Abstract:
Eye fixation patterns for older adults and young adults were monitored as they read sentences containing temporary syntactic ambiguities such as "The experienced soldiers warned about the dangers conducted the midnight raid." Young and older adults' fixation patterns were similar except that older adults made many more regressions to the Subject NP for ambiguous sentences. In a second experiment, high and low span older adults were compared to high and low young adults. First pass fixation times for high and low span readers were similar; however, high and low span readers adopted different processing strategies when they encountered disambiguating information. High span readers were able to quickly resolve the ambiguity whereas low span readers required many regressions to the Subject NP in order to resolve the ambiguity. As a consequence, total fixation times for low span readers were longer than those for high span readers. High span readers were also able to use the focus operator ONLY (e.g., "Only experienced soldiers warned about the dangers…") to immediately resolve the temporary ambiguity. No age group differences were observed. These results are discussed with reference to contemporary theories of the role of working memory in sentence processing.

Text of paper:

Eye Fixation Patterns of High and Low Span Young and Older Adults: Down the Garden Path and Back Again.

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Eye Fixation Patterns of High and Low Span Young and Older Adults: Down the Garden Path and Back Again

Two experiments were conducted to provide new data relevant to the on-going debate over the role of working memory capacity limitations in sentence processing and the possibility of age differences in the processing of complex syntactic constructions (Just & Carpenter, 1992). This debate has focused on the processing of complex sentences containing temporary syntactic ambiguities, such as "The experienced soldiers warned about the dangers conducted the midnight raid." At issue is whether or not both young and older adults or high and low span individuals experience garden-path effects: an increasing in processing time reflecting the initial misinterpretation of the first verb "warned" as the main verb (MV) of the sentence, rather than as the verb of a reduced relative clause (RRC). Existing studies have been severely criticized on a number of methodological and procedural grounds (see Caplan & Waters, 1999 and subsequent responses).

Just and his colleagues (Just & Carpenter, 1992; Just & Varma, 2002; King & Just, 1991; MacDonald, Just, & Carpenter, 1992)) have claimed that working memory capacity constrains the interpretation of temporary syntactic ambiguities, limiting the ability of older or low span readers to make and sustain multiple interpretations of the ambiguous phrases. In contrast, Caplan and Waters in another series of reviews and publications (Caplan & Waters, 1999; 2002; Waters & Caplan, 1996 a & b, 2001, 2002) have argued that syntactic parsing and other interpretative processes including lexical access, assignment of thematic roles, and the determination of topic, focus, and co-reference, rely on a specialized processing system with a separate sentence-interpretation resource (SSIR), unrelated to traditional span measures of working memory.

According to the Just and Carpenter (1972) capacity-constrained (CC) theory (see also the 3CAPS model of Just & Varma, 2002), older or low span readers should have difficulty processing the temporary syntactic ambiguities and should exhibit garden path effects, initially mis-interpreting reduced relative clause constructions as main verbs only to re-interpret the constructions once disambiguating information is encountered. Young or high span readers should be able to avoid garden-path effects, by constructing multiple syntactic interpretations of the ambiguous phrases and retaining these interpretations until disambiguating information is encountered. The Caplan and Waters' SLIR theory (1999) predicts similar patterns of on-line processing for all readers since interpretative processes are buffered from working memory limitations. All readers should show increased processing delays at points of maximal syntactic complexity.

Because it is well established that older adults typically show impairments of working memory on span tests, research findings from studies comparing sentence processing by young and older adults have been critical to this debate. For example, Kemtes and Kemper (1997) attempted to replicate the finding by MacDonald et al. (1992) that high and low span readers would allocate processing time differently to sentences containing temporary syntactic ambiguities. Kemtes and Kemper compared young and older adults differing in working memory span. They hypothesized that older adults as a group should resemble low span young adults, and exhibit garden path effects. Kemtes and Kemper failed to replicate the report by MacDonald et al.: they found that all readers, regardless of age or span group showed garden path effects for sentences with temporary syntactic ambiguities. They also reported that older, low span readers had difficulty answering probe questions about the ambiguous sentences. Caplan and Waters (1999) take these results as support for their theory that interpretative processes are buffered from working memory limitations.

Kemtes and Kemper (1997) suggested that subtle differences between their procedures and those of MacDonald et al. (1992) may have contributed to the discrepant findings. In order to resolve this issue and address the criticisms raised by Caplan and Waters (1999), this experiment was repeated using an alternative

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methodology- eye tracking. Eye tracking was chosen over other methods because it is natural and unobtrusive. It is widely used to develop and test theories of sentence processing and has superceded other reading methods, such as word-by-word reading, cross-modal priming, or lexical decision (see Ferreira & Anes, 1994). It permits participants to utilize parafoveal information to "preview" upcoming words and phrases and to make regressive fixations to "review" previous words and phrases. These may be important components of skilled reading. Eye tracking has been shown to very highly sensitive to a variety of linguistic and discourse manipulations that affect the time course of sentence processing. It has the advantage over the auditory moving window paradigm used by Waters and Caplan (2001, 2002) in that the reading task imposes few demands on the participant: the eye tracking system used in the present study does not require the use of a bite bar or other device to constrain head movements; stimuli are presented naturally and no artificial segments are imposed on the flow of information; sentences are read for content without additional processing demands such as the acceptability judgment task used by Waters and Caplan. Although Waters and Caplan claim that the auditory moving windows paradigm presents stimuli in the "primary modality of language reception " (p. 130), it is arguable whether syntactically complex sentences, such as those used in the present experiment, commonly occur in oral language; indeed, they may be rarely used in oral language just because they are difficult to produce and understand (Beaman, 1984; Chafe, 1982; Hildyard & Olson, 1982). Hence, monitoring eye fixation patterns while reading may be a more sensitive and naturalistic method for examining the immediate processing of the complex syntactic constructions than word-by-word reading and auditory moving windows procedures.

Experiment 1

Eye fixation patterns of young and older adults were compared as they read sentences containing temporary syntactic ambiguities. Three measures were obtained from the eye fixation records: first pass fixation times, leftward regressions to previous parts of the sentence, and total fixation times reflecting first pass fixations plus subsequent fixations arising from regressions and re-reading the sentence in whole or in part. First pass fixations were assumed to reflect immediate syntactic processing and semantic analysis, corresponding to Waters and Caplan's interpretative processes. They define interpretative processes as "largely unconscious, obligatory, on-line, first-pass comprehension processes devoted to assignment of the literal, preferred, discourse-congruent meaning…[including] acoustic-phonetic conversion; lexical access; recognition of intonation contours; assignment of propositional values, such as thematic roles, attribution of modification, and scope of quantification; and determination of discourse-level semantic values, such as topic, focus, co-reference, and others…" (2001, p. 128). First pass fixations were expected to vary with the time course of syntactic processing, peaking at the most complex region of the sentence. In particular, first pass fixations were expected to peak when multiple interpretations of the temporary ambiguity were made and/or resolved. First pass fixations were therefore expected to vary if young and older adults use different strategies. The Just and Carpenter (1972) model implies that older span readers should exhibit a peak in first pass fixations late in ambiguous RRC sentences when they encounter the second verb. Having been lead down the garden path, older readers must attempt to re-analyze the first verb phrase as a reduced relative clause. Young readers should exhibit a peak in first pass fixations early in ambiguous MV and RRC sentences when they encounter the ambiguous first verb if they compute both the main verb and reduced relative clause interpretations. They may also exhibit a peak late in the sentence when they encounter disambiguating information.

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Regressions were expected to reflect breakdowns of immediate processing, peaking whenever readers were unable to assign a syntactic interpretation (Ehrlich & Rayner, 1983; Frazier & Rayner, 1982; Kennedy, 1983). According to the Just and Carpenter (1972) model, regressions to previous parts of the sentence were expected to peak for older readers when they encounter the second verb of ambiguous RRC sentences and re-read previous parts of the sentence in order to re-analyze the first verb phrase. The target "landing site" of the regression was expected to indicate whether they resorted to re-reading the entire sentence, by regressing to the subject noun phrase, or to re-reading just the critical first verb phrase. Young readers may also make regressions to previous parts of the sentence when they encounter disambiguating information in MV and RRC sentences. Total fixation times were assumed to reflect the time course of immediate processing as well as any re-processing of the sentence in whole or in part following regressions. Older adults were expected to spend more time re-reading the initial parts of ambiguous RRC sentences in order to correctly re-interpret the first verb phrase as a reduced relative clause.

Method

Participants.

Ten older adults and ten young adults participated. All older participants were community-dwelling adults who were recruited from a registry of prior research participants. All young participants were college-students recruited via postings on campus bulletin boards and class announcements. All participants were monolingual speakers of English. All were paid a modest honorium for their participation. The participants are described more fully in Table 1. Based on a 2-way ANOVA comparing age groups, the participants did not differ in educational level although they did differ in working memory span as measured by the Digits Forward and Digits Backwards tests from the Wechsler Adult Intelligence Scales-Revised (Wechsler, 1958) and the Daneman and Carpenter reading test (Daneman & Carpenter, 1970). An α level of .05 was set for this and all subsequent *t* and *F* tests.

Materials.

The MV/RRC sentences were originally developed by MacDonald et al. (1992) and supplemented by Kemtes & Kemper (1997). The critical contrast is between sentences 1a and 1b: in 1a, the sentence ends in a prepositional phrase (PP) whereas the sentence in 1b ends with a second verb predicate (2^{nd} V). Hence, in 1a, the first verb is initially and correctly interpreted as a main verb (MV); in 1b, that initial main verb interpretation of the first verb must be re-analyzed as a reduced relative clause (RRC) once the disambiguating second verb is encountered. Sentences 1c and 1d serve as controls. Sentence 1c is an unambiguous main verb sentence; the verb cannot be used in a reduced relative clause. Sentence 1d is an unambiguous reduced relative clause sentence; the relative pronoun *who* serves to immediately disambiguate its structure. Each sentence was divided into 3 critical regions: the subject noun phrase (Subject NP), the first verb phrase (1^{st} VP), the second verb phrase or prepositional phrase (2^{nd} VP/PP). These critical regions were used in the analysis of the eye movement data.

1. SUBJECT NP	$\|1^{st}$ VP	$\|2^{nd}$ V / PP
a The experienced soldiers	| warned about the dangers	| before the midnight raid.
b The experienced soldiers	| warned about the dangers	| conducted the midnight raid.
c The experienced soldiers	| spoke about the dangers	| before the midnight raid.
d The experienced soldiers	| who were told about the dangers	| conducted the midnight raid.

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There were 40 sets of MV/RRC sentences. They were assigned to 4 stimulus lists such that each list contained 10 examples of each type (a-d) of MV/RRC sentence but only 1 sentence from each set. In addition to the experimental sentences, each list contained 60 filler sentences of various syntactic forms. Unlike the studies of Waters and Caplan (2001 & 2002), only grammatically well-formed, semantically acceptable sentences were used in the reading study. The lists were randomized and each was broken into 2 blocks of 50 sentences.

Procedure and Apparatus.

Participants were first acquainted with the equipment and then given a block of 20 practice sentences to read. Each participant was assigned randomly to 1 of 4 stimulus lists. Then 2 blocks of sentences were presented; order of the blocks was counter-balanced across participants.

Each trial consisted of a fixation point centered on a blank screen for 500 msec followed automatically by the presentation of a sentence. The participants controlled presentation by pressing the mouse when they had completed reading the sentence. Participants sat in an adjustable chair with a head rest. They wore reading glasses if they normally did so. The chair could be raised or lowered to accommodate to bi- or tri-focals. The participants also wore a visor with an small magnetic sensor attached. The sensor was interfaced with a headtracker to monitor head movements. The sentences were presented in a 17 in flat panel computer screen at a viewing distance of 16 in. The fixation point an stimulus items were presented in white (125.5 lux) on a black background (0.03 lux) to maximize pupil size. Text was presented in Arial typeface with a mean size for individual letters of 0.57^{o}. The participants held a computer mouse in their preferred hand which was used to control sentence presentation.

An Applied Sciences Laboratories eye tracker (Model 504) with a magnetic headtracker was used to record eye movements. Eye movements were sampled 60 times per sec with an accuracy rating of 0.5^{o} visual angle. This translates to approximately 0.5 to 1 cm accuracy at 16 in. The headtracker noted displacements of the sensor attached to the readers' visor relative to a base unit and corrected the record of eye movements for head movements. Head movements were sampled 100 times per sec with an accuracy of 0.03^{o} at 12 in. Stimuli were presented using GazeTracker software (Lankford, 2001) which also analyzed the eye movement data. The eyetracker was calibrated at the start of each session and between blocks for each participant. One microcomputer controlled the eye tracker; it was interfaced with a second computer running the GazeTracker software for presentation and analysis.

Sentences were segmented into critical regions as in example (1). Two measures were computed for each critical region: the duration of the first pass fixations to the region and the total duration of all fixations to a region. First pass fixation duration is the sum of all fixations to a region beginning with the initial fixation inside a region and ending with the first fixation outside the region to leftward to a prior region or rightward to a successive region. Total fixation duration included all first-pass fixations as well as any fixations resulting from regressions to the region or subsequent re-fixation after a leftward or rightward fixation to another region. In addition, first pass regressions from one region leftward to a previous region were also identified. The total number of first pass regressions to the Subject NP from subsequent regions was determined; regressions to other regions were infrequent (< 5% of all regressions) and were not analyzed further although they did contribute to the calculation of total fixation durations. Fixations were defined as a minimum of two successive eye positions occurring with a fixation diameter of 30 pixels.

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Since the critical regions differed in length, the fixation durations were analyzed in two ways. First, they were converted to msec per character (letters and spaces), yielding first pass fixation time in msec/character and total fixation time in msec/character. Second, following Trueswell, Tanenhaus, & Garnsey, 1994, the fixation durations for each participant were first regressed on the number of characters (letters and spaces) in each region and then the residuals, reflecting length-corrected reading times, were used in the second analysis. Both approaches yielded equivalent results but only those using the msec/character times are presented. Appendix A presents raw, unadjusted first pass and total fixation durations.

