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Age Differences In Memory-Load Interference Effects In Syntactic Processing

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Abstract

The effects of a memory load on syntactic processing by younger and older adults were examined. Participants were asked to remember a noun phrase (NP) memory load while they read sentences varying in syntactic complexity. Two types of NPs were used as memory loads: proper names or definite descriptions referring to occupations or roles. The NPs used in the sentence and memory load either matched, e.g., all proper names or all occupations, or mismatched. Complex sentences were read more slowly than simpler sentences; for young adults, this complexity effect was exacerbated when memory interference was generated by matching NPs in the sentence and memory load, whereas for older adults, memory load interference did not vary with sentence complexity or memory load matching. These results suggest that a general reduction in older adults' processing capacity was produced by the memory load whereas the matching memory loads and sentence NPs produced a more specific form of interference that affected young adults' on-line processing.

Age Differences In Memory-Load Interference Effects In Syntactic Processing

It is generally agreed that the analysis of complex syntactic structures depends on working memory capacity (Gordon , Hendrick, & Johnson, 2001; Gordon , Hendrick, & Levine, 2002; Just, Carpenter, & Keller, 1996; Kemtes & Kemper, 1997; Kemtes & Kemper, 1999; Miyake, Just, & Carpenter, 1994). However, the exact nature of this working memory capacity is a subject of current debate (Caplan & Waters, 1999; Daneman & Carpenter, 1980; Gibson, 1998; Just & Carpenter, 1992; Lewis, 1996; Waters & Caplan, 1996a, 1996b). It is also generally agreed upon that working memory as measured by digit span and reading span measures declines with age (cf. Carpenter, Miyake, & Just, 1994 for a review). At issue is whether or not tests of working memory capacity such as digit span and reading span measures the same working memory required for syntactic processing. If so, age-related changes in language processing may be attributed to working memory capacity limitations affecting syntactic processing.

Just and Carpenter (1992) argue that working memory is composed not only of a storage component but also of a central executive component. This central executive component is responsible for computations such as syntactic parsing in language comprehension. Both of these components draw on the same working memory capacity and in the case of older adults, this competition contributes to the age related decline in syntactic processing efficacy

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[1]Gordon et al. (2002) report a non-significant interaction between the sentence complexity manipulation and the match between the type of NP used in the memory load and the sentence for the critical reading time measure. Our procedures differed from Gordon et al. in three regards: First, proper names and descriptions were matched for syllable length and word frequency to control for possible confounds in Memorability. Second, we analyzed reading times only from participants who demonstrated good comprehension of the probe questions and only for trials when they were able to recall the memory load correctly. Third, we added a "no load" condition consisting of strings of XXXXs.

(Carpenter, Miyake, & Just, 1994). Alternatively, Caplan and Waters (1999a, 1999b) argue that the working memory resources used for syntactic processing are separate from those used for information storage. This separate-sentence-interpretation resource theory (SSIR) holds that syntactic processing is a highly practiced set of computations that has a specialized resource facility that is independent of other non-syntactic working memory tasks. Therefore, the age-related syntactic processing effects observed in previous research cannot be contributed to age-related declines in working memory (Waters & Caplan, 2001). They argue that most of the research supporting the single resource memory theory relied upon off-line comprehension measures whereas on-line measures of sentence processing show no working memory effects on syntactic processing (Waters & Caplan, 2001).

The current study tests the single resource model with Caplan & Waters (1999a, 1999b) SSIR model using a procedure similar to that of Gordon, Hendrick, & Levine (2002). Participants were asked to remember a memory load while reading syntactically complex object-extracted cleft sentences (as in 1) or simpler subject-extracted cleft sentences (as in 2). In cleft sentences, an NP is extracted from its clause and moved to the front of the sentence following an introductory phrase “It was...” which highlights or emphasizes the fronted NP; the remainder of the clause is turned into a relative clause modifying the fronted NP. Either the subject of the clause “the thief thanked the nurse” may be fronted, producing “It was the thief that thanked the nurse,” or the object may be fronted, “It was nurse that the thief thanked.”

1. Example subject-extracted cleft sentences.

   It was Kenneth that thanked Robert after winning the race.

   It was the judge that thanked the nurse after winning the race.

2. Example object-extracted cleft sentences.

   It was Kenneth that Robert thanked after winning the race.

   It was the judge that the nurse thanked after winning the race.

Descriptions of human occupations or roles (e.g., the banker) or proper names (e.g., John) were used as the subject and object of the sentences. Two memory load conditions were compared. The memory load consisted of 3 noun phrases (NPs), either 3 human occupations or roles, e.g., thief, banker, pilot, or 3 proper nouns, e.g., James, Peter, Paul Gordon et al. demonstrated that memory loads that matched the type of NP used in the sentence impaired sentence comprehension and this effect was greater for the more complex object-extracted clefts than for the simpler subject-extracted clefts. Both the capacity-constrained model of Just and Carpenter (1992) and the SSIR model of Caplan and Waters (1999a) predict on-line reading time differences for complex object-extracted clefts compared to the simpler sentences. However, the SSIR model postulates that sentence processing taps language-specific processing resources that are independent of general memory resources required to retain the memory load whereas the capacity-constrained model holds that both sentence processing and general memory processes draw upon a common, limited-capacity resource. Gordon et al. (2002) findings favor the capacity-constrained model since the matching memory loads impaired on-line sentence processing, indicating that syntactic processes required for the analysis of complex structures rely on working memory resources that are also used for non-syntactic processes such as retaining the memory load. If so, older adults with more limited working memory resources should be prone to more interference during sentence comprehension than young adults.

