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Eye Movements of Young and Older Adults during Reading

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Abstract

The eye movements of young and older adults were tracked as they read sentences varying in syntactic complexity. In Experiment 1, cleft object and object relative clause sentences were more difficult to process than cleft subject and subject relative clause sentences; however, older adults made many more regressions, resulting in increased regression path fixation times and total fixation times, than young adults while processing cleft object and object relative clause sentences. In Experiment 2, older adults experience more difficulty than young adults while reading cleft and relative clause sentences with temporary syntactic ambiguities created by deleting the "that" complementizers. Regression analyses indicated that readers with smaller working memories need more regressions and longer fixation times to process cleft object and object relative clause sentences. These results suggest that age-associated declines in working memory do affect syntactic processing.

Caplan and Waters (1999) have argued that syntactic processing and other interpretive processes rely on a specialized processing system with a separate sentence-interpretation resource, unrelated to traditional span measures of working memory. The Caplan and Waters' theory (1999) predicts similar patterns of on-line processing for all readers since interpretive processes are buffered from individual differences in working memory. Waters and Caplan (1996, 1997, 2001) have directly examined the hypothesis that working memory limitations affect older adults' ability to process complex sentences. These studies have used the auditory moving windows paradigm (Ferreira, Henderson, Anes, Weeks, & McFarlane, 1996). This technique allows the listener to start and stop the presentation of sentence and permits the analysis of phrase-by-phrase listening times, analogous to visual moving windows paradigms which permit the analysis of word-by-word or phrase-by-phrase reading times. The studies by Caplan and Waters typically examine the processing of subject- and object-relative clause constructions, such as those below:

Subject Relative Clause:

The lawyer that knew the banker asked for a loan.

Object Relative Clause:

The lawyer that the banker knew asked for a loan.

The subject relative clause construction imposes few processing demands on the reader or the listener: the subject of the main clause, *the lawyer*, is also the subject of the embedded relative clause. The object relative clause construction challenges the reader or listener to assign the correct syntactic relations: the subject of the main clause, *the lawyer*, must also be interpreted

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as the object of the embedded clause. A number of hypotheses have been put forth to account for the processing difficulty of object relative clauses including accounts based on working memory limitations (Gibson, 1998; Gordon, Hendrick, & Johnson, 2001; Traxler, Williams, Blozis, & Morris, 2005; Wanner & Maratsos, 1978), syntactic misanalyses (Clifton & Frazier, 1989; Traxler, Pickering, & Clifton, 1998), or semantic and pragmatic factors (Trueswell, Tanenhaus, & Kello, 1993). Recently, Traxler, Williams, Blozis, and Morris (2005) suggest that greater working memory capacity allows readers to more easily process complex constructions, perhaps because they are more sensitive to syntactic, semantic, and pragmatic cues to syntactic structure (Pearlmutter & MacDonald, 1995).

In order to examine whether working memory limitations affect syntactic processing, Waters and Caplan (2001) have compared how young and older readers process relative clause sentences. Despite age-group differences in working memory, listening times were distributed similarity across segments by young and older listeners. All paused longer when they heard the embedded verb in the object relative clause sentences than when they heard the corresponding verb in the subject relative clause version; this additional time was attributed to the extra processing required to recover the direct object of the embedded verb. They found no evidence that differences in age or working memory lead to different processing strategies.

A similar conclusion was reached by DeDe, Caplan, Kemtes, and Waters (2004) who used structural equation modeling to examine the contributions of traditional span measures of working memory to age-related differences in syntactic processing using the auditory moving windows paradigm. In their analyses, age was significantly related to working memory and to syntactic processing but there was no direct effect of working memory on syntactic processing. Working memory did mediate age differences in other measures of language processing such as text comprehension. They conclude that syntactic processing involves a separate working memory than that measured by span measures.

Waters and Caplan's choice of the auditory moving window paradigm over other, more widely accepted techniques such as word-by-word reading paradigms or eye tracking paradigms is problematic. They defend the auditory moving window paradigm as “not obviously less natural” (Waters & Caplan, 2001, p. 130) than other techniques. However, it may conflict with the findings of Wingfield and his colleagues who compared young and older adults' segmentation strategies, preferred presentation times, and allocation of processing time during listening and reading tasks. Wingfield et al. (1989, 1999) showed that older adults prefer slower speech rates but also smaller segments than young adults. Stine-Morrow et al. (1995) showed that older adults ignore clause, phrase, and sentence boundaries. Waters and Caplan segment the sentences so that they can compare listening times for words or phrases used in different constructions. Some segments are single words, some noun phrases, some a “that” complementizer plus a noun phrase. Hence, participants do not control the length of segments or the location of segment boundaries, only the interval between the presentation of one segment and the next. It may be that this imposed segmentation conflicts with older adults' natural segmentation strategies, obscuring any difference in the remaining processing parameter, time, due to age or working memory. A task that permits participants to control both segmentation and presentation may be more sensitive to individual differences in syntactic processing than the auditory moving window paradigm.

A recent study by Kemper, Crow, and Kemtes (2004) using eye-tracking methodology re-examined these issues. Eye-tracking is a naturalistic task that imposes few restrictions on readers; they are free to skip words or phrases, read ahead and glance backwards, and re-read entire segments. Eye-tracking has been shown to be sensitive to working memory, syntactic, semantic, and pragmatic factors that affect sentence processing (Rayner, 1998; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989; Traxler, Morris, Seely, 2002; Traxler et al., 2005). Using this technology, Kemper et al. examined three aspects of reading: first fixations to key phrases, regressions to earlier phrases, and the total time key phrases were fixated. They examined reduced relative clause sentences such as those below:

Reduced Relative Clause Sentence:

Several angry workers warned about the low wages decided to file complaints.

Main Clause Sentence:

Several angry workers warned about the low wages during the holiday season.

Focused Reduced Relative Clause Sentence:

Only angry workers warned about the low wages decided to file complaints.