Data from 4% of the experimental sentences was lost due to eye blinks, large head movements, or other eye tracking failures.

Results

The analysis of the MV/RRC sentences involved 3 measures: first pass fixation times, regressions to the Subject NP, and total fixation times. An omnibus ANOVA with age group, critical region, sentence type, and ambiguity is reported followed by a region-by-region decomposition of significant effects and interactions. Lower-order main effects and interactions subsumed by higher order interactions are not reported.

First Pass Fixation Time. A 2 (age group) x 3 (region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared first pass fixation times. The results are summarized in Figure 1. The 4-way interaction was significant, $F(2, 16) = 6.257$, $p = .010$, $\eta^2 = .439$. At region 1, the Subject NP, there were no significant effects or interactions: first pass fixation time did not vary ($M = 31.52$ msec/character, $SE = 0.32$) with age group, ambiguity, or sentence type. At region 2, only the main effect of age group was significant, $F(1, 18) = 21.519$, $p < .001$, $\eta^2 = .559$. Older adults read region 2 more slowly ($M = 33.42$, $SE = .58$) than young adults ($M = 27.63$, $SE = .43$). At region 3, the 2nd V/PP, the two-way interaction of sentence type and ambiguity, $F(1, 18) = 28.758$, $p < .001$, $\eta^2 = .628$. First pass fixations to region 3 by young and older adults were longer for ambiguous RRC sentences ($M = 44.41$, $SE = 0.84$) than for the other three types of sentences ($M = 34.42$, $SE = 0.77$).

Regressions to the Subject NP. A 2 (age group) x 2 (region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared the total number of regressions to the Subject NP from the other two critical regions, the 1st VP and the 2nd V/PP. The results are summarized in Figure 2. The 2-way interaction of age group and ambiguity was significant, $F(1, 18) = 10.766$, $p = .004$, $\eta^2 = .374$. Young adults made few regressions from ambiguous ($M = 0.25$, $SE = 0.11$) or unambiguous sentences ($M = 0.35$, $SE = 0.14$) regardless of type. Older adults made few regressions from unambiguous sentences ($M = 0.30$, $SE = 0.13$) but made many regressions back to the Subject NP for the ambiguous sentences ($M = 1.28$, $SE = 0.23$).

Total Fixation Times. A 2 (age group) x 3 (region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared total fixation times for the 3 critical regions, Subject NP, 1st VP, and 2nd V/PP. The results are summarized in Figure 3. At regions 1 and 2, the 3-way age group by sentence type by ambiguity interaction was significant, $F(1, 18) = 5.811$, $p = .021$, $\eta^2 = .133$, and $F(2, 16) = 4.033$, $p = .052$, $\eta^2 = .096$, respectively. Total fixations by young adults did not differ with sentence type and ambiguity ($M = 34.85$, $SE = 0.91$) whereas total fixations by older adults for ambiguous RRC sentences ($M = 46.78$, $SE = 0.87$) were longer than for the other types of sentences ($M = 39.24$, $SE = 0.88$). At region 3, only the type by ambiguity interaction was significant, $F(1, 18) = 5.811$, $p = .021$, $\eta^2 = .133$. Total fixations to ambiguous RRC sentences were longer ($M = 49.05$, $SE = 0.51$) than those for the other types of sentences ($M = 38.70$, $SE = 0.36$)

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Discussion

First pass fixations to the Subject NP or 1st VP did not vary by sentence type or ambiguity although older adults' first pass fixation times were longer than young adults' for the 1st VP. Only at region 3 did first pass fixations diverge as a function of sentence type, ambiguity, and age group. Region 3 corresponds to the 2nd VP of the RRC sentences or the PP of MV sentences; it thus disambiguates the syntactic role of the 1st VP in region 2. At region 3, first pass fixations by older adults to RRC sentences with temporary syntactic ambiguities were longer than those to MV sentences or unambiguous control sentences. First pass fixations by young adults did not vary with sentence type or ambiguity. Older adults also made many regressions to the Subject NP from regions 2, the 1st VP, and region 3, the 2nd V/PP, in order to interpret the ambiguous sentences. These regressions contributed to the increase in total fixation times for older adults for regions 1 and 2 of the ambiguous RRC sentences. Young adults made few regressions back to the Subject NP. Total fixation times for both young and older adults were longer for the ambiguous RRC sentences at region 3, corresponding to the disambiguating information.

These results are not fully consistent with either the CC model of Just and Carpenter (1992) (also the 3CAPS model of Just & Varma, 2002) or the SLIR model of Waters and Caplan (1996). According to the CC model fixation patterns by young and older adults should differ, reflecting the effects of working memory limitations on sentence processing. The similarity of the first pass fixations and total fixation times for young and older adults for MV and RRC sentences does not support the CC model; both young and older adults experienced a garden path effect for the RRC sentences at region 3. The regression data do support the Just and Carpenter model since young adults were able to revolve the temporary syntactic ambiguity without re-reading the sentence, presumably by drawing on information in working memory, whereas the older adults could do so only by re-reading the sentence.

Nor are the results fully consistent with the SLIR model. This model holds that there is a specialized working memory system for interpretative processing that is at least partially distinct from a more general working memory system involved in post-interpretative processing. The similarity of first pass fixations for young and older readers does support the Waters and Caplan model. The regression data do not. Waters and Caplan have never discussed the role of regressive eye fixations with regards to interpretative versus post-interpretative processes. If regressive eye movements reflect interpretative processes, the regressions to the Subject NP from regions 2 and 3 in ambiguous sentences, by older adults would be inconsistent with the SLIR model. Alternatively, regressions and total fixation times may reflect post-interpretative processes and thus the age group differences in fixations from regions 2 and 3 to the Subject NP, and the resulting increase in total fixation times for these regions, would be consistent with the SLIR model.

Experiment II

In order to clearly determine the role of working memory limitations in sentence processing, eye fixation patterns of high and low span older adults were compared to those of high and low span young adults. In order to clearly establish the role of working memory in sentence processing, an "excluded middle" design was used to select a group of high span older adults and a group of low span older adults, excluding older adults with intermediate memory spans. Then high and low span young adults were carefully selected to match the span scores of the two groups of older adults. Age group differences were expected to be minimized in Experiment II if working memory capacity is a primary determinate of older adults' reading problems. If so, the high and low span groups should differ in fixation patterns according to the CC model. If working memory capacity does not

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affect sentence processing, high and low span groups should exhibit similar fixation patterns, according the SSIR model.

In addition to the MV/RRC sentences used in the first experiment, a second type of reduced relative clause sentence was used to assess the participants' sensitivity to a subtle grammatical contrast in ambiguity. These sentences contrasting two types of reduced relative clause constructions, ones marked by the determine "the" versus ones marked by the focus operator "only" (Kemtes, 1998; Ni et al., 1996). The focus operator sets up an expectation of contrasting set, blocking the main verb interpretation, as in "Only businessmen loaned money at low interest rates…" Ni et al. claim that this contrast is semantic or referential and biases the initial interpretation of the verb as a reduced relative clause. Ni et al. reported that high span readers did not experience a garden path effect for ONLY sentences whereas low span readers had equivalent first pass fixation times for THE and ONLY sentences.

Experiment I did not investigate whether young and older readers differed in their comprehension of MV and RRC sentences. In Experiment II, probe questions were inserted after 50% of the sentences to monitor the participants' comprehension.

Method

Participants.

A group of 24 older adults were given a battery of working memory tests (described below). Based on their performance on these tests, 8 high span and 8 low span older adults were selected for inclusion in the reading study. The 8 older adults with the highest span scores, on at least 3 of 4 measures, and the 8 older adults with the lowest span scores, on at least 3 of 4 measures, were selected. From a group of 32 young adults who were also given the battery of working memory tests, 8 high span and 8 low span young adults were selected to match the distributions of the groups of high and low span older adults on the working memory battery. Ten very high span young adults, who working memory scores fell above of the range of scores by the older adults on at least 3 of the 4 span measures, were excluded. In addition, 6 young adults were excluded because their scores were intermediate between those of the high and low span older adults. All older participants were community-dwelling adults who were recruited from a registry of prior research participants. All young participants were college-students recruited via postings on campus bulletin boards and class announcements. All participants were monolingual speakers of English. All were paid a modest honorium for their participation. The participants are described more fully in Table 2. Based on a 2 x 2 ANOVA comparing age groups and span groups, the participants did not differ in educational level.

Insert Table 2 here

The participants were also given a survey of reading habits, eliciting information on how many hours per week they spent reading and what types of materials they read. The age groups and span groups did not differ in how much reading they did per week (M = 28 hours/week, SD = 8.3). The age groups did differ in how they distributed these hours across different types of reading materials: not surprisingly, the young adults reported reading college text books as well as readings assigned by their classes including literary works such as novels and plays as well as books on contemporary social issues. The older adults reported more newspaper and magazine reading, and reading of historical nonfiction. The older adults (M = 35.6 of 40 correct, SD = 3.8) did score higher on the vocabulary test than the young adults (M = 30.6, SD = 2.8), $F(1,28) = 15.099$, $p = .001$, $\eta^2 = .962$; the span group main effect and the age group by span group interaction were not significant.

Working Memory measures.

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The battery of working memory tests including the Digits Forward and Digits Backwards tests from the Wechsler Adult Intelligence Scales- Revised (Wechsler, 1958) as well as the Daneman and Carpenter reading test (Daneman & Carpenter, 1970). In addition, a grammaticality judgment test modeled after that of Waters and Caplan (1996a & b) was administered. Grammatically acceptable sentences, e.g., *It was the mother that carried the baby*, and unacceptable sentences, e.g., *It was the baby that carried the mother*, were presented one at a time on a computer screen. Participants were timed as they decided whether or not the sentence "makes sense." Response time and accuracy were recorded. The sentences were also divided into sets of increasing length, as in the Daneman and Carpenter test. After the final sentence in each set had been presented, participants were asked to recall the final word of each sentence in the set. Thus, this test yields 3 measures, a span measure, referred to the W & C span, a reaction time measure, W & C RT, and an accuracy score, W & C accuracy. Waters and Caplan also computed a composite measure, Comp Z, by converting each score to a z-score and averaging the 3 z-scores; this composite was not used in the present study. All of the working memory measures were highly correlated and the W & C accuracy measure was highly correlated with the participants' educational level and vocabulary scores, see Table 3. These correlations are based on the entire sample of 24 older adults and 36 young adults who were screened for participation in the reading study.

A series of 2 x 2 ANOVAs was conducted to compare the participants based on age group and span group. High and low span groups did differ on the 4 span measures (Digits Forward, Digits Backward, reading span, W & C span), all $F(1, 28) \geq 11.532$, $p < .001$, $\eta^2 \geq .712$. They also differed in W & C RT, $F(1, 28) = 89.275$, $p < .001$, $\eta^2 = .781$, but not on the W & C accuracy score, $F(1, 28) = 2.908$, $p = .101$ $\eta^2 = .018$. The age groups did not differ on any of the span measures, the W & C accuracy measure, or W & C RT. None of the age group by span group interactions were significant.

Materials.

Two types of sentences were used in the study. In addition to the MV/RRC sentences used in the first experiment, a second type of sentence was also used. The second type also contained temporary syntactic ambiguities distinguished by the use of *the* or *only* in the initial subject noun phrase (THE/ONLY sentences). They were originally developed by Ni et al. (1996). They differ somewhat in their internal phrase structure and decomposition into critical regions from the MacDonald et al. sentences. The critical contrast is between sentences 2a and 2b; each contains a reduced relative clause followed by a main verb. The quantifier *Only* in 2b, according to Ni et al., serves to block the ambiguity by focusing the interpretation of the subject noun phrase on a subset of the Subject NP; that subset is denoted by the following expression, the 1st Verb. Hence, hence, the first verb is immediately interpreted as a reduced relative modifying the subject noun phrase, not as a main verb. Sentences 2c and 2d are controls; both contain unambiguous reduced relative clause sentences (the main verb interpretation of the first verb is blocked by its morphological form).

2	Subject NP	1st Verb	2nd V	2nd VP
a	The businessmen	loaned money at low interest	were told	to record their expenses.
b	Only businessmen	loaned money at low interest	were told	to record their expenses.
c	The vans	stolen from the parking lot	were found	in a back alley.
d	Only vans	stolen from the parking lot	were found	in a back alley.

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There were 40 sets of MV/RRC sentences and 48 sets of THE/ONLY sentences. They were assigned to 4 stimulus lists such that each list contained 10 examples of each type (a-d) of MV/RRC sentence and 12 examples of each type (a–d) of THE/ONLY sentences but only 1 sentence from each set. In addition to the experimental sentences, each list contained 112 filler sentences of various syntactic forms. Unlike the studies of Waters and Caplan (2001 & 2002), only grammatically well-formed, semantically acceptable sentences were used in the reading study. The lists were randomized and each was broken into 4 blocks of 50 sentences.

Probe questions were inserted after 50% of the sentences, randomly selected. The probe questions for the fillers and control sentences tested for comprehension of the main verb or sentence predicate. "Don't know" was the correct answer to 10% of the probe questions about filler sentences. The probe questions for the experimental MV/RRC sentences tested for the correct interpretation of the first verb phrase. Thus for 1a and 1b, the probe as "Who warned about the dangers?" For 1a, it is correctly answered by "the soldiers" indicating a main verb interpretation; for 1b, answering "the soldiers" indicates an incorrect main verb interpretation. Correct answers to 1b were " don't know" or "someone else." There were two types of questions for the THE/ONLY sentences. One-half probed for correct interpretation of the first verb phrase. For 2a and 2b, the probe was "Who loaned the money?" Answering "the businessmen" indicates an incorrect main verb interpretation in either case. Correct answers for 2a or 2b were "the bank," "don't know," or "someone else." The second type of question for the THE/ONLY sentences probed for correct interpretation of the second verb phrase. For 2a and 2b, the probe was "Who recorded their expenses?" The correct answer was "the businessmen."