The present study was undertaken to compare the sentence processing by young and older adults using Gordon et al. (2002) memory-load interference paradigm. We predicted an age group by sentence complexity by memory load interaction such that older adults would have more difficulty processing the sentences than young adults and that the age differences would be exacerbated for the more complex object-extracted clefts, particularly when a matching memory load was imposed. We examined both on-line processing the sentences using reading time measures and off-line sentence comprehension. Our procedures differed from Gordon et al. in three regards: First, both types of memory loads were matched for syllable length and word frequency to control for possible confounds in memorability. Second, we analyzed reading times only for trials when the participants were able to answer a probe question about the sentence correctly and able to recall the memory load. Third, we added a "no load" condition consisting of strings of XXXXs to provide a baseline against which to compare the interference effects of both types of memory loads.

Method

Participants

Thirty-one young adults, 19 to 30 years of age, and 30 older adults, 66 to 84 years of age, participated. The young adults were recruited by signs and other solicitations on campus and paid $10 for participating. The older adults were recruited from a registry of previous research participants; all were living at home alone or with family. The participants were paid a modest honorarium; for the older adults, this honorarium also included compensation for their travel to an off-campus research site to participate in this research. Older adults were initially screened for possible dementia using the Short Portable Cognitive Status Questionnaire (Pfeiffer, 1975); the exclusion criterion was failing four or more questions. Data from participants who performed poorly on the sentence processing task in the no-load condition were also excluded from further analysis. A criterion of 7 of 10 correct was required for inclusion to ensure participants were reading the sentences for comprehension. Eleven young adults and 10 older adults were excluded from the analysis as a result of this criterion. The remaining 20 young adults (M = 22.6, SD = 3.1) and 20 older adults (M = 72.2, SD = 5.8) were given a battery of cognitive tests designed to assess individual and age group differences in verbal ability, working memory, inhibition, and processing speed. The young adults had completed approximately the same number of years of formal education as the older group (M_Y = 14.8 years, SD = 1.9 years; M_O = 14.2 years, SD = 2.5), F (1, 39) = .412, p = .524. The older adults scored higher on the Shipley (1940) vocabulary test (M_O = 35.5 of 40 correct, SD = 3.6) than young adults (M_Y = 30.5, SD = 6.7), F (1, 39) = 6.115, p = .017. The young adults scored higher on the Digits Forward and on Digits Backwards tests (Wechsler, 1958) (M_Y = 9.7, SD = 2.5 and 7.9, SD = 2.5), respectively, than the older adults (M_O = 8.2, SD = 2.6 and 6.4, SD = 2.4 respectively), F (1, 39) = 9.680, p = .004 and F (1, 39) = 3.268, p = .079, respectively. The young adults had higher scores on the Daneman and Carpenter (1980) Reading Span test, (M_Y = 4.4, SD = .62; M_O = 3.1, SD = .54), F (1, 39) = 11.080, p = .002. A composite working memory score was formed by conducting a confirmatory factor analysis with a single latent working memory factor (Loehlin, 1992). Young adults had a higher composite working memory score than older adults, F(1,39) = 10.676, p = .002. The young adults also scored higher on the Digit Symbol test (Wechsler, 1958), (M_Y = 35.88, SD = 6.2; M_O = 25.2, SD = 4.7), F(1, 39) = 54.953, p < .001. The participants were also given a Stroop test. The Stroop test required participants to name the color of blocks of X's printed in colored inks or to name the color of color words printed in contrasting colored inks, e.g., RED printed in blue ink; participants were given 45s to complete the tasks; the participant's score is the number of colors correctly named in 45s. On this task, the young adults named the colors of the words more rapidly than the older adults (M_Y = 64.1, SD = 11.4 years; M_O = 40.3, SD = 11.3), F (1, 39) = 70.473, p < .001; they also named the colors of the X's more rapidly (M_Y = 88.3, SD = 11.3 years; M_O = 70.5, SD = 13.5), F (1, 39) = 27.368, p < .001. A relative difference score was created by subtracting scores for the color X's condition from scores for the color word condition and dividing by the scores for the color X's condition; young adults also had smaller difference scores than older adults, $F(1, 39) = 19.258$, $p < .001$, indicating greater inhibition of the competing responses. An alpha level of .05 was set for these and all subsequent *t* and *F* tests.

Materials

The stimuli were constructed to follow the materials used in the Gordon et al. (2002) study. The experimental sentences consisted of 120 cleft sentences, 24 modified from Appendix 2 of Gordon et al. (2001). Twelve conditions (see Figure 1) were created by crossing syntactic complexity (subject-extracted versus object-extracted cleft sentences), type of noun phrase (NP) used in the sentence (descriptions or names), and the type of NPs used in the memory load (matching type of NP used in the sentence, mismatching, or none). Two types of NPs were used: familiar descriptions of human occupations or roles (e.g. the thief, the nurse) or familiar proper names. The memory load consisted of three NPs, either 3 descriptions or 3 proper names, or a sequence of 3 blocks of XXXXs. The no-load condition was intended to provide a baseline for the comparison of the effects of the matching versus mismatching memory loads. All NPs were of medium frequency (15 to 50 occurrences per million words, Kucera & Frances, 1967). The sets of proper names and descriptions were matched for character and syllable length and frequency of occurrence. The sentences used either descriptions or proper names as both the sentence subject and the sentence object. When proper names were used, all three memory load items and the sentence subject and object matched for gender. A true/false statement was written for each sentence; it required the participant to verify the syntactic-semantic relationship between the two NPs and the verb of each sentence, e.g., who did what to whom. One-half of the statements were true and one-half were false. In addition to the experimental items, filler sentences were also constructed. The fillers were simple subject-verb-object sentences containing no clefts.

Design and Procedure

Twelve lists were created by counterbalancing sentence complexity (subject-extracted clefts vs. object-extracted clefts) with sentence NP type (descriptions vs. proