountering either type of anomaly, readers immediately engaged in regressive fixations to earlier parts of the sentence, indicating that the anomalies were indeed detected when they were first encountered, and that readers are sensitive to syntactic structures and semantic content early during online sentence processing. However, Fodor et al. (1996) found that readers were able to recover from syntactic anomalies faster than from semantic anomalies. Readers engaged in increased regressive fixations from the word following a syntactic anomaly but quickly returned to levels similar to the baseline condition. On the other hand, readers continued to display increased regressive fixations relative to baseline until the end of the sentence after encountering a semantic anomaly. Subsequent eye-tracking research has confirmed the finding that syntactic anomalies are detected early and are resolved relatively quickly, whereas semantic anomalies disrupt processing until the end of the sentence (Braze et al., 2002; De Vincenzi et al., 2003; Ni et al., 1998). Thus, unlike research that reported individuals can have problems relating thematic roles to verbs, research investigating the time course of syntactic anomaly detection suggests that readers are not particularly susceptible to incomplete or shallow syntactic processing.
The syntactic anomalies presented by Fodor et al. (1996) and in subsequent investigations (Braze et al., 2002; Ni et al., 1998) were chosen because they were rated as highly unacceptable errors by a separate group of readers in a pretest, and, therefore, were quite obvious anomalies. Although readers were not warned about possible anomalies during testing, the authors appeared to assume that readers would notice the anomalous information. For example, Fodor et al. (1996) described that “No pretest was run to validate that the anomalous versions were indeed perceived by subjects as anomalous; the results of the main experiments sufficiently confirmed that they were” (p. 31). De Vincenzi et al. (2003) employed more subtle subject-verb number violations in their eye-tracking investigation of the time course of syntactic anomaly detection; however, they informed their participants that the sentences would be strange or incorrect. Consequently, while there is evidence that readers are able to detect and recover from syntactic violations quickly during online reading, whether there are circumstances in which readers are less likely to fully process syntactic information remains an open question. Specifically, the likelihood of spontaneous detection of subtle syntactic violations, such as the subject-verb number violations used by De Vincenzi et al., remains to be seen. Furthermore, it is still unknown whether the extent of incomplete syntactic processing varies as a function of reading skill or age in a manner that echoes incomplete semantic processing.

By recording readers’ eye movements, this study explored reading skill- and age-related differences in the time course of spontaneous online detection and recovery of subtle syntactic violations. In addition, the effects of two text variables – domain familiarity and content relevance – on syntactic anomaly detection were examined. In what follows, the known effects of the text variables on text processing will first be described. The effects of reading comprehension skill and age on text processing, and how they may interact with the text variables will then be discussed.
**Domain Familiarity**

Evidence from error detection studies demonstrates that one of the most influential factors for intentional error detection is text familiarity (Daneman & Stainton, 1993; Levy, 1983; Levy & Begin, 1984; Levy, Di Persio, & Hollingshead, 1992; Levy, Newell, Snyder, & Timmins, 1986; Pilotti, Chodorow, & Thornton, 2004, 2005). In Levy’s research, participants were instructed to identify any word or nonword errors encountered in familiar and unfamiliar texts. To induce familiarity, participants read error-free versions of short passages followed by repeated exposures of the same texts into which nonword (e.g. *gnounds* for *grounds*) and word errors (*ago* for *age*) had been inserted. For unfamiliar passages, participants were given only one presentation of the error-laden version. The participants’ task was to cross out all of the errors they detected during each reading. The results demonstrated that this experimentally-induced familiarity led to faster and more accurate error detection rates in familiar text relative to unfamiliar text that had not previously been proofread. In this situation, text familiarity seemingly allowed the redistribution of processing resources from higher-level comprehension processes to the lower level analyses required for error detection.

In contrast, research by Daneman and Stainton (1993; see also Pilotti et al., 2004, 2005) compared error detection in familiar and unfamiliar texts using two familiarity manipulations. Daneman and Stainton induced familiarity by providing readers with repeated exposures to an error-free passage, into which word errors (e.g. *ace* for *are*) were later inserted. Detection rates in an error-laden version of this so-called other-generated familiar text were compared to error detection rates in a self-generated passage, in which participants created an essay themselves and then proofread an error-laden version of their self-generated text. The two familiarity manipulations produced qualitative differences in error detection rates. In accordance with Levy’s findings, familiarity of other-generated texts facilitated error detection relative to
unfamiliar text. However, when participants proofread an error-laden version of their self-generated text, Daneman and Stainton found readers detected fewer errors relative to unfamiliar text. Here, it seemed that readers were so familiar with their self-generated text that they engaged in top-down rather than bottom-up processing during the proofreading task, making error detection difficult.

Another way that knowledge can differ between readers is in the amount of domain familiarity a reader possesses. There is considerable evidence that domain familiarity can facilitate discourse processing, resulting in improved recall and recognition (Chiesi, Spilich, & Voss, 1979; Hambrick & Engle, 2002; Hambrick & Oswald, 2005; McKeown, Beck, Sinatra, & Loxterman, 1992; McNamara & Kintsch, 1996; Spilich, Vesonder, Chiesi, & Voss, 1979), more elaborate representations (Rawson & Kintsch, 2002), and even compensation for poor reading ability (Adams, Bell, & Perfetti, 1995; Recht & Leslie, 1988; Taylor, 1979). It is thought that extensive domain knowledge provides retrieval structures that help map incoming information with the existing knowledge base (e.g. Ericsson & Kintsch, 1995; Kintsch, Patel, & Ericsson, 1999) and, hence, facilitate encoding and retrieval. In this study I investigated the role of knowledge by manipulating the amount of domain familiarity readers had about the texts they read. Participants read two texts adapted from Kaakinen, et al. (2003), one about familiar diseases about which they had ample prior knowledge (e.g., the flu and diarrhea), and another about rare diseases about which they had little prior knowledge (e.g., trigeminal neuralgia and typhus). If domain familiarity facilitates discourse processing, we might expect readers to be more likely to detect subtle syntactic anomalies in familiar text relative to unfamiliar text, in a manner similar to that observed following experimentally-induced rereading. Readers may have more resources available to direct to the syntactic analysis required for anomaly detection. Alternatively, if readers are sufficiently familiar with the content of the text for which they have
high domain knowledge, they may engage in increased top-down processing. This could result in a reduced likelihood of syntactic anomaly detection in a manner similar to that observed for self-generated text.

**Content Relevance**

An additional factor that has been shown to affect anomaly detection is linguistic focus. Specifically, semantic anomalies are more salient when they are the focus of a sentence’s information structure than when they are not (Bredart & Modolo, 1988; Sturt et al., 2004). That is, information that is highlighted as somehow more “important” is represented in more detail than information that is not; hence, anomalies that are focalized are more likely to be detected than those that are not. For example, Bredart & Modolo (1988) demonstrated that readers were more likely to detect the anomaly in “It was Moses who took two of each kind of animal on the Ark” than in a sentence where the focus was not on Moses, such as “Moses took two of each kind of animal on the Ark.”

In the current study, focus was manipulated by altering content relevance of the text. Participants were given instructions prior to reading each text to increase the content relevance of only one of the diseases described in the text. For example, a flu-relevant perspective was induced with the following instructions: “Imagine that you are going to give a health education class for elementary school pupils. You are supposed to tell them about flu: for example, what causes it, how you can treat it, and how to prevent getting the disease.” Relevance has been shown to reliably influence text recall and the allocation of processing resources (Anderson & Pichert, 1978; Anderson, Pichert, & Shirey, 1983; Baillet & Keenan, 1986; Burton & Daneman, 2007; Goetz, Schallert, Reynolds, & Radin, 1983; Kaakinen et al., 2002, 2003; Kardash, Royer, & Greene, 1988; McDaniel & Kerwin, 1987). The general finding from this research is that readers spend longer processing, and recall more information that is relevant to their current
processing goals than information that is not relevant to their processing goals. Although there is some individual variability among readers (e.g. Burton & Daneman, 2007; Kaakinen et al., 2003), the improved recall appears to be a result of increased processing time on content relevant text, compared to time spent processing content irrelevant text. If readers spend increased time processing content relevant text in this study, we may predict the likelihood of syntactic anomaly detection to be greater for content relevant text relative to content irrelevant text.

**Reading Comprehension Skill**

There is ample reason to believe that reading comprehension skill plays a role in anomaly detection during reading. Reading skill is associated with automatic/efficient lexical processing, such that skilled readers are those who can quickly and efficiently decode a word and retrieve knowledge of word forms and meanings (Braze, et al, 2007; Perfetti, 1985, 1992, 2007; Perfetti & Hart, 2002). Indeed, children’s decoding skills are correlated with comprehension (Perfetti, 1985) and there is no reason to believe this relationship disappears into adulthood (Shankweiler et al., 1999). As reading skill develops, linguistic knowledge becomes increasingly automatic, thereby freeing resources for comprehension. Reading skill in adults is, therefore, related to the degree to which fluency is attained in these lower-level word recognition processes (Perfetti & Hart, 2002; Perfetti, 2007). In addition to lower-level word identification processing, reading comprehension skill has been linked to increased syntactic knowledge and syntactic processing efficiency (Cuples & Holmes, 1987; Cupples & Holmes, 1992; Holsgrove & Garton, 2006). Armed with more available resources, better syntactic knowledge and more efficient syntactic processing, the skilled readers in my study were predicted to be more likely to detect syntactic anomalies than their less-skilled counterparts. This prediction corresponds to the skill-related differences that are observed in semantic
anomaly detection rates (Daneman et al., 2007). That is, less-skilled readers’ reduced processing efficiency, coupled with their tendency to focus their processing resources on global comprehension at the expense of local processing may reduce the likelihood that less-skilled readers will detect syntactic anomalies relative to more skilled readers.

However, there is some evidence to suggest that less-skilled readers may actually be more likely to detect syntactic anomalies. Flores d’Arcais (1987) has maintained that skilled and less-skilled readers are differentially sensitive to semantic and syntactic structure. Using a serial presentation of sentences containing either semantic (“The old lady drank the chair”) or syntactic (“The old lady sat the chair”) errors, Flores d’Arcais found that “good” readers reported fewer syntactic errors than did “poor” readers. Based on this finding, he concluded that good readers make use of higher-order semantic strategies for text comprehension and rely less on syntactic computations relative to poor readers. If skilled readers are not making full use their syntactic analysis as Flores d’Arcais suggests, the skilled readers in the current investigation may be less likely to detect the subtle syntactic anomalies compared to less-skilled readers. However, two unique features in the methodology employed by Flores d’Arcais provide a reason to believe that the increased sensitivity to syntactic structures by “poor” readers was task specific. First, Flores d’Arcais used a visual presentation rate of 450 wpm, which is significantly faster than most normal reading (e.g. Rayner, White, Johnson, Liversedge, 2006). Under impoverished reading conditions, skilled readers may strategically reallocate their processing resources to increase global comprehension at the expense of local processing; however, under more natural reading conditions they may be equally sensitive, if not more so, to syntactic structures as their less-skilled counterparts. Second, Flores d’Arcais did not use an independent measure of reading skill to delineate his “good” from “poor” readers. Instead, those readers who performed well answering comprehension questions about the same sentences that
were used for the anomaly detection task were classified as “good” readers, whereas those who performed relatively poorly on the same task were classified as “poor” readers. It is therefore impossible to determine whether “good” readers are less sensitive to syntactic structures, or whether a reduced focus on syntax allowed readers to be classified as “good” readers for that particular task. The current study used a self-paced reading task, and administered a standardized, independent measure of reading comprehension skill to identify skilled and less-skilled readers. Under the natural reading conditions of the present investigation, it was predicted that skilled readers would be able to make use of their efficient processing and syntactic skills to increase the likelihood they will detect subtle syntactic anomalies.

**Aging**

Age is another reader variable that has received considerable attention in the literature concerning text recall and comprehension. Yet, existing evidence from the aging literature makes it difficult to predict older readers’ tendency to engage in shallow syntactic processing. Age-related reductions in perceptual and cognitive resources (Baltes, 1997; Brébion, 2003; Salthouse, 1991, 1996) and corresponding deficits of memory for text (see Gupta & Srivastava, 2000; Johnson, 2003 for meta-analyses) are well documented in the literature. However, despite these declines in cognitive mechanics, other abilities, such as linguistic and world knowledge, remain stable or even grow with age (Baltes, 1997; Baltes, et al, 1999; Salthouse, 1988). Furthermore, when performance is scored for text comprehension or for the understanding of a situation represented in the text rather than for recall, older readers’ performance is often equivalent to that of younger readers (Hultch & Dixon, 1984; Kemper & Liu, 2007; Miller, et al, 2004; Radvansky, et al, 2003; Radvansky, Zwaan, Curiel, & Copeland, 2001; Stine-Morrow et al., 2002, 2004). On the one hand, we might expect older readers to be more likely to engage in shallow processing relative to younger readers as a result of their emphasis on global
comprehension over local processing (e.g. Stine-Morrow et al., 2006). On the other hand, older readers may be able to use their superior linguistic and world knowledge (e.g. Baltes, 1997; Kempler & Zelinski, 1994; Light, 1990) to improve processing efficiency at a local level, resulting in similar levels of shallow processing in both age groups.

Christianson, Williams, Zacks, and Ferreira (2006) have provided some evidence that older reader may rely on semantic inferences and heuristics to generate "good enough" text representations more frequently than younger readers. Using a procedure similar to Christianson, et al., (2001), Christianson, et al., (2006) asked older and younger participants to read garden-path sentences such as “While Anna dressed the baby that was small and cute played in the crib.” Later, when asked questions to determine readers’ representations of the sentences, such as "Did Anna dress the baby?", older readers answered "yes" more frequently than did younger readers. This suggested that older readers were more likely to rely on semantic inferences to create "good enough" representations of the sentences than were younger readers. Christianson, et al.'s results, therefore, demonstrate that older readers are more likely to engage in incomplete syntactic reanalysis, potentially due to their increased reliance on knowledge and heuristics; however, the garden-path sentences used in their investigations did not contain syntactic anomalies. In fact, the "good enough" account of language processing does not claim that good enough representations are completely wrong, rather comprehenders fail to engage in full syntactic reanalysis when confronted with difficult or complex information, resulting in representations with both accurate (e.g. Anna dressed herself) and inaccurate (e.g. Anna dressed the baby) information. As such, the question of the likelihood of syntactic anomaly detection by older readers remains to be addressed.

The findings from Experiment 1 of age-related effects on shallow semantic processing can be used to inform the predictions of older readers’ likelihood to engage in shallow syntactic
processing. Those results revealed that older readers were not more likely to engage in shallow semantic processing of text. When the anomalies were relatively easy to detect, older readers who reported noticing the anomaly did so earlier than younger readers who reported the anomaly. In this situation, older readers were most likely able to use their linguistic knowledge for quick lexical access and to detect the inherent contradiction of burying individuals who are still alive, for example. Using this observation, one might predict that older readers will be equally likely to detect syntactic anomalies.

One caution against this prediction is that the semantic anomalies used by Daneman et al. altered the meaning of the phrase; it is quite a different thing to bury the dead than to bury the survivors. Stine-Morrow et al. have suggested that older readers selectively allocate their processing resources to comprehend the text rather than memorizing specific word or sentence information in order to compensate for a reduction in cognitive mechanics (Stine-Morrow et al., 1996, 2004, 2006, 2008). If older readers selectively allocate their resources to text comprehension, they may be particularly well-suited to detect anomalies that affect text meaning, but they may not be equally proficient at detecting more subtle anomalies that do not influence overall comprehension. The syntactic anomalies used in this investigation were number violations that made the sentences grammatically incorrect; however, the meaning of the intended message was not altered. For instance, a participant might have read “The flu is a viral infection that tend to affect the very young and very old most severely.” The meaning of that sentence is clear regardless of the presence of the syntactic anomaly. Older readers who reallocate their resources away from word-level processing toward global comprehension may be less likely to notice such a subtle syntactic error.

Although I am not aware of any investigations that explored age-related effects of syntactic anomaly detection, a handful of investigations have compared online processing of
sentences with temporary syntactic ambiguities by older and younger adults (DeDe, et al, 2004; Kemper, et al, 2004; Kemper & Liu, 2007; Kemtes & Kemper, 1997; Waters & Caplan, 2001). Two studies conducted by Kemper are particularly relevant to the current investigation because they monitored readers’ eye movements as they read temporary syntactic ambiguities such as “The experienced soldiers warned about the dangers conducted the midnight raid” (Kemper et al., 2004, Kemper & Liu, 2007). In both of these investigations, eye movement patterns reflecting initial processing were similar for older and younger readers. Both age groups spent more time initially fixating ambiguous sentences compared to unambiguous ones, demonstrating the difficulty encountered with syntactically ambiguous sentences by all readers. However, age-differences were observed in the pattern of regressive fixations to syntactic ambiguities: older readers engaged in many more regressive fixations than did younger readers. Although these studies compared older and younger readers’ processing of temporary ambiguities rather than syntactic anomaly detection, per se, the results suggest that older readers require increased processing time to achieve comparable syntactic analysis. The increases in regressive fixations to temporary syntactic ambiguities by older readers reported by Kemper and Liu are consistent with the increased regressive fixation times to semantic anomalies by older readers described in Experiment 1. If performance on semantic anomaly detection and syntactic ambiguity resolution is related to syntactic anomaly detection, one might expect older readers in the current study to engage in more regressive fixations to the syntactic anomalies relative to younger readers.

The preceding evidence implies that older readers may not be able to detect and recover from the subtle syntactic anomalies in the current investigation as easily as younger readers. However, past research on performance skill and domain familiarity in older adults suggests that older readers may be able to benefit from reading comprehension skill and domain familiarity to improve their likelihood of syntactic anomaly detection. Indeed, research on expert performance
shows that performance is maintained in skilled older typists (Salthouse, 1984), musicians (Krampe & Ericsson, 1996), pilots (Morrow, Leirer, Altieri, & Fitzsimmons, 1994) and chess players (Charness, 1981). For example, Charness demonstrated that despite reductions in recall accuracy for chess positions, older skilled chess players were matched with younger skilled chess players in their ability to choose the best move and evaluate end-game positions. Furthermore, older skilled players were able to achieve high levels of performance in less time than younger skilled players, suggesting older skilled players engaged in a more efficient search process. Based on these findings, one can predict that the skilled older readers in this study will be able to take advantage of their lexical and syntactic processing efficiency to increase their likelihood of syntactic anomaly detection relative to less-skilled older readers.

The benefits of domain skill on performance are frequently attributed to a large, well-organized knowledge base within a particular domain (e.g. Ericsson & Charness, 1994). Considering the continued growth in linguistic and world knowledge with age, we might expect older adults to rely increasingly on knowledge in later life in an attempt to maintain performance on resource-demanding tasks. In the domain of reading comprehension, Miller and colleagues have shown that older readers take disproportionate advantage of knowledge to allow for strategic allocation of their resources in order to maintain satisfactory comprehension (Miller, 2001, 2003; Miller & Stine-Morrow, 1998; Miller, et al, 2004). Research demonstrating that domain knowledge can lead to a functional increase in processing resources (Fincher-Kiefer, Post, Greene, Voss, 1988; Ricks & Wiley, 2009) indicates that the increased use of knowledge by older readers can indeed be an effective compensatory strategy. Based on these findings, we may predict that older readers would use their knowledge of the familiar diseases to compensate for reductions in cognitive resources, thereby increasing the likelihood they will detect the syntactic anomalies in the familiar diseases text. Therefore, while older readers are
expected to be at a disadvantage for detecting syntactic anomalies relative to younger readers, both reading comprehension skill and domain familiarity could improve syntactic anomaly detection by older readers in the present study. In the case of reading skill, older skilled readers may be able to access their lexical and syntactic knowledge more efficiently to detect the syntactic anomalies. In the case of domain familiarity, older readers may use their knowledge of the familiar diseases to effectively increase the processing resources available for syntactic anomaly detection. Moreover, the combination of both increased processing efficiency and the availability of prior knowledge in the familiar text could put skilled older readers at a particular advantage for detecting syntactic anomalies relative to less-skilled older readers.

**Method**

**Participants**

Participants were 48 younger adults whose ages ranged from 17 to 23 years ($M = 18.77$, $SD = 1.34$) and 48 older adults whose ages ranged from 65 to 85 years ($M = 72.14$; $SD = 5.48$). Younger adults were University of Toronto undergraduate students who received credit toward an introductory psychology course for their participation. Older adults were volunteers from the local community in Mississauga, Ontario and were paid $15 for their participation. A questionnaire was administered to screen for general health, hearing and vision. Only older adults who reported that they were in good health and had no history of serious pathology were included in the study. All participants were fluent speakers of English and had normal or corrected-to-normal vision. Participants completed three tasks in the following order: (a) a text reading task in which they read two successive texts, one about familiar diseases and another about unfamiliar diseases with syntactic errors inserted throughout, during which their eye movements were monitored; (b) a standardized test of reading comprehension ability called the Nelson-Denny (Form E: Brown, et al, 1981); and (c) a familiarity check questionnaire designed
to ensure that the contents of the two texts did indeed differ in familiarity. The entire session lasted approximately 90 minutes.

**Reading task**

Participants read two texts, one about familiar diseases (e.g., the flu and diarrhea) and another about unfamiliar diseases (e.g., trigeminal neuralgia and typhus), that were presented on successive screens of a computer monitor. For the familiar text, half the participants were instructed to focus on the flu and the other half were instructed to focus on diarrhea. For the unfamiliar text, half of the participants were instructed to focus on trigeminal neuralgia and the other half were instructed to focus on typhus. Syntactic errors, in which the letter *s* was either added to the end of a word or deleted from the end of a word, were inserted into the texts. Eye movements were tracked while participants read the two texts. At the end of the session, participants recalled as much as they could about both texts.

**Materials and design.** The two texts, each approximately 1500 words in length, were English translations of the original Finnish texts used by Kaakinen et al. (2003; see also Burton & Daneman, 2007). One text presented information concerning four familiar diseases, and the other presented information about four rare or less familiar diseases. The familiar diseases text presented information about the flu, diarrhea, chicken pox, and AIDS. Information was organized under five subheadings within the text: Symptoms, In Mild Cases Home Treatment is Enough, Medication, When to Consult a Doctor, and How to Avoid an Infection. The unfamiliar diseases text presented information about trigeminal neuralgia, typhus, cystic fibrosis, and scleroderma. Information was organized under five subheadings within the text: Distinguishing Symptoms, Origin and Causes, Treatment, Prevention, and Support Groups. Each participant read both texts; half read the familiar diseases text first, and the other half read the unfamiliar diseases text first. Table 4 provides an excerpt for each text (see Appendix B for complete texts).
There were two possible content relevances that could be assigned to participants prior to reading each text. For the familiar diseases text, half of the participants were given a flu perspective, while the other half were given a diarrhea perspective. The perspective was induced with the following instructions: “Imagine that you are going to give a health education class for elementary school pupils. You are supposed to tell them about flu/diarrhea: for example, what causes it, how you can treat it, and how to prevent getting the disease,” (see Kaakinen et al., 2003, p. 450). For the unfamiliar diseases text, half of the participants were given a trigeminal neuralgia perspective, and half were given a typhus perspective. The content relevance was induced with the following instructions: “Imagine that a close friend of yours has been diagnosed with trigeminal neuralgia/typhus. Everybody is very worried about this common friend, and you have agreed to find out some facts about the disease and to inform the others about it,” (see Kaakinen et al, 2003, p. 450). The title was always consistent with the content relevance (e.g., “The Flu is a Scourge of Mankind;” “Trigeminal Neuralgia: A Rare and Difficult Disease”).

Each text contained 18 designated target sentences into which syntactic errors were inserted. The familiar diseases text included nine designated target sentences that were relevant to the flu (e.g., “The flu is a viral infection that tends to affect the very young and very old most severely.”) and nine that were relevant to diarrhea (e.g., “During diarrhea the body loses a lot of liquids and there is a danger of dehydration.”). The unfamiliar diseases text included nine designated target sentences that were relevant to trigeminal neuralgia (“For example, doctors and researchers don’t know what causes trigeminal neuralgia”) and nine that were relevant to typhus (e.g., “A typhus bacterium transfers to humans via a bedbug or louse bite”). Because content relevance was counterbalanced across participants, each target sentence was a content relevant sentence for half of the participants and a content irrelevant sentence for the other half.
of the participants. In other words, for half of the participants, the flu-relevant target sentences were the content relevant sentences for the familiar diseases text, whereas the diarrhea-relevant sentences were the content irrelevant sentences. For the other half of the participants, the diarrhea-relevant target sentences were the content relevant sentences, whereas the flu-relevant sentences were the content irrelevant sentences. Similarly, for half of the participants, the trigeminal neuralgia-relevant target sentences were the content relevant sentences for the unfamiliar diseases text, whereas the typhus-relevant sentences were the content irrelevant sentences. For the other half of the participants, the typhus-relevant target sentences were the content relevant sentences, whereas the trigeminal neuralgia-relevant sentences were the content irrelevant sentences.

Errors consisted of either the addition or deletion of the letter s at the end of one word in each of the target sentences, resulting in either a noun-noun number violation (e.g. “During diarrhea the body loses a lot of liquids and there is a dangers of dehydration.”), or a noun-verb number violation (e.g. “The flu is a viral infection that tend to affect the very young and very old most severely.”). An equal number of noun-noun violations and noun-verb violations were presented in each text. Of the nine target sentences for each disease, three sentences contained an addition error, 3 sentences contained a deletion error, and 3 sentences served as error-free controls. Because each text contained target sentences for both relevant and irrelevant content, there were 12 syntactic errors (3 relevant-addition, 3 relevant-deletion, 3 irrelevant-addition, and 3 irrelevant-deletion) and 6 error-free control sentences (containing 12 error-free control words) in both the familiar and unfamiliar texts. Three versions of each text were created such that each target sentence contained all three manipulations (addition error, deletion error, error-free control). Each participant read only one version of each text.
Table 4
Excerpts from the Familiar Diseases and Unfamiliar Diseases Texts (with target sentences in bold and syntactic anomalies in italics)

| The Flu/Diarrhea is a Scourge of Mankind |
| In addition to some life-threatening infectious diseases like AIDS, there are other less dramatic, yet still contagious, diseases. Everybody is familiar with the flu, chicken pox, and diarrhea. This text introduces different infectious diseases and their symptoms, treatment, and prevention. |
| Winter and spring are peak periods for viral diseases. A virus called Varicellazoster, which is very contagious, causes chicken pox. In Canada, nearly all children get chicken pox before adulthood. Usually the disease is caught during the early school years of a child. Chicken pox is most common during winter and springtime, just like the ordinary flu. **The flu is a viral infection that tends to affect the very young and very old most severely**/ **The flu is a viral infection that tends to affect the very young and very old most severely**/ **The flu is a viral infection that tend to affect the very young and very old most severely**. Flu should not be confused with influenza, which is an epidemic illness of the respiratory organs and also causes a high fever. |
| Travellers should be wary of certain diseases. AIDS is the most severe form of the disease caused by the Human Immunodeficiency Virus, referred to as HIV. HIV sets itself up in the human cells’ DNA. The virus destroys the body’s ability to resist infections, and as time goes on, the disease inevitably causes death. People travelling abroad should remember that most people infected with the virus have contracted it by unprotected sexual intercourse while on vacation. A lot less dangerous and more common ‘travellers’ disease than AIDS is diarrhea; every third Canadian tourist gets tourist diarrhea. In most cases diarrhea is related to food. A common cause of diarrhea is when a person ingests bacteria found in food, for example, the salmonella bacterium/ A common causes of diarrhea is when a person ingests bacteria found in food, for example, the salmonella bacterium/ A common cause of diarrhea is when a person ingest bacteria found in food, for example, the salmonella bacterium. |

| Typhus/Trigeminal Neuralgia: A Rare and Difficult Disease |
| Knowledge about the origins and causes of different diseases increases as medical research advances. There still are, however, several rare diseases whose causes remain largely unknown. There are so few patients suffering from these diseases that systematic research may be almost impossible to conduct. This text will introduce you to four very rare diseases: typhus, trigeminal neuralgia, cystic fibrosis, and sclerodermis. The text will deal with the typical symptoms, possible origins and causes, treatment, and prevention of the diseases. |
| The symptoms of rare disease are sometimes difficult to recognize because even doctors might not have very much knowledge about them. Typhus is a very easily transmitted infectious disease. The typical symptoms include a very high fever of over 40 degrees Celsius. In addition, muscle and joint stiffness, as well as brain dysfunctions can be related to the disease. On the fifth day after infection, a dark red rash appears on the body. Pimples can be seen in the rash. During the second week of the infection, the patient starts to experience delusions. **After this, a patient either recovers or, as more often happens, dies/ After this, a patients either recovers or, as more often happens, dies/ After this, a patient either recover or, as more often happens, dies** The death rate is high: half of the people who have been infected eventually die if proper treatment is not available. |
| Cystic fibrosis is a hereditary metabolic disease. Because of this metabolic dysfunction, the patient’s mucous is exceptionally viscous. The exceptionally viscous mucous causes a hard, continuous cough and recurring lung infections that are caused by various bacteria. |
| Trigeminal neuralgia refers to experiences of pain in the largest sensory nerve of the face, the trigeminal nerve. **The pain is sudden and comes in the form of a cutting pain accompanied by seizures resembling small electric shocks/ The pain is sudden and comes in the form of a cutting pains accompanied by seizures resembling small electric shocks/ The pain is sudden and come in the form of a cutting pain accompanied by seizures resembling small electric shocks.** |
Procedure. The texts were presented on a computer screen in double-spaced Arial 24 font so that approximately 10 lines of text were presented on one screen at a time. In no case was a sentence interrupted by a screen break, and in no case was a target sentence the last sentence on a screen. Participants were able to control the rate of presentation of successive screens of text by pressing a button on a game pad to move forward in the text; however, participants were unable to return to previous screens. To maintain naturalistic reading conditions and error detection, participants were not informed of the syntactic errors in the texts and were simply instructed to read for comprehension at their own pace. The experimenter read instructions to each participant describing the eye tracking procedure and how to control the self-paced text progression. Participants were instructed not to proceed to the next screen until they fully understood the information on the current screen. A content relevance was introduced in these instructions, and presented again on the monitor for participants to read as a practice trial.

While reading, participants’ eye movements were recorded using an eye-tracker system: the EyeLink II by SR Research Ltd. Each participant wore the EyeLink headband that contains three small cameras that allow simultaneous tracking of both eyes and head position, making possible the computation of true gaze position with unrestrained head motion. However, to prevent excessive motion on the part of the participant, participants rested their chins on a chin-rest positioned 0.5 m from the computer screen. The movements of both the right and left eye were recorded, and data from the right eye were analyzed. The on-line saccade detector of the eye tracker was set to detect saccades with an amplitude of 0.5˚ or greater, using an acceleration threshold of 9500˚/sec² and a velocity threshold of 30˚/sec (see Shen, et al, 2003, for a similar set-up). The EyeLink system uses an Ethernet link between the eye tracker and the display computers so that real-time gaze position data can be displayed. For the text
comprehension task, there were two computer monitors. One was used to display the texts to the participant. The second was used to display real-time feedback about the participants’ eye movements to the experimenter; this allowed the experimenter to monitor performance and recalibrate the eye tracking system as necessary. Previous research has shown that readers pause longer on words and phrases that are inconsistent with previously read information, and frequently make regressive fixation as they attempt to resolve the inconsistency (Braze et al., 2002; Daneman, et al, 1995; Frazier & Rayner, 1982; Ni et al., 1998; Rayner, et al, 2006). Any additional time spent fixating the anomalous word relative to a nonanomalous control word, therefore, would indicate the anomaly was detected during reading.

Participants’ recall of both texts was assessed approximately 10 minutes after completion of the reading task. Participants were presented with the title of each text one at a time and instructed to write down everything they could remember from the text, not only the information related to the title. If participants failed to recall any information about the diseases irrelevant to their content relevance, they were prompted to try to remember anything they could about the other diseases. Participants were limited to 10 minutes for the recall of each text, which provided more than sufficient time for each participant to complete the task.

**Reading Comprehension Test**

Reading comprehension skill was assessed using the Nelson-Denny test of reading comprehension ability. The Nelson-Denny consists of eight prose passages and 36 multiple-choice questions. Participants were given 20 minutes to read the passages and answer the questions. Mean performance on the Nelson-Denny was 22.25 out of a possible 36 (SD = 5.46). Participants with a score of 23 or above were classified as skilled readers ($n = 53, M = 27.16, SD = 3.50$); participants with a score of 22 or below were classified as less-skilled readers ($n = 43, M = 18.26, SD = 2.75$).
Familiarity Check Questionnaire

To ensure that participants were indeed more familiar with the diseases discussed in the familiar text than they were with the diseases discussed in the unfamiliar text, they were administered a familiarity check questionnaire (see also Kaakinen et al., 2003) at the end of the experimental session. Using a 5-point scale (1 = I had never heard of the disease before; 5 = the disease was very familiar to me), participants rated how familiar they were with each of the diseases prior to encountering them in our texts. Results demonstrated that readers had more prior knowledge about the diseases presented in the familiar diseases text (mean rating = 3.68) than those presented in the rare diseases text (mean rating = 1.96), \( F(1,92) = 382.33, \, MSE = .34, \, p < .001 \). Although both age groups reported higher familiarity with the diseases in the familiar text than the unfamiliar text, older readers reported being more familiar with the diseases in the unfamiliar text (mean rating = 2.34) than did younger readers (mean rating = 1.57), \( F(1,92) = 6.39, \, MSE = .34, \, p < .01 \). However, as will be demonstrated below, this apparent increased familiarity with unfamiliar diseases by older adults did not increase their likelihood of detecting syntactic anomalies in the unfamiliar passage.

Results and Discussion

Investigation of Text Manipulations

Before exploring syntactic anomaly detection, free recall and reading times for the 18 target sentences in each text (nine content relevant, nine content irrelevant) were analysed to ascertain the effectiveness of the text manipulations. Table 5 presents the free recall data and Table 6 presents the reading time data. Each of the dependent measures was subjected to a mixed factors analysis of variance (ANOVA) with text familiarity (familiar, unfamiliar) and content relevance (relevant, irrelevant) as within-subject variables, and reading skill (skilled, less-skilled) and age (younger, older) as between-subjects variables.
Overall, the results replicate the common findings in the literature and demonstrate that familiarity and content relevance were effective in increasing recall scores and influencing processing time. In addition, both older readers and skilled readers recalled disproportionately more content relevant than content irrelevant information.

**Free recall.** The recall protocols were scored for the number of target sentences recalled by each participant. To get credit for recalling a target sentence, participants needed to recall the gist rather than the verbatim wording. For example, if a participant recalled “after a typhus infection, a person becomes delusional” he or she received credit for the target sentence, “During the second week of the infection, the patient starts to experience delusions.” A score of 1 was awarded for each target sentence correctly recalled, such that the maximum recall score was nine for both the familiar and unfamiliar texts.

Although recall of the designated target sentences was generally low, the pattern of recall replicated the typical findings in the literature with respect to text familiarity and content relevance. As Table 5 shows, readers recalled on average 1.77 target sentences from the familiar diseases text, whereas they recalled only 1.02 target sentences from the unfamiliar diseases text, $F(1, 92) = 36.37, MSE = 1.39, p < .001$ (see also, Hambrick & Engle, 2002; Gagné, Yarbrough, Weidemann, & Bell, 1984; Marr & Gormley, 1982; McKeown et al., 1992; McNamara & Kintsch, 1996; Rawson & Kintsch, 2002; Recht & Leslie, 1988). Readers also recalled more content relevant target sentences ($M = 2.38$) than content irrelevant target sentences ($M = 0.40$), $F(1, 92) = 175.67, MSE = 1.88, p < .001$, a finding which replicates the classic perspective effect (Anderson & Pichert, 1978; Baillet & Keenan, 1986; Borland & Flammer, 1985; Pichert & Anderson, 1977). As can also be seen in Table 5, an interaction between familiarity and relevance revealed that participants had particular difficulty recalling information from the unfamiliar, content irrelevant text, $F(1, 92) = 18.20, MSE = 0.95 p < .001$, reflecting the joint
influence of text familiarity and perspective relevance on text recall. Interestingly, older readers correctly recalled more target information than did younger readers, $F(1, 92) = 14.71, MSE = 1.69, p < .001$, a finding that is inconsistent with the typically reported reduction in text recall with age (e.g. Gupta & Srivastava, 2000; Johnson, 2003; Verhaeghen, et al, 1993).