Procedure

Testing took place over two days. On the first day, participants were given the battery of working memory tests. Those selected for inclusion in the high or low span groups were then invited back for a second day. The reading study was administered on the second day. Participants were first acquainted with the equipment and then given a block of 20 practice sentences to read; probe questions accompanied 50%. The experimenter recorded the participants' responses to the probe questions. Each participant was assigned randomly to 1 of 4 stimulus lists. Then 4 blocks of 50 sentences were presented; blocks were counter-balanced across participants. Other details of the presentation and analysis of eye fixation patterns were the same as those followed in Experiment I. As in Experiment I, first pass and total fixation times were analyzed using two approaches: first in terms of msec/character times and second, in terms of length-adjusted residual reading times. These approaches yielded equivalent results and only the first set of analyses are reported. Unadjusted, raw first pass and total fixation times are given in Appendix B.

Results

The MV/RRC sentences and THE/ONLY sentences were analyzed separately. Each analysis involved 4 measures: first pass fixation times, regressions to the Subject NP, total fixation times, and accuracy in answering the probe questions. An omnibus ANOVA with age group, critical region, sentence type, and ambiguity is reported followed by a region-by-region decomposition of significant effects and interactions. Lower-order main effects and interactions subsumed by higher order interactions are not reported. Note: none of the main effects for age group and interactions involving this factor were significant.

MV/RRC sentences[1]

First Pass Fixation Time. A 2 (span group) x 2 (age group) x 3 (region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared first pass fixation times for the 3 critical regions. The results are summarized in Figure 4.

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The 3-way region x sentence type x ambiguity interaction was the only significant finding, $F(2, 27) = 48.186$, $p < .001$, $\eta^2 = .766$. At region 1, the Subject NP, there were no significant effects or interactions: first pass fixation time did not vary ($M = 31.54$ msec/character, $SE = 0.32$). This was also true for region 2, the 1st VP, ($M = 33.458$, $SE = 0.72$) . At region 3, the 2nd V/PP, first pass fixations by all participants to unambiguous control sentences and ambiguous MV sentences ($M = 30.99$, $SE = 0.64$) were faster than those to ambiguous RRC sentences ($M = 35.15$, $SE = 0.97$).

Regressions to the Subject NP. Two 2 (span group) x 2 (age group) x 2 (region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared the total number of regressions to the Subject NP from the other two critical regions, the 1st VP and the 2nd V/PP. The results are summarized in Figure 5. Only the span group by ambiguity interaction was significant, $F(1, 28) = 47.687$, $p = .001$, $\eta^2 = .614$. High span participants made few regressions from the 1st VP or 2nd V/PP region ($M = 0.21$, $SE = 0.11$) to the Subject NP. Low span readers made few regressions for unambiguous sentences from the 1st VP or 2nd V/PP ($M = 0.27$, $SE = 0.12$) to the Subject NP but many more for ambiguous sentences ($M= 0.89$, $SE = 0.10$).

Total Fixation Times. Three 2 (age group) x 2 (span group) x 3 (region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared total fixation times for the 3 critical regions, Subject NP, 1st VP, and 2nd V/PP. The results are summarized in Figure 6. The 4-way interaction of span group, region, sentence type, and ambiguity was significant, $F(2, 27) = 8.733$, $p = .001$, $\eta^2 = .393$. At the first region, the Subject NP, the sentence type by ambiguity by span group interaction was significant, $F(1, 28) = 9.437$, $p = .004$, $\eta^2 = .239$. Total fixation time for high span readers did not vary with sentence type or ambiguity ($M = 33.97$, $SE = 0.94$) and total fixation times for high span readers were shorter than those for low span readers ($M = 39.90$, $SE = 0.92$). Total fixation times to the Subject NP for low span readers for ambiguous RRC sentences were inflated by regressions to this region from regions 2 and 3. As a result total fixation times for low span readers to ambiguous RRC sentences were longer ($M = 54.06$, $SE = 1.52$) than those for the other types of sentences ($M = 43.13$, $SE = 1.89$).

Total fixation times for region 2, the 1st VP, followed a similar pattern. The sentence type by ambiguity by span group interaction was significant, $F(1, 28) = 9.688$, $p = .004$, $\eta^2 = .244$. Total fixation times for high span readers did not vary with sentence type or ambiguity ($M = 34.00$, $SE = 0.80$). Total fixation times to the 1st VP for low span readers for ambiguous RRC sentences were inflated by re-fixations to this region following regressions to the Subject NP. As a result, total fixation times for low span readers to ambiguous RRC sentences were longer ($M = 54.69.06$, $SE = 0.95$) than for the other types of sentences ($M = 44.53$, $SE = 2.24$).

In the analysis of total fixation times for region 3, the 2nd V/PP, the sentence type by ambiguity interaction was significant, $F(1, 28) = 23.451$, $p < .001$, $\eta^2 = .439$. For both high and low span readers, total fixation times to the disambiguating 2nd V in ambiguous RRC sentences ($M = 48.96$, $SE = 0.67$) were longer than those to the disambiguating PP in ambiguous MV sentences ($M = 41.31$, $SE = 1.541$) or the 2nd V or PP in unambiguous sentences ($M = 42.87$, $SE = 0.84$).

Probe questions. A 2 (age group) x 2 (span group) x 2 (sentence type) x 2 (ambiguity) ANOVA was used to analyze the percentage of probe questions answered correctly. The results are reported in Table 4. The type by ambiguity by span interaction was significant, $F(1, 28) = 10.968$, $p < .001$, $\eta^2 = .281$. High span readers answered 88% of the questions correctly regardless of sentence type or ambiguity. Low span readers answered 76% correctly for questions about ambiguous and unambiguous MV sentences and unambiguous RRC sentences. Low span readers answered only 54% of the probe questions about the ambiguous RRC sentences. Note that

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the correct answer was "Don't know." [2] Low span readers incorrectly answered questions about the RRC sentences with the subject noun phrase 35% of the time.

Summary. First pass fixations to the Subject NP or 1st VP did not vary by sentence type, ambiguity, or span group. Only at region 3 did first pass fixations begin to diverge as a function of sentence type, ambiguity, and span group. Region 3 corresponds to the 2nd VP of the RRC sentences or the PP of MV sentences; it thus disambiguates the syntactic role of the 1st VP in region 2. At region 3, first pass fixations by both high and low span readers to RRC sentences with temporary syntactic ambiguities were longer than those to MV sentences or unambiguous control sentences. Low span readers encountered difficulty interpreting the ambiguous MV and RRC sentences and made many regressions to the Subject NP in order to interpret the 1st V and 2nd V/PP regions. Their total fixation times were inflated, particularly for regions 1 and 2 of the ambiguous RRC sentences. Total fixation times for all readers were longer for region 3, corresponding to the disambiguating information. Despite their attempts to resolve the ambiguity by making regressions to the Subject NP, low span readers often did not correctly interpret the RRC sentences as indicated by their responses to the probe questions. Although high and low span readers produced different patterns of eye fixations while reading MV/RRC sentence, those of young and older adults were similar when matched for memory span.

THE/ONLY sentences[3]

First Pass Fixation Times. Four 2 (span group) x 2 (age group) x 4 (region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared first pass fixation times for the 4 critical regions, the Subject NP, the 1st V, the 2nd V, and the 2nd VP. The results are summarized in Figure 7. The 4-way interaction of span group, region, sentence type, and ambiguity was significant, $F(3, 26) = 8.150$, $p = .001$, $\eta^2 = .485$. At region 1, the Subject NP, the type x span interaction was significant, $F(1, 28) = 19.261$, $p < .001$, $\eta^2 = .391$. First pass fixations for low span readers averaged 31.38 msec/character ($SE = 1.16$) regardless of sentence type. First pass fixations for high span readers varied with sentence type; their first pass fixations to ONLY sentences ($M = 43.49$, $SE = 0.88$) were longer than their first pass fixations to THE sentences ($M = 28.59$, $SE = 0.81$). For region 2, the 1st VP, there were no significant effects or interactions. First pass fixations averaged 31.69 msec/character ($SE = 0.61$).

For region 3, the 2nd V, the type by ambiguity by span interaction was significant, $F(1, 28) = 24.355$, $p < .001$, $\eta^2 = .448$, interactions. Low span readers' first pass fixations to unambiguous sentences were similar for THE and ONLY sentences ($M = 31.03$, $SE = 1.03$); first pass fixations to unambiguous ONLY sentences ($M = 29.51$, $SE = 1.14$) were faster than those to ambiguous ONLY sentences ($M = 43.81$, $SE = 1.99$) which were faster than those to ambiguous THE sentences ($M = 53.12$, $SE = 1.28$). For high span readers, first pass fixations for unambiguous THE and ONLY sentences were similar ($M = 30.18$, $SE = 1.51$) and similar to those for ambiguous ONLY sentences ($M = 35.39$, $SE = 1.88$) whereas first pass fixations to ambiguous THE sentences ($M = 50.44$, $SE = 1.21$) were slower than those to ambiguous ONLY sentences.

For region 4, the 2nd VP, there was a significant main effect for span, $F(1, 28) = 48.114$, $p < .001$, $\eta^2 = .616$, and a significant main effect of ambiguity, $F(1, 28) = 5.135$, $p = .031$, $\eta^2 = .146$. First pass fixations by high span readers ($M = 28.83$, $SE = 0.58$) were faster than those by low span readers ($M = 34.69$, $SE = 0.61$) and first pass fixations to unambiguous sentences ($M = 31.73$, $SE = 0.52$) were faster than those to ambiguous sentences ($M = 33.79$, $SE = 0.71$) .

Regressions to the Subject NP. Three 2 (span group) x 2 (age group) x 3 (region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared the total number of regressions to the Subject NP from the other three critical regions, the 1st VP, the 2nd V, and the 2nd VP. The results are summarized in Figure 8. The 3-way span group by

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region by ambiguity interaction was significant, $F(2, 27) = 6.811$, $p = .004$, $\eta^2 = .320$. High span participants made few regressions from the 1st VP or 2nd V to the Subject NP for either ambiguous or unambiguous sentences ($M = 0.17$, $SE = 0.08$). Low span readers made more regressions than high span readers and low span readers made more regressions from region 3, the 2nd V, ($M = 1.37$, $SE = 0.08$) than from region 2, the 1st VP, ($M = 1.08$, $SE = 0.11$) or region 4 (M = 0.48, SE = 0.11) for ambiguous sentences. Low span readers may few regressions from any region of unambiguous sentences ($M = 0.21$, $SE = 0.11$).

Total Fixation Times. Four 2 (age group) x 2 (span group) x 4(region) x 2 (sentence type) x 2 (ambiguity) ANOVAs compared total fixation times for the 4 critical regions, Subject NP, 1st VP, 2nd V, and the 2nd VP. The results are summarized in Figure 9. The 4-way span group by region by sentence type by ambiguity interaction was significant, $F(3, 26) = 4.570$, $p = .011$, $\eta^2 = .345$. For the first region, the Subject NP, the sentence type by span group, $F(1, 28) = 49.740$, $p < .001$, $\eta^2 = .624$. and ambiguity by span group interactions were significant, $F(1, 28) = 39.390$, $p < .001$, $\eta^2 = .568$. Total fixation times for high span readers for THE sentences ($M = 31.09$, $SE = 0.94$) were shorter than their total fixation times to ONLY sentences ($M = 43.31$, $SE = 0.84$). In contrast, for low span readers, total fixation times to THE and ONLY sentences ($M = 68.06$, $SE = 0.89$) did not differ. Total fixation times for high span readers for ambiguous and unambiguous sentences were similar ($M = 37.15$, $SE = 0.94$) but total fixation times for low span readers were longer for ambiguous sentences than for unambiguous sentences ($M = 59.92$, $SE = 0.94$) reflecting their many regressions to the Subject NP from the 1st VP or 2nd V for the ambiguous sentences.

For total fixation times for region 2, the 1st VP, the main effect of span group was significant, $F(1, 28) = 46.804$, $p < .001$, $\eta^2 = .609$, as was the ambiguity main effect interaction, $F(1, 28) = 14.197$, $p = .001$, $\eta^2 = .321$. Total fixation times for high span readers ($M = 33.09$, $SE = 0.94$) were shorter than those for low span readers ($M = 54.00$, $SE = 0.80$) and total fixation times for unambiguous sentences were shorter ($M = 40.52$, $SE = 1.04$) than those for ambiguous sentences ($M = 48.24.06$, $SE = 0.85$).

In the analysis of total fixation times for region 3, the 2nd VP, the span group main effect, $F(1, 28) = 88.648$, $p < .001$, $\eta^2 = .747$, and sentence type by ambiguity interaction was significant, $F(1, 28) = 13.227$, $p = .001$, $\eta^2 = .306$. Total fixation times for high span readers ($M = 39.21$, $SE = 0.84$) were faster than those for low span readers ($M = 58.27$, $SE = 0.92$). For both high and low span readers, total fixation times to the disambiguating 2nd V in ambiguous THE sentences ($M = 62.03$, $SE = 0.87$) were longer than those to the disambiguating 2nd V in ambiguous ONLY sentences ($M = 48.97$, $SE = 1.171$) which were longer than those to the 2nd V in unambiguous THE sentences ($M = 42.74$, $SE = 1.07$). Total fixation times to the 2nd V in unambiguous THE sentences were similar to those for unambiguous ONLY sentences ($M = 40.05$, $SE = 0.89$).

At region 4, the 2nd V, only the main effect of span group, $F(1, 28) = 172.724$, $p < .001$, $\eta^2 = .852$, was significant. Total fixation times for high span readers ($M = 28.85$, $SE = 0.52$) were shorter than those for low span readers, ($M = 51.91$, $SE = 1.08$).