Kemper, Crow, and Kemtes (2004) found partial support for Waters and Caplan's theory: young and older adults' first pass fixations were alike and both groups showed a clear “garden path” effect: a peak in fixation time at the second verb in reduced relative clause sentences but not at the verb in main clause sentences. This garden path effect suggests that all readers initially interpret the first verb as the main verb and must reanalyze it when they encounter the second verb in the reduced relative clause sentence. However, Kemper et al. also observed an increase in regressions and in regression path times for older readers for the reduced relative clause sentences, suggesting that older adults were unable to correctly parse these sentences. Further, low span readers, identified by their scores on a battery of working memory tests, also produced more regressions and an increase in regression path times for reduced relative clause sentences, suggesting that they were unable to correctly parse the sentences. The results from the eye-tracking analysis of the focused reduced relative clauses sentences also posed problems for Caplan and Water's theory: high span readers initially allocated additional processing time the first noun phrase and then were able to avoid the “garden path” because the focus operator “only” led them to correctly interpret the first verb phrase as a reduced relative clause.

Thus eye-tracking studies poses some challenges to Waters and Caplan's theory by revealing age group and span group differences in reading. Eye-tracking may be more sensitive to individual differences in language processing that the auditory-moving window paradigm and may reveal subtle differences in processing strategies that other techniques miss. The present experiment used eye-tracking to compare young and older adults' processing of unambiguous clauses differing in the locus of embedding and the form of the embedded sentences that are similar to the sentence paradigms used by Waters and Caplan (2001). According to Caplan and Waters theory (1999), if working memory limitations indexed by span measures do not affect syntactic processing, older and young adults differing in working memory span should show similar patterns of eye fixations.

Experiment 1

Method

Participants—Twenty-nine young and 39 older adults were tested in the present study. Young participants were recruited by signs posted on campus or by word of mouth through referrals. Older adults were recruited by phone solicitation from a panel of past research participants and through referrals by participants. All were native English speakers. The eye tracking system could not record the eye-movements of 4 young participants and 11 older participants due to technical problems caused by their eyeglasses or contact lens. One young participant and four older participants made more than 20% errors on the on-line processing test (see below) and were excluded from further analysis. As a result, 24 young and 24 older adults were included in the final analysis. The mean age for young adults was 20.5 years (*SD* = 3.1) and for older adults was 72.8 years (*SD* = 5.9). The mean years of education for young adults was 13.8 years (*SD* = 1.4) and for older adults was 15.6 years (*SD* = 2.6), $F(1, 46) = 9.32$, $p = .004$. The Digits Forward and Digits Backward tests (Wechsler, 1958) and the Daneman and Carpenter (1980) reading span tests were used to measure working memory capacity. The data were presented in Table 1. Young and older adults did not differ significantly on either digit span test but older adults had significantly lower reading spans than young adults; a composite (Loehlin, 1992) formed from these variables using confirmatory factor analysis did differ significantly between groups, $F(1, 46) = 23.30$, $p < .001$. Shipley's (1940) vocabulary test was used to measure vocabulary ability. Older adults had higher scores than young adults.

Materials—Sentence stimuli were constructed by varying the location and type of an embedded clause. They consisted of pairs of cleft object and cleft subject sentences and pairs of subject relative clause sentences and object relative clause sentences. See Table 2 for example sentences. There were 10 pairs of each type of sentence. All noun phrases were animate. The sentences were segmented into critical regions following Traxler et al. (2002). For cleft sentences, the critical region was the relative clause. For object- and subject- relative clause sentences, there were two critical regions, the relative clause and the main verb.

Two lists of experimental sentences were constructed by assigning the members of each pair of sentences to different lists and randomly ordering the sentences within each list. In addition, there were 80 filler sentences in each list for a total of 120 sentences. There were 18 practice sentences followed by four blocks of 30 sentences. The eye tracker was re-calibrated between blocks. Participants were randomly assigned to sentence lists. One-half of the experimental sentences and one-half of the fillers were followed by probe questions. The probe questions for the experimental sentences required the participant to correctly identify the subject or object of the relative clause.

In addition, a sentence acceptability judgment task was administered after the reading task. It was modeled after that of Waters and Caplan (2001). This task was included to verify whether all readers were able to comprehend the experimental stimuli. Cleft-subject, cleft-object, subject-relative, and object-relative clause sentences were tested. Forty new meaningful sentences and 40 meaningless sentences, e.g., *It was the food that saw the dog* or *The gardener that planted the cloud was fired*, were used. Experimental or filler sentences used in the reading task were not repeated. Meaningless sentences were semantically anomalous but grammatically well-formed.

Task and Procedure—Participants were first given the battery of working memory tests and the vocabulary test. They were then seated before the eyetracker computer monitor. 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-focal glasses. The participants also wore a visor with a small magnetic sensor attached. 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. The sentences were presented in a 17 in flat panel computer screen at a viewing distance of 16 in. The fixation point a 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° (horizontal). The participants held a computer mouse in their preferred hand which was used to control sentence presentation. Participants answered the probe questions aloud and their responses were recorded by the experimenter.

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° 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° 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 microcomputer running the GazeTracker software for presentation and analysis.

Four fixation measures were computed for each critical region of the sentences: the duration of the first pass fixations to the region, the number of first-pass regressions from the region, the regression path time for the region, and the total fixation time to the region. Fixations were defined as a minimum of two sampled eye positions occurring with a fixation diameter of .5° of visual angle (approximately 1 character), or with a minimum duration of 100 msec. First pass fixation duration was defined as the summed duration of all fixations to a region beginning with the first fixation to the region and ending with first fixation rightward or leftward outside of the region. First-pass regressions were defined as left-ward regressions from a region following a first-pass fixation. Regression path time included fixations from the first fixation to a region until the first fixation rightward outside of the region (or until the participant looked away from the sentence); it included re-fixations resulting from leftward regressions to a critical region. Total time is the sum of all fixations to a region; on occasion, participants re-read sentences after briefly looking away from the sentence, increasing total reading times to all regions. Participants with a high error rate, defined as 20% or greater errors on the probe questions, were excluded from the analysis. For the remaining participants, accuracy rates were uniformly high, averaging over 90% correct, and did not differ with age group or sentence type.

Following the reading task, the participants were given a sentence acceptability judgment task. EPRIME (Schneider, Eschman, & Zuccolotto, 2002) was used to collect the acceptability judgments and decision times. Participants were instructed to read each sentence and to decide if the sentence was an “acceptable English sentence” or not. Reaction times, from the onset of the sentence until the participant pressed a response key, were recorded along with the judgment.

Results

Results of the analysis of eye fixation patterns are first presented followed by a regression analysis examining how individual differences affect fixation patterns. Finally, the results of the off-line sentence acceptability judgment task are presented. All fixations were analyzed with square root transformations to normalize distributions. The results are organized by sentence type. Separate analyses were conducted for each critical region as specified below. Lower order main effects of age group or sentence type that are subsumed by significant age group by sentence type interactions are not reported.

Cleft sentences—First pass fixation times, regressions, regression path times, and total times for subject and object cleft sentences were averaged across trials for each participant and analyzed with 2 (age group) by 2 (sentence type) ANOVAs for the critical region, the relative clause. Readers had more difficulty processing the relative clause in cleft object sentences than in cleft subject sentences as indicated by significant main effects for regressions ($F1(1, 46) = 15.949$, $p < .001$, $\eta^2 = .423$, $F2(1, 18) = 8.325$ $p < .01$, $\eta^2 = .431$), regression path times ($F(1, 46) = 37.681$, $p < .001$, $\eta^2 = .450$, $F2(1, 18) = 6.607$, $p < .05$, $\eta^2 = .433$), and total times ($F(1, 46) = 52.325$, $p < .001$, $\eta^2 = .783$, $F2(1, 18) = 7.125$, $p < .05$, $\eta^2 = .456$); the main effect for first pass fixations was not significant, $F1(1, 46) = 1.532$, $p > .05$, $F2(1, 18) < 1.0$, $p > .05$.

Older adults experienced additional difficulty processing the relative clause region of the cleft object sentences, leading to significant age group by sentence type interactions for regressions, regression path fixations, and total time measures (first pass fixations: $F(1, 46) < 1.00$, $F2(1, 20) < 1.0$; regressions: $F1(1, 46) = 5.124$, $p = .05$, $\eta^2 = .124$, $F2(1, 18) = 3.45$, $p > .05$, $\eta^2 = .131$; regression path times: $(F(1, 46) = 52.414$, $p < .001$, $\eta^2 = .622$, $F2(1, 18) = 24.409$, $p < .001$, $\eta^2 = .503$; and total times: $F(1, 46) = 58.538$, $p < .001$, $\eta^2 = .675$, $F2(1, 18) = 23.392$, $p < .001$, $\eta^2 = .475$). As indicated in Table 3, the subject-object difference for the relative clause region was greater for older adults than for young adults for regressions (OA: 4.0 regressions; YA: 1.1 regressions), regression path fixations (OA: 664 ms; YA: 302 ms), and total times (OA: 553 ms; YA: 232 ms), all $t(46) > 5.36$, $p < .05$.

Relative Clause Sentences—First pass fixation times, regressions, regression path times, and total times for subject and object relative clause sentences were analyzed with a 2 (age group) by 2 (sentence type) ANOVAs for the two critical regions, the relative clause and the main verb. Readers had more difficulty processing the relative clause in object relative clause sentences than in subject relative clause sentences as indicated by significant main effects for regressions ($F1(1, 46) = 6.016$, $p < .05$, $\eta^2 = .216$, $F2(1, 18) = 7.082$, $p < .05$, $\eta^2 = .244$), regression path times $(F1(1, 46) = 21.457$, $p < .001$, $\eta^2 = .718$, $F2(1, 18) = 5.984$, $p < .05$, $\eta^2 = .233$), and total times $(F1(1, 46) = 43.281$, $p < .001$, $\eta^2 = .674$, $F2(1, 18) = 6.531$, $p < .05$, $\eta^2 = .324$); the main effect for first pass fixations was not significant, $F1(1, 46) = 1.365$, $p > .05$, $F2(1, 18) = 1.637$, $p > .05$.

Older adults experienced additional difficulty processing the relative clause region of the object relative clause sentences, leading to significant age group by sentence type interactions for regressions, regression path fixations, and total time measures (first pass fixations: $F(1, 46) < 1.00$, $F2(1, 20) < 1.0$; regressions: $F1(1, 46) = 4.295$, $p < .05$, $\eta^2 = .085$, $F2(1, 18) < 1.0$, $p > .05$, $\eta^2 = .031$; regression path times: $(F1(1, 46) = 6.830$, $p < .05$, $\eta^2 = .113$, $F2(1, 18) = 3.562$, $p > .05$, $\eta^2 = .103$; and total times: $F1(1, 46) = 28.483$, $p < .001$, $\eta^2 = .652$, $F2(1, 18) = 12.654$, $p < .001$, $\eta^2 = .425$). As indicated in Table 4, the subject-object difference for the relative clause region was greater for older adults than for young adults for regressions (OA: 3.1 regressions; YA: 1.6 regressions), regression path fixations (OA: 643 ms; YA: 335 ms), and total times (OA: 891 ms; YA: 398 ms), all $t(46) \geq 4.83$, $p < .05$

Readers also had more difficulty processing the main verb in object relative clause sentences than in subject relative clause sentences as indicated by significant main effects for regressions ($F1(1, 46) = 5.874$, $p < .05$, $\eta^2 = .216$, $F2(1, 18) = 7.082$, $p < .05$, $\eta^2 = .244$), regression path times $(F1(1, 46) = 7.979$, $p < .01$, $\eta^2 = .510$, $F2(1, 18) = 9.002$, $p < .01$, $\eta^2 = .440$), and total times $(F1(1, 46) = 23.048$, $p < .001$, $\eta^2 = .653$, $F2(1, 18) = 5.61$, $p < .05$, $\eta^2 = .294$); the main effect for first pass fixations was not significant, $F1(1, 46) = 1.365$, $p > .05$, $F2(1, 18) = 1.637$, $p > .05$.

Older adults' difficulty processing object relative clause sentences extended to the main verb region, leading to significant age group by sentence type interactions for regressions, regression path fixations, and total time measures (first pass fixations: $F1(1, 46) < 1.00$, $F2(1, 20) < 1.0$; regressions: $F1(1, 46) = 5.787$, $p < .05$, $\eta^2 = .124$, $F2(1, 18) < 1.0$, $p > .05$, $\eta^2 = .005$; regression path times: $(F1(1, 46) = 9.071$, $p < .01$, $\eta^2 = .452$, $F2(1, 18) = 2.478$, $p > .05$, $\eta^2 = .115$; and total times: $F1(1, 46) = 14.280$, $p < .01$, $\eta^2 = .465$, $F2(1, 18) = 5.890$, $p < .05$, $\eta^2 = .291$). As indicated in Table 4, the subject-object difference for the main verbs were greater for older adults than for young adults for regressions (OA: 12.8 regressions; YA: 10.3 regressions), regression path fixations (OA: 502 ms; YA: 300 ms), and total times (OA: 718 ms; YA: 315 ms), all $t(46) \geq 6.91$, $p < .05$.

Summary of Eye Tracking Results—Cleft object and object relative clause sentences were more difficult to process than cleft subject and subject relative clause sentences, as indicated by increased regressions, increased regression path fixation times, and increased total fixation time. Older adults made many more regressions, resulting in increased regression path fixation times and total fixation times, than young adults while processing cleft object and object relative clause sentences. This finding suggests that aging exacerbates the processing problems created by cleft objects and object relative clause.

Regression analysis—A series of regression analyses were conducted to examine how individual differences affected fixations to the critical regions. The predictor variables were the participants' age, years of education, score on the Shipley vocabulary test, and the working memory composite latent factor score derived from the digit span and reading span scores. The dependent variables were the number of regressions, regression path fixations, and total fixation times for the critical regions of the cleft object and object relative clause sentences. The analysis was conducted in two stages. First: fixation measures for cleft subject and subject relative clause sentences were entered into the regression models for the cleft object and object relative clause sentences, respectively, to control for basic syntactic processes. Second, the participants' age, education, vocabulary, and working memory scores were entered simultaneously. Table 5 summarizes the results. The working memory composite did account for significant variance in the number of regressions, regression path fixation times, and total fixation times required to process cleft object and object relative clause sentences after controlling for processing of cleft subject and subject relative clause sentences, respectively.

Sentence Acceptability—Accuracy rates and reaction times for cleft sentences and relative clause sentences for the off-line acceptability judgment task analyzed with 2 (age group) × 2 (sentence meaningfulness) × 2 (sentence type) ANOVAs. For cleft sentences, there were no age differences in accuracy rate, $F(1, 46) < 1.0$, $p > .05$. Both age groups were highly accurate ($M_Y = 96\%$, $SD_Y = 10$; $M_O = 97\%$, $SD_O = 7$). Older adults had longer reaction times ($M = 4332$ ms, $SD = 1761$ ms) than young adults ($M = 3471$ ms, $SD =$ ms), $F(1, 46) = 4.94$, $p < .05$. None of the interactions were significant. For relative clause sentences, there were no age differences in accuracy rate, $F(1, 46) < 1.0$, $p > .05$. Both age groups were highly accurate ($M_Y = 96\%$, $SD_Y = 10$; $M_O = 97\%$, $SD_O = 7$). Older adults had longer reaction times ($M = 5578$ ms, $SD = 2721$ ms) than young adults ($M = 3842$ ms, $SD = 1824$ ms), $F(1, 46) = 5.24$, $p < .05$, and reaction times to object relative clauses ($M = 4223$ ms, $SD = 1721$ ms) were longer than those to subject relative clauses ($M = 3842$ ms, $SD = 1824$ ms), $F(1, 46) = 7.93$, $p < .01$, but the age group by sentence type interaction was not significant. Meaningless sentences ($M = 4873$ ms, $SD = 1411$ ms) were responded to more slowly than meaningful ones ($M = 4232$ ms, $SD = 1242$ ms), $F(1, 46) = 6.93$, $p < .05$ but this contrast did not interact with age group or sentence type. Older adults were somewhat slower to process the cleft and relative clause sentences than young adults but no less accurate in detecting semantic anomalies.

Discussion

This study used eye tracking to compare young and older adults' processing of unambiguous cleft and relative sentences which differed in the locus of embedding and the form of the embedded sentences. As expected, cleft object and object relative clause sentences were more difficult to process than cleft subject and subject relative clause sentences. However, older adults experienced more difficulty processing these types of sentences than young adults, resulting in larger object-subject differences in regressions, regression path fixations, and total fixation times for both cleft and relative clause sentences. Since first pass fixations were similar for young and older adults, this pattern of results suggest that age-associated working memory limitations do not affect the initial interpretation of the cleft object and object relative clause sentences but the ability of older readers to resolve temporary ambiguities and misanalyses arising from conflicting syntactic, semantic, and pragmatic cues (Traxler, et al., 2005).

Kemper et al. (2004) found age group and span group differences in regressions and total fixation durations for reduced relative clause sentences containing temporary ambiguities. The cleft sentences and relative clause sentences used in the present experiment were unambiguous. One way to increase processing demands for the present types of sentences is to delete the optional “that” complementizers from cleft object and object relative clause sentences, creating temporary ambiguities and the possibility for mis-analysis.

Experiment 2

A second experiment was conducted to compare eye fixation patterns by young and older adults to cleft object and object relative clause sentences marked by “that” complementizers and temporarily ambiguous versions without “that” complementizers, e.g., *It was the lawyer the banker knew* or *The lawyer the banker knew asked for a loan*. (In English, complementizers are obligatory for cleft subjects and subject relative clause sentences.) The complementizer signals that the prior noun phrase must be temporarily buffered until required as the subject or object of the embedded clause verb. In the absence of a complementizer, the sentence subject may be initially mis-analyzed as consisting of a sequence of noun phrases, e.g., *the lawyer, the banker… and the doctor*, rather than as a noun phrase plus relative clause. Re-analysis is triggered when the reader encounters the verb and must determine its object. Increasing the processing difficulty of cleft object and object relative clause sentences by deleting the complementizers should exacerbate age group differences in fixation patterns if working memory limitations affect readers' ability to re-analyze temporary syntactic ambiguities. Working memory limitations may affect readers' ability to overcome initial mis-analyzes resulting from temporary ambiguities.