Table 5
Mean Free Recall of Target Sentences (out of 9) as a Function of Text Familiarity, Content Relevance, Reading Skill, and age. Standard errors are in parentheses

<table>
<thead>
<tr>
<th></th>
<th>Familiar</th>
<th>Unfamiliar</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relevant</td>
<td>Irrelevant</td>
<td>Mean</td>
<td>Relevant</td>
<td>Irrelevant</td>
</tr>
<tr>
<td>Younger</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>2.19 (0.3)</td>
<td>0.78 (0.2)</td>
<td>1.49 (0.3)</td>
<td>1.45 (0.3)</td>
<td>0.59 (0.2)</td>
</tr>
<tr>
<td>Less-skilled</td>
<td>2.14 (0.3)</td>
<td>1.48 (0.3)</td>
<td>1.81 (0.3)</td>
<td>0.48 (0.2)</td>
<td>0.47 (0.2)</td>
</tr>
<tr>
<td>Overall</td>
<td>2.17 (0.2)</td>
<td>1.08 (0.2)</td>
<td>1.63 (0.2)</td>
<td>1.02 (0.2)</td>
<td>0.45 (0.1)</td>
</tr>
<tr>
<td>Older</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>4.06 (0.4)</td>
<td>0.19 (0.2)</td>
<td>2.12 (0.3)</td>
<td>3.13 (0.4)</td>
<td>0.25 (0.2)</td>
</tr>
<tr>
<td>Less-skilled</td>
<td>3.66 (0.4)</td>
<td>0.19 (0.1)</td>
<td>1.93 (0.2)</td>
<td>2.30 (0.3)</td>
<td>0.06 (0.1)</td>
</tr>
<tr>
<td>Overall</td>
<td>3.79 (0.2)</td>
<td>0.19 (0.1)</td>
<td>2.02 (0.1)</td>
<td>2.54 (0.2)</td>
<td>0.13 (0.1)</td>
</tr>
</tbody>
</table>

One reason for the better recall by older readers in the current study may be related to the scoring procedure of the recall protocols. The recall protocols were scored for gist memory of ideas in entire sentences that were centrally relevant to the main theme of the texts, all of which have been shown to reduce the age-related declines observed for memory of text (see Johnson, 2003 for a meta-analysis). However, this atypical age-related effect was mediated by an age X relevance interaction, $F(1, 92) = 67.16, MSE = 1.88, p < .001$. As can be seen in Table 5, the increased recall scores found in older readers was due to particularly high recall of content relevant information by older readers compared to younger readers. Although older readers recalled on average 3.17 content relevant target sentences compared to younger readers who only recalled 1.56 content relevant target sentences, $t(94) = 6.48, SE = 0.24, p < .001$, older readers recalled significantly fewer content irrelevant target sentences than did younger readers,
Readers with lower working memory spans have been found to allocate their processing resources to relevant information at the expense of less-relevant information (Kaakinen et al., 2003; Lee-Sammons & Whitney, 1991). This observation could explain the relevance X age interaction found here. Although working memory span scores were not obtained in the current study, age-related declines in working memory capacity have been regularly reported in the literature (e.g. Brebion, 2003; Carpenter, et al, 1994; DeDe, et al, 2004; Salthouse, 1991; Salthouse & Babcock, 1991; Stine & Wingfield, 1990; Van der Linden, et al, 1994). As such, older readers may reallocate their limited resources to relevant text as a strategy to increase their memory for “more important” information at the expense of memory for “less important” content irrelevant text in a manner similar to that reported in younger low-span readers. Finally, two interactions with reader skill were observed. Skilled readers demonstrated a greater effect of perspective relevance, $F(1, 92) = 5.40, MSE = 1.88, p < .05,$ but were less influenced by text familiarity than less-skilled readers, $F(1, 92) = 5.81, MSE = 1.39, p < .05.$

**Reading time on target sentences.** Total reading time on each target sentence was collected from the eye movement data to investigate whether the effects of the text manipulations on processing time replicated those reported in the literature, and can be found in Table 6. Consistent with previous findings, readers spend more time reading unfamiliar text than familiar text, $F(1, 92) = 26.21, MSE = 706 568, p < .001,$ (Adams, et al, 1995; Burton & Daneman, 2007; Kaakinen et al., 2003; Miller et al., 1998; Wiley & Rayner, 2000), and more time reading relevant text than irrelevant text, $F(1, 92) = 5.04, MSE = 489 077, p < .05$ (Burton & Daneman, 2007; Goetz, et al, 1983, Kaakinen et al., 2002, 2003). Neither age nor reader skill produced reliable effects on total reading time, both $ps > .10.$
Table 6
Mean Reading Times (in milliseconds) on Target Sentences as a Function of Text Familiarity, Content Relevance, Reading Skill, and Age. Standard errors are in parentheses

<table>
<thead>
<tr>
<th></th>
<th>Familiar</th>
<th></th>
<th>Unfamiliar</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relevant</td>
<td>Irrelevant</td>
<td>Mean</td>
<td>Relevant</td>
</tr>
<tr>
<td>Younger</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>4129 (211)</td>
<td>3542 (211)</td>
<td>3836 (191)</td>
<td>4464 (275)</td>
</tr>
<tr>
<td>Less-skilled</td>
<td>3794 (156)</td>
<td>3765 (199)</td>
<td>3779 (162)</td>
<td>4394 (223)</td>
</tr>
<tr>
<td>Overall</td>
<td>3984 (139)</td>
<td>3639 (147)</td>
<td>3808 (129)</td>
<td>4434 (181)</td>
</tr>
<tr>
<td>Older</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skilled</td>
<td>2891 (381)</td>
<td>3242 (203)</td>
<td>3067 (255)</td>
<td>3841 (402)</td>
</tr>
<tr>
<td>Less-skilled</td>
<td>4108 (222)</td>
<td>3900 (200)</td>
<td>4004 (192)</td>
<td>4395 (262)</td>
</tr>
<tr>
<td>Overall</td>
<td>3740 (209)</td>
<td>3107 (158)</td>
<td>3424 (169)</td>
<td>4228 (220)</td>
</tr>
</tbody>
</table>

Evidence of Syntactic Anomaly Detection from Eye-Movement Data

Two dependent measures were used to investigate whether there were age differences in the time course of syntactic anomaly detection and recovery: first-pass fixation duration\(^4\) and go-past time. First-pass fixation duration is the sum of all fixations on the syntactically anomalous or control word when it is first encountered and before the reader moves on to a subsequent or previous word. First-pass fixation duration was used to determine whether syntactic anomaly detection occurs when the reader first encounters the error. Go-past time is the sum of all fixations from the first fixation on the syntactically anomalous word (or equivalent control word) until moving on to the subsequent word to the right, including any regressions to previously encountered (leftward) words and any refixations on the target word itself. Go-past time is considered a later measure of comprehension reflecting integration and possible ambiguity resolution. This measure was used to determine whether syntactic anomaly

\(^4\) First-pass fixation duration was used as an early measure of inconsistency detection rather than first fixation duration because it is more likely to represent the time needed for both lexical access and the integration (Inhoff, 1984) required to detect the mismatch between the target word and the preceding text. However, first fixation duration on the target word was also analysed here, and while the data showed a similar pattern as the first-pass fixation duration data, the effects were weaker.
detection occurred relatively late in processing, and as an estimate of the time required to recover from the anomaly.

For all analyses, the eye movement data were averaged across addition errors and deletion errors. Fixation durations that were greater than 3 standard deviations from the mean within each condition were discarded, resulting in less than 2% of the data being discarded. A mixed factors analysis of variance (ANOVA) was conducted on each of the dependent measures with text familiarity (familiar, unfamiliar), content relevance (relevant, irrelevant), and anomaly (anomalous, nonanomalous) as within-subject variables, and reading comprehension skill (skilled, less-skilled) and age (younger, older) as between-subjects variables. All reported effects were significant beyond the .05 level, unless noted otherwise.

Contrary to the prediction that content relevance would help improve syntactic anomaly detection, readers were not more likely to detect anomalies in content relevant text than content irrelevant text, \( F(1, 92) = 1.73, MSE = 2453, p = .20 \). Because content relevance did not influence syntactic anomaly detection, nor did it interact with any other factors, the analysis was repeated without content relevance as a factor, and it was excluded from subsequent analyses.

The eye fixation data reveal two age-related effects. First, although syntactic anomaly detection can be achieved early in processing with the support of reading skill and domain familiarity, there were age differences in the amount of support required. Younger readers were likely to detect syntactic anomalies with the support of either reader skill or familiarity, while older readers required both skill and familiarity to detect the anomalies when first encountering them. Second, older readers demonstrated increased go-past times to syntactic anomalies compared to their younger counterparts.

**First-pass fixation duration.** Although a main effect of anomaly demonstrated that readers provided evidence of early detection of the syntactic anomalies, \( F(1, 92) = 4.31, MSE = \)
1317, a significant 4-way interaction between anomaly, age, reading skill, and familiarity, $F(1, 92) = 4.15, MSE = 1396$, revealed that this was not true for all readers, as shown in Figure 3. To further investigate this interaction, separate analyses were performed for each of the four groups of readers (younger skilled, younger less-skilled, older skilled, older less-skilled) with anomaly (anomalous, nonanomalous) and familiarity (familiar, unfamiliar) as within-subject variables. These analyses revealed that younger skilled readers demonstrated early detection of syntactic anomalies across both the familiar and unfamiliar texts; whereas, younger less-skilled readers only displayed evidence of early syntactic anomaly detection in the more familiar text. Older readers were particularly unlikely to detect the syntactic anomalies when they first encountered them – only those older readers with sufficient skill showed evidence of early detection in the familiar text. As can be seen in Panel A of Figure 3, the analysis for the group of younger skilled readers revealed a main effect of anomaly, $F(1, 25) = 4.78, MSE = 736$, demonstrating that younger skilled readers were able to detect the syntactic anomalies in both familiar and unfamiliar texts upon first encountering them. This group of younger skilled readers spent on average 227 ms fixating syntactic anomalies when first encountering them, compared to 215 ms fixating nonanomalous controls. Presumably, the efficient lexical processing afforded by reading skill (Bell & Perfetti, 1994; Dixon, LeFevre, & Twilley, 1988; Perfetti, 1985; Perfetti & Hart, 2002; Stanovich, 1980, 1990), accompanied by the comparatively high resource availability in younger readers, provided these readers with sufficient resources to detect the syntactic anomalies even in the more resource-demanding unfamiliar text. Inspection of Panel B suggests that without the benefit of reading skill, younger less-skilled readers were less likely to detect the syntactic anomalies in the more difficult unfamiliar text; however, they were able to compensate for their reduced skill by relying on their knowledge of the diseases in the familiar text. Although the anomaly X familiarity interaction did not reach significance for this group of
younger less-skilled readers, $F(1, 21) = 2.96, MSE = 916, p = .09,$ separate analyses for the familiar text and unfamiliar text show that first-pass fixation durations for younger less-skilled readers were on average 27 ms longer for syntactic anomalies than nonanomalous controls in the familiar text, $t(21) = 2.69, p = .01,$ but only 5 ms longer in the unfamiliar text, a difference that was not significant, $t(21) = .46, p = .65.$

![Figure 3. Mean first-pass fixation durations (in milliseconds) on target words as a function of anomaly, familiarity, and age](image-url)
Consequently, it appears as though domain familiarity allowed younger less-skilled readers to increase their likelihood of early syntactic anomaly detection. This is consistent with findings in the literature that poor readers use knowledge to compensate for reduced reading skill on comprehension and recall tasks (Adams et al., 1995; Recht & Leslie, 1988; Taylor, 1979). It is likely that readers were able to use their knowledge of the diseases in the familiar text to facilitate higher-level comprehension processes, subsequently freeing resources for lower-level syntactic processing and increasing the likelihood of syntactic anomaly detection. Without the presence of knowledge structures in semantic memory for the diseases described in the unfamiliar text, readers were required to allocate additional resources to text comprehension, leaving few resources for syntactic anomaly detection.

Inspection of the average first-pass fixation durations of older readers reveals that older readers were less likely to detect syntactic anomalies when first encountering them than were younger readers (see Panels C and D of Figure 3). However, an interaction between anomaly and familiarity among older skilled readers suggests that this group of older readers did demonstrate early syntactic anomaly detection, \( F(1, 15) = 4.14, MSE = 1250, p = .06 \). As can be seen in Panel C, their performance was similar to that of the younger less-skilled readers. Older skilled readers may have been able to benefit from their knowledge of the familiar diseases in the same manner as younger less-skilled readers, allowing for the redistribution of resources to syntactic anomaly detection. An important distinction between younger and older readers, however, is that only those older readers with sufficient reading skill showed any indication that they were able to benefit from their knowledge of the familiar text. That is, older readers appeared to require the double benefit of the increased efficiency provided by reading skill and text familiarity in order to make adequate resources available for potential syntactic anomaly detection. Accordingly, older less-skilled readers did not demonstrate any evidence of early
syntactic anomaly detection, all $F$s < 1. This group of less-skilled readers had the double burden of age-related deficits in processing accompanied by inferior linguistic skills. Knowledge about the diseases described in the familiar text could not provide enough facilitation to overcome the limitations of the older less-skilled readers, thereby eliminating any resources that might be used for syntactic anomaly detection.

Finally, two effects were revealed in the analysis of first-pass fixation duration that were independent of syntactic anomaly detection. Younger readers read the target words faster overall than did older readers, $F(1, 92) = 14.91, \text{MSE} = 6628$, and skilled readers read the target words faster overall than did less-skilled readers, $(1, 92) = 7.85, \text{MSE} = 6628$.

**Go-past time.** A main effect of anomaly, $F(1, 92) = 42.90, \text{MSE} = 4437$, suggests that a significant number of readers did eventually detect the syntactic anomaly and required some time to recover from the error before proceeding forward in the text. Although an overt detection measure was not used as in Experiment 1, the main effect of anomaly indicates that a significant number of readers were sensitive to syntactic computations and detected the subtle syntactic anomalies online, albeit, not necessarily when they first encountered them. This result is consistent with the findings from the literature that anomalous syntactic information is relatively easy to detect and resolve compared to anomalous semantic information (Braze, et al., 2002; De Vincenzi, et al., 2003; Fodor, et al., 1996; Ni, et al, 1998) and suggests that readers are not particularly prone to incomplete syntactic processing.

Despite evidence that readers on the whole were not susceptible to shallow syntactic processing, age did affect the time course of syntactic anomaly detection. A significant age X anomaly interaction, $F(1, 92) = 6.50, \text{MSE} = 18855$, showed that older readers displayed particularly long go-past times for syntactic anomalies compared to younger readers. As can be seen in Table 7, go-past times by younger readers were on average 29 ms longer for syntactic
anomalies than nonanomalous controls across both texts, whereas older readers’ average go-past times for syntactic anomalies was 68 ms longer than for nonanomalous controls. The additional time most likely reflects the processing time required to detect the anomaly as well as attempting to repair it (see also Braze, et al, 2002; Daneman, et al, 1995; Ni, et al, 1998). In other words, older readers spent more than twice as long as younger readers to detect and recover from syntactic anomalies.

Table 7
Mean Go-past Times (in milliseconds) on Anomalous and Nonanomalous Control Target Words as a Function of Text Familiarity, Reading Skill, and Age. Standard errors are in parentheses

| Familiar | | | Unfamiliar | | |
|----------|-----------------|-----------------|-----------------|-----------------|
|          | Anomalous       | Control         | Anomalous       | Control         |
| Younger  |                 |                 |                 |                 |
| Skilled  | 290 (15)        | 246 (13)        | 273 (23)        | 251 (21)        |
| Less-skilled | 303 (16)        | 273 (12)        | 330 (22)        | 314 (20)        |
| Overall  | 296 (11)        | 258 (9)         | 298 (16)        | 279 (15)        |
| Older    |                 |                 |                 |                 |
| Skilled  | 280 (25)        | 214 (12)        | 269 (25)        | 231 (23)        |
| Less-skilled | 350 (17)        | 268 (11)        | 357 (26)        | 286 (15)        |
| Overall  | 326 (15)        | 250 (9)         | 328 (20)        | 268 (13)        |

The finding of longer go-past times by older readers suggests they may need to devote increased resources to the detection and recovery of errors to achieve similar levels of comprehension as younger readers (see also Kemper & Liu, 2007). On the other hand, the extra processing time may reflect older readers’ greater need or motivation to resolve the anomaly. According to this view, older readers do not display longer reading times as a requirement to achieve successful comprehension (see Miller & Stine-Morrow, 1998; Miller, et.al., 2004; Stine-Morrow et al., 2001), rather, increased processing time on anomalies may reflect different coherence goals set by older readers (e.g. van den Broek, et al, 2001; van den Broek, Rapp, & Kendeou, 2005). Although the current study does not address this issue directly, tentative support for the latter comes from the observation that while older readers devoted extra
processing resources to syntactic anomalies which have little impact on the readers’ understanding of the text, they showed no evidence of slower reading speeds overall. Older adults read the nonanomalous control words on average 9 ms faster than younger readers, and spent on average 155 ms less reading each of the 36 target sentences than younger readers, though neither difference was significant, both $t_s < 1$. Although the older readers did not demonstrate increased reading times, they still outperformed younger readers on the text recall task. Together this suggests that although older readers may allocate increased processing resources to anomaly detection and recovery, this extra time is not a requirement for text comprehension.

Unlike was observed in the analysis of early detection, familiarity and reading skill did not influence the likelihood of delayed syntactic anomaly detection. Average go-past time was faster for skilled readers than less-skilled readers, $F(1, 92) = 13.54, MSE = 18855$, however, this was independent of whether an anomaly was present.

**Summary and Conclusions**

Evidence is growing that readers (and listeners) create representations of discourse that are merely “good enough” (Ferreira et al., 2002; Ferreira & Patson, 2007) rather than complete. Young adults frequently engage in shallow or incomplete processing of both semantic and syntactic information when an interpretation (albeit not always the correct one) can be sufficiently supported by context or a reader’s background knowledge (Barton & Sanford, 1993; Erickson & Mattson, 1981; Hannon & Daneman, 2001, 2004; Ferreira, 2003; Ferreira et al., 2002; van Oostendorp & de Mul, 1990; van Oostendorp & Kok, 1990). So, for example, readers would let authorities bury *surviving* passengers from a plane crash, ignoring the fact that, by definition, survivors are alive (Barton & Sanford, 1993). Similarly, after reading the sentence “The dog was bitten by the man” readers might believe that it was the dog that bit the man
(Ferreira, 2003). In each case, readers are satisfied with relying on their expectations to compute a partial analysis instead of one that is accurate and complete. Research on the time-course of syntactic anomaly detection indicates that readers detect syntactic anomalies early and resolve the anomaly quickly. However, despite evidence that the likelihood of semantic anomaly detection varies as a function of age and reading comprehension skill, there have not been any investigations into similar effects on syntactic anomaly detection. This study used eye-tracking to investigate factors that could influence the time-course of syntactic anomaly detection and recovery by skilled and less-skilled younger and older readers. Domain knowledge and content relevance influence the allocation of resources during passage reading (Braze, et al, 2007; Burton & Daneman, 2007; Goetz, et al, 1983; Kaakinen et al., 2002, 2003; Miller et al., 1998; Wiley & Rayner, 2000) and may, thus, increase readers’ sensitivity to subtle syntactic anomalies. Although older readers were predicted to be less likely to detect syntactic anomalies than were younger readers, the likelihood of detection was expected to be mediated by reading skill and domain familiarity. Older adults have fewer resources available than their younger counterparts and have been shown to require more time to process temporary syntactic ambiguities in text (Kemper et al., 2004; Kemper & Liu, 2007). Such findings could lead to the prediction that older adults would be less able to detect syntactic anomalies during an online reading task. However, aging also brings growth in crystallized knowledge, and older readers are able to make use of their linguistic and schema-based knowledge to improve their reading performance (Miller, 2001, Miller & Stine-Morrow, 1998; Miller et al., 2004). As such, older readers were expected to be able to compensate for their limited resources by relying on their linguistic knowledge and their existing knowledge for the material in the familiar text.

This study replicated the findings of content relevance and domain familiarity on text recall. Readers recalled more information from the text for which they had relatively high
domain knowledge compared to the one for which they had little previous knowledge. Readers also recalled more content relevant information than content irrelevant information. These results are consistent with the existing literature demonstrating that memory for text is best when readers are familiar with the material and when they read with a particular goal in mind (Anderson & Pichert, 1978; Anderson et al., 1983; Baillet & Keenan, 1986; Borland & Flamer, 1985; Burton & Daneman, 2007; Goetz et al., 1983; Kaakinen et al., 2002, 2003; Kardash et al., 1988; McDaniel & Kerwin, 1987). Older readers in particular recalled relatively more content relevant information to the extent that their recall performance was actually better than that of younger readers. Older readers were seemingly devoting their attention to the material that would result in the maximum learning for the goal at hand (Miller et al., 2006; van den Broek et al., 2001, 2005).

Surprisingly, little evidence was found to indicate readers were susceptible to shallow syntactic processing. Readers spent more time processing syntactic anomalies than nonanomalous control words, suggesting that they detected the anomalies online, although not necessarily when immediately encountering them. Unlike research that has found evidence of incomplete syntactic processing when individuals are faced with temporary ambiguities and difficult syntactic structures, the current investigation supports the literature that directly examines syntactic anomaly detection and reports that readers are quite good at detecting syntactic anomalies online (Braze, et al., 2002; De Vincenzi, et al., 2003; Fodor, et al., 1996; Ni, et al, 1998). One important difference between investigations using difficult or complex syntactic structures and those investigating syntactic anomaly detection may be that readers are able to use their schematic knowledge to resolve ambiguities in garden path sentences or predict thematic roles in sentences with difficult or unusual syntactic structures. Readers may only create “good enough” syntactic representations when difficult syntactic processing can be
supported by context and knowledge (e.g. Ferreira & Patson, 2007). The current study inserted relatively simple morpho-syntactic errors that would not be expected to benefit from a reader’s schematic or background knowledge. Although not all readers detected these syntactic anomalies when they immediately encountered them, a significant number of readers appeared to be sensitive to the syntactic violations used in the current study.