Probe questions. The two types of probe questions were analyzed separately. A 2 (age group) x 2 (span group) x 2 (sentence type) x 2 (ambiguity) ANOVA was used to analyze the percentage of probe questions about the first verb which were answered correctly. For the first probe question about the 1st VP, the ambiguity by span interaction was significant, $F(1, 28) = 57.869$, $p < .001$, $\eta^2 = .870$. High span readers answered correctly 94% of the questions about unambiguous sentences and ambiguous THE/ONLY sentences. Low span readers answered correctly 90% of the questions about unambiguous sentences correctly but only 45% of the questions

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about ambiguous sentences. Note that the correct answer to the first probe question was "Don't know." The results are reported in Table 5.

For the second probe question about the 2nd VP, only the main effect of sentence type was significant, $F(1, 28) = 8.795$, $p = .006$, $\eta^2 = .239$. Readers answered correctly 94% of the questions about THE sentences but only 87% of the questions about ONLY sentences.

Summary. When the quantifier ONLY is first encountered, first pass fixations by high span readers tended to be longer than those by the low span readers. When the ambiguity is resolved, in region 3 by the 2nd V, first pass fixations by both high and low span readers to ambiguous THE sentences with temporary syntactic ambiguities were longer than those to unambiguous THE sentences. High span readers were able to avoid this ambiguity effect at region 3 for ONLY sentences, because they had allocated more time to region 1 for ONLY sentences. Low span readers did not take advantage of the ONLY quantifier; consequently their first pass fixation times for region 3 of ambiguous ONLY and ambiguous THE sentences were similar. Low span readers encountered difficulty interpreting the ambiguous sentences and made many regressions to the Subject NP in order to interpret the 1st V and 2nd VP regions. As a result, their total fixation times were inflated, particularly for regions 1 and 2 of the ambiguous sentences. High span readers often incorrectly interpreted the ambiguous THE sentences but were able to use the ONLY quantifier to focus on the correct interpretation of ambiguous ONLY sentences. Despite their attempts to resolve the ambiguity by making regressions to the Subject NP, low span readers often did not correctly interpret either ambiguous THE or ONLY sentences. Although high and low span readers produced different patterns of eye fixations while reading THE/ONLY sentence, those of young and older adults were similar when matched for memory span.

General Discussion

Comparing the eye fixation patterns of young and older adults in Experiment I with those of high and low span readers in Experiment II supports the hypothesis that older adults, as a group, resemble low span readers. First pass fixation times for ambiguous MV and RRC sentences show similar garden path effects: all readers, regardless of age or working memory span, experience garden path effects for ambiguous RRC sentences, with first pass fixations peaking in region 3. However, young and older adults in Experiment I and high and low span readers in Experiment II did produce different patterns of eye fixations when regressions and total fixation times were analyzed. Like older adults in Experiment 1, low span readers in Experiment II made many regressions from regions 2 and 3 to the Subject NP for ambiguous MV/RRC sentences in order to resolve the ambiguity. In contrast, young adults in Experiment I and high span readers in Experiment II were able to resolve the syntactic ambiguities without recourse to leftward regressions by relying on information in working memory. Total fixation times for older adults in Experiment I also mirrored those for low span readers in Experiment II, further supporting the hypothesis that working memory limitations underlie older adults' sentence processing problems.

Experiment II revealed two differences between high and low span readers that were not assessed in Experiment I. High span readers were able to answer probe questions about all types of sentences correctly with 80% or better accuracy. Low span readers were able to answer the probe questions about unambiguous sentences as well as those about MV sentences with a similar level of accuracy. However, they often misinterpreted ambiguous RRC sentences, incorrectly assigning a MV interpretation.

THE/ONLY sentences In Experiment II revealed another difference in first-pass fixation times as a function of working memory span: First pass fixation times for high and low span readers diverged when the

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focus operator ONLY was used to restrict the interpretation of the Subject NP. High span readers allocated additional fixation time to the Subject NP marked by the ONLY operator in order to assess its discourse function; low span readers did not appear to be sensitive to the discourse function of ONLY. First pass fixations by all readers revealed a garden-path effect for the ambiguous THE sentences; however, high span readers, unlike low span readers, were now able to avoid the garden-path effect for the ONLY sentences because they had allocated extra first pass fixation time to Subject NPs marked by the ONLY operator,.

These results are not fully consistent with either of the two dominate theories of working memory and language processing, the CC model of Just and Carpenter (1992) (also the 3CAPS model of Just & Varma, 2002) or the SLIR model of Waters and Caplan (1996a; Caplan & Waters, 1999). The CC model argues that the capacity of working memory constraints language processing as well as other cognitive abilities. Individuals with working memory limitations should not only have increased difficulty processing syntactically complex sentences but the time course of sentence processing for simple versus complex sentences should vary with working memory. Low span readers should allocate additional processing time at points of processing difficulty and be unable to retain multiple, alternative syntactic representations of ambiguous phrases. In contrast, high span readers should be able to avoid garden-path effects in that they can compute and retain multiple representations of ambiguous phrases until disambiguating information is available. The CC model is supported by the regression patterns: low span readers had more difficulty processing the ambiguous sentences, particularly regions 2 and 3, and they were unable to rely on information in working memory in order to do so. The finding that low span individuals had difficulty correctly answering the probe questions about the ambiguous RRC and THE sentences also supports this model. However, the similarity of first pass fixation times for high and low span individuals for MV/RRC sentences in Experiment II does not support the CC model. Further, both high and low span readers showed a marked garden-path effect at region 3 for the RRC sentences. The differences in first pass fixations for high and low span readers for the THE/ONLY sentences are consistent with CC model: high span readers allocated additional time to interpreting the Subject NP in ONLY sentences and were able to avoid the garden-path for region 3. However, high and low span readers' produced similar first pass fixations patterns for the THE sentences as they did for the MV/RRC sentences and both groups experienced marked garden path effects for these sentences, contrary to the CC model's predictions.

Nor are the results fully consistent with the SLIR model. This model holds that there is a specialized working memory system for interpretative processing that is at least partially distinct from a more general working memory system involved in post-interpretative processing. Individual or group differences as measured by general working memory tests are linked to differences in post-interpretative processing affecting, e.g., question-answering and sentence recall. Interpretative processing, involved in lexical access, syntactic analysis, focus and thematic role assignment, should not affected by such working memory limitations. Hence, the time course of immediate, interpretative processing should be invariant across groups and individuals. This model is supported by several findings in the present studies. First, both young and older adults experienced a garden-path effect for first pass fixation times with ambiguous RRC sentences in Experiment I and both high and low span readers experienced similar garden path effects for ambiguous RRC sentences in Experiment II. However, several aspects of the results are not consistent with the SLIR model. First, although first pass fixations by high and low span readers were similar for the MV, RRC sentences, and the THE sentences in Experiment II, they differed markedly for ONLY sentences. High span readers allocated additional first-pass time to processing Subject NPs with the ONLY operator and this represents a difference in interpretative processing. Second, it is unclear whether regressions and total fixation times reflect interpretative or post-interpretative processing.

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Waters and Caplan have never specified when interpretative processes give way to post-interpretative processes during the time course of sentence processing. Interpretative and post-interpretative processes may be strictly sequential with post-interpretative processes being initiated only after a sentence or clause boundary is reached. If so, the regressions to the Subject NP from regions 2 and 3, and the resulting inflation of total fixation times for ambiguous RRC sentences, by older adults in Experiment I or low span readers in Experiment II would serve interpretative processes. This view is supported by Waters and Caplan's (2001) criticism of the Ferreira and Clifton (1986) study for using a moving window paradigm which did not permit regressive eye fixations, suggesting they would consider regression data to be relevant to interpretative processing. Alternatively, interpretative and post-interpretative processes may be parallel and incremental such that once an syntactic interpretation of one phrase or syntactic constituent is reached, post-interpretative processing can begin while interpretative processing of other phrases or constituents proceeds. If so, the regressions and total fixation times would be seen as serving post-interpretative processes. Waters and Caplan may not have observed such differences between high and low span readers because they have relied on the auditory-moving window paradigm, which does not permit regressions or distinguish first pass from total listening times and they have not studied sentences involving a contrast in focus.

These results are also inconsistent with a more recent model put forth by MacDonald and Christiansen (2002). This model concedes an overall advantage to high span individuals in terms of speed and accuracy of sentence processing but predicts similar patterns of on-line processing. This model also equates span differences in working memory with a general account of expertise in language processing. Hence, the finding that span scores were not highly correlated with vocabulary scores is inconsistent with this model. This model is also unable to account for the marked differences in regressions for high and low span readers; it was not simply that low span readers made more regressions but they made more regressions for ambiguous sentences than for unambiguous sentences, an interaction that is inconsistent with the model. The model is supported by the finding that high span readers do appreciate the significance of the low frequency ONLY operator and are able to avoid garden path effects for this type of sentence.

In summary, the results from this study of the eye movement patterns of high and low span individuals suggests that revised version of the Just and Carpenter (1972) in which a single capacity-limited working memory system is involved in sentence processing and other cognitive abilities. High and low span individuals experience garden-path effects due to temporary syntactic ambiguities. However, immediate sentence processing is affected by working memory limitations in two ways: First, low span individuals are unable to quickly resolve temporary syntactic ambiguities; as a consequence, low span individuals engage in regressive eye movements in order to recover from misanalyses, inflating total fixation times. High span individuals can access relevant information in working memory to quickly resolve temporary syntactic ambiguities once they are detected. Second, low span individuals are either not sensitive to the contrast in focus between THE and ONLY or they are unable to apply the ONLY operator to restrict the interpretation of the subsequent NP. High span readers can avoid garden path effects by applying the focus operator to restrict their initial interpretation. Hence, a larger working memory enables readers to retain linguistic information and access it quickly to recover from initial mis-analyses and to apply linguistic constraints to avoid such misanalyses; a smaller working memory limits readers' access to low frequency linguistic information and to forces them to compensate for initial mis-analyses by re-reading and re-analyzing critical linguistic information.

In general, the fixation patterns of older adults in Experiment I resembled those of low span readers in Experiment II: Older adults and low span readers who were led down the garden path by ambiguous RRC

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sentences made many regressions to the Subject NP in order to resolve temporary syntactic ambiguities in RRC sentences. These regressions also inflated their total fixation times. Young adults and high span readers were also lead down the garden path but they were able to resolve the temporary ambiguity without re-reading the sentence. These parallels between the reading patterns of older adults and low span individuals suggest that other differences between young and older adults, such as overall differences in vocabulary, processing speed, or the efficiency of inhibitory processes do not substantially contribute to older adults' sentence processing problems.

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Footnotes

[1] A secondary analysis compared first pass fixation times, regressions to the subject NP, and total fixation times for the 1st versus 4th block of trials. There were no significant effects of block or interactions with the block factor. A second follow-up analysis examined fixation times and regression data for those sentences corresponding to probe questions the participants answered correctly. The overall pattern of results was similar to that reported.

[2] High span readers answered 98% of the questions correctly about the filler sentences; low span readers answered 84% correctly, including the 10% of the filler probe questions that were correctly answered by "Don't know." This suggests that the low span readers were able to respond "Don't know" when they were uncertain of the answer to the probe question and that their incorrect answers to the questions about ambiguous sentences represent actual misinterpretations, rather than a reluctance to respond "Don't know."

[3] A secondary analysis compared first pass fixation times, regressions to the subject NP, and total fixation times for the 1st versus 4th block of trials. There was a marginally significant interaction between block and span, $F(1,28) = 3.020$, $p = .093$, $\eta 2 = .091$ for total fixation times to region 1. High span readers showed no effects of block but total fixation times for low span readers increased from block 1 to block 4 for all types of sentences. This suggests that Low span readers were becoming more sensitive to potential ambiguities by repeated exposure to these types of sentences. A second follow-up analysis examined fixation times and regression data for those sentences corresponding to probe questions the participants answered correctly. The overall pattern of results was similar to that reported.

Kemper, S., Crow, A., & Kemtes, K. (2004). Eye fixation patterns of high and low span young and older adults: Down the garden path and back again. *Psychology and Aging, 19*, 157-170..
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Table 1. Comparison of Young and Older Adults who Participated In Experiment I.

	Older Adults		Young adults			
Measure	*M*	*SD*	*M*	*SD*	*F*(1,19)	*p*
Age	75.2	3.0	19.7	1.9		
Education	15.2	2.6	13.5	0.6	3.935	.063
Vocabulary	33.2	2.3	30.3	3.2	5.342	.033
Digits Forward	4.9	1.6	7.1	1.2	12.168	.003
Digits Backward	3.7	0.9	5.6	1.3	13.261	.002
Reading Span	2.3	3.9	0.5	0.8	25.600	< .001

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Table 2. Comparison of Young and Older Adults classified as High and Low Span Participants In Experiment II.

	Young Adults				Older Adults			
	Low Span		High Span		Low Span		High Span	
Measure	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age	19.5	1.6	20.0	2.1	74.4	5.1	75.6	3.2
Education	13.6	0.5	13.5	0.5	14.5	3.0	14.8	2.2
Vocabulary	30.8	3.5	30.4	1.4	35.0	4.6	36.1	2.6
Digits Forward	5.5	0.5	7.5	0.9	4.2	0.9	6.8	0.8
Digits Backward	3.4	0.5	6.1	0.8	3.4	0.5	5.9	0.7
Reading Span	2.8	0.5	4.3	0.5	2.1	0.4	4.2	0.4
Waters & Caplan								
Span	2.3	0.4	3.8	0.3	2.1	0.5	3.6	0.3
RT (s)	5.8	0.4	3.9	0.5	6.1	0.6	4.3	0.6
Accuracy (%)	96.8	2.4	98.5	(1.4)	97.0	(1.3)	97.6	1.1

Table 3: Correlations between participants' scores on the working memory measures, education and vocabulary. Correlations for 36 young adults screen for participation are presented in the upper half-matrix; those for the 24 older adults screened for participation are presented in the lower half-matrix.