Method

Participants—Thirty young adults and 32 older adults were recruited from the same sources used in Experiment I. Excessive eye tracking failures and other technical problems resulted in excluding 5 young adults and 8 older adults. One young adult was also excluded due to excessive errors (greater than 20%) on the on-line processing task. As a result, 24 young adults and 24 older adults were included in the final analysis. The mean age for young adults was 19.79 years (SD = 3.3) and for older adults was 76.1 years (SD = 6.3). The mean years of education for young adults was 12.9 years (SD = 1.2) and for older adults was 15.3 years (SD = 2.6), $F(1, 46) = 16.683$, $p < .001$. Further information about the participants is presented in Table 1. Young and older adults did not differ significantly on the digits forward test but older adults had significantly lower digits backwards spans and reading spans than young adults; a composite (Loehlin, 1992) formed from these variables using confirmatory factor analysis did differ significantly between groups, $F(1, 46) = 8.593$, $p = .005$. Shipley's (1940) vocabulary test was used to measure vocabulary ability. Older adults had higher scores than young adults as shown in Table 1.

Materials—The 10 cleft object and 10 object relative clause sentences prepared for Experiment I were used as experimental items. Two versions of each sentence were created by deleting the “that” complementizer from one version. Two lists of experimental sentences were constructed by assigning the members of each pair of sentences to different lists. In addition, there were 10 cleft subject sentences, 10 subject relative clause sentence, and 80 other types of sentences used as fillers in each list for a total of 120 sentences. There were 18 practice sentences followed by four blocks of 30 sentences. Participants were randomly assigned to sentence lists. The eye tracker was re-calibrated between blocks. One-half of the experimental cleft object and object relative clause sentences and one-half of the fillers were followed by probe questions. The probe questions for the experimental sentences required the participant to correctly identify the subject or object of the embedded verb.

Task and Procedure—The task and procedure were identical to those of Experiment I. First pass fixations and the regression path time were computed for each critical region as well as first pass regressions to previous regions. With the exception of one young adult dropped from the analysis, comprehension accuracy rates were uniformly high, averaging over 92%, and did not vary with age group or sentence type. On the sentence acceptability judgment task, cleft object and object relative clause sentences with and without "that" complementizers were tested along with a variety of filler sentences.

Results

Results of the analysis of eye fixation patterns are first presented followed by a regression analysis examining how individual differences affect fixation patterns. Finally, the results of the sentence acceptability judgment task are presented.

Cleft sentences—First pass fixation times, regressions, regression path times, and total times for subject and object cleft sentences were averaged across trials for each participant and analyzed with 2 (age group) by 2 (sentence type) ANOVAs for the critical region, the relative clause. Readers had more difficulty processing the relative clauses in 'that-less" cleft object sentences than in the versions containing complementizers as indicated by significant main effects for regressions ($F1(1, 46) = 5.039$, $p < .05$, $\eta^2 = .099$, $F2(1, 18) = 5.046$ $p < .05$, $\eta^2 = .180$), regression path times ($F(1, 46) = 69.946$, $p < .001$, $\eta^2 = .589$, $F2(1, 18) = 36.559$, $p < .001$, $\eta^2 = .624$), and total times ($F(1, 46) = 19.364$, $p < .001$, $\eta^2 = .246$, $F2(1, 18) = 5.386$, $p < .05$, $\eta^2 = .197$); the main effect for first pass fixations was not significant, $F1(1, 46) = 1.0$, $p > .05$, $F2(1, 18) < 1.0$ $p > .05$.

Older adults experienced additional difficulty processing the relative clause region of the "that-less" cleft object sentences, leading to significant age group by sentence type interactions for regressions, regression path fixations, and total time measures (first pass fixations: $F(1, 46) < 1.00$, $F2(1, 20) < 1.0$; regressions: $F1(1, 46) = 83.851$, $p < .001$, $\eta^2 = .851$, $F2(1, 18) = 51.197$, $p < .001$, $\eta^2 = .180$; regression path times: ($F(1, 46) = 56.915$, $p < .001$, $\eta^2 = .717$, $F2(1, 18) = 28.143$, $p < .001$, $\eta^2 = .728$; and total times: $F(1, 46) = 149.770$, $p < .001$, $\eta^2 = .868$, $F2(1, 18) = 95.679$, $p < .001$, $\eta^2 = .901$). As indicated in Table 6, deleting the complementizers affected older adults more than young adults, resulting in larger increases in regressions (OA: 2.3; YA: 0.8), regression path fixations (OA: 571 ms; YA: 350 ms), and total times (OA: 717 ms; YA: 226 ms) for the older adults for the "that-less" sentences compared to the versions with complementizers, all $t(46) > 5.85$, $p < .05$.

Object Relative Clause Sentences—First pass fixation times, regressions, regression path times, and total times for relative clause sentences with and without complementizers were analyzed with a 2 (age group) by 2 (sentence type) ANOVAs for the two critical regions, the relative clause and the main verb. Readers had more difficulty processing the relative clauses in "that-less" object relative clause sentences than in versions with complementizers as indicated by significant main effects for regressions ($F1(1, 46) = 5.838$, $p < .05$, $\eta^2 = .125$, $F2(1, 18) = 7.332$, $p < .05$, $\eta^2 = .144$), regression path times ($F1(1, 46) = 22.644$, $p < .001$, $\eta^2 = .330$, $F2(1, 18) = 6.848$, $p < .05$, $\eta^2 = .197$), and total times ($F1(1, 46) = 24.943$, $p < .001$, $\eta^2 = .581$, $F2(1, 18) = 6.932$, $p < .05$, $\eta^2 = .343$); the main effect for first pass fixations was not significant, $F1(1, 46) = 1.365$, $p > .05$, $F2(1, 18) = 1.637$, $p > .05$.