Given that a significant number of readers were seemingly sensitive to the syntactic anomalies inserted into text, this investigation indicates that neither younger nor older readers were particularly susceptible to shallow processing at the surface level of text representation. On the other hand, age differences did occur in the time course of anomaly detection and recovery. Older readers were less likely to detect the syntactic anomalies during early processing than were younger readers. Nevertheless, in some cases older readers provided some evidence that they were able to compensate for their age-related processing declines to detect the anomalies. Skilled older readers may have used their greater linguistic knowledge in combination with their existing knowledge about familiar diseases to free adequate resources to detect the anomalies upon first encountering them in the familiar text. Any benefit from readers’ knowledge about the familiar text was not sufficient to overcome the processing deficits of less-skilled older readers. In other words, older readers appeared to need the double benefit of reading comprehension skill and domain knowledge to overcome age-related processing deficits. In addition, older readers required more time to process these anomalies relative to younger readers. This is consistent with the finding that older readers compensate for a reduction in cognitive mechanics by spending more time processing what they read (Kemper & Liu, 2007; Miller & Stine-Morrow, 1998; Miller, et.al., 2004; Stine-Morrow et al., 2001). However, rather than being a requirement for comprehension, longer reading times may also reflect a greater need by older readers to resolve the anomaly and integrate it with prior text.
The benefit of reading skill and domain familiarity was not only observed in older adults. Younger readers were equally able to use their knowledge to increase their likelihood of syntactic anomaly detection in the familiar text. Unlike older readers, less-skilled younger readers had sufficient resources at their disposal to take advantage of their knowledge for the familiar text, resulting in early detection of the anomalies in the familiar text by all younger readers. Also in contrast to older readers, skilled younger readers were able to use their superior linguistic knowledge to detect the anomalies early without the added benefit of domain knowledge. It therefore seems that even though older readers can use their reading skill and existing knowledge to improve syntactic anomaly detection in text, younger readers with the same tools at their disposal outperform older readers.

It is important to remember that despite a specific deficit in the time course of syntactic anomaly detection, older readers’ comprehension was intact. Older readers may thus engage in strategic resource allocation with the goal of achieving a good understanding of what they read. If older readers demonstrated delayed detection of syntactic anomalies because they selectively allocated their processing resources to understanding discourse, we might expect older readers to be particularly good at detecting anomalous information that occurs at the discourse level. That is, older readers might be less prone to shallow processing of discourse and thereby able to detect discourse-level anomalies during early processing. With this in mind, Experiment 3 investigated the propensity toward shallow processing by older and younger readers at a level that specifically tapped readers’ comprehension of a situation being described in a text. In addition, to further explore the role of world knowledge in older readers’ likelihood to engage in shallow processing, the anomalies presented in Experiment 3 required readers to access their knowledge base in order detected.
Chapter 4

Experiment 3: Age differences in shallow temporal processing

When readers encounter a text they create a mental representation that describes the situation it portrays. These representations depict the goals and actions of characters that unfold over time in a real or imagined world. This type of mental representation, in which information from the text is integrated with a reader’s background knowledge and inferences, composes a reader’s situation model (Johnson-Laird, 1983; van Dijk & Kintsch, 1983). Zwaan, et al. (1995) have proposed an event-indexing model, in which readers use events and characters’ actions to organize their situation models, and monitor these events around five dimensions: space, time, characters, causality, and intentionality. If a change occurs in any of the five dimensions, the reader will update their situation model to include the new information, or create a new model that represents the change. For example, if the text indicates a time shift relative to a previous clause, the reader would update the temporal dimension to incorporate the time change. The current study focuses on the extent to which readers represent the temporal dimension of situation models. Readers’ eye movements were recorded in order to explore whether there are age- and memory-related declines in readers’ likelihood to spontaneously monitor and detect inconsistencies in the duration of events.

Recently, Therriault and Raney (2007) investigated whether readers monitor the duration of events using an inconsistency detection paradigm. They presented readers with passages containing inconsistent event durations, such as the following:

Angel and Richard were on their way out to have dinner. They made reservations at a chic new restaurant. They hadn’t been to dinner in several weeks because they just had a baby. Tonight they were going out with their new baby for the first time. Angel realized that the baby needed to be
changed. She told Richard to go start the car and she would be right out.

Richard had listened to an entire talk show when Angel brought the baby out.

Richard drove them to the restaurant. They missed their reservation and could not eat dinner. They decided to go out again next week. Richard called and made another reservation.

This passage implicitly contrasts the duration of two events. The passage presents a base event that sets up a target duration, which, in this case is waiting for a diaper to be changed. The next sentence is a duration comparison sentence that contains the inconsistent duration information.

Radio talk shows typically last at least one hour, but it should not take a full hour to change a diaper; thus, the base event and the comparison event are inconsistent. Therriault and Raney (2007) measured participants’ sentence by sentence reading time of the passages and predicted that if readers monitored the duration of events they should have difficulty integrating the two inconsistent event durations, which would be reflected in longer reading times. As predicted, readers spent 347 ms longer reading duration comparison sentences that were too long for the base event relative to sentences that matched the duration of the base event (e.g. “Richard had defrosted the car windows when Angel brought the baby out.”) Thus, readers appeared to spontaneously monitor the duration of events described in a narrative and encountered processing difficulty when the story events did not match their expected time frames. Now consider that readers encountered the following comparison event sentence: “Richard had just unlocked the car doors when Angel brought the baby out.” This sentence is also inconsistent with the duration set up by the base event; however, this time the comparison duration is too short. It is highly unlikely that someone could change a diaper in the time it takes to unlock a car door. Although unlocking the car door does not exceed the duration of the base event (changing a diaper), the inconsistency between the base event and duration comparison sentence
was expected to lead to duration-related comprehension difficulties because of the unlikely apparent speed of the base event (changing a diaper in mere seconds). Indeed, readers displayed on average 140 ms longer reading times when the duration comparison sentence was too short for the base-event duration relative to when the event matched the base time frame. So, although the short duration comparison sentences were not as disruptive as the long duration comparison sentences, readers nevertheless encountered comprehension problems when the events did not match their expected time frames, providing support that readers spontaneously monitor event durations. The current study expands on Therriault and Raney (2007) by using eye tracking to investigate online monitoring of the temporal dimension of situation models in both younger and older readers.

A number of investigations have demonstrated the importance of time in the construction of readers’ situation models (Anderson, Garrod, & Sanford, 1983; Radvansky & Zacks, 1991; Radvansky, Zwaan, Federico, & Franklin, 1998; Rinck & Bower, 2000; Speer & Zacks, 2005; Zwaan, 1996) and have shown that the more the order of events described in a text deviates from chronological order, the more comprehension suffers (Ohtsuka & Brewer, 1992). For example, Zwaan (1996) asked participants to read narratives containing one of three possible time shifts. The short time shift condition was marked by phrases such as *a moment later* and suggested that very little time had passed between events. An intermediate time shift condition was marked by phrases such as *an hour later*; and a long time shift was marked by phrases such as *a day later*. Zwaan reported that reading times increased when readers encountered an intermediate or long time shift, such as “An hour later, the telephone rang” and “A day later, the telephone rang”, relative to when only a short time shift occurred (e.g. “A moment later, the telephone rang.”) Response times to probe words denoting events before a time shift were also greater following an intermediate or long time shift, indicating that
information is less accessible if it occurred during an earlier time frame. Even segmentation markers that do not explicitly denote a time shift (e.g. *then*) can reduce the availability of previous information (Bestgen & Vonk, 1995). Thus, time has been shown to be an important dimension along which readers structure and update their situation models.

Other research has used an inconsistency detection paradigm to investigate whether readers spontaneously monitor temporal information and integrate it into their situation models (Rinck, Gámez, Díaz, & De Vega, 2003; Rinck, Hähnel, & Becker, 2001). Using specific time terms, Rinck et al. (2001) reported increased reading times on sentences that were inconsistent with previously stated duration information. For example, participants took longer to read sentence (2) after reading sentence (1b) than (1a).

(1a) Claudia’s train arrived in Dresden on time at 4:10pm, and Markus’s train arrived at 4:30 p.m.

(1b) Markus’s train arrived in Dresden on time at 4:10pm, and Claudia’s train arrived at 4:30 p.m.

(2) Claudia was already waiting for Markus when he got off the train.

Although the increased reading times for inconsistent temporal information suggested that readers monitored the temporal information unfolding in the text, only half of readers explicitly reported noticing the inconsistencies when probed. In a follow-up study, Rinck et al. (2003) found only 36% of readers reported a similar inconsistency. Therefore, while readers are capable of monitoring the order of temporal events, it may not be a requirement for a coherent text representation and may not be observed in all readers.

Therriault and Raney’s (2007) inconsistency detection task was unique because, unlike previous investigations on the temporal component of situation models, Therriault and Raney did not use explicit time terms to highlight the temporal inconsistencies; instead the duration of
events had to be inferred by the reader. Readers had to access their knowledge of the typical
duration of events to recognize the temporal inconsistencies between them. For example,
without knowledge of the typical duration of a radio talk show, or the time required to change a
diaper, it would be impossible to recognize an inconsistency between the two events described
in the opening passage. It is widely accepted that knowledge plays an important role in the
construction of situation models; after all, a situation model includes inferences based on
information given in a text and from a reader’s knowledge base (Zwaan & Radvansky, 1998;
Zwaan & Singer, 2003). Zwaan and Radvansky (1998) have suggested that readers use a
combination of linguistic cues and world knowledge to foreground information that will remain
active in working memory to be integrated with incoming text. For example, Albrecht and
O’Brien (1995) presented readers with passages in which a protagonist was described as being a
vegetarian. Several sentences later, the protagonist was described as ordering a hamburger,
something that is inconsistent with the earlier description of being a vegetarian. Reading times
for sentences describing the inconsistency were longer relative to a control sentence, suggesting
that readers had used their knowledge of vegetarians to foreground traits related to the
protagonist and, therefore, detect the inconsistency of a vegetarian ordering a hamburger.
Therriault and Raney’s investigation (2007) was the first to explore whether readers use their
knowledge base in a similar manner to infer temporal information and detect duration
inconsistencies.

Zwaan and Radvansky (1998) argue that temporal information is crucial to the
construction of situation models and that readers likely use their knowledge of situations stored
in long-term memory to derive an appropriate length of time for time frames that are not defined
explicitly in a text. However, they highlight that although establishing a time frame is likely a
requirement for coherent situation models, monitoring the sequence of events may not be
required for comprehension. Evidence from reading times suggest readers are able to detect temporal inconsistencies in text (Rinck, et al., 2001, 2003; Therriault & Raney, 2007); however, results from postreading questionnaires suggest that such inconsistencies are frequently missed (Rinck, et al., 2001, 2003). The current investigation uses eye tracking to monitor whether readers use their knowledge of the duration of events to detect temporal inconsistencies online, or if readers are prone to shallow processing of the temporal dimension of situation models, thereby failing to detect implicit temporal inconsistencies.

Situation models are multidimensional representations of a situation described in a text; that is, they integrate information about characters’ goals and actions across time and space. However, few studies have investigated how the dimensions represented in situation models interact (but see Zwaan, Magliano, & Graesser, 1995; Zwaan, Radvansky, Hilliard, & Curiel, 1998). An additional goal of this study is to explore whether temporal information interacts with goal achievement. In other words, do readers foreground event durations and integrate them later with the goal outcomes of the protagonist? Consider the passage from Therriault and Raney (2007) described above. Here, the target event takes considerably more time than the base event: listening to an entire talk show takes more time than is typically required to change a diaper. Therefore, comprehension difficulties are expected to arise when readers encounter this long-inconsistent duration comparison sentence. However, no comprehension problems would be expected when readers encounter the final goal outcome sentence (“They missed their reservation and could not eat dinner”). If changing a diaper takes so long that it is possible to listen to an entire talk show, readers might reasonably expect that dinner reservations will be missed. In contrast, comprehension difficulties are more likely if the goal is achieved. If readers retain duration information when they encounter the goal outcome sentence, processing delays would be expected as readers wonder how it is possible to make dinner reservations on time if it
took so long to change a diaper. Therriault and Raney (2007) explored the interaction of
duration information and goal outcome with their sentence by sentence procedure; however,
they did not find evidence that readers retained previously read duration information when they
encountered the goal outcome sentence. The current investigation monitored readers’ eye
movements as they read passages adapted from Therriault and Raney (2007) to examine
whether there is evidence that readers integrate duration information with goal outcome online.
Unlike the sentence by sentence reading procedure used by Therriault and Raney, eye tracking
allows for the observation of potential processing difficulties as they occur from moment to
moment during natural reading. An additional benefit of monitoring eye movements is that it
allows the differentiation between initial fixations and later regressions to review previously
processed words. If inconsistent information is detected online, eye tracking allows the
researcher to determine whether detection was immediate or delayed, as well as the ease and
speed of error recovery and integration with previous text. If detection of inconsistent
information is delayed, processing disruptions would only be observed after the reader has
proceeded beyond the inconsistent text. Unlike sentence by sentence reading times, the current
procedure allows readers to reread previously encountered sentences, allowing for a more
sensitive measure of potential processing difficulties.

**Age Differences in Temporal Processing**

Past research indicates that younger and older readers may perform similarly on the
duration monitoring task. Studies focusing on the creation and representation of situation
models demonstrate that older readers are not impaired relative to their younger counterparts
(see Radvansky & Dijkstra, 2007 for review). In fact, older readers show greater sensitivity to
processing at the situation model level relative to younger readers (Stine-Morrow, et al., 2004;
Stine-Morrow, et al, 1996) and may use their focus on situation model representations to
compensate for their inability to remember verbatim or textbase information (Stine-Morrow, et al, 2006, 2008). For example, Stine-Morrow et al. (2004) reported that older readers spent more time reading and rereading information relevant to the situation model (operationalized as time allocated to text that was more important to the discourse as a whole) compared to younger readers who engaged in the most time reading information related to the textbase (operationalized as time allocated to propositionally dense text). Furthermore, the increased allocation of processing resources to situation model construction was accompanied by better comprehension scores. With respect to temporal processing in particular, Radvansky et al. (2003) found that both younger and older participants were slower to read time shifts that described a shift over a longer period of time (a day later) than they were for shorter temporal shifts (a moment later). This extra time presumably represented the extra cognitive effort required to update the situation model within a new time frame. Both age groups were also less accurate and slower to respond to probe questions referring to events before a longer time shift relative to probe questions referring to events before a shorter time shift. Therefore, although readers displayed increased difficulty processing temporal information that represented longer time shifts, older readers were not impaired relative to their younger counterparts.

Unlike previous research on temporal representations by older readers, the current study does not present explicit duration information to readers; instead it must be inferred from readers’ knowledge. This requirement may put older readers at an advantage over younger readers if older readers are able to make use of their schema-based and world knowledge to improve their reading performance (Miller, 2001, Miller & Stine-Morrow, 1998; Miller, et al., 2004). As Radvansky, et al., (2001) remind us, “The creation of a situation model is essentially an inference-making process in which the given information and general world knowledge is used to construct an understanding of the described situation” (p. 156). Recently, Hannon and
Daneman (2009) demonstrated that the processes used for accessing prior knowledge are less susceptible to age-related declines than are processes related to gaining new knowledge, such as text memory. The growth in linguistic and world knowledge that is observed with age (Baltes, 1997; Baltes, et al, 1999; Salthouse, 1988) may put older readers at an advantage to make use of that knowledge compared to younger readers. So, despite cognitive declines, older readers may be able to readily access their knowledge of the typical duration of events to recognize the inconsistencies between the desired goal and the duration of the events.

One caveat to the prediction of few age differences in spontaneous duration monitoring is that the use of implicit duration information in the current investigation places a high demand on working memory, as readers must maintain information about the base event and access duration information from their knowledge base while processing the incoming duration comparison sentence. In a series of experiments, Radvansky and Copeland (2001, 2004, 2006) failed to find evidence that readers’ working memory capacity influenced their situation model processing. For example, measures of working memory capacity were found to be unrelated to readers’ ability to understand a situation described in a text, detect situational inconsistencies, or integrate information into situation models. Despite the apparent lack of relationship between traditional measures of working memory capacity and situation model processing, however, Radvansky and Copeland acknowledge that situation model processing likely requires some form of working memory involvement because it requires readers to actively maintain several pieces of information at one time. They have suggested that situation model processing may involve the ability to access the appropriate knowledge from long-term memory and maintain only relevant information active in working memory (Radvansky & Copeland, 2001; see also Zwaan & Radvansky, 1998). Elsewhere, it has been suggested that high span readers might be those individuals who are able to make the most efficient use of their knowledge from long-term
memory (Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995). According to this model, readers use retrieval structures in working memory to provide quick access to text-relevant prior knowledge, thus allowing for the construction of a coherent text representation (Kintsch, et al, 1999). Because the current investigation requires readers to access their knowledge base to detect the inconsistent duration information, high span readers may be more likely to detect the inconsistencies if they are able to access their long-term memory more efficiently than readers with lower working memory capacities.

Older adults display reductions in working memory capacity compared to younger readers (Brebion, 2003; Carpenter, et al., 1994; DeDe, et al., 2004; Norman, Kemper, & Kynette, 1992; Salthouse, 1991; Salthouse & Babcock, 1991; Stine & Wingfield, 1990) and may, therefore, be less able to maintain all of the information required to detect the temporal inconsistency in the current investigation. In contrast, older readers’ increased reliance on existing knowledge relative to younger readers (Miller & Stine-Morrow, 1998; Miller, et al., 2004) makes it possible that any age-related deficits could be offset by older readers’ use of knowledge. Accordingly, a working memory span task (Daneman & Carpenter, 1980) was included in this study in order to investigate the potential role of working memory on duration monitoring independently of age.

Method

Participants

Participants were 84 younger adults whose ages ranged from 17 to 25 ($M = 19.21, SD = 1.62$), and 48 older adults whose ages ranged from 65 to 86 ($M = 74.71, SD = 5.82$). Younger adults were University of Toronto undergraduate students who received credit toward an introductory psychology course for their participation. Older adults were volunteers from the local community in Mississauga, Ontario and were paid $10 for their participation. A
questionnaire was administered in order to screen for general health, hearing and vision. Only older adults who reported that they were in good health and had no history of serious pathology were included in the study. All participants were fluent speakers of English and had normal or corrected-to-normal vision. Participants completed three tasks in the following order: (a) a passage reading task in which they read 20 passages, 8 of which contained inconsistent temporal information, during which their eye movements were monitored; (b) a recognition questionnaire designed to assess whether participants had detected the temporal inconsistencies; and (c) a variant of Daneman and Carpenter’s (1980) working memory span test (see Daneman & Hannon, 2001) designed to measure the combined processing and storage capacity of working memory. The entire session lasted approximately one hour.

**Passage reading task**

Participants read 20 passages and responded to two questions after each of them. Twelve of the passages were experimental passages (four containing a short-inconsistent sentence, four containing a long-inconsistent sentence, and four containing a consistent control sentence) and eight were filler passages that did not contain any inconsistencies. Participants’ eye movement were monitored and recorded while reading the passages.

**Materials and design.** The experimental passages were adapted from Therriault and Raney (2007) and consisted of a base event that set up a time frame for the following events, a duration comparison sentence containing one of three possible temporal events (consistent, short-inconsistent, long-inconsistent), an intervening sentence, an outcome sentence in which the protagonist’s goal was either achieved or not achieved, and conclusion sentences that completed the passage (see Table 8 for a sample passage; see Appendix C for all passages). The passages were designed so as not to include any specific mention of time terms to assess whether readers monitor temporal information in the absence of explicit time terms.
Furthermore, the inclusion of an outcome sentence allows for the investigation of possible interactions between temporal information and goal achievement.