	Education	Vocabulary	Digits Forward	Digits Backward	Reading Span	W & C Span	W & C RT	W & C Accuracy
Education	--	.228	-.105	-.113	-.186	-.125	.013	.457*
Vocabulary	.361	--	.231	.187	.142	.213	.011	.428*
Digits Forward	-.164	.224	--	.746**	.753**	.336	.659**	-.212
Digits Backward	.084	.071	.731**	--	.652**	.475*	.631**	-.174
Reading Span	-.202	.246	.690**	.694**	--	.465*	.642**	-.215
W & C Span	-.076	.126	.289	.407*	.417*	--	.625**	-.127
W & C RT	.058	-.048	-.700**	-.775**	-.730**	-.650**	--	-.179
W & C Accuracy	.478*	.435*	-.312	-.310	-.255	-.215	-.118	--

$p < .05$; ** $p < .01$

Table 4. Percentage of questions answered correctly by High and Low Span participants for MV and RRC sentences.

	Young Adults				Older Adults			
	Low Span		High Span		Low Span		High Span	
Sentence Type	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
MV Ambiguous	75%	3.4	88%	3.4	73%	3.4	91%	3.4
RRC Ambiguous	54%	3.2	84%	3.2	54%	3.2	86%	3.3
MV Control	77%	3.3	84%	3.2	76%	3.3	82%	3.4
RRC Control	76%	2.9	85%	2.9	78%	2.9	86%	3.3

Table 5. Percentage of probe questions about the first verb phrase answered correctly by High and Low Span participants for THE and ONLY sentences.

	Young Adults				Older Adults			
	Low Span		High Span		Low Span		High Span	
Sentence Type	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
THE Ambiguous	44%	3.9	63%	0.9	45%	1.4	94%	2.4
ONLY Ambiguous	42%	3.9	93%	0.9	45%	2.9	94%	1.1
THE Unambiguous	90%	0.6	94%	0.7	90%	0.8	94%	0.7
ONLY Unambiguous	94%	0.9	93%	1.4	88%	2.3	92%	3.5

Figure Captions

Figure 1. First pass fixation times in msec/character (and *SE*s) for Older Adults and Young adults for ambiguous MV and RRC sentences and their unambiguous controls.

Figure 2. Regressions (and *SE*s) to the Subject NP for Older Adults and Young Adults for ambiguous MV and RRC sentences and their unambiguous controls.

Figure 3. Total fixation times in msec/character (and *SE*s) for Older Adults and Young Adults for ambiguous MV and RRC sentences and their unambiguous controls.

Figure 4. First pass fixation times in msec/character (and *SE*s) for High and Low Span readers for ambiguous MV and RRC sentences and their unambiguous controls.

Figure 5. Regressions (and *SE*s) to the Subject NP for High and Low Span readers for ambiguous MV and RRC sentences and their unambiguous controls.

Figure 6. Total fixation times in msec/character (and *SE*s) for High and Low Span readers for ambiguous MV and RRC sentences and their unambiguous controls.

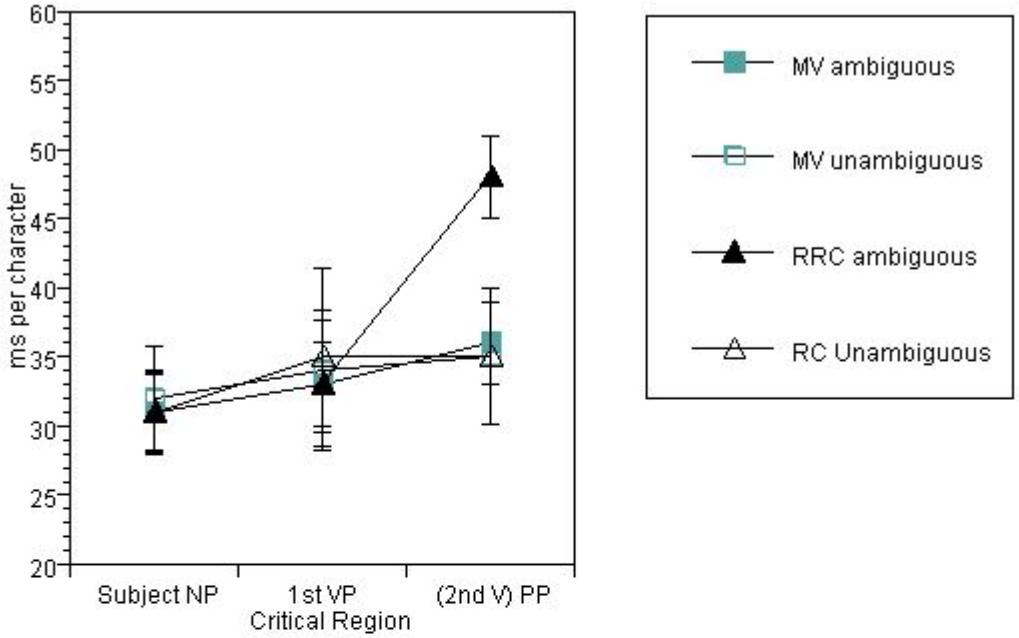
Figure 7. First pass fixation times in msec/character (and *SE*s) for High and Low Span readers for ambiguous THE and ONLY sentences and their unambiguous controls.

Figure 8. Regressions (and *SE*s) to the Subject NP for High and Low Span readers for ambiguous THE and ONLY sentences and their unambiguous controls.

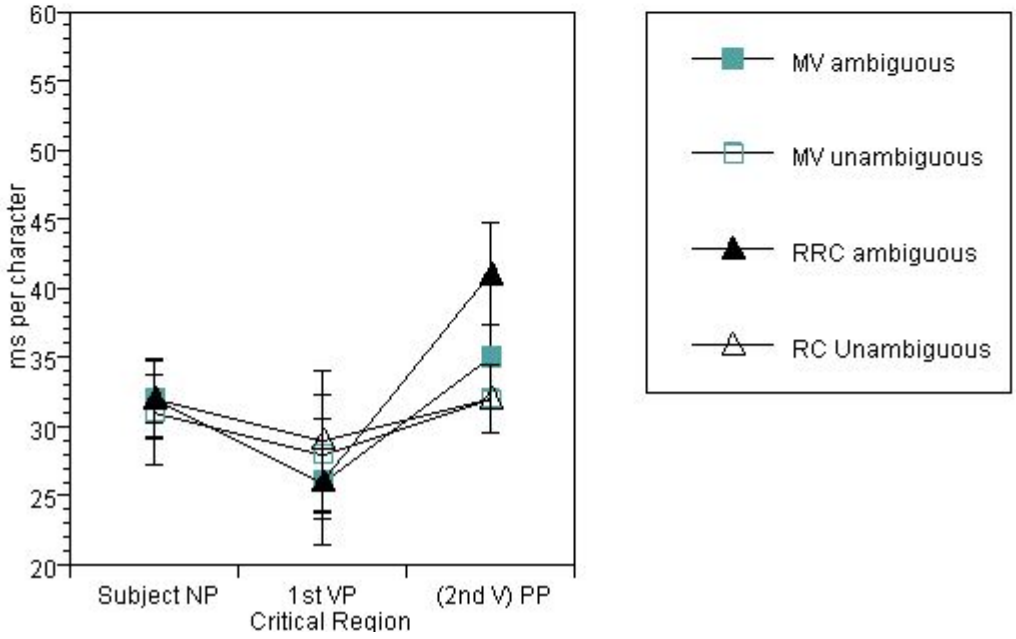
Figure 9. Total fixation times in msec/character (and *SE*s) for High and Low Span readers for ambiguous THE and ONLY sentences and their unambiguous controls.