Older adults experienced additional difficulty processing the relative clause region of the "that-less" object relative clause sentences, leading to significant age group by sentence type interactions for regressions, regression path fixations, and total time measures (first pass fixations: $F(1, 46) < 1.00$, $F2(1, 20) < 1.0$; regressions: $F1(1, 46) = 21.052$, $p < .001$, $\eta^2 = .314$, $F2(1, 18) = 17.045$, $p < .001$, $\eta^2 = .437$; regression path times: $(F1(1, 46) = 4.611$, $p < .05$, $\eta^2 = .090$, $F2(1, 18) = 3.281$, $p > .05$, $\eta^2 = .130$; and total times: $F1(1, 46) = 30.709$, $p < .001$, $\eta^2 = .741$, $F2(1, 18) = 20.973$, $p < .001$, $\eta^2 = .815$). As indicated in Table 7, the penalty for deleting the complementizer was greater for older adults than for young adults for regressions (OA: 3.9 regressions; YA: 0.3 regressions), regression path fixations (OA: 403 ms; YA: 357 ms), and total times (OA: 520 ms; YA: 239 ms), all $t(46) \geq 4.83$, $p < .05$

However, readers had no more difficulty processing the main verbs in “that-less” object relative clause sentences than those in relative clause sentences with complementizers as indicated by nonsignificant main effects for first pass fixations ($F1(1, 46) = 1.365$, $p > .05$, $F2(1, 18) = 1.037$, $p > .05$), regressions ($F1(1, 46) < 1.0$, $p > .05$, $F2(1, 18) < 1.0$, $p > .05$), regression path times $(F1(1, 46) = 1.04$, $p > .05$, $\eta^2 = .110$, $F2(1, 18) < 1.0$, $p > .05$), and total times $(F1(1, 46) = 1.211$, $p > .05$, $F2(1, 18) < 1.0$, $p > .05$). Older adults' difficulties with “that-less” object relatives were resolved by the time they processed the main verbs, as indicated by nonsignificant age group by sentence type interactions (first pass fixations: $F1(1, 46) < 1.00$, $p > .05$, $F2(1, 20) < 1.0$, $p > .05$; regressions: $F1(1, 46) = 1.0$, $p > .05$, $F2(1, 18) < 1.0$, $p > .05$; regression path times: $(F1(1, 46) = 1.24$, $p > .05$, $F2(1, 18) = 1.32$, $p > .05$; and total times: $F1(1, 46) = 1.080$, $p < .05$, $F2(1, 18) < 1.0$, $p > .05$).

Summary of the Eye Tracking Results—Deleting the complementizers increased the difficulty of both cleft object and object relative clause sentences, particularly for older adults. Older adults made many more leftward regressions and had longer regression path times and total fixation times to the relative clause region of the “that-less” cleft object and object relative clause sentences than to the versions containing complementizers as they attempted to resolve the temporary ambiguities created by the missing complementizers.

Regression analysis—A series of regression analyses were conducted to examine how individual differences affected fixations to the critical regions. The predictor variables were the participants' age, years of education, score on the Shipley vocabulary test, and the working memory composite latent factor score derived from the digit span and reading span scores. The dependent variables were the number of regressions, regression path fixations, and total fixation times for the critical regions of “that-less” cleft object and object relative clause sentences. The analysis was conducted in two stages. First, the fixation measures for cleft object and object relative clause sentences containing complementizers were entered into the regression models for the corresponding “that-less” sentences; second, the participants' age, education, vocabulary and working memory scores were entered simultaneously. Hence, at issue was whether any of the individual difference measures would account for additional variance arising the deletion of the complementizers after controlling for processing of the versions with complementizers. Table 8 summarizes the results. The working memory composite did account for significant variance in the number of regressions, regression path fixation times, and total fixation times required to process the relative clause regions of “that-less” cleft object and object relative clause sentences after controlling for processing of the corresponding sentences containing complementizers.

Sentence Acceptability—Accuracy rates and reaction times for young and older adults for the off-line sentence acceptability judgment task were analyzed with a 2 (age group) × 2 (sentence acceptability) × 2 (sentence type) × 2 (complementizer) ANOVA. There were no significant main effects or interactions for the accuracy scores; accuracy rates were high, averaging 91% for both young and older adults. There was a significant age group by complementizer interaction for the reaction times, $F1(1,46) = 35.972$, $p < .001$, $\eta^2 = .770$; $F2(1,22) = 61.198$, $p < .001$, $\eta^2 = .928$. Older adults required an additional second to respond to "that-less" sentences (*M* = 5708 ms, *SD* = 1263 ms) than to sentences with complementizers (*M* = 4726 ms, *SD* = 1518 ms) whereas young adults' reaction times (*M* = 3590 ms, *SD* = 1111 ms) were unaffected by deleting the complementizers.

Discussion and General Conclusions

Cleft subject and subject relative clause sentences can be parsed as two sequential clauses: the main clause is followed by an embedded clause signaled by a "that" complementizer which is indexed to the preceding noun phrase. Cleft object sentences are somewhat more challenging to parse since the cleft object also serves as the object of the embedded clause and must be temporarily buffered while the embedded clause is processed. Object relative clause sentences impose yet greater demands for processing since the subject of the main clause must also be assigned as the object of the verb in the embedded clause; further, the embedded clause interrupts the main clause, so that the main clause subject must be temporarily buffered if it is to be correctly assigned as the object of the verb in the embedding clause.

The results of Experiments 1 and 2 suggest that individual and age group differences in the size of the working memory buffer affect the syntactic analysis of cleft object and object relative clause sentences. Compared to young adults, older adults, with smaller working memories must make more regressions and allocate additional processing time to analyzing the embedded clauses of cleft object and object relative clause sentences. Deleting the complementizer affected both young and older adults; however, deleting the complementizer had a greater impact on older adults. Older adults, with smaller working memories, made significantly more leftward regressions in order to interpret "that-less" cleft object and object relative clause sentences. The complementizer marks the presence of a relative clause and signals that the preceding noun phrase must be temporarily retained until required as either the subject or object of the embedded verb. Deleting the complementizer meant that older adults, with smaller working memories, were unable to buffer this noun phrase and therefore older adults were forced to engage in additional re-analysis when they encountered the embedded verb.

Eye tracking provides a visual trace of the strategies used by young and older adults as they process complex sentences. They reveal that older adults must engaged in more reprocessing, as revealed by leftward regressions and longer regression path times and total fixation times, than young adults, for some, order to resolve incorrect initial interpretations and mis-analyzes. The auditory moving windows paradigm may not be sensitive to such age group differences in processing strategies. This technique may force older adults to adopt artificial processing strategies to cope with the imposed segmentation, restricted opportunity for playback, implicit pressure to respond in a timely fashion, or additional requirements of monitoring sentences for semantic anomalies. Under more naturalistic conditions when they are listening for comprehension, older adults may seek to avoid processing problems by cuing speakers to adopt syntactic simplifications or to provide paraphrases or repetitions of complex sentences. When they are unable to do so, older adults' comprehension of complex sentences may break down whenever they encounter temporary syntactic ambiguities, missing complementizers, or other complex syntactic structures.