Table 8
*Sample Passage with Duration Inconsistencies and Outcome Sentences*

| Base event | Angel and Richard were on their way out to have dinner. They made reservations at a chic new restaurant. They hadn’t been to dinner in several weeks because they just had a baby. Tonight they were going out with their new baby for the first time. Angel realized that the baby needed to be changed. She told Richard to go start the car and she would be right out. |
| Comparison sentence | Consistent: Richard had defrosted the car windows when Angel brought the baby out. |
| | Short-Inconsistent: Richard had just unlocked the car door when Angel brought the baby out. |
| | Long-Inconsistent: Richard had listened to an entire talk show when Angel brought the baby out. |
| Intervening sentence | Richard drove them to the restaurant. |
| Goal outcome sentence | Achieved: They made their reservation and had a great dinner. |
| | Unachieved: They missed their reservation and could not eat dinner. |
| Conclusion | They decided to go out again next week. Richard called and made another reservation. |

**Procedure.** Passages were presented on a computer screen in double-spaced Arial 24 font. Participants read the passages silently at their own pace and were able to control the rate of presentation of successive passages by pressing a button on a game pad. The experimenter read instructions to each participant describing the eye tracking procedure and how to control the self-paced text progression. Participants were instructed to read for comprehension and not to proceed to the next passage until they fully understood the information on the current screen. Participants were informed that they would be asked comprehension questions after each passage. After each passage, two true-or-false questions were presented on the computer monitor, which participants answered by pressing one of two buttons on a game pad (e.g. **Base event**)}
“Angel and Richard were going out with their baby for the first time”). None of the questions asked about information related to the duration comparison sentences or goal outcome sentences. The next passage followed immediately after the second question. Participants were not told about potential inconsistencies prior to reading the passages. While reading, participants’ eye movements were recorded using an eye-tracker system: the EyeLink II by SR Research Ltd. Each participant wore the EyeLink headband that contains three small cameras that allow simultaneous tracking of both eyes and head position, making possible the computation of true gaze position with unrestrained head motion. However, to prevent excessive motion on the part of the participant, participants rested their chins on a chin-rest positioned 1.5 m from the computer screen. The movements of both the right and left eye were recorded, and data from the right eye were analyzed. The on-line saccade detector of the eye tracker was set to detect saccades with an amplitude of 0.5° or greater, using an acceleration threshold of 9500°/sec² and a velocity threshold of 30°/sec (see Shen, et al, 2003, for a similar set-up). The EyeLink system uses an Ethernet link between the eye tracker and the display computers so that real-time gaze position data can be displayed. For the passage reading task, there were two computer monitors. One was used to display the passages to the participant. The second was used to display real-time feedback about the participants’ eye movements to the experimenter; this allowed the experimenter to monitor performance and recalibrate the eye tracking system as necessary.

**Recognition Questionnaire**

Participants completed a recognition questionnaire to assess overt detection of the inconsistencies. Participants were presented with a booklet containing all of the experimental passages as well as the three possible duration comparison sentences and two possible goal outcomes. Participants were instructed to read through the passages again and circle the version
they remembered reading previously. Complete passages were provided to cue participants’ memory for the passages and to avoid confusion between them. Participants’ recognition of the passages was quite high: readers correctly recognized the version of the experimental passage they had read previously 88% of the time. After identifying the previously encountered version, participants were instructed to write about anything unusual or surprising they remembered reading the first time they encountered the passage. If they did not recall anything unusual, participants were instructed to leave the section blank. No indication was given to participants about temporal inconsistencies, and the responses to this section were used to assess overt detection of the inconsistencies.

**Working Memory Span Test**

Participants read aloud a set of unrelated sentences, made a sensibility judgment for each one, and then at the end of the set, they recalled the last word of each sentence in the set (see Daneman & Hannon, 2001). The test was constructed with 100 unrelated sentences, 8 to 12 words in length, each ending with a different word. Sentences were presented one at a time on a computer screen. After the participant responded with a ‘yes’ or ‘no’ to indicate whether the sentence made sense, they pressed the space bar for the next sentence. The procedure was repeated until a blue screen indicated that the trial was over, at which point the participant recalled the last word of each of the sentences in the set. For example, in a two-sentence set, participants might read, “An eerie breeze suddenly chilled the warm, humid air. The umbrella grabbed its bat and stepped up to the plate.” They would respond ‘yes’ after reading the first sentence, ‘no’ after reading the second sentence, and then recall *air* and *plate* when prompted by the blue screen. Sentences were arranged in five sets of 2, 3, 4, 5, and 6 sentences, respectively. Participants were presented with increasingly longer sentence sets until all 100 sentences had been presented. Working memory span was the total number of sentence-final words out of 100
that the participant could recall. The mean score on the working memory span test was 49.02 out of a possible 100 ($SD = 10.58$). Participants with scores of 49 or less were classified as low span readers ($n = 71, M = 41.3, SD = 7.01$); participants with spans of 50 or more were classified as high span readers ($n = 61, M = 58.0, SD = 6.00$).

**Results and Discussion**

Three sets of analyses are described in the following section. First, evidence of overt inconsistency detection is investigated in an analysis of the recognition questionnaire results. Evidence for spontaneous online duration monitoring is then investigated with analyses of the eye movement data. Because different predictions were made concerning participants’ behaviour when encountering short duration inconsistencies and long duration inconsistencies, the duration inconsistencies were investigated in separate analyses. There were two regions of interest for the analyses of online duration monitoring. First, the eye-fixation data on the duration comparison sentence was analyzed as a function of type of duration, age, and working memory capacity. Second, the eye-fixation data on the goal outcome sentence was analyzed as a function of goal achievement, duration, age, and working memory capacity. In all analyses, fixation durations that were greater than 3 standard deviations from the mean within each condition were discarded, resulting in less than 3% of the data being discarded.

**Evidence of Inconsistency Detection from Recognition Questionnaire**

Questionnaires were scored for the number of duration inconsistencies detected in each passage. For each of the passages, participants received a two-point score if they explicitly mentioned the duration inconsistency. If participants demonstrated some awareness of the inconsistency but were unable to identify it, they were given a score of 1. For example, if participants responded “How did they still make it to their reservation on time?” after reading the passage that contained the sentence “Richard had listened to an entire talk show when Angel
brought the baby out,” they received a score of 1. If they responded “Angel took a really long time to change the baby,” after reading the same passage, they received a score of 2. Because each participant read four passages containing short-inconsistent sentences, and four passages containing long-inconsistent sentences, the maximum score for each type of inconsistency was eight points. Questionnaire scores were subjected to a mixed factors analysis of variance (ANOVA) with duration (short, long) and goal achievement (achieved, unachieved) as within-subject variables, and age (younger readers, older readers) and working memory (low, high) as between-subject variables. Mean scores are presented in Table 9.

Duration inconsistencies that were too long for the time frame of the base event were found to be more salient than those that were too short. Importantly, although goal outcome and working memory mediated inconsistency detection, there were no age differences in detection rates. Postreading questionnaire responses demonstrated that, overall, detection of duration inconsistencies was quite low. Readers reported noticing a duration-related inconsistency during only 19% of the trials; however, detection rates were not equivalent for the two durations.

Table 9
Mean Percentage of Inconsistent Duration Information Reported by Readers as a Function of Age, Working Memory and Goal Achievement. Standard errors are in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>Short Achieved</th>
<th>Short Unachieved</th>
<th>Long Achieved</th>
<th>Long Unachieved</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Younger</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low WM</td>
<td>11.1 (4.2)</td>
<td>12.5 (3.9)</td>
<td>26.4 (5.4)</td>
<td>24.3 (5.3)</td>
</tr>
<tr>
<td>High WM</td>
<td>9.4 (2.7)</td>
<td>22.9 (4.0)</td>
<td>20.8 (4.1)</td>
<td>26.6 (4.9)</td>
</tr>
<tr>
<td>Overall</td>
<td>10.1 (2.4)</td>
<td>18.4 (2.9)</td>
<td>23.2 (3.3)</td>
<td>25.6 (3.6)</td>
</tr>
<tr>
<td><strong>Older</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low WM</td>
<td>7.1 (3.0)</td>
<td>12.9 (4.3)</td>
<td>26.4 (5.4)</td>
<td>25.7 (5.7)</td>
</tr>
<tr>
<td>High WM</td>
<td>7.7 (5.2)</td>
<td>17.3 (6.5)</td>
<td>19.2 (6.4)</td>
<td>38.5 (9.2)</td>
</tr>
<tr>
<td>Overall</td>
<td>7.3 (2.6)</td>
<td>14.1 (3.6)</td>
<td>24.5 (4.3)</td>
<td>29.2 (4.9)</td>
</tr>
</tbody>
</table>
Readers detected more inconsistencies that overshot the time frame than those that were too short for the time frame set up by the base event, $F(1,128) = 23.13, MSE = 803.40, p < .001$. Readers reported noticing long-inconsistent sentences on 25.28% of the trials, whereas they only reported noticing short-inconsistent sentences on 12.98% of the trials. This is consistent with the results reported by Therriault and Raney (2007) who found that long duration inconsistencies caused more comprehension difficulty than short duration inconsistencies. Although both types of inconsistencies violate the time frame set up by the base event, the event described in the long-inconsistent duration comparison sentence cannot be completed in the time frame provided. The combination of a time frame violation and the inability to complete the event could have resulted in long duration inconsistencies being more salient to the reader.

Importantly, no significant effects of age were found in detection rates, all $Fs < 1$, demonstrating that older readers are not less likely to detect duration inconsistencies. In fact, both older and younger readers reported noticing duration inconsistencies in 19% of trials. This result is consistent with the observation from Experiment 1 that older readers are as likely to detect semantic anomalies in text as younger readers, as well as previous findings that processing of the situation model remains stable with age (Morrow, et al., 1994; Radvansky, 1999; Radvansky, et al., 2003; Radvansky, et al., 2003; Radvansky & Curiel, 1998; Radvansky, et al., 2001; Stine-Morrow, et al., 2002, 2004).

Goal achievement also influenced whether readers reported noticing a duration inconsistency, $F(1,128) = 10.66, MSE = 418.39, p < .01$. As can be seen in Table 9, readers were more likely to report duration inconsistencies if they were followed by an unachieved goal, a result that is also consistent with Therriault and Raney (2007). Intentionality research has shown that readers require additional cognitive effort to integrate unachieved goals in text (Lutz & Radvansky, 1997; Suh & Trabasso, 1993). It is possible that upon encountering an unachieved
goal, readers may have engaged in a search for a cause of the failed goal, thereby retroactively drawing awareness to duration inconsistencies encountered earlier in the text. An additional finding in this investigation is a goal achievement X working memory interaction, $F(1,128) = 7.44, MSE = 418.39, p < .01$, such that the goal-directed behaviour described above was observed primarily in high-span readers. One view of text comprehension proposes that comprehension is guided by a search for meaning (e.g. Graesser, Singer, & Trabasso, 1994); therefore, information remains available in working memory if readers believe that it is necessary for comprehension (Zwaan, et al., 1995; Zwaan & Radvansky, 1998). According to this view, unachieved goal information is likely to remain available in working memory until a resolution is encountered. Indeed, evidence demonstrates that unachieved goal information is more accessible than completed goal information (Lutz & Radvansky, 1997; Magliano & Radvansky, 2001; Radvansky & Curiel, 1998; Suh & Trabasso, 1993; Trabasso & Suh, 1993).

In an attempt to construct a coherent representation in the current investigation, readers needed to maintain both the unachieved goal status and the duration information from the previously read duration comparison sentence. Accessibility of goal information by readers with high and low working memory spans was not the main focus of this study, however, it does suggest that it is only those readers with high working memory capacity who can successfully access earlier information regarding the duration of previous events in an attempt to resolve an unachieved goal. An unachieved goal may have served to highlight the duration problems readers encountered earlier in the text. With fewer resources available, low-span readers were unable to access the appropriate duration information upon encountering the unachieved goal statement.

**Evidence of Duration Inconsistency Detection from Eye-Movement Data**

Two dependent measures were used to investigate online duration monitoring in younger and older readers: *go-past time* and *proportion of look back fixations*. Go-past time is the sum of
all fixations from the first fixation on the target sentence until moving on to the subsequent sentence, including any regressions to previously encountered (leftward) words and any refixations on the target sentence itself. Go-past time is considered a measure of comprehension that reflects early processing and integration. If readers detected a duration inconsistency as they read, this measure was used as an estimate of the time required to detect and resolve the inconsistency before progressing in the text. Proportion of look back fixations is a measure of later processing. Look back fixations are fixations that return to a sentence after the reader has already commenced reading one or more new sentence(s) in the forward direction but then wishes to reinstate previously processed information into working memory. Proportion of look back fixations was calculated as the number of target sentences that contained look back fixations out of the total number of target sentences. If readers display increased look back fixations to inconsistent duration comparison sentences, this could reflect delayed inconsistency detection or an attempt to integrate the temporal information with newly processed text.

**Long Duration Inconsistencies**

There were two regions of interest for the analysis of online duration monitoring. First, a mixed factors analysis of variance (ANOVA) was conducted on the duration comparison sentence for each of the fixation time measures with duration (control, long) as the within-subject variable, and age (younger readers, older readers) and working memory (low, high) as between-subject variables. Next, the fixation time measures for the goal outcome sentence were subjected to a mixed factors analysis of variance (ANOVA) with duration (control, long) and goal achievement (achieved, unachieved) as within-subject variables, and age (younger readers, older readers) and working memory (low, high) as between-subject variables. All reported effects were significant beyond the .05 level, unless noted otherwise.
Readers from both age groups provided evidence of long duration inconsistency detection regardless of working memory capacity, which corroborates the questionnaire results that long duration inconsistencies are particularly salient. However, readers with high working memory capacities detected the inconsistencies earlier than those with lower working memory capacities. Finally, there was evidence that duration information had a delayed influence on goal processing.

**Duration comparison sentence.** On average, go-past times by readers on long-inconsistent duration comparison sentences were 2488 ms compared to 2369 ms for consistent control sentences, $F(1,128) = 9.45$, $MSE = 152,751$, suggesting a significant number of readers detected the inconsistent temporal information early during processing, as can be seen in Figure 4. Importantly, older readers were not impaired at detecting long duration inconsistencies relative to younger readers; neither a main effect of age, nor the duration X age interaction reached significance, $F(1,128) = .49$, $MSE = 720,882$, $p = .49$, $F(1,128) = 1.99$, $MSE = 152,751$, $p = .16$, respectively. This result is consistent with the findings from the recognition questionnaire that revealed equivalent temporal inconsistency detection rates for older and younger readers and the findings from Experiment 1 that revealed similar detection rates of semantic anomalies among younger and older readers.

As can also be seen in Figure 4, individuals with high working memory capacity read the passages on average 217 ms faster overall than did readers with lower working memory capacity, an observation that is supported by a main effect of working memory, $F(1,128) = MSE = 720,882$. Furthermore, a duration X working memory interaction revealed that it was only readers with high working memory capacities who provided evidence of early detection of the long duration inconsistencies, $F(1,128) = 4.86$, $MSE = 152,751$. Figure 4 shows that high-span readers spent 2413 ms processing the long-inconsistent duration comparison sentences,
which was 203 ms longer than they spent on consistent control sentences, $t(60) = 2.91$, $SE = 69.5$, $p < .01$. Low-span readers, on the other hand, spent 2552 ms processing the long-inconsistent duration comparison sentences, which was a nonsignificant difference of only 47 ms relative to control sentences, $t(70) = .71$, $SE = 67$, $p = .47$. It appears readers with larger working memory capacity were able to access their knowledge of the typical duration of events and apply it online to detect the long duration inconsistencies faster than their lower capacity counterparts.

Figure 4. Mean go-past times (in milliseconds) on long-inconsistent and consistent duration comparison sentences as a function of age and working memory.

The analysis of the proportion of look back fixations to the duration comparison sentence provided evidence that readers eventually detected the long duration inconsistencies regardless of their age or working memory capacity. The only significant effect from this analysis was a main effect of duration, $F(1,128) = 1.99$, $MSE = 152 751$. As can be seen in Figure 5, readers looked back on average to 54% of the sentences containing a long duration inconsistency but only looked back to 37% of the consistent control sentences. Thus, a significant number of readers were eventually disrupted by these easier-to-detect long duration inconsistencies and
engaged in regressive fixations, presumably in an attempt to resolve them. No other effects reached significance, all $F$s < 1.

![Figure 5. Mean proportion of look back fixations to long inconsistent and consistent duration comparison sentences as a function of age and working memory.](image)

To confirm that the look back fixations to the comparison duration sentences were a result of inconsistency detection rather than driven by goal outcome, the proportion of look back fixations to the duration comparison sentences were analysed as a function of whether they were followed by an achieved goal or an unachieved goal. Neither a main effect of goal achievement nor any of its interactions were significant in this analysis, all $p$s > .20. This indicates that readers did not look back to the duration comparison sentences only after encountering an unachieved goal in an attempt to explain that unachieved goal; rather the increased proportion of look back fixations to the long-inconsistent duration comparison sentences by readers reflects the delayed detection of these inconsistencies.

**Goal outcome sentence.** Data from the analysis of go-past time on the goal outcome sentence can be found in Table 10. Readers did not provide evidence that the duration inconsistency caused any early disruption to the processing of the goal outcome sentence.
Neither a main effect of duration nor a duration X goal interaction reached significance, $F(1,128) = 2.21$, $MSE = 330\ 982$, $p = 0.15$, $F(1,128) = 0.006$, $MSE = 395\ 966$, $p = 0.94$, respectively. Similar to the analysis of the duration comparison sentence, high-span readers read the goal outcome sentence faster than did low-span readers, $F(1,128) = 5.99$, $MSE = 1\ 249\ 649$, but the effect was independent of duration inconsistency. No other effects from the analysis of go-past times on the goal outcome sentence were significant, all $ps >.20$.

Table 10
Mean Go-past Times (in milliseconds) to Goal Outcome Sentence as a Function of Duration, Age, Working Memory and Goal Achievement. Standard errors are in parentheses.

<table>
<thead>
<tr>
<th></th>
<th>Consistent Achieved</th>
<th>Consistent Unachieved</th>
<th>Short Inconsistent Achieved</th>
<th>Short Inconsistent Unachieved</th>
<th>Long Inconsistent Achieved</th>
<th>Long Inconsistent Unachieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Go-past time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Older</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High WM</td>
<td>1812 (215)</td>
<td>1853 (229)</td>
<td>1815 (234)</td>
<td>1639 (194)</td>
<td>1715 (193)</td>
<td>1692 (171)</td>
</tr>
<tr>
<td>Low WM</td>
<td>2269 (144)</td>
<td>2079 (94)</td>
<td>2180 (118)</td>
<td>2101 (108)</td>
<td>2165 (130)</td>
<td>2170 (103)</td>
</tr>
<tr>
<td>Overall</td>
<td>2041 (123)</td>
<td>1996 (92)</td>
<td>1998 (108)</td>
<td>1870 (98)</td>
<td>1940 (111)</td>
<td>1931 (93)</td>
</tr>
<tr>
<td>Younger</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High WM</td>
<td>1876 (96)</td>
<td>2082 (208)</td>
<td>1893 (68)</td>
<td>1888 (78)</td>
<td>1794 (75)</td>
<td>1909 (85)</td>
</tr>
<tr>
<td>Low WM</td>
<td>2108 (127)</td>
<td>2064 (92)</td>
<td>2006 (100)</td>
<td>2033 (89)</td>
<td>2036 (102)</td>
<td>1990 (102)</td>
</tr>
<tr>
<td>Overall</td>
<td>1992 (78)</td>
<td>2074 (124)</td>
<td>1950 (58)</td>
<td>1961 (59)</td>
<td>1915 (62)</td>
<td>1950 (65)</td>
</tr>
</tbody>
</table>

On the other hand, the analysis of proportion of look back fixations to the goal outcome sentences demonstrated delayed evidence that readers retained the duration information to evaluate subsequent goal outcome. This observation is supported by a duration X goal achievement interaction, $F(1,128) = 7.27$, $MSE = .21$. As shown in Table 11, relative to achieved goal sentences, readers engaged in more look back fixations to unachieved goal sentences that followed consistent duration comparison sentences, an observation that is consistent with the claim that readers attempt to keep unachieved goal information available in working memory (Lutz & Radvansky, 1997; Radvansky & Curiel, 1998; Suh & Trabasso,
1993). Yet, readers engaged in more look back fixations to *achieved* goal sentences that followed long-inconsistent duration comparison sentences relative to unachieved goal sentences.