First Pass Fixation Times

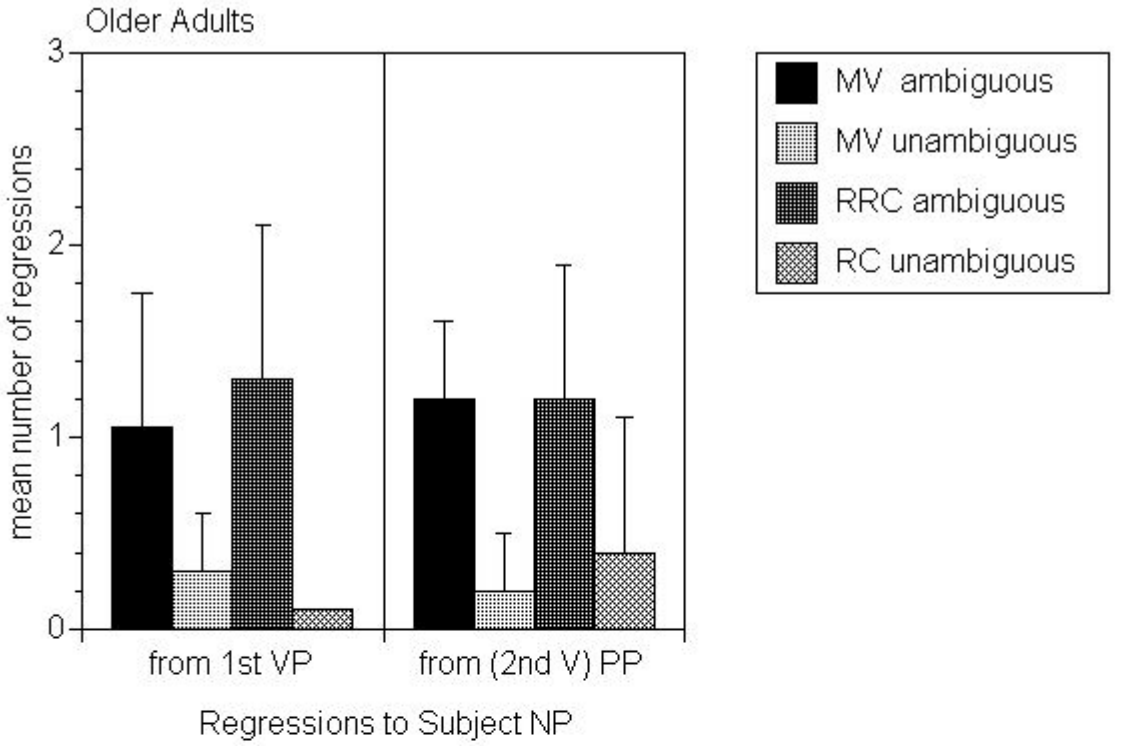
Older Adults

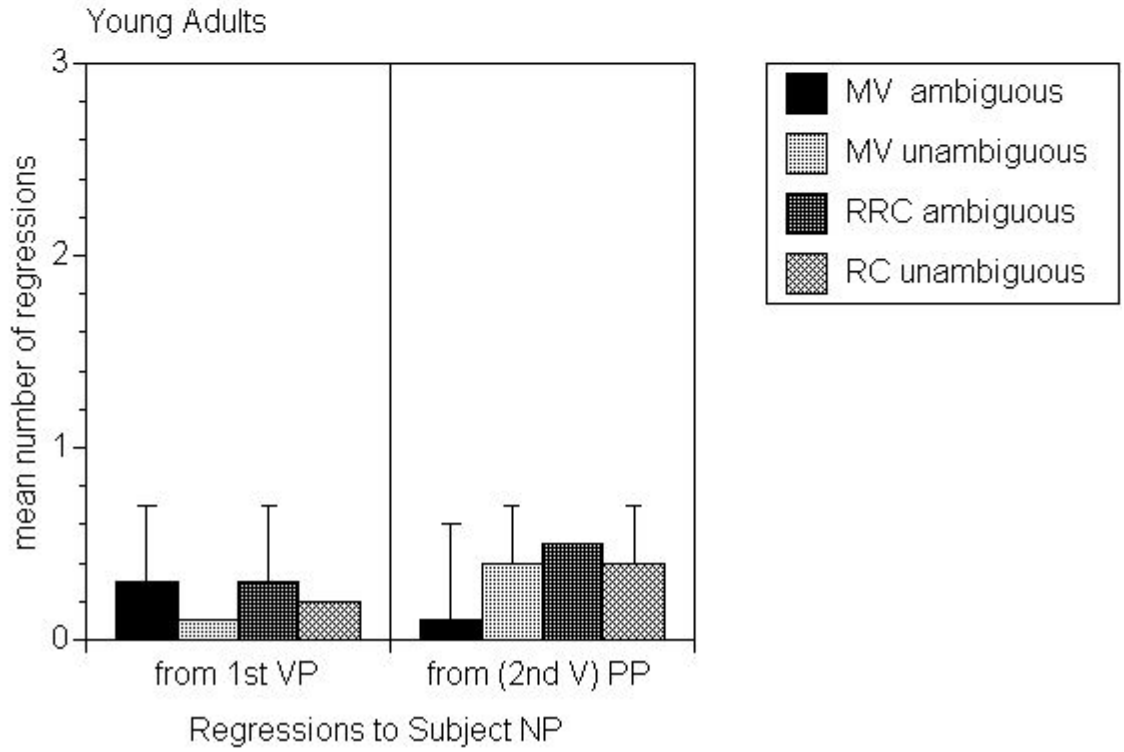


Young Adults

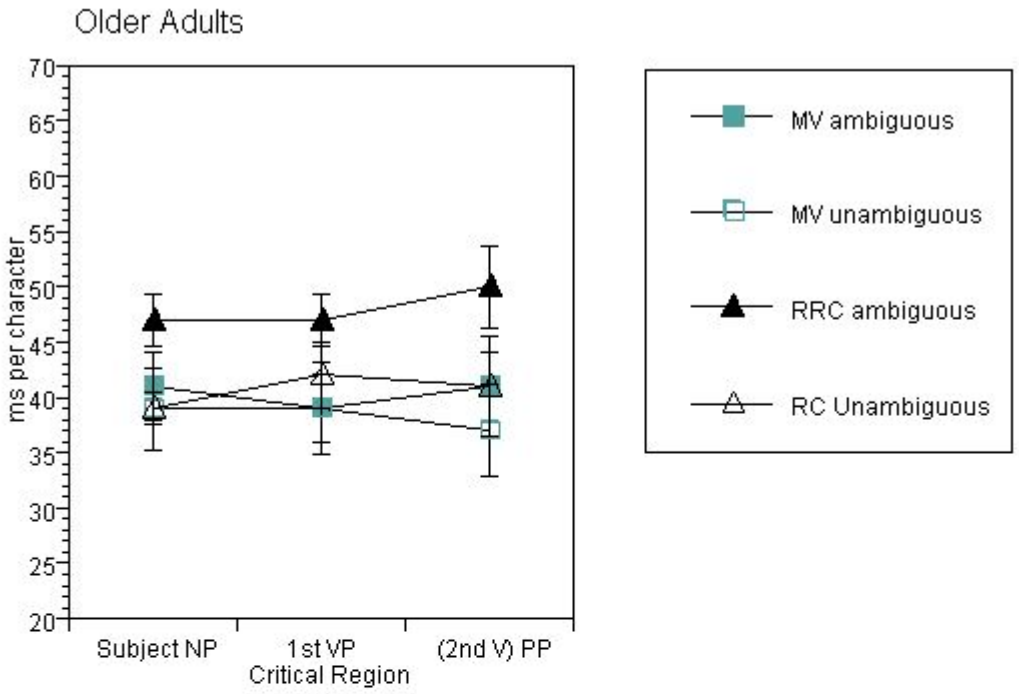


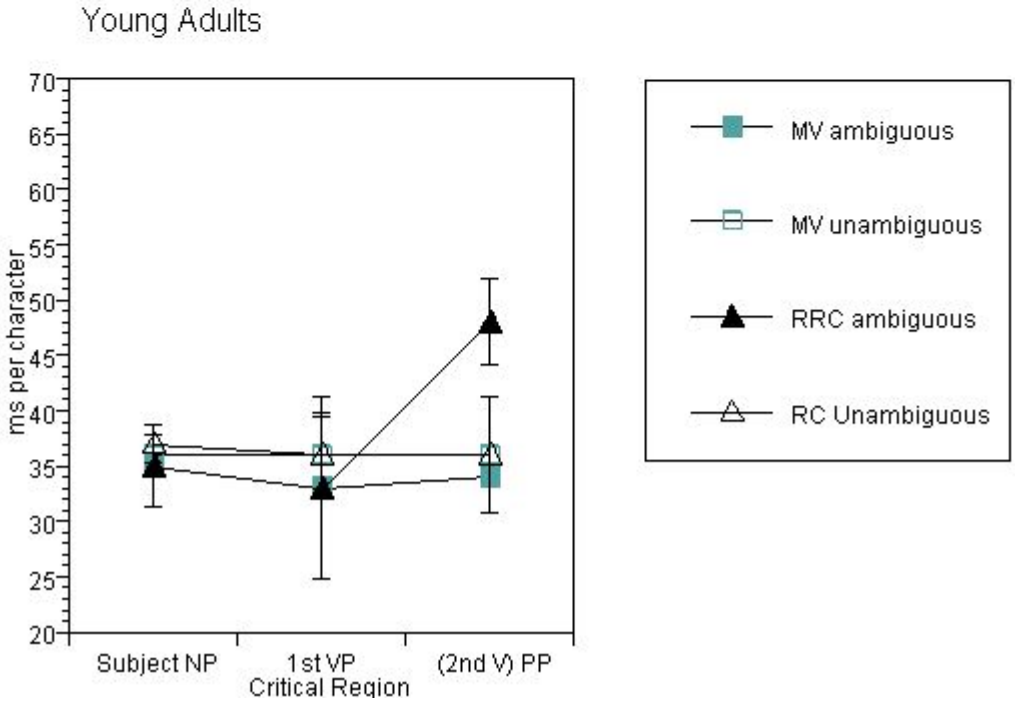
Regressions to SUBJECT NP





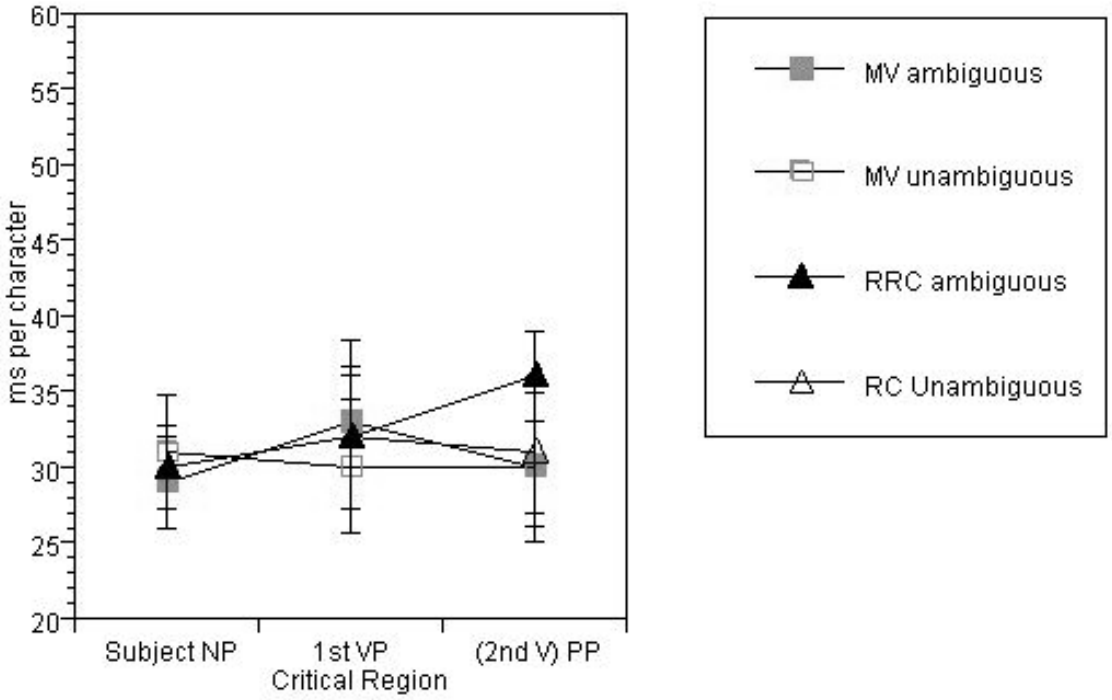
Total Fixation Times



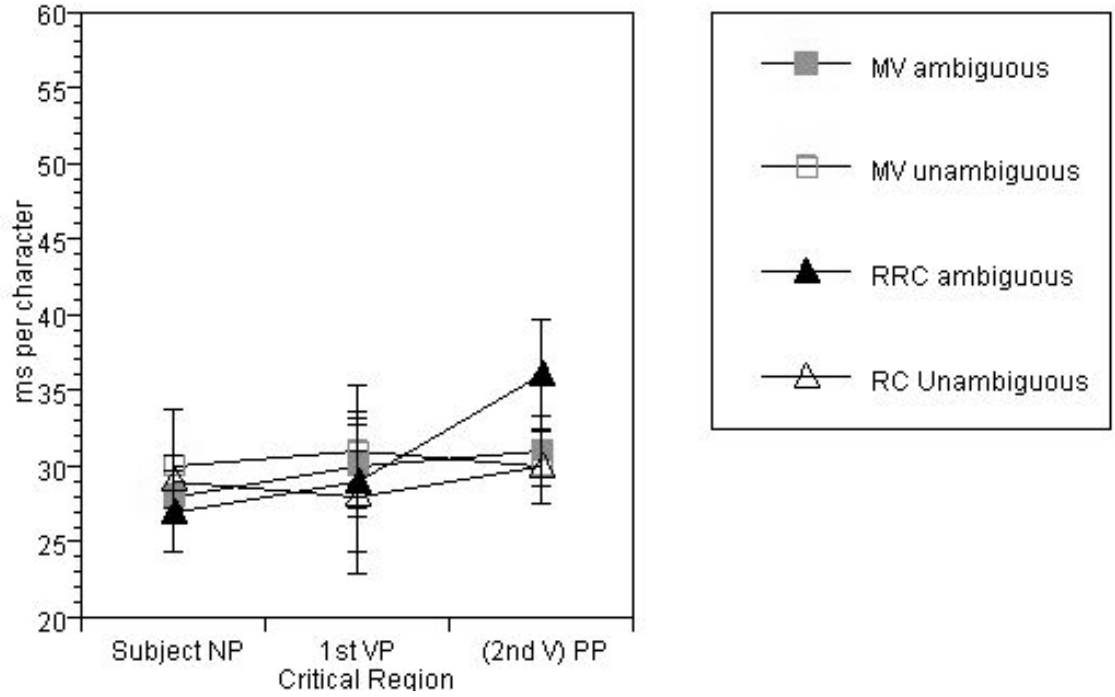


First Pass Fixation Times