Several cautions must noted with regards to these experiments. First, many participants, particularly older adults, were dropped from the analyses due to technical problems with the eyetracker. Many of these older adults had had corrective surgery for cataracts or wore corrective lens, consequently, eyetracking may be of limited utility to study how visual impairments and sensory loss may affect older adults' reading and sentence processing. Second, the experiments compared relatively few sentences of each type although the item analyses, in general, suggest that the results do generalize across sentences. Lexical, semantic, and pragmatic factors have been shown to affect syntactic processing and it may be fruitful to study how aging affects the use of such linguistic cues to syntactic structure. Third, eyetracking ignores the contributions of prosody, gaze, gesture, and the visual world to linguistic processing, all topics of active psycholinguistic investigation. Aging may affect the ability of individuals to combine multiple sources of linguistic and non-linguistic information in order to analyze complex syntactic structures or to by-pass their analysis.

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References

Caplan D, Waters G. Verbal working memory and sentence comprehension. Behavioral and Brain Sciences 1999;22:114–126.

Clifton, C., Jr.; Frazier, L. Comprehending sentences with long distance dependencies. In: Carlson, G.; Tanenhaus, M., editors. Linguistic structure in language processing. Kluwer; Dordrecht, The Netherlands: 1989. p. 273-317.

Daneman M, Carpenter PA. Individual differences in working memory and reading. Journal of Verbal Learning and Verbal Ability 1980;19:450–466.

DeDe G, Caplan D, Kemtes K, Waters G. The Relationship Between Age, Verbal Working Memory, and Language Comprehension. Psychology and Aging 2004;19:601–616. [PubMed: 15584786]

Ferreira F, Henderson JM, Anes MD, Weeks PA, McFarlane DK. Effects of lexical frequency and syntactic complexity in spoken-language comprehension: Evidence from the auditory moving-window technique. Journal of Experimental Psychology: Learning, Memory, and Cognition 1996;22:324–335.

Gibson E. Linguistic complexity: Locality of syntactic dependencies. Cognition 1998;68:1–76. [PubMed: 9775516]

Gordon PC, Hendrick R, Johnson M. Memory interference during language processing. Journal of Experimental Psychology: Learning, Memory, and Cognition 2001;27:1411–1423.

Kemper S, Crow A, Kemtes K. Eye fixation patterns of high and low span young and older adults: Down the garden path and back again. Psychology and Aging 2004;19:157–170. [PubMed: 15065939]

Lankford, C. GazeTracker: Software designed to facilitate eye movement analysis; Presented at the Eyetracking Research and Applications Symposium; Palm Beach Gardens, FL. 2000.

Loehlin, JC. Latent variable models: An introduction to factor, path, and structural analysis. Erlbaum; Hillsdale, NJ: 1992.

Pearlmutter NJ, MacDonald MC. Individual differences and probabilistic constraints in syntactic ambiguity resolution. Journal of Memory and Language 1995;34:521–542.

Schneider, W.; Eschman, A.; Zuccolotto, A. E-Prime User's Guide. Psychology Software Tool Inc.; Pittsburgh: 2002.

Stine EAL, Cheung H, Henderson D. Adult age differences in the on-line processing of new concepts in discourse. Aging and Cognition 1995;2:1–18.

Traxler MJ, Pickering MJ, Clifton C Jr. Adjunct attachment is not a form of lexical ambiguity resolution. Journal of Memory and Language 1998;39:558–592.

Traxler MJ, Williams RS, Blozis SA, Morris RK. Working memory, animacy, and verb class in the processing of relative clauses. Journal of Memory and Language 2005;53:204–224.

Trueswell JC, Tanenhaus MK, Kello C. Verb-specific constraints in sentence processing: Separating effects of lexical preference from garden-paths. Journal of Experimental Psychology: Learning, Memory, and Cognition 1993;19:528–553.

Wanner, E.; Maratsos, M. An ATN approach to comprehension. In: Halle, M.; Miller, GA., editors. Linguistic theory and psychological reality. MIT Press; Cambridge, MA: 1978. p. 119-161.

Warren T, Gibson E. The influence of referential processing on syntactic complexity. Cognition 2002;85:79–112. [PubMed: 12086714]

Waters GS, Caplan D. The measurement of verbal working memory capacity and its relation to reading comprehension. Quarterly Journal of Experimental Psychology 1996;49A:51–79. [PubMed: 8920099]

Waters GS, Caplan D. Age, working memory, and on-line syntactic processing in sentence comprehension. Psychology and Aging 2001;16:128–144. [PubMed: 11302362]

Wechsler, D. The measurement and appraisal of adult intelligence. Williams & Wilkins; Baltimore: 1958.

Wingfield A, Ducharme JL. Effects of age and passage difficulty on listening-rate preferences for time-altered speech. Journals of Gerontology: Psychological Sciences and Social Sciences 1999;54B:199–202.

Wingfield A, Lahar CJ, Stine EL. Age and decision strategies in running memory for speech: Effects of prosody and linguistic structure. Journal of Gerontology: Psychological Sciences 1989;44:106–113.

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Table 1

Means and Standard Deviations (in parentheses) for Working Memory and Vocabulary Tests for the Participants in Experiments I and II.

	Experiment I				Experiment II			
	Young adults	**Older adults**	***F*(1, 46)**	***p***	**Young adults**	**Older adults**	***F*(1, 46)**	***p***
Digit Forward	8.96 (2.05)	7.83 (2.49)	2.91	.10	8.96 (2.56)	8.75 (2.03)	0.17	.68
Digit Backward	7.46 (2.25)	7.04 (2.46)	0.37	.54	6.96 (1.96)	5.29 (1.45)	6.18	.02
Reading Span	3.77 (0.75)	3.25 (0.75)	5.76	.02	3.71 (0.99)	2.85 (0.45)	14.54	< .001
Vocabulary	32.41 (4.41)	35.88 (3.05)	16.56	< .001	30.83 (3.93)	35.67 (2.53)	25.65	< .001

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Table 2

Critical Regions for Cleft and Relative Clause Sentences.