<table>
<thead>
<tr>
<th>Proportion of look back fixations</th>
<th>Consistent</th>
<th>Short Inconsistent</th>
<th>Long Inconsistent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Achieved</td>
<td>Unachieved</td>
<td>Achieved</td>
</tr>
<tr>
<td>Older</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High WM</td>
<td>.46 (.14)</td>
<td>.38 (.14)</td>
<td>.15 (.11)</td>
</tr>
<tr>
<td>Low WM</td>
<td>.29 (.08)</td>
<td>.31 (.08)</td>
<td>.23 (.07)</td>
</tr>
<tr>
<td>Overall</td>
<td>.38 (.07)</td>
<td>.35 (.07)</td>
<td>.20 (.06)</td>
</tr>
<tr>
<td>Younger</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High WM</td>
<td>.19 (.06)</td>
<td>.35 (.07)</td>
<td>.27 (.06)</td>
</tr>
<tr>
<td>Low WM</td>
<td>.22 (.07)</td>
<td>.36 (.08)</td>
<td>.19 (.07)</td>
</tr>
<tr>
<td>Overall</td>
<td>.20 (.04)</td>
<td>.36 (.05)</td>
<td>.23 (.05)</td>
</tr>
</tbody>
</table>

After reading a consistent duration comparison sentence, readers later looked back to 10% more unachieved goal sentences than achieved ones, $t(131) = 1.71, SE = .58, p = .09$. However, after encountering a long-inconsistent duration comparison sentence, readers later looked back to 15% *fewer* unachieved goal sentences relative to achieved goals, $t(131) = 2.74, SE = .54, p < .01$. Following a long-inconsistent sentence, readers likely noticed that the protagonists engaged in activities that would be too long to achieve their goals, so readers were already expecting the unachieved goal sentences that they later encountered. If readers instead read an achieved goal sentence, this would have violated their expectations of a failed goal, resulting in increased difficulty integrating the goal sentence into their situation model, as reflected by an increased proportion of look back fixations. In the investigation by Therriault and Raney (2007) a similar interaction between duration information and goal outcome was expected, however, they failed to find support for their prediction in their analysis of participants’ sentence by sentence reading time. The current investigation revealed that readers do, at least on occasion, maintain
previously encountered temporal information when processing goal outcome, but it appears to be a relatively difficult task because it was only observed during later processing.

**Short Duration Inconsistencies**

Similar to the analysis of long duration inconsistencies, there were two regions of interest for the analysis of online duration monitoring. First, a mixed factors analysis of variance (ANOVA) was done on the duration comparison sentence for each of the fixation time measures with duration (control, short) as the within-subject variable, and age (younger readers, older readers) and working memory (low, high) as between-subject variables. Next, the fixation time measures for the goal outcome sentence were subjected to a mixed factors analysis of variance (ANOVA) with duration (control, short) and goal achievement (achieved, unachieved) as within-subject variables, and age (younger readers, older readers) and working memory (low, high) as between-subject variables. All reported effects were significant beyond the .05 level, unless noted otherwise.

Only readers with high working memory capacity provided evidence of online detection of the short duration inconsistencies. However, there was little evidence that the inconsistency continued to disrupt readers when they read the goal outcome sentence. The results also produced an interesting age effect: older readers who were likely to detect the inconsistent duration did so earlier than did younger readers.

**Duration comparison sentence.** Similar to the analysis of long duration inconsistencies, go-past times by readers on short-inconsistent duration comparison sentences were 2429 ms compared to 2369 ms for consistent control sentences, $F(1,128) = 7.74, MSE = 114,215$, suggesting a significant number of readers detected the inconsistent temporal information early during processing. However, a duration X age interaction revealed that it was only the older readers who detected the short-inconsistent sentence when they first encountered it, $F(1,128) =$
9.40, \( MSE = 114 \, 215 \). As Figure 6 shows, the duration \( \times \) age interaction was further mediated by a 3-way interaction between duration, age, and working memory, \( F(1,128) = 3.79, MSE = 114 \, 215, p = .05 \). This interaction illustrates that it was those older readers with high working memory capacity who detected the duration inconsistency online and attempted to resolve it when they first encountered it. Older high span readers displayed on average 456 ms longer go-past times for the short-inconsistent duration comparison sentences than they did for consistent duration comparison sentences, \( t(12) = 2.70, SE = 169, p < .02 \), while go-past times by older readers with lower working memory capacity were on average only 92 ms longer for short-inconsistent sentences than consistent controls, a difference that was not significant, \( t(34) = 1.17, SE = 79, p = .25 \).

Figure 6. Mean go-past times (in milliseconds) on short-inconsistent and consistent duration comparison sentences as a function of age and working memory.

Both groups of younger readers with high and low working memory capacity displayed on average 13 ms faster go-past times for short-inconsistent duration comparison sentences than consistent control sentences; however, the different was not significant for either group, \( t(47) = \)}
.21, SE = 66, p = .83; t(35) = .16, SE = 77, p = .87, for younger high span and low span readers, respectively. Finally, in addition to the interaction described above, individuals with high working memory capacity read the passages on average 271 ms faster overall than did readers with lower working memory capacity, F(1,128) = 7.52, MSE = 66 1903, regardless of duration inconsistency.

Research on situation model processing has typically not reported any differences between age groups (Morrow, et al., 1994; Radvansky, 1999; Radvansky, et al., 2003; Radvansky, et al., 2003; Radvansky, et al., 2003; Radvansky & Curiel, 1998; Radvansky, Gerard, Zacks, & Hasher, 1990; Radvansky, et al., 2001; Stine-Morrow, et al., 2002) or working memory span groups (Radvansky & Copeland, 2001, 2004, 2006). Unlike earlier studies that investigated age-related differences in situation model processing, however, the current investigation required readers to access their own knowledge of the duration of events to detect an inconsistency because this information was not provided in the text. The ability to access this knowledge quickly and efficiently may have been what allowed older readers to detect the short duration inconsistencies when they first read them. Radvansky and Copeland (2001) have argued that knowledge access can play an important role in situation model processing by regulating the contents of working memory in a manner similar to that proposed by Ericsson and Kintsch’s (1998) LTWM model (see also Radvansky & Dijkstra, 2007). According to this model readers use retrieval structures in working memory to provide quick access to text-relevant prior knowledge, thus allowing for the construction of a coherent text representation (Kintsch, et al, 1999). High span readers would be those individuals who are able to make the most efficient use of their long-term memory by using pre-existing knowledge structures (Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995). In a series of experiments, Miller (2001, 2003; Miller & Stine-Morrow, 1998; Miller, et al, 2004) has shown that older readers take disproportionate advantage of knowledge
to maintain satisfactory comprehension. Of particular relevance for this study is the finding that older readers benefited more from knowledge that clarified the content of a vague, ill-defined passage than did younger readers (Miller & Stine-Morrow, 1998). In that study, older high-knowledge readers displayed reduced reading times at sentence boundaries compared to other readers but still attained among the highest recall scores. This result demonstrates that older readers are able to make particular use of their knowledge to improve reading efficiency. Consequently, if high span readers use stored retrieval structures to make prior knowledge more accessible, and older readers rely disproportionately more on their prior knowledge for comprehension, then older readers with high working memory capacities would have been in the best position to access their knowledge of the duration of events to use for inconsistency detection in the current experiment. So, for example, when older high-span readers read that “Richard had just unlocked the car door when Angel brought the baby out” they were able to access their knowledge of the length of time required to change a diaper and immediately recognize that sufficient time had not elapsed. Younger readers appeared to be unable to recognize the inconsistency as quickly.

Another possibility is that younger readers noticed that the short-inconsistent duration comparison sentences were too short to fill the time set up by the base event but delayed their analysis until they progressed in the text. After all, it is possible that the sentence immediately following the duration inconsistency included information about another event that could have filled the expected amount of time. Younger readers may have only needed to reprocess the short-inconsistent duration comparison sentence when they discovered the text did not include any such additional information. Although early duration inconsistency detection by younger readers cannot be ruled out with certainty in the current study, it is more likely that younger readers failed to detect them when they were first encountered. Previous eye-tracking research
has shown that readers pause longer on words and phrases that are inconsistent with previously read information when it is first encountered (Braze, et al., 2002; Daneman, et al, 1995; Frazier & Rayner, 1982; Rayner, et al, 2006). Although the short duration inconsistencies would not have prevented the protagonists’ from achieving their goals, the events described in the short-inconsistent sentences were surprisingly short in themselves. For example, in the sample passage presented in the Table 8, while Richard and Angel could make their reservation on time in both the consistent control and the short-inconsistent conditions, it is unusual that Angel would be able to change a baby in the time it takes to unlock car doors. Such an unlikely event is apparent when it is first encountered, yet younger readers did not provide evidence of increased reading times when first encountering the inconsistency. Furthermore, younger readers did pause longer on the long-inconsistent duration inconsistencies when they were first encountered. This increased processing time on long-inconsistent duration comparison sentences by younger readers suggests that younger readers did indeed fail to detect the short inconsistencies when they first encountered them, rather than simply delaying their attempt to repair them. If younger readers had detected the short inconsistencies when they read them the first time, one might expect that they would have engaged in longer go-past times on the short-inconsistent duration comparison sentences, much like they did for the long-inconsistent sentences.

The analysis of the proportion of look back fixations to the duration comparison sentence revealed that some younger readers did detect the short duration inconsistency, albeit, later than older readers. However, it was only readers with high working memory capacities who engaged in increased look backs to short-inconsistent duration comparison sentences relative to the consistent control sentences. Similar to the analysis of go-past times, a main effect of duration, $F(1,128) = 7.31$, $MSE = .22$, was mediated by an duration X working memory
interaction, $F(1,128) = 5.21$, $MSE = .22$, demonstrating that only high span readers looked back more frequently to short inconsistent information. As Figure 7 demonstrates, high-span readers looked back to 64% of the short-inconsistent duration comparison sentences compared to only 39% of the consistent control sentences, $t(60) = 3.08$, $SE = .08$, $p < .01$. On the other hand, low span readers looked back to short-inconsistent duration comparison sentences and consistent control sentences 39% and 37%, respectively, a difference that was not significant, $t(70) = .34$, $SE = .08$, $p = .73$. Unlike was observed for go-past times, however, older and younger high-span readers were both disrupted by the duration inconsistency, all $ps > .10$ for age effects, as shown in Figure 7. Thus, high-span readers in both age groups were disrupted by the inconsistency and engaged in regressive fixations in an attempt to resolve it.

![Figure 7](image_url)

**Figure 7.** Mean proportion of look back fixations to short-inconsistent and consistent duration comparison sentences as a function of age and working memory.

The observation that older readers continue to be disrupted by the inconsistent duration information during later processing suggests that they may require additional time to resolve the inconsistency compared to younger readers. Furthermore, an examination of Figure 7 suggests that older readers who detected the inconsistent duration information engaged in
disproportionately more look back fixations to the disruption-causing information relative to younger readers. Older high span readers engaged in 46% more regressive fixations to the short-inconsistent duration comparison sentences relative to consistent sentences; whereas the same comparison in younger high span readers only revealed a 19% difference between the short-inconsistent and consistent duration comparison sentences. However, this numerical difference between age groups did not reach significance, \( t(59) = 1.42, SE = .19, p = .16. \)

Another possible reason that high-span readers looked back to the short duration inconsistent information could be that after reading an unachieved goal sentence, they were retroactively searching for a reason that the protagonists did not achieve their goals. To investigate this possibility, the proportion of look back fixations to the duration comparison sentences by high-span readers were analysed as a function of whether they followed an achieved goal or an unachieved goal. Neither a main effect of goal achievement nor the duration X goal achievement interaction was significant in this analysis, both \( F_s < 1, \) lending support to the claim that the increased proportion of look back fixations by high-span readers indeed reflected a disruption caused by the duration inconsistencies.

**Goal outcome sentence.** Data from the analysis of go-past time on the goal outcome sentence can be found in Table 10. Readers did not provide any evidence that the duration inconsistency caused any early disruption to the processing of the goal outcome sentence. Neither a main effect of duration nor a duration X goal interaction reached significance, \( F(1,128) = 1.63, MSE = 343 833, p = 0.2, F(1,128) = .027, MSE = 369 332, p = 0.7, \) respectively. High-span readers read the goal outcome sentence faster than low-span readers, \( F(1,128) = 5.19, MSE = 1 228 303, \) but the effect was independent of duration inconsistency. No other effects from the analysis of go-past times on the goal outcome sentence were significant, all \( ps >.20. \)
Data from the analysis of proportion of look back fixations to the goal outcome sentence can be found in Table 11. The analysis of proportion of look back fixations to the goal outcome sentence demonstrated that the pattern of look back fixations was affected by goal outcome. As can be seen from Table 11, readers looked back to 31% of unachieved goal outcome sentences compared to only 24% of achieved goal outcome sentences, $F(1,128) = 3.83$, $MSE = .16$, $p = .05$. This finding is consistent with Therriault and Raney’s (2007) finding that readers took longer to read unachieved goal outcomes relative to achieved goals, and supports the proposal that readers attempt to keep goal information active in working memory to relate currently read information with unfulfilled goals (Lutz & Radvansky, 1997; Suh & Trabasso, 1993). Although this result suggests that readers look back to unachieved goals, potentially in an attempt to integrate them with new information, it is difficult to draw conclusions regarding an effect of duration information on the processing of these goal outcome sentences. The interaction between duration and goal achievement was not significant, $F < 1$, but this is what would be expected if readers either integrated the duration information with the goal outcome sentence, or if readers were simply disrupted upon encountering an unachieved goal. In both the short-inconsistent condition and the consistent control condition, the protagonists have no explicit reason not to achieve their goals. Whether the temporal event is too short to fill the time required to accomplish the base event, or it is just the right amount of time, the protagonists have ample time to achieve their goals. For example, in the passage presented in Table 8, Richard and Angel had sufficient time to make their reservation whether Richard defrosted the car windows while Angel changed the baby or merely unlocked the car doors. Consequently, readers may have engaged in increased look back fixations to the unachieved goal sentence in an attempt to resolve the inconsistency between the duration comparison sentence and the goal outcome sentence. Alternatively, readers may have looked back to unachieved goals in an
attempt to reinstate them in working memory independently of the previous duration comparison sentence. These results, in combination with the finding that readers integrated the more salient long-inconsistent duration information with goal outcome, suggests that readers are able to maintain temporal information and integrate it with future text, but that it is a difficult task and may not be done by all readers on all occasions.

**Summary and Conclusions**

This study used eye tracking to investigate the roles of aging and working memory on duration monitoring and integration into the situation model. Duration information was not explicitly given in the passages; therefore, readers had to access their own knowledge of typical event durations to detect inconsistent duration information. Readers provided evidence of spontaneous duration monitoring: readers reported noticing duration-inconsistent information and spent longer reading duration-inconsistent sentences. Importantly, there were no age differences found in the percentage of duration-inconsistent information reported by readers. Despite cognitive declines in some domains older readers were not impaired in their ability to access their own knowledge of the duration of events to use for online duration monitoring. Additionally, questionnaire results showed that for both older and younger readers, information that was too long for the time frame set by a base event was easier to detect than information that was too short for the base event. Both the long-inconsistent and short-inconsistent conditions violated the time frame set by the base event, but because the events that were too short could be completed within the established time frame, they caused less disruption than the events that were too long and were impossible to complete in the same time frame.

The eye-tracking results demonstrated that working memory and age influenced the detection of inconsistent duration information; however, a different pattern of results was observed for the long-inconsistent condition and the short-inconsistent condition. While readers
appeared to eventually detect the long-inconsistent information regardless of age or working memory capacity, readers with high working memory spans detected the problem when they first encountered the inconsistencies. Readers with fewer resources only displayed delayed detection of the same inconsistent information. For the more difficult-to-detect short-inconsistent information, on the other hand, only high span readers provided any evidence that they detected the inconsistent information at all. The results from both analyses are consistent with the claim that working memory involves the efficient use of pre-existing knowledge structures to access relevant information from long-term memory (Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995). While reading information that was too long for the base time frame high span readers were able to access information about the duration of events quickly to detect the inconsistency immediately; whereas this process may have required more time by low span readers. For the trickier-to-detect short-inconsistent information, low span readers were seemingly unable to access the information required to detect the inconsistency at all.

Of particular importance was the finding that older readers were not impaired at online duration monitoring. In fact, older readers detected the short-inconsistent information earlier than did younger readers. Older high span readers were the only group of participants who provided evidence of early detection of these more difficult-to-detect short duration inconsistencies. Younger high span readers, on the other hand, only provided evidence of later detection. Both age groups displayed similar detection patterns for the long duration inconsistencies. Duration-related inconsistency detection required readers to access their knowledge base in the current investigation, and older readers place more importance on their own knowledge during reading comprehension (Miller & Stine-Morrow, 1998; Miller, et al., 2004). The knowledge-driven reading observed in older adults, therefore, may have served to highlight the incompatibility between the duration of the events described in the passages and
their knowledge of event durations. Despite the advantage in detection, however, older readers continued to show comprehension difficulties related to the inconsistent information in a later processing measure. This is consistent with the findings from Experiments 1 and 2 as well as the literature that older readers allocate more processing resources and make more regressive fixations than younger readers to resolving information that is unclear or anomalous (Kemper, et al., 2004; Kemper & Liu, 2007).

The results also provided evidence that, at least on occasion, readers integrated duration information with the protagonists’ goals. After reading duration information that overshot the time frame set by a base event, readers were more likely to look back to the duration information if the protagonists were still able to reach their goals. The comprehension difficulty posed by the mismatch between the expected outcome based on duration information and the actual goal outcome indicates that readers do spontaneously use duration information in later processing, although it was not used immediately. However, a similar interaction between event duration and goal outcome was not observed following the short-inconsistent information, so the extent to which readers engage in such behaviour remains to be seen.
Chapter 5
Concluding Comments

Although traditional models of reading comprehension describe a system in which the reader exhaustively processes each word as it is successively encountered in a text (e.g. Just & Carpenter, 1980; Kintsch & van Dijk, 1978), current research supports a view of reading comprehension that more closely resembles readers’ anecdotal experiences of everyday reading. That is, rather than processing each word as thoroughly as possible upon first encountering it, readers appear to frequently engage in shallow processing such that their representations of a text is merely “good enough” for their comprehension goals (e.g. Ferreira et al., 2002; Ferreira & Patson, 2007). Despite a significant amount of research devoted to age-related effects on text processing, there has been little research concerning this so-called shallow processing by older readers. This series of experiments monitored readers’ eye movements to examine possible age-related effects on shallow processing across different levels of text representation. If readers fully process each word as it is encountered, they would be expected to detect information that is inconsistent with the rest of the text. Conversely, if readers are prone to shallow processing of text, they may be less likely to spontaneously detect anomalous information within a text. A benefit of eye-tracking technology is that if readers do provide evidence of spontaneous inconsistency detection, the time course of this detection can be investigated. As such, this series of experiments explored whether there was evidence that readers detected the inconsistent information when they first encountered it, or whether readers instead displayed delayed detection.