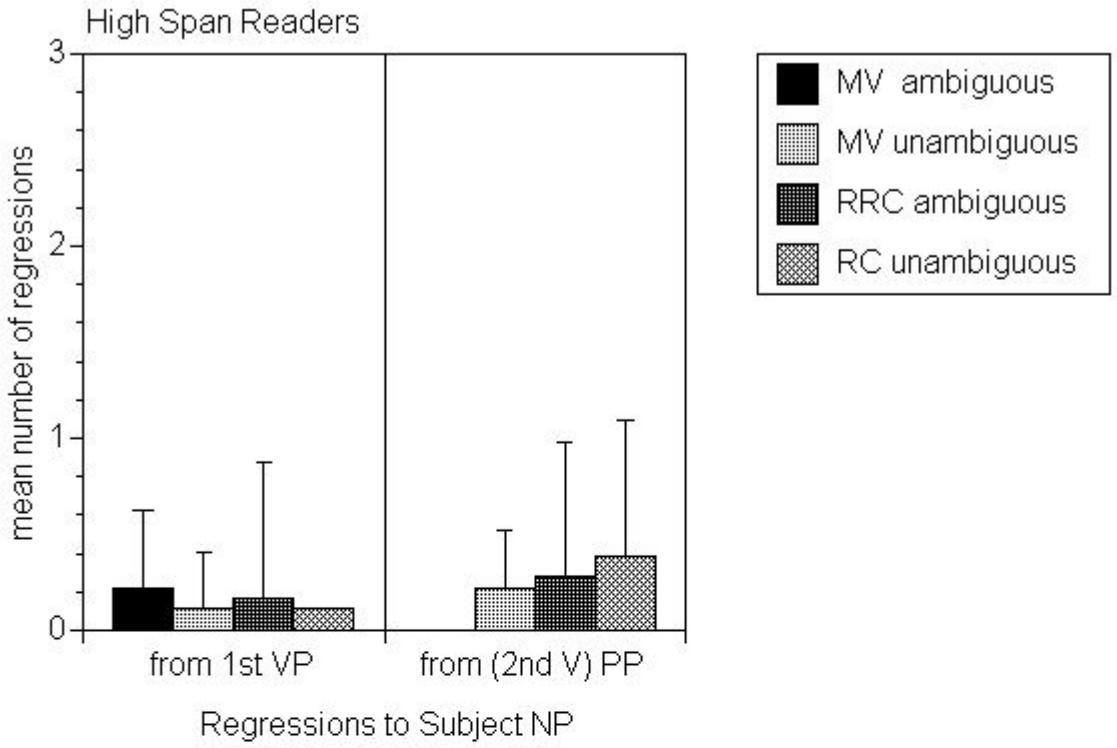
High Span Readers

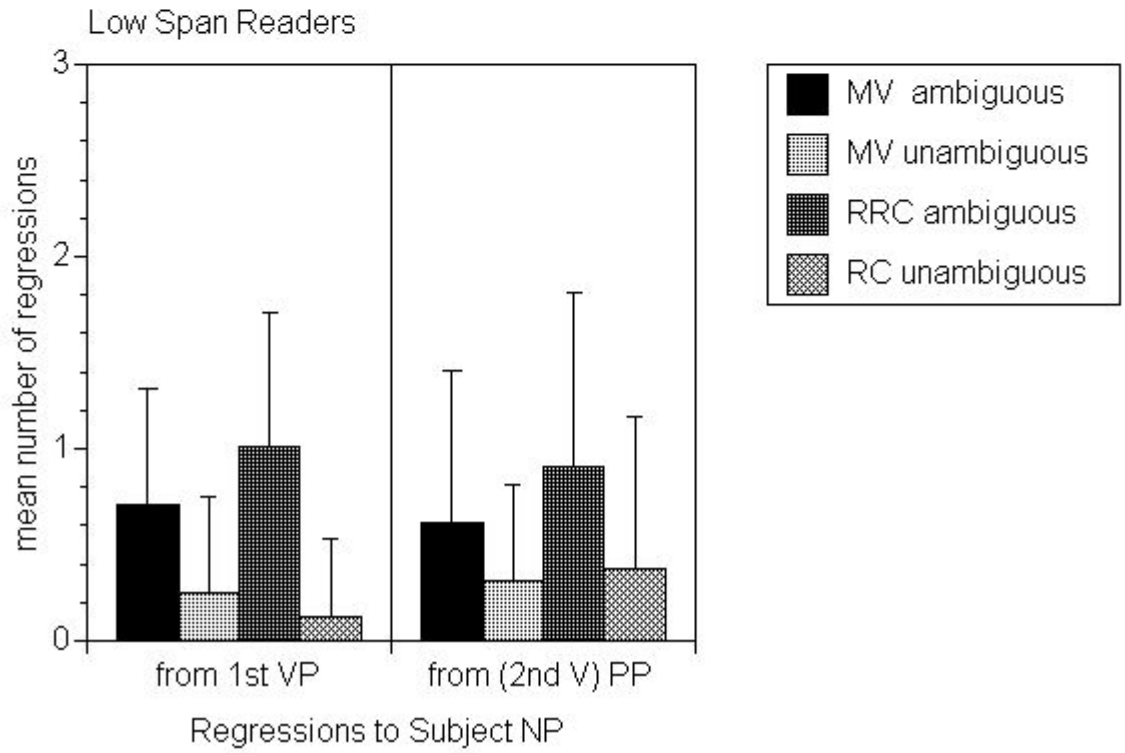


Low Span Readers



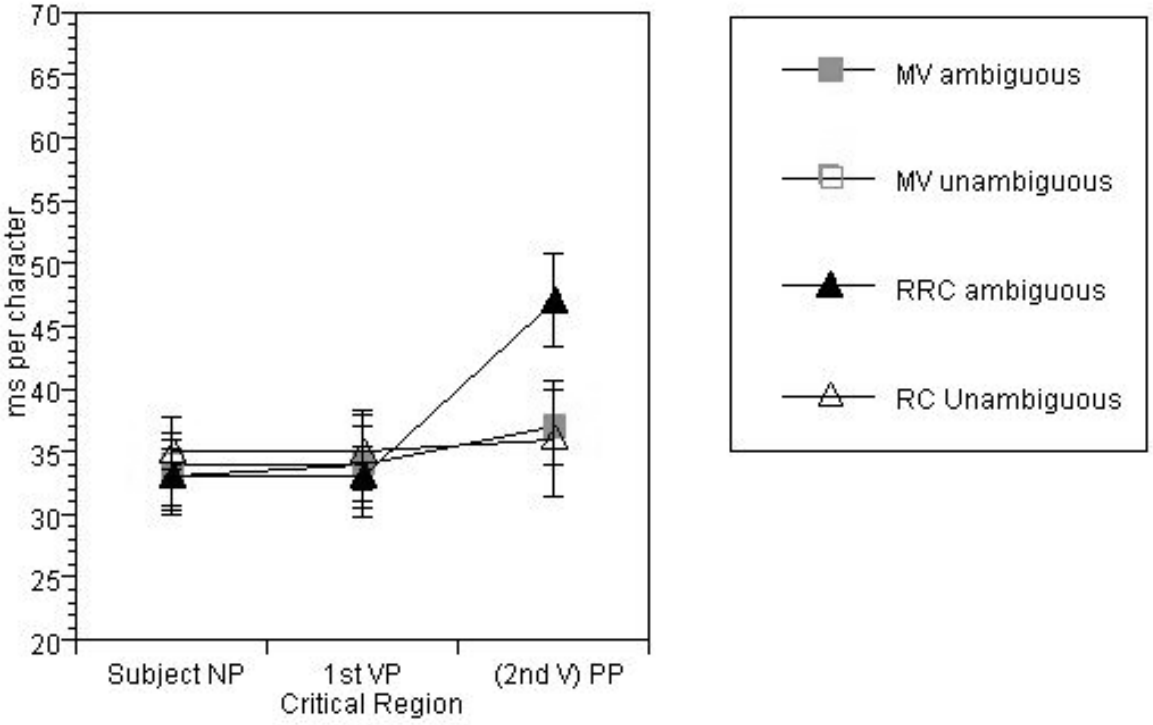
Regressions to SUBJECT NP



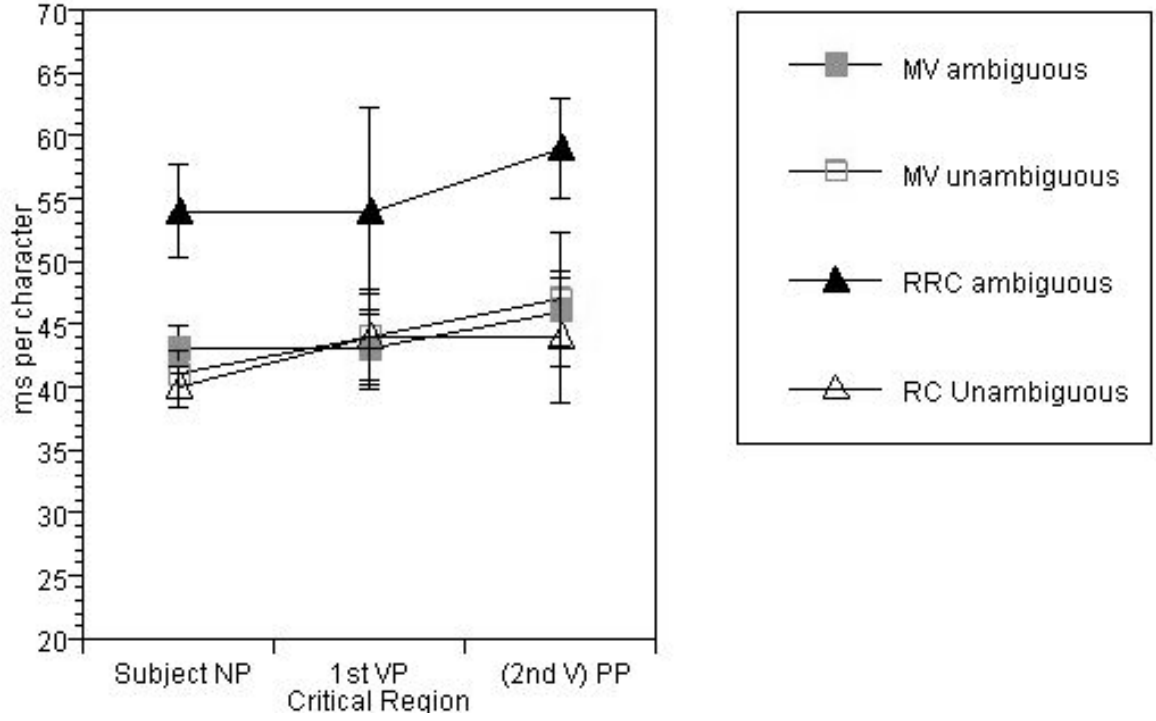


Total Fixation Times

High Span Readers



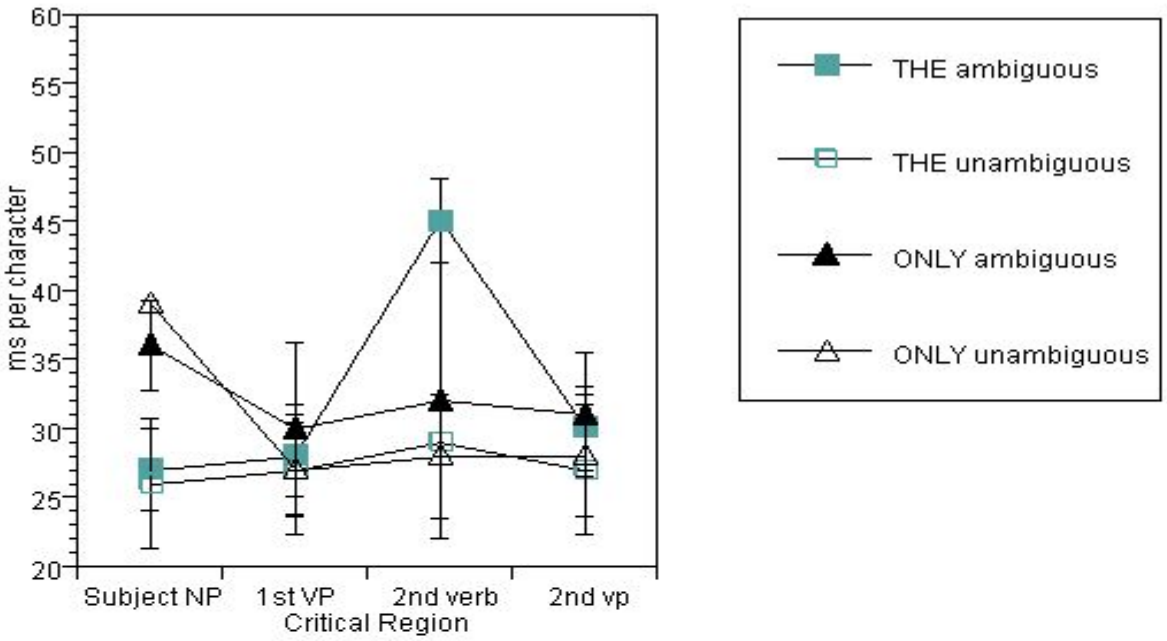
Low Span Readers



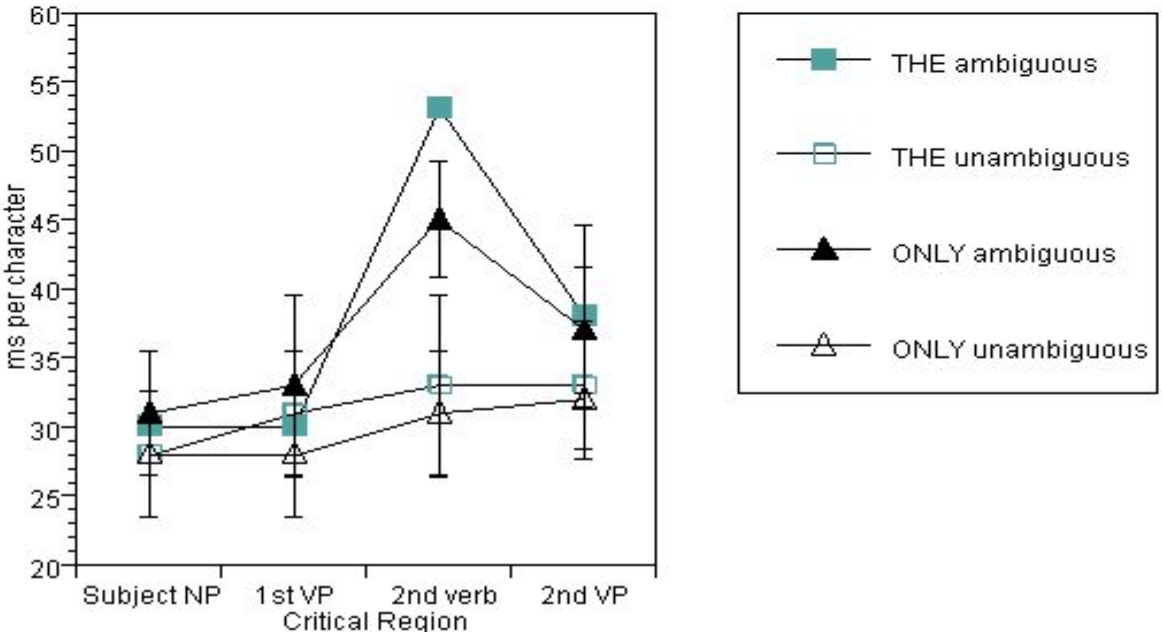
Fixation Patterns of High and Low Span Readers