Sentence type	Sentence example
Cleft subject Critical Region	It was the doctor / that knew the banker. / relative clause /
Cleft object Critical Region	It was the banker / that the doctor knew. / relative clause /
Subject Relative Critical Regions	The farmer / that knew the banker / asked / for a loan . / relative clause / main verb /
Object Relative Critical Regions	The farmer / that the banker knew / asked / for a loan. / relative clause / main verb /

Table 3

Mean First Pass Fixations, First-Pass Regressions, Regression Path Fixations, and Total Regression times to the Relative Clauses in Cleft-Subject and Cleft-Object Sentences by Young Adults and Older Adults.

	First Pass Fixations		Regressions		Regression Path Fixations		Total Times	
	X	***SD***	***X***	***SD***	***X***	***SD***	***X***	***SD***
Cleft Subject								
Young Adults	727	110	2.3	1.7	1183	150	1292	375
Older Adults	846	310	2.7	1.3	1367	280	1472	319
Cleft Object								
Young Adults	783	300	3.4	1.9	1485	375	1524	384
Older Adults	894	320	6.7	1.9	2025	419	2031	587

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Table 4

Mean First Pass Fixations, First-Pass Regressions, Regression Path Fixations, and Total Regression times to the Critical Regions in Subject Relative Clause and Object Relative Clause Sentences by Young Adults and Older Adults.

	First Pass Fixations		**Regressions**		**Regression Path Fixations**		**Total Times**	
	X	***SD***	***X***	***SD***	***X***	***SD***	***X***	***SD***
Subject Relative								
Young Adults								
Relative Clause	660	190	7.8	1.5	844	250	1194	344
Main Verb	314	100	3.7	1.8	448	160	539	237
Older Adults								
Relative Clause	711	224	11.0	4.2	976	435	1372	387
Main Verb	344	160	12.1	2.5	551	320	623	249
Object Relative								
Young Adults								
Relative Clause	725	256	9.4	3.5	1179	340	1592	690
Main Verb	425	110	14.0	4.8	748	160	938	360
Older Adults								
Relative Clause	1003	300	14.1	5.5	1619	480	2263	548
Main Verb	597	270	18.7	8.5	1053	310	1341	420

Table 5

Results of Regressing Fixation Measures from the Critical Regions of the Cleft Object and Object Relative Clause Sentences on the Participants' Age, Education, Vocabulary, and Working Memory Scores after First Controlling for Processing of Cleft Subject and Subject Relative Clause Sentences, respectively.

	Regressions		**Regression Path Fixations**		**Total Times**	
	β	***p***	**β**	***p***	**β**	***p***
			Cleft Object Sentences			
Relative Clause						
Age	.091	.07	.116	.21	.089	.13
Education	.055	.64	.048	.75	.004	.63
Vocabulary	.054	.56	.043	.72	.003	.58
Working Memory	−.114	.01	−.167	< .01	−.120	< .01
			Object Relative Clause Sentences			
Relative Clause						
Age	.422	.03	.364	.02	.659	.04
Education	.055	.63	.092	.42	.043	.74
Vocabulary	.082	.51	.056	.60	.092	.43
Working Memory	−.804	< .01	−.728	<.01	−.892	< .01
Main Verb						
Age	.277	.08	.432	.04	.373	.02
Education	.034	.97	.112	.62	.042	.88
Vocabulary	.135	.82	.056	.78	.062	.82
Working Memory	−.675	<.01	−.714	< .01	−.440	<.01

Table 6

Mean First Pass Fixations, First-Pass Regressions, Regression Path Fixations, and Total Regression times to the Relative Clauses in two versions of Cleft-Object Sentences by Young Adults and Older Adults.

	First Pass Fixations		**Regressions**		**Regression Path Fixations**		**Total Times**	
	X	***SD***	***X***	***SD***	***X***	***SD***	***X***	***SD***
Cleft Object Sentences with Complementizers								
Young Adults	764	284	3.1	1.4	1504	359	1685	357
Older Adults	837	314	7.2	1.3	2154	614	2228	483
Cleft Object Sentences without Complementizers								
Young Adults	792	325	3.9	1.2	1854	343	1911	392
Older Adults	914	342	9.5	2.4	2325	583	2643	508

Table 7

Mean First Pass Fixations, First-Pass Regressions, Regression Path Fixations, and Total Regression times to the Critical Regions in two versions of Object Relative Clause Sentences by Young Adults and Older Adults.

	First Pass Fixations		Regressions		Regression Path Fixations		Total Times	
	X	***SD***	***X***	***SD***	***X***	***SD***	***X***	***SD***
Object Relative Clause Sentences with Complementizers								
Young Adults								
Relative Clause	732	256	8.7	3.2	1095	318	1582	648
Main Verb	408	110	12.5	4.1	723	123	894	247
Older Adults								
Relative Clause	964	285	12.1	4.5	1589	445	2187	486
Main Verb	538	173	16.3	7.3	993	287	1286	418
Object Relative Clause Sentences without Complementizers								
Young Adults								
Relative Clause	765	311	9.0	3.2	1452	330	1821	780
Main Verb	425	160	12.9	3.8	788	167	902	254
Older Adults								
Relative Clause	973	315	14.0	5.3	1992	523	2707	492
Main Verb	541	170	15.7	6.5	1004	343	1305	458

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Table 8

Results of Regressing Fixation Measures from the Critical Regions of the “That-less” Cleft Object and Object Relative Clause Sentences on the Participants' Age, Education, Vocabulary, and Working Memory Scores after first Controlling for the Processing of the corresponding Sentences with Complementizers.

	Regressions		Regression Path Fixations		Total Times	
	β	***p***	**β**	***p***	**β**	***p***
			Cleft Object Sentences			
Relative Clause						
Age	.065	.08	.073	.07	.067	.07
Education	.014	.73	.003	.82	.004	.91
Vocabulary	.023	.56	.034	.64	.042	.59
Working Memory	−.112	.03	−.113	.04	−.132	.02
			Object Relative Clause Sentences			
Relative Clause						
Age	.382	.02	.395	.04	.221	.04
Education	.007	.72	.003	.82	.004	.79
Vocabulary	.012	.38	.009	.83	.005	.88
Working Memory	−.543	<.01	−.728	< .01	−.654	<.01
Main Verb						
Age	.019	.64	.021	.78	.009	.72
Education	.013	.72	.015	.83	.003	.97
Vocabulary	.004	.83	.002.	.97	.012	.79
Working Memory	.058	.56	.085	.63	.002	.98