The results demonstrated three key findings. First, older readers were not more likely to engage in shallow processing of text than were younger readers, and in some cases, older readers detected inconsistencies earlier than did younger readers. However, older readers
required increased processing time relative to younger readers to detect and recover from the inconsistencies. Second, when the inconsistent information altered the meaning of the text, older readers were able to efficiently use their existing knowledge base to improve inconsistency detection, resulting in earlier detection relative to younger readers. Finally, when existing context and world knowledge could not be used directly to support inconsistency detection, older readers needed a double benefit of domain knowledge and reading comprehension skill to match the likelihood of inconsistency detection by younger readers.

All three experiments revealed that while older readers were susceptible to shallow processing of text, they were not necessarily more likely to engage in shallow processing than were younger readers. Any age-related effects in this series of experiments occurred in the time course of inconsistency detection and recovery, rather than in the likelihood to detect the inconsistent information. Eye movement data revealed that when the inconsistent information affected the overall meaning of a text, older readers detected it earlier than did younger readers (Experiments 1 and 3). However, if the meaning of the text was not affected by the presence of an inconsistency, older readers displayed delayed detection of the inconsistent information relative to younger readers (Experiment 2). Notwithstanding the relative stability of shallow processing with age, older readers were found to devote additional processing time to the anomalous information across all three experiments relative to their younger counterparts. This additional time likely reflected extra time required to detect and resolve the inconsistencies compared to younger readers. These results are consistent with the findings in the literature that older readers require increased resource allocation to achieve similar levels of reading performance as younger readers (Kemper et al., 2004; Kemper & Liu, 2007; Stine-Morrow et al., 2001, 2004, 2008). Stine-Morrow and colleagues (Stine-Morrow et al., 2006) propose a model in which readers selectively allocate their processing resources to three levels of text
representation (word, textbase, and discourse) to achieve a certain standard of coherence. Processes that lead to adequate text understanding are more resource-consuming in older readers relative to younger readers; as such, older readers are required to devote increasingly more of their limited resources to text processing to maintain adequate text comprehension, as reflected by increased processing time. However, rather than reflecting a general slowing effect, Stine-Morrow et al. (2006; Miller et al., 2004) suggest that the increased processing time observed by older readers acts as a compensatory mechanism for cognitive slowing. As such, Stine-Morrow et al. (2008) reported that a composite processing speed measure was not predictive of resource allocation among older readers, but that increased resource allocation lead to improved text recall such that older readers’ performance was at least as good as that of younger readers. The current results are consistent with such a model in which older readers require increased processing resources to achieve similar performance as younger readers, but that the increased time does not reflect a general cognitive slowing effect. While older readers devoted increased processing time to detecting and resolving inconsistencies in the current series of experiments, there was no evidence that older adults devoted more time to processing text overall. Given that there was no evidence that older readers were more susceptible to shallow processing than their younger counterparts, the increased processing time devoted to processing inconsistent information by older readers appeared to be an effective strategy. Rather than being a requirement of comprehension, increased processing resources directed toward inconsistencies by older readers may have reflected a greater need or greater motivation to attempt to repair or understand the source of the inconsistency.

It is well established that crystallized intelligence and schematic knowledge remain relatively stable or grow with increasing age (Baltes, 1997; Baltes et al., 1999; Salthouse, 1988). The older adults in this series of experiments appeared to benefit from such knowledge to
support inconsistency detection, particularly when the inconsistent information altered the
meaning of the text. Experiment 1 investigated shallow processing of the textbase by inserting
semantic anomalies in passages read by participants, thereby altering the meaning of a target phrase. For example, after reading a passage in which a student, Amanda, drank numerous cups of coffee to stay awake to study all night, participants read “Amanda was bouncing all over because she’d had too many tranquilizing sedatives.” The phrase tranquilizing sedatives is inconsistent with earlier information that Amanda had drunk a lot of coffee, but also interferes with the meaning of the passage; it does not make sense that Amanda would be excited because she had too many sedatives. The results from Experiment 1 demonstrated that older readers were as likely to detect this type of semantic inconsistency as were younger readers, and were able to detect certain easier-to-detect anomalies earlier than were younger readers. Older adults are frequently found to be more linguistically sophisticated than younger adults (Baltes, 1997; Salthouse, 1988) and are able to use their reading experience and past knowledge to guide word recognition (Pichora-Fuller et al., 1995; Spieler & Balota, 2000) and text comprehension (Miller & Stine-Morrow, 1998; Miller et al., 2004); accordingly, it is likely that the older readers in Experiment 1 were able to take advantage of their superior linguistic skills and a lifetime of verbal experience to perform efficiently and effectively on the inconsistency detection task. Similarly, Experiment 3, which investigated shallow processing of the situation model, required readers to access their knowledge base to detect inconsistent temporal information about the duration of events described in the passages. For example, participants read a passage describing a man who planned to pick up a gift for his wife before work. Later, participants read the following information “He woke up early the next morning and got in the shower. He listened to an entire talk show and then got out of the shower.” An entire talk show lasts much longer than a typical shower, especially if the character’s goal was to leave early to get a gift for his wife.
Therefore, the text presents a temporal inconsistency but also interferes with understanding the meaning of the passage. As was observed in Experiment 1, older readers were as likely to detect the inconsistent information as were younger readers and were able to detect certain easier-to-detect inconsistencies earlier than were younger readers. Because both Experiment 1 and Experiment 3 contained inconsistent information that resulted in the overall meaning of the passage to be disrupted, it appears that older readers are particularly attuned to disruptions in the meaning of a text and may take advantage of an expanded knowledge base to quickly and efficiently access and apply the information required to detect inconsistent information.

Only Experiment 2, which investigated shallow processing at the surface level of text representation, provided evidence of delayed inconsistency detection by older readers relative to younger readers. Sentences containing number agreement violations such as “Similarly, people used to think a sneeze could transmits the flu virus to others through the air” were interspersed in texts about diseases, but these inconsistencies did not interfere with the meaning of the text. Interestingly, neither age group appeared to be particularly susceptible to shallow processing at the surface level of text, as a significant number of readers provided online evidence of syntactic anomaly detection. Thus, when readers could not rely on context or background knowledge to support an interpretation of the anomaly, readers were not likely to engage in partial processing. Although older readers were not more susceptible to shallow syntactic processing than were younger readers, they demonstrated delayed detection relative to younger readers. Because the anomalous information occurred at the surface level, neither increased vocabulary nor an expanded knowledge base could be exploited to support the correct interpretation of the inconsistency. Nevertheless, a subset of older skilled readers was able to detect some of the syntactic inconsistencies as early as were younger readers. This early detection occurred when older skilled readers were sufficiently familiar with the content of the text. Although older
readers may not have been able to use their knowledge base to directly support the correct interpretation of the syntactic inconsistencies, familiarity with text content could have reduced the resources required for text comprehension, thereby, freeing resources for syntactic inconsistency detection. Given that less-skilled older readers did not show a similar benefit of domain knowledge, older readers appeared to require a double benefit of reading comprehension skill and domain knowledge to make sufficient resources available to detect syntactic anomalies as early as younger readers.

The results from the three experiments are consistent with the view that older readers selectively allocate their limited resources to achieving discourse-level coherence and that an expanded knowledge base among older readers reduces the demands of lexical processing to provide an alternate route for constructing adequate language representations (Stine-Morrow, et al., 2006; 2008). The knowledge-compensation strategy used by older readers in the current investigation to improve inconsistency detection mirrors findings from cognitive aging literature that suggests older adults may use their expanded knowledge base to compensate for reductions in cognitive resources in order to maintain their everyday decision making and problem solving abilities (e.g. Peters, Hess, Västfjäll, & Auman, 2007; Thornton & Dumke, 2005). Indeed, older adults have been found to perform similarly on decision making tasks involving driving (Walker, Fain, Fisk, & McGuire, 1997), finance (Chen & Sun, 2003; Kim & Hasher, 2005; Tentori, Osherson, Hasher, & May, 2001), and social judgments (Blanchard-Fields, Mienaltowski, & Seay, 2007; Crawford & Channon, 2002), and to match or outperform younger adults on a range of everyday problem solving tasks (Cornelius & Caspi, 1987; Denney & Pearce, 1989; Marsiske & Willis, 1995). A commonly held view of decision making maintains that the decision maker creates a mental model that represents their understanding of the global situation at hand and possible outcomes by incorporating given information and the individual’s

Thus, the processing involved in everyday decision making can be viewed as the same
processing that is involved in discourse comprehension. That is, whether reading for pleasure or
making a decision, individuals create a representation of their understanding of the situation at
hand, rather than an exhaustive representation of all possible information. From this perspective,
emphasizing mental models that incorporate past knowledge could be viewed as a general aging
strategy that allows for a reduced reliance on the cognitive resources that decline with age.

If similar representations are used during reading comprehension and everyday decision
making, and older adults place particular focus on such models, it is not surprising to observe
similar resistance to age-related reductions in performance in both domains. In the current
investigation, older readers were found to be particularly good at quickly detecting inconsistent
information that interfered with their understanding of discourse. Similarly, older adults may be
able to quickly and efficiently detect information that is inconsistent with their existing
knowledge to perform decision making and problem solving tasks at least as well as younger
adults. There are countless examples of the importance of inconsistency detection for everyday
problem solving and decision making. For example, Johnson-Laird, Girotto, and Legrenzi
(2004) illustrate that the Chernobyl disaster was exacerbated because engineers failed to
recognize the inconsistency between warning signs indicating that the reactor had been
destroyed and information that the reactor was indeed safe. More recently, experts and
laypeople alike wondered how an industry could fail to detect the inconsistency that contributed
to the 2007 global financial crisis between financial models that predicted continued growth and
a financial market that did not match this prediction (Bernanke, 2009). On an individual level,
failure to detect contraindications between medications could have a potentially disastrous
effect. Despite the importance of inconsistency detection for many everyday situations, as
Johnson-Laird, et al., (2004) indicate, inconsistency detection has received relatively little research attention. These authors suggest that individuals are able to detect inconsistencies by comparing information between mental models: when individuals are unable to incorporate information into their existing mental models they detect an inconsistency, however, if the mental model is inaccurate they will fail to detect an inconsistency. Although there has been some evidence to support this view among younger adults (Johnson-Laird, Legrenzi, Girotto, & Legrenzi, 2000; Legrenzi, Girotto, & Johnson-Laird, 2003), as far as I am aware, the ability to detect inconsistencies between mental models has not been directly investigated in older adults. Based on the findings from the current series of experiments, it is reasonable to predict that older adults will be at least as good as younger adults at detecting inconsistent everyday information, provided they are sufficiently familiar with the situations.

The view of knowledge-based compensation by older adults is akin to an expertise account of everyday problem solving in which expert performance is a result of the efficient use of knowledge that has accumulated over time. Provided older adults have had sufficient experience with a particular situation, they should be capable of drawing on that wealth of experience to apply the appropriate knowledge to solving a problem, despite limited cognitive resources. Indeed, older experts have been shown to have as much domain knowledge as younger experts (Ericsson & Charness, 1994) and demonstrate stable performance on domain-specific tasks such as playing chess (Charness, 1981) and pilot communication and decision making (Morrow, Menard, Stine-Morrow, Teller, & Bryant, 2001; Morrow et al., 2009). Expert performance research presumes that skilled performance by experts is a result of years of deliberate practice through training and experience, and that older experts are able to maintain performance with increasing age as a result of such deliberate practice (Krampe & Charness, 2006). Deliberate practice, in turn, is believed to lead to a structured knowledge-base that
supports decision making and problem solving despite cognitive constraints (e.g. Charness, 1991; Ericsson & Charness, 1994). Consequently, domain familiarity and expert-level skill necessarily co-occur in expert performance research. In the current investigation, Experiment 2 examined the effects of domain familiarity and reading comprehension skill independently. Consistent with existing research, domain familiarity and comprehension skill helped to bolster inconsistency detection by older readers; however, neither knowledge nor skill alone was sufficient to support inconsistency detection by older readers. Older readers required the double-benefit of both domain knowledge and skill in order to perform similarly to younger readers. On the other hand, younger readers’ ability to detect inconsistencies was enhanced by either domain knowledge or reading comprehension skill alone. This finding has implications for skill-training among older adults. Older adults may not perform as well as younger adults within a domain as it changes, despite being skilled in that domain, because they lack familiarity with the new knowledge and skills that are required. Research has demonstrated that true expert performance can be maintained throughout adulthood via continued training (see Krampe & Charness, 2006 for a review); however, the type of skilled performance measured in the current investigation likely did not meet the criterion for “expert” performance. That is, reading comprehension skill has likely become automatic in older adults such that they no longer engage in deliberate practice. The type of skilled activity older adults engage in on a daily basis is also most likely a skill that has become automatic, rather than true expert skill. As such, older adults may not spontaneously engage in the training required to maintain high performance levels. However, breadth of knowledge has been found to be a predictor of learning (Beier & Ackerman, 2005; Charness, Kelley, Bosman, & Mottram, 2001; Hambrick & Engle, 2002) and older adults are able to benefit from explicit task training (Ball et al., 2002; Jobe et al., 2001; Schaie & Willis,
Accordingly, task-specific training would be particularly important in older to increase their familiarity within a changing domain in order to maintain performance.
References


Appendix A

Complete set of passages from Experiment 1 with semantic anomalies

Anomalous noun phrases in each passage are highlighted in bold text. The nonanomalous control phrase is presented first, followed by the internally coherent anomalous phrase, and then the internally incoherent anomalous phrase.

1. There was a tourist flight traveling from Vienna to Barcelona. On the last leg of the journey, it developed engine trouble. Over the Pyrenees, the pilot started to lose control. The plane eventually crashed right on the border. Wreckage was equally strewn in France and Spain. The authorities were trying to decide where to bury the unfortunate dead / surviving injured / surviving dead from the plane crash.

2. Once again Amanda was studying all night for exam. She entered the school and picked up her third extra large coffee. After drinking her black coffee and entered the library. But when she sat down she found she could not focus. She was so hyperactive that she couldn’t even sit still. Amanda was bouncing all over because she’d had too many potent stimulants / tranquilizing sedatives / tranquilizing stimulants in one day.

3. Liang, a recent arrivee from China, was having problems adapting to Canada. She could not speak English or French. She enjoyed spicy foods and found Canadian food very bland. She asked for help but people either ignored her or regarded her as stupid. Frustrated by her entire more to Canada, she sat down and cried. Liang still felt very much like an obvious foreigner / native resident / native foreigner in her new home.
Appendix B

Complete familiar and unfamiliar texts from Experiment 2 with all inconsistencies

Syntactic inconsistencies are highlighted in italics within their target sentences, which are written in bold text. The error free control sentence is presented first, followed by the sentence containing the addition of the letter ‘s’, and lastly the sentence containing the deletion of the letter ‘s’.

Familiar Passage

The Flu/Diarrhea is a Scourge of Mankind

In addition to some life-threatening infectious diseases like AIDS, there are other less dramatic, yet still contagious, diseases. Everybody is familiar with the flu, chicken pox, and diarrhea. This text introduces different infectious diseases and their symptoms, treatment, and prevention.

Winter and spring are peak periods for viral diseases. A virus called Varicellazoster, which is very contagious, causes chicken pox. In Canada, nearly all children get chicken pox before adulthood. Usually the disease is caught during the early school years of a child. Chicken pox is most common during winter and springtime, just like the ordinary flu. The flu is a viral infection that tends to affect the very young and very old most severely / The flu is a viral infections that tends to affect the very young and very old most severely / The flu is a viral infection that tend to affect the very young and very old most severely. Flu should not be confused with influenza, which is an epidemic illness of the respiratory organs and also causes a high fever.

Travellers should be wary of certain diseases. AIDS is the most severe form of the disease caused by the Human Immunodeficiency Virus, referred to as HIV. HIV sets itself up in the human cells’ DNA. The virus destroys the body’s ability to resist infections, and as time
goes on, the disease inevitably causes death. People travelling abroad should remember that most people infected with the virus have contracted it by unprotected sexual intercourse while on vacation. A lot less dangerous and more common ‘travellers’ disease than AIDS is diarrhea; every third Canadian tourist gets tourist diarrhea. A common cause of diarrhea is when a person ingests bacteria found in food, for example, the salmonella bacterium. A common cause of diarrhea is when a person ingests bacteria found in food, for example, the salmonella bacterium. In most cases diarrhea is related to food.

Symptoms
Correctly recognizing the symptoms is very important for securing the right treatment for these diseases. The chicken pox rash is a visible symptom of chicken pox. A mild increase of temperature may precede the rash. The rash starts as small pimples, which quickly develop into blisters. The rash phase lasts for about 1-6 days and is followed by drying of the blisters and scarring, which lasts for about two weeks. Chicken pox is contagious even 4-5 days after the appearance of the rash. The chicken pox rash is not painful – but is usually very itchy. A high fever and vomiting are rarely related to chicken pox but are sometimes observed in teenagers and adults. However, a person suffering from diarrhea can sometimes experience vomiting. Runny feces is the most common symptom of diarrhea and often disturbs the patient to a great extent.
diarrhea and often disturb the patient to a great extent. Unlike other common diseases, a high fever is not a common symptom of diarrhea. However, it is not uncommon for diarrhea sufferers to experience stomach pains. However, it is not uncommon for diarrhea sufferers to experience stomach pains. Unlike other common diseases, a high fever is not a common symptom of diarrhea. However, it is not uncommon for diarrhea sufferers to experience stomach pains. In healthy adults diarrhea is not dangerous but for small children and weak elderly people, diarrhea and vomiting can be fatal. During diarrhea, the body loses a lot of liquids and there is a danger of dehydration. During diarrhea, the body loses a lot of liquids and there is a danger of dehydration. As a consequence, mucous membranes get dry, the patient is tired and pale, eyes slump into their orbits, the amount of urine decreases and the patient either refuses to drink or vomits immediately after drinking.

HIV may be dormant in the body without showing any symptoms. About two weeks after infection some patients get symptoms that resemble ordinary flu. Ordinary flu is often accompanied by sinus irritation. Other very common symptoms include a cough and a sore throat. Other very common symptoms includes a cough and a sore throat. Other very common symptom include a cough and a sore throat. In addition, mild temperature increases are a common symptom of the flu. In addition, mild temperature increases are a common symptom of the flu. In addition, mild temperature increase are a common symptom of the flu. The first symptoms caused by HIV, on the other hand, include swelling of the lymphatic nodes, headache, difficulties in concentration and sometimes a rash. It is not known what percentage of HIV positive patients get these initial symptoms. Some do not get them at all. After the initial phase there is a symptomless phase. Little by little, more symptoms appear, such as swelling of lymphatic nodes, fever, a significant loss of body weight, excessive
sweating at night, fatigue, depression, and memory dysfunctions. The fatal terminal phase of the disease is called AIDS.

In milder diseases home treatment is enough

The most common infectious diseases can be treated at home. The itching caused by chicken pox can be relieved by applying menthol oil to the skin. With diarrhea, it is very important to drink a lot in order to compensate for the lost minerals and liquids / With diarrhea, it is very important to drinks a lot in order to compensate for the lost minerals and liquids / With diarrhea, it is very important to drink a lot in order to compensate for the lost mineral and liquids. The best home treatment is to drink a lot of liquids, for example soup or fruit juices. After the diarrhea begins to improve, it is advisable to slowly transfer from liquids to solid food / After the diarrhea begins to improve, it is advisable to slowly transfers from liquids to solid food / After the diarrhea begin to improve, it is advisable to slowly transfer from liquids to solid food. This process does not typically last very long.

Fortunately, diarrhea cures on its own and the symptoms typically only last a few days / Fortunately, diarrhea cures on its own and the symptoms typically only lasts a few days / Fortunately, diarrhea cure on its own and the symptoms typically only last a few days. A similar course is usually observed in people suffering from the flu. One of the best home treatments for the flu, on the other hand, is rest / One of the best home treatments for the flu, on the other hands, is rest / One of the best home treatment for the flu, on the other hand, is rest. One should avoid strenuous exercise during the flu because it may cause complications. It is also good to drink hot beverages, for example hot juice / It is also good to drinks hot beverages, for example hot juice / It is also good to drink hot beverage, for example hot juice. In addition to rest and hot drinks, inhaling steam may also help the condition of a flu patient.
Medication

Usually mild viral infections do not require medication. There is, however, medication against the virus that causes chicken pox. This medication is used in the treatment of severe viral infections. The medication is recommended for the treatment of chicken pox of patients older than 12 years. The medication should be started within one day after the rash breaks out. Usually chicken pox does not require medication, just like the flu. **The flu goes away on its own in about one week and antibiotics are not needed.** Most of the medications are sold without prescriptions. For example, people can buy the medicine that relieves the symptoms of the flu at a pharmacy without a prescription. The flu medications do not, however, shorten the length of the sickness or prevent it; rather, they only relieve the symptoms of flu. Also, diarrhea medication, which slows the bowel movement, is available at pharmacies without a prescription. Medication that depresses the functions of the bowel does not remove the bacteria from the system, but only reduces the embarrassing symptoms. Instead, medicinal charcoal or charcoal pills, absorb liquids from the bowel and the bacteria exit the system with excrement. It should be remembered that medical charcoal also efficiently absorbs useful elements from the digestive system.

AIDS cannot be cured because there is no known treatment for it at the moment. There is medication that slows down the progress of the disease. In some parts of the world, the medications prescribed for HIV infection are free of charge if the prescriptions are given in health care centres, in other communal health care institutes, or in a national institution.
When to consult a doctor

If you suspect you might have an HIV infection contact a doctor immediately for a blood test. One cannot know if somebody has HIV by simply looking. The blood test is free of charge. Most people who are HIV positive have antibodies in their system that can be traced with a blood test. Even if the result of the HIV test is negative, it should be done again in about 6 months after the potential infection, so that the possibility of an infection can be ruled out with certainty.

In the milder diseases, it is not necessary to see a doctor except in special cases. A diarrhea patient should consult a doctor if there are other symptoms, such as blood in the excrement or a clear worsening of the patient’s general condition. A doctor should be contacted also if the diarrhea was contracted on a trip abroad. It is possible that salmonella bacteria caused the disease, and this requires a follow-up. A flu patient should contact a doctor if the symptoms are very severe and especially if a high fever continues for several days. An infection caused by a virus can be followed by bacterial infections, in which case the sickness usually gets longer and more difficult.

How to avoid an infection

Most of the viral diseases are transmitted very easily. Chicken pox can be transmitted 2-3 days before the rash breaks out. It can be transmitted both via the blisters and via air. The incubation period is 10-20 days. The child should not go to school or day care until the blisters have dried. However, he or she should stay home for at least 10 days after the rash appears so that the disease is not transmitted to others. It is very difficult to avoid chicken pox because the virus is very contagious and is airborne. Similarly, people used to think a sneeze could transmit the flu virus to others through the air / Similarly, people used to think a sneeze could transmit the flu virus to others through the air / Similarly, people used to think a
sneeze could transmit the flu virus to other through the air. Although this is still a common belief, we now know the flu is not transmitted through the air. It has been shown that the primary transmission pathway is touch, which brings the viral secretions to the mucous membranes and the body. It has been shown that the primary transmissions pathway is touch, which brings the viral secretions to the mucous membranes and the body. It has been shown that the primary transmission pathway is touch, which bring the viral secretions to the mucous membranes and the body. The viruses end up directly on our mucous membranes when we first shake hands with somebody who has the virus and we then lick our fingers, for example when turning the page of a book. The best way to avoid flu is to regularly wash one’s hands and to avoid shaking hands with flu patients. The best way to avoid diarrhea is not to eat foods that often cause stomach problems, such as fresh salads and mayonnaise. The best way to avoid diarrhea is not to eat foods that often cause stomach problems, such as fresh salads and mayonnaise. The best way to avoid diarrhea is not to eat foods that often cause stomach problem, such as fresh salads and mayonnaise.

Hygiene is also important in the prevention of diarrhea.

HIV is not as easily transmitted as the virus causing chicken pox. One can get HIV from a diseased person in sexual intercourse if the mucous membranes interact. The most sensitive membranes are the sexual organs, the mouth, and the anus. The most secure way to prevent HIV is to always use a condom in short-term relationships. HIV can be transmitted when even small amounts of viral secretion, such as blood, are transmitted to the body. The virus can thus be transmitted via used needles.
Unfamiliar Passage

Typhus/Trigeminal Neuralgia: A Rare and Difficult Disease

Knowledge about the origins and causes of different diseases increases as medical research advances. There still are, however, several rare diseases whose causes remain largely unknown. There are so few patients suffering from these diseases that systematic research may be almost impossible to conduct. This text will introduce you to four very rare diseases: typhus, trigeminal neuralgia, cystic fibrosis, and scleroderma. The text will deal with the typical symptoms, possible origins and causes, treatment, and prevention of the diseases.

Distinguishing Symptoms

The symptoms of rare disease are sometimes difficult to recognize because even doctors might not have very much knowledge about them. Typhus is a very easily transmitted infectious disease. The typical symptoms include a very high fever of over 40 degrees Celsius. In addition, muscle and joint stiffness, as well as brain dysfunctions can be related to the disease. On the fifth day after infection, a dark red rash appears on the body. Pimples can be seen in the rash. During the second week of the infection, the patient starts to experience delusions. During the second weeks of the infection, the patient starts to experience delusions. During the second week of the infection, the patient start to experience delusions. After this, the patient either recovers or, as more often happens, dies. The death rate is high: half of the people who have been infected eventually die if proper treatment is not available.

Cystic fibrosis is a hereditary metabolic disease. Because of this metabolic dysfunction, the patient’s mucous is exceptionally viscous. The exceptionally viscous mucous causes a hard, continuous cough and recurring lung infections that are caused by various bacteria.
Trigeminal neuralgia refers to experiences of pain in the largest sensory nerve of the face, the trigeminal nerve. The pain is sudden and comes in the form of a cutting pain or is accompanied by seizures resembling small electric shocks. A typical seizure lasts only for a few seconds but there can be several seizures during one minute and the pain can last for hours. The stimulation of so-called trigger points triggers the onset of seizures. Patients typically cannot predict when stimulation of these trigger points will result in pain. Typical trigger points are lips, the side of the chin, and eyes.

Scleroderma is a rheumatic disease that causes atypical thickening of the skin. The name of the disease comes from the most typical symptom of the disease: the word “scleroderma” means hard skin. The first symptoms are white fingers in cold weather. After this, the color of the skin turns blue or even dark purple. The first change in the skin is a thickening of the tips of the fingers and toes. The face becomes smoother, radial furrows appear around the mouth, and the mouth gets smaller. Some patients also suffer from excessive growth of connective tissue in the digestive tract, which causes indigestion. Finally, scleroderma may lead to hardened skin and even hardened viscera. Due to these typical symptoms, the disease is also known as the “disease that turns people into rock”.
Origins and causes

For some of the diseases described in this text, the origin and causes are rather well known. However, for other diseases, the origins are uncertain. For example, doctors and researchers don’t know what causes trigeminal neuralgia. However, researchers have isolated some possible causes. The most likely cause is that some of the cephalic veins press the root of the nerve. An injury of the myelin sheath protecting the nerve, as in multiple sclerosis, may also cause pain. It is like a short-circuit in which the experience of pressure is misdirected to the pain nerve and experienced as pain rather than pressure. In addition, various accidents or inflammations related to dental surgery may cause injury to the nerve, which results in the experience of pain. However, it is not always possible to discover the primary cause of trigeminal neuralgia. In these cases, ‘psychological reasons’ are often mentioned as one possible cause. The origins of scleroderma are also still a mystery. Changes in complexion are caused by the dysfunction of the immune system, which starts to produce excessive scar tissue. However, what actually causes this dysfunction is still unknown. Possible explanations include bacterial infections, chemical irritation, and genetic mutations. For example, silicone breast implants have been shown to be related to scleroderma.
For the other diseases, the causes are well known. Cystic fibrosis is caused by a mutation in the gene that regulates the salt metabolism of the cell membrane. The dysfunction of the salt metabolism changes the composition of mucous so that it is more viscous than normal. A person gets the disease if a defective gene is inherited from both parents. In genetic investigations, it has been found that mutations in chromosome 7 cause the disease. 

On the other hand, a rare bacterium that is not related to any other disease germs results in typhus. Although typhus is caused by bacteria, it is not easily caught today because it is not airborne. A typhus bacterium transfers to humans via a bedbug or louse bite. In cases, the symptoms of typhus appear immediately after infection. In some variations of the disease, the bacterium may nest in the lymphatic nodes of the patient after the initial infection. In these cases, the patient feels well at first but the fatal symptoms appear later.

**Treatment**

Most of the diseases are treatable or at least their symptoms can be somewhat relieved. Typhus is nearly extinct because there is an efficient treatment for it. Strong antibiotics can be used to treat the disease. Tetracyclic antibiotics are very effective. The best way to treat scleroderma is to protect the sensitive skin from injuries and cold. Blood
circulation can be enhanced with medication that expands the vessels. Stopping smoking also enhances circulation. However, there is no actual cure for scleroderma. The metabolic dysfunction in cystic fibrosis can be balanced with pancreatic enzymes. In addition, regular, moderate exercise helps to remove viscous mucous from the lungs. Treatment of trigeminal neuralgia is a lot more difficult. Over-the-counter pain reducing drugs hardly help at all. Instead, doctors prescribed much stronger medication in the hopes of managing the pain. Combinations of drugs used to manage depression and epilepsy are the most frequently used treatment. However, even with treatment using multiple drugs the pain rarely goes away completely. In addition, it is possible to treat the pain with surgery of the many tactile nerves in the face. Either the nerve can be cut or it can be injected with glycerol or alcohol. The problem is that one side of the face goes numb, which might be uncomfortable.

Prevention

It is evident that not all diseases can be prevented. Cystic fibrosis is a familial disease and there is no preventive treatment for it. Developing gene technology, however, might open new prospects. Trigeminal neuralgia cannot be prevented because the exact mechanism of how it develops is not known. For the same reasons, scleroderma is difficult to prevent. Because chemical irritation has been shown to be related to the disease, a healthy way of life may reduce the risk of falling ill. For example, avoiding food additives could be important. In contrast,
typhus can be efficiently prevented. **The most important thing to do is to ensure good hygiene so that lice and bedbugs cannot reproduce and transmit the disease to humans.**

For the most part, the spread of typhus via bedbugs has been controlled. **Different kinds of pesticides can be used to stop the reproduction of parasites.** In earlier days, DDT was used to prevent parasites. Nowadays other toxins that are as efficient but less harmful to the environment are used. **Doctors also give vaccinations to children free of charge, which prevents the spread of typhus.**

Doctors also give vaccinations to children free of charge, which prevents the spread of typhus. The disease easily turns into an epidemic in situations where it is difficult or impossible to keep up the standards of hygiene and where there are many people together in confined places. Examples of such situations are war, long sailing trips, and bad prison conditions.

**Support groups**

Because scientific knowledge about some of the rare diseases is so scarce, patients might feel alone with their disease. For example, medical doctors can often abandon trigeminal neuralgia patients. Because it is so difficult to find out the exact cause of the pain, the symptoms may be seen as psychological. In the worst case, the patient is left without any medical attention. Trigeminal neuralgia patients have, however, struggled to form support groups. The goal of the support groups is to let people meet other patients and to relieve the feelings of loneliness.
Another important goal is to spread knowledge among doctors and patients. Cystic fibrosis patients also have their own support organisation, which functions under the National Association of Pulmonary Diseases. The organisation organizes rehabilitation and adjustment training together with governmental health care agencies. The Association of the Rheumatic Diseases, which delivers information and publishes a journal, serves scleroderma patients.
Appendix C

Complete set of passages from Experiment 3 with temporal and goal outcome inconsistent information

Duration comparison sentences are highlighted in bold text. The consistent control comparison sentence is presented first, followed by the long-inconsistent comparison sentence, and lastly the short-inconsistent comparison sentence. Goal outcome sentences are highlighted in italicized bold text. The achieved goal sentence is presented first followed by the unachieved goal sentence.

1. Tyler was usually the first person to arrive at the office on Mondays. He would often make a pot of coffee for himself. Tyler always needed a cup of coffee in the morning to get started. He put coffee and water in the coffee maker and turned it on. He then put a frozen pastry in the toaster oven to warm it up. He washed out his coffee cup in the office sink / He went to run a virus scan on his computer / He grabbed a napkin from the nearby cabinet. Tyler was especially sleepy. He took the pastry out of the oven and ate it / He took the pastry out of the oven but it was burnt. He wished there was another pastry. There wasn’t, so he took his coffee back to his desk.

2. David and Sue were next-door neighbours who both enjoyed movies. Today they had seen each other working in their front yards. David remembered that tonight was the premier of the Spider-Man Movie. David called Sue and asked her if she would go with him. Sue agreed. David told her that he would take a quick shower and then come right over to pick her up. Sue washed some dirty dishes and then she heard David ring her doorbell / Sue made an elaborate dinner and then she heard David ring her doorbell / Sue went to lock the back door and then she heard David ring her doorbell. Sue was in a good mood. When they arrived at the theatre they purchased
the last tickets / When they arrived at the theatre the movie had already started. They
decided to get a quick cup of coffee at the theatre. Sue told David that the movie had
been favourably reviewed.

3. Joan woke up with a sore throat. She definitely wasn’t feeling well enough to work. Joan
called her boss and then decided to go to a walk-in clinic. She went to the doctor’s office
and checked in with the office assistant who said there was one doctor available. Joan
noticed that there were a few other people waiting in the office. She sat down in one of
the chairs to wait. Joan read two magazines and then her name was called / Joan
read six magazines and then her name was called / Joan opened a magazine and
then her name was called. She thought that her throat was getting worse. The office
assistant told Joan that the doctor would be right with her / The office assistant told
Joan that the doctor could not see her today. She gathered up her belongings. She
really hoped that she would feel better soon.

4. Sally was an avid nature watcher. She enjoyed keeping a list of all the species of birds
that lived near her. Sally decided to go for a walk this afternoon and watch the birds. She
put her portable CD player and binoculars in her backpack. As she was leaving, a florist
called. He wanted to be sure she would be home because he was going to deliver a
bouquet to her at the end of his route. Sally grabbed her backpack and went outside. She
listened to one of her favourite CDs and then came in from her walk / She listened
to six of her favourite CDs and then came in from her walk / She listened to one of
her favourite songs and then came in from her walk. Sally had enjoyed her walk.
Sally signed for her flowers when they arrived / Sally had missed her flower delivery
for today. She decided to go for another walk tomorrow. She hoped that she would see other birds on her list.

5. Noel and Ginger lived in Illinois. They were about to take a four-month road trip across the U.S. This week was the first leg of their journey. Their goal was to get to Utah before the end of the week. Near the end of the week, they hit a pothole and the right front tire went flat. While Noel changed the tire, Ginger looked on the map for a place to stay for the night / While Noel changed the tire, Ginger looked on the map and planned the stops for their whole trip / While Noel changed the tire, Ginger reached and grabbed the map out of her purse. Noel got back into the car and they drove off. Ginger was happy that they would make it to Utah on schedule / Ginger was unhappy that they would not make it to Utah on schedule. They stayed in a small hotel that evening. They would get an early start driving tomorrow.

6. Tomorrow is Randy and Lynne’s 10-year anniversary. Lynne already gave Randy a fancy shower radio for his gift. Randy was planning to surprise Lynne with a custom-designed cocktail ring. Unfortunately, the jeweller didn’t finish the ring when promised, but he told Randy it would be still be ready in time for their anniversary. Randy decided to stop by the jeweller before work tomorrow to pick it up. He woke up early the next morning and got in the shower. He listened to several popular songs and then got out of the shower / He listened to an entire talk show and then got out of the shower / He listened to a restaurant commercial and then got out of the shower. Rand dried off and got dressed. Randy stopped to pick up the ring from the jeweller on the way to work / Randy did not have time to pick up the ring on the way to work. Randy arrived to a dozen messages at work. He had a very busy day ahead of him.
7. Melody’s son Fred had just finished his first day of high school. She had promised to make him a pie when he came home. Melody was trying out a new recipe. She was curious if the pie would be good. When Fred arrived home she put the pie in the oven.

While Melody waited for the pie to cook she decided to mop the floor / While Melody waited for the pie to cook she decided to organize the pantry / While Melody waited for the pie to cook she decided to feed the cat. Fred came into the kitchen and asked for some pie. Melody took out the pie and gave him a big piece / Melody took out the pie but the crust was black. Fred sat down and told his mom about his first day at school. He said that Chemistry class might be hard.

8. Kara was going to the beach today. The temperature would be 30 degrees all day and there was going to be plenty of sun. Kara was looking forward to getting some sun and just taking it easy. She picked out a nice spot to put her blanket and got settled on the beach. Kara read a few chapters of a novel and then packed up and drove home / Kara read through an entire novel and then packed up and drove home / Kara read a few pages of a novel and then packed up and drove home. Kara listened to the radio on her drive home. When Kara got home she noticed that her skin was nicelygolden / When Kara got home she noticed that her skin was an ugly red. Kara was thirsty and wanted some lemonade. She began to make some from fresh lemons.

9. Brian got up late on Saturday. It had been a hard week working in the office and he worked until 11:00 on Friday night. Today Brian had tentative plans to do some work around the house and watch one of his favourite TV shows. Brian turned on the TV and noticed that another whole show was playing before his favourite show would be on. Brian went into the bathroom and cleaned the sink and tub / Brian went into the
bathroom and painted all the walls / Brian went into the bathroom and emptied the garbage can. He was pleased he was taking initiative. When Brian came back he sat down and enjoyed is show / When Brian came back he discovered he had missed his show. Brian recalled that his friend Lisa was also a big fan of the show. Brian decided he would call up Lisa and chat.

10. Chris was a huge baseball fan. His favorite team was the Cubs. Today, Chris had planned on going to a game. He drove to the stadium and bought a ticket in left field. His favorite part of the game was the traditional seventh inning stretch. Around the fifth inning Chris was getting hungry. He decided to check out the food vendors in the stadium. He walked to the nearby concession area to check the different vendors / He walked around the entire stadium to check all the different vendors / He stood up and looked at what other people around him were eating. Chris decided to buy a hot dog and sit back down. He enjoyed singing out loud during the 7th inning stretch / He missed his chance to sing during the 7th inning stretch. Chris cheered for his team the remainder of the game. The Cubs won over the White Sox 6 to 5.

11. Angel and Richard were on their way out to have dinner. They made reservations at a chic new restaurant. They hadn’t been to dinner in several weeks because they just had a baby. Tonight they were going out with their new baby for the first time. Angel realized that the baby needed to be changed. She told Richard to go start the car and she would be right out. Richard had defrosted the car windows when Angel brought the baby out / Richard had listened to an entire talk show when Angel brought the baby out / Richard had just unlocked the car doors when Angel brought the baby out. Richard drove them to the restaurant. They made their reservation and had a great
dinner / They missed their reservation and could not eat dinner. They decided to go out again next week. Richard called and made another reservation.

12. Genie had just sprained her knee in a skiing accident and was in bed. Her boyfriend Tim offered to make her something to eat. Tim told Genie that he would make her some soup. He went into the kitchen and heated up a can of soup for her. Genie watched some commercials and then Tim came back with the soup / Genie watched three sitcoms and then Tim came back with the soup / Genie swallowed two aspirin and then Tim came back with the soup. Tim set the soup on the nightstand. Genie hungrily ate the soup and then fell asleep / Genie had fallen asleep while waiting for the soup. Tim knew she needed some rest. He turned out the lights and left her alone.