First Pass Fixation Times

High Span Readers

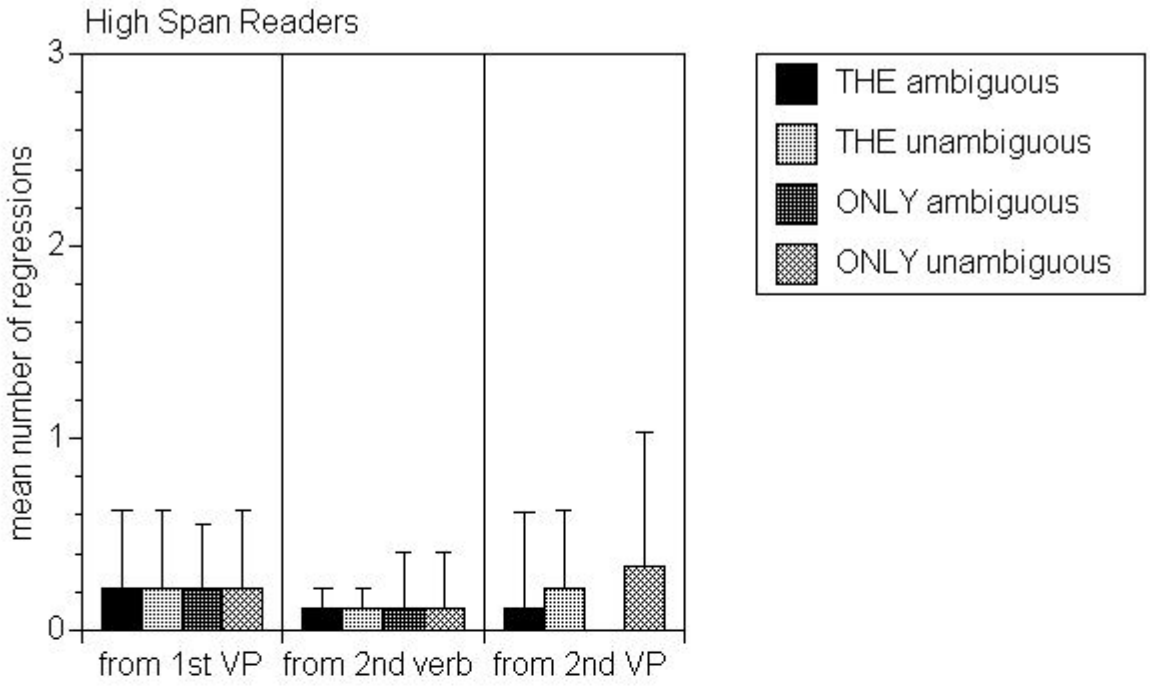


Low Span Readers

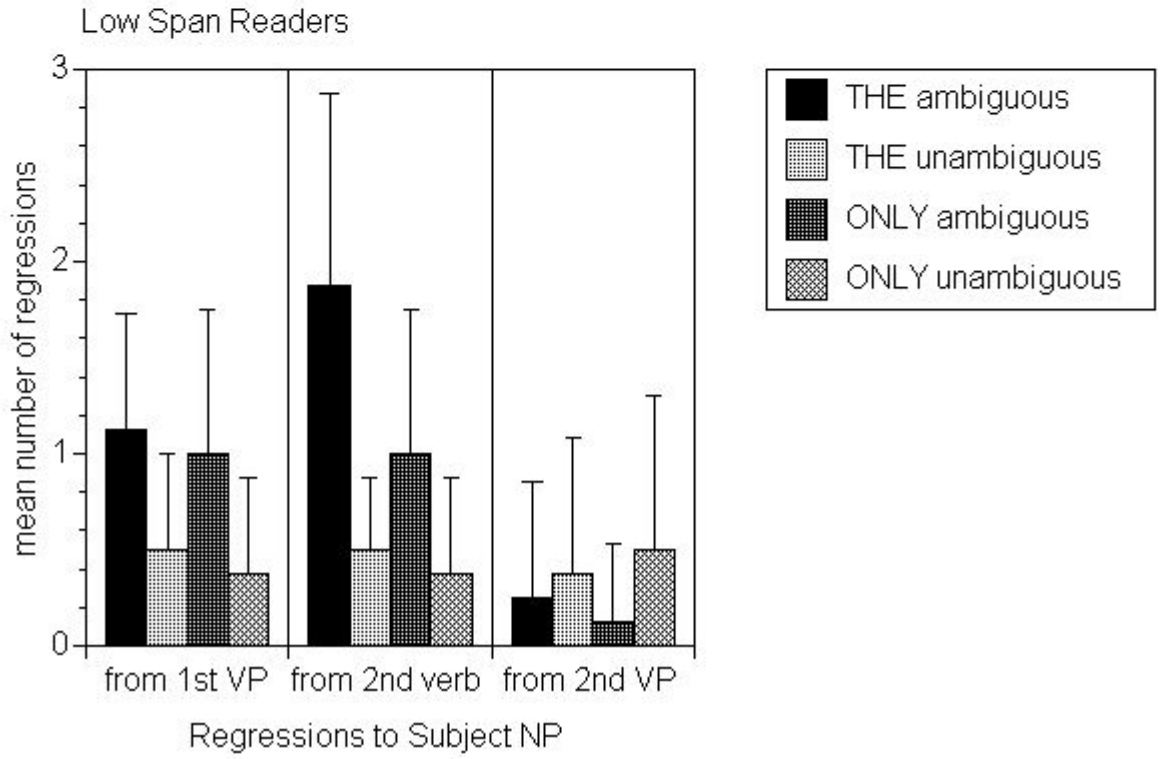


Fixation Patterns of High and Low Span Readers

Regressions to SUBJECT NP



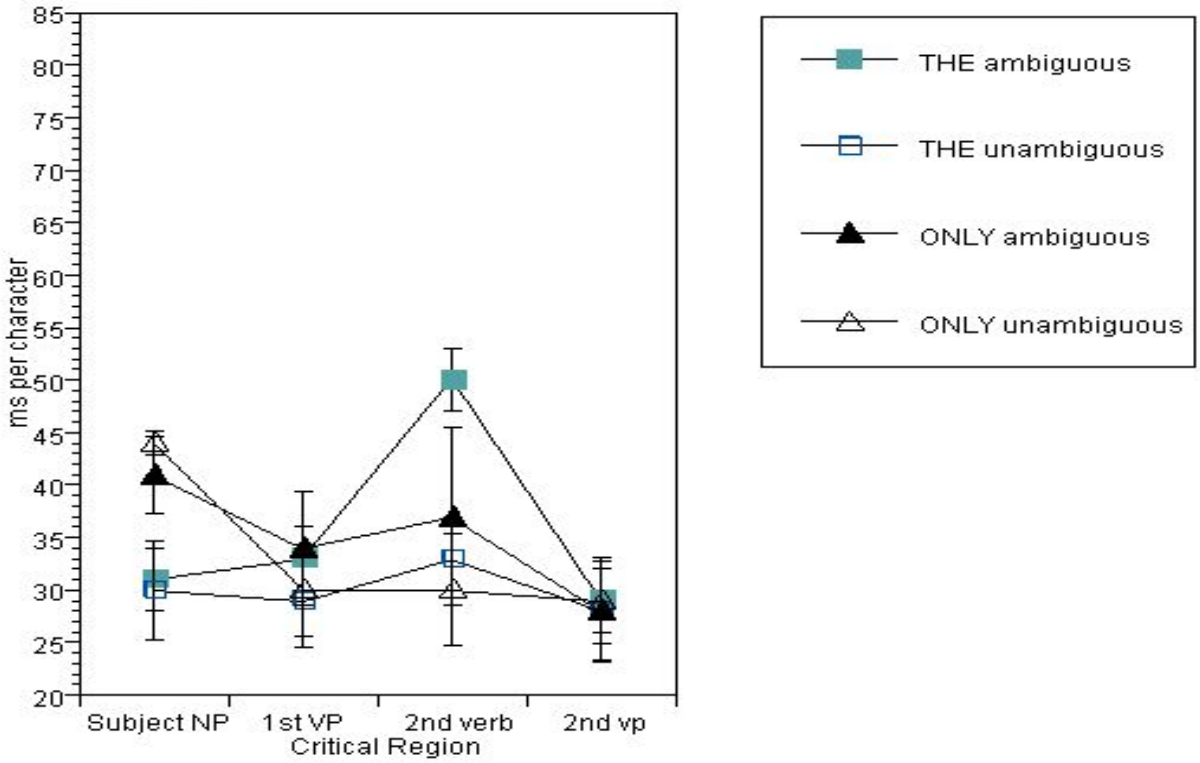
Regressions to Subject NP



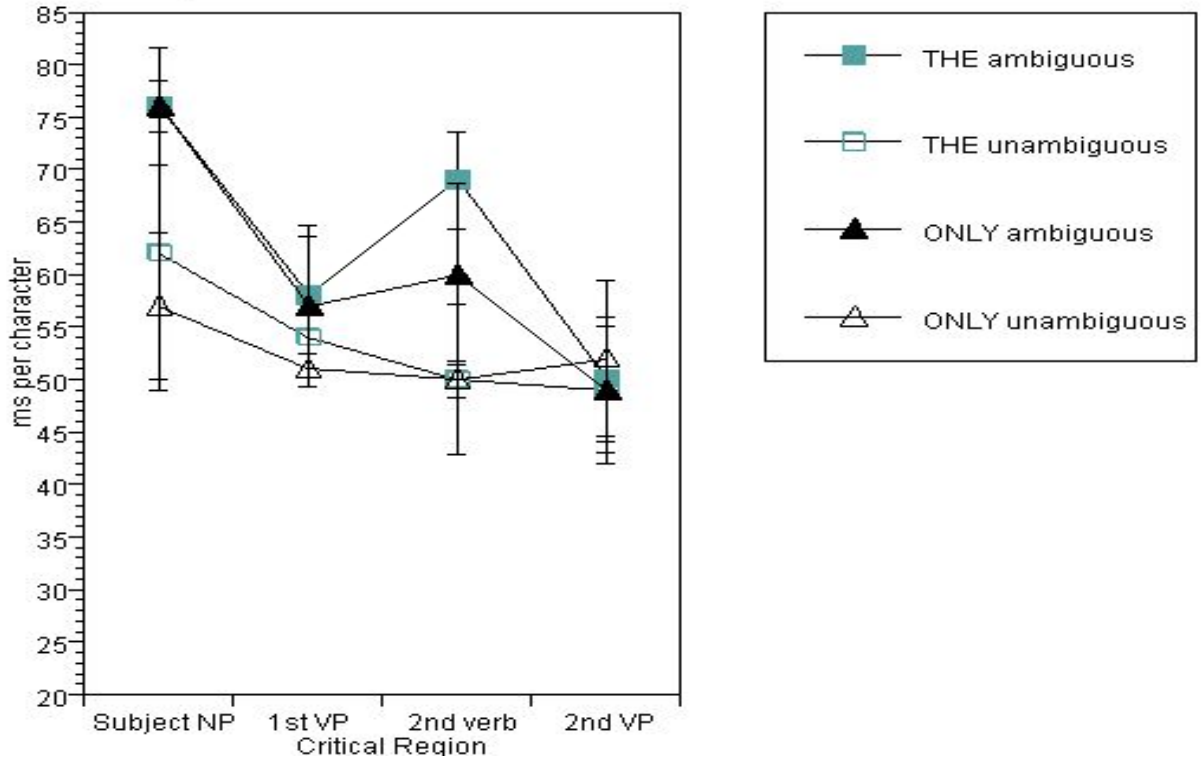
Fixation Patterns of High and Low Span Readers

Total Fixation Time

High Span Readers



Low Span Readers



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Appendix A

Unadjusted, raw reading time (msec) (SD) for MV/RRC sentences, Experiment 1.

	First Pass Fixations			Total Fixations		
	Region 1	Region 2	Region 3	Region 1	Region 2	Region 3
Young Adults						
Ambiguous						
MV	704 (358)	579 (251)	731 (342)	778 (358)	715 (364)	808 (415)
RRC	712 (372)	583 (260)	735 (361)	782 (363)	717 (351)	938 (451)
Unambiguous						
MV	705 (349)	568 (247)	728 (347)	787 (347)	720 (360)	815 (421)
RRC	709 (361)	562 (271)	732 (345)	769 (351)	714 (352)	801 (403)
Older Adults						
Ambiguous						
MV	712 (363)	693 (347)	728 (342)	965 (442)	984 (438)	989 (428)
RRC	707 (358)	701 (351)	995 (481)	962 (437)	978 (440)	1167 (524)
Unambiguous						
MV	717 (342)	684 (334)	722 (315)	960 (451)	987 (447)	974 (455)
RRC	701 (352)	694 (342)	718 (312)	968 (421)	981 (431)	978 (458)

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Appendix B

Unadjusted raw reading time (msec) (SD) for MV/RRC sentences, Experiment 2.

	First Pass Fixations			Total Fixations		
	Region 1	Region 2	Region 3	Region 1	Region 2	Region 3
Young Adults- High Span						
Ambiguous						
MV	661 (238)	702 (357)	681 (317)	714 (315)	718 (322)	767 (335)
RRC	657 (243)	682 (352)	772 (374)	722 (308)	701 (331)	979 (463)
Unambiguous						
MV	672 (231)	696 (343)	674 (325)	709 (312)	724 (334)	761 (347)
RRC	658 (245)	714 (325)	688 (323)	715 (324)	715 (327)	772 (341)
Young Adults- Low Span						
Ambiguous						
MV	671 (294)	684 (354)	670 (316)	934 (431)	923 (510)	963 (452)
RRC	654 (231)	692 (332)	784 (365)	1188 (592)	1142 (571)	1271 (563)
Unambiguous						
MV	645 (265)	707 (331)	672 (323)	948 (421)	917 (522)	951 (464)
RRC	672 (203)	709 (343)	684 (315)	937 (418)	907 (519)	942 (451)
Older Adults- High Span						
Ambiguous						
MV	662 (237)	691 (351)	677 (339)	725 (312)	731 (313)	754 (344)
RRC	654 (288)	715 (319)	778 (347)	719 (309)	720 (327)	981 (467)
Unambiguous						
MV	668 (254)	684 (333)	683 (312)	707 (308)	718 (315)	763 (342)
RRC	649 (233)	703 (349)	680 (310)	724 (315)	715 (337)	758 (337)
Older Adults- Low Span						
Ambiguous						
MV	652 (245)	697 (335)	672 (324)	946 (408)	922 (475)	962 (453)
RRC	684 (236)	685 (327)	788 (352)	1201 (603)	1137 (547)	1263 (548)
Unambiguous						
MV	672 (251)	712 (324)	678 (317)	951 (412)	913 (464)	947 (458)
RRC	649 (243)	693 (340)	687 (326)	948 (415)	910 (501)	938 (463)

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Appendix B, continued

Unadjusted, raw reading time (msec) (SD) for THE/ONLY sentences, Experiment 2.

	First Pass Fixations				Total Fixations			
	Region 1	Region 2	Region 3	Region 4	Region 1	Region 2	Region 3	Region 4
Young Adults – High Span								
Ambiguous								
THE	343 (205)	632 (351)	457 (283)	578 (284)	372 (287)	690 (342)	527 (391)	598 (331)
ONLY	432 (275)	647 (372)	388 (212)	563 (291)	516 (315)	692 (358)	420 (252)	593 (321)
Unambiguous								
THE	347 (215)	638 (363)	341 (224)	572 (281)	379 (241)	681 (373)	362 (278)	583 (314)
ONLY	447 (283)	642 (355)	337 (227)	568 (279)	524 (275)	683 (359)	348 (291)	592 (308)
Young Adults- Low Span								
Ambiguous								
THE	372 (214)	645 (362)	543 (319)	697 (359)	874 (417)	1287 (583)	643 (358)	978 (978)
ONLY	368 (263)	627 (365)	421 (201)	683 (363)	883 (421)	1283 (592)	587 (314)	983 (387)
Unambiguous								
THE	375 (231)	617 (353)	334 (208)	677 (351)	748 (394)	1115 (524)	494 (279)	972 (392)
ONLY	378 (215)	642 (368)	297 (211)	692 (357)	711 (385)	1078 (514)	504 (294)	977 (404)
Older Adults – High Span								
Ambiguous								
THE	351 (214)	637 (359)	463 (272)	574 (279)	367	658	418	563
ONLY	438 (289)	642 (357)	393 (207)	573 (274)	521	689	392	584
Unambiguous								
THE	342 (203)	638 (366)	339 (217)	568 (281)	371 (214)	703 (379)	351 (243)	564 (324)
ONLY	452 (280)	643 (355)	321 (221)	573 (274)	375 (227)	692 (382)	342 (251)	574 (337)
Older Adults- Low Span								
Ambiguous								
THE	368 (211)	644 (367)	547 (312)	681 (351)	864 (385)	1291 (587)	653 (372)	981 (458)
ONLY	374 (219)	649 (363)	451 (281)	694 (349)	879 (378)	1264 (572)	571 (319)	974 (463)
Unambiguous								
THE	362 (224)	657 (361)	325 (231)	696 (337)	735 (364)	1092 (491)	478(263)	958 (425)
ONLY	372 (219)	646 (347)	327 (235)	683 (342)	720 (342)	1015 (435)	514 (276)	963 (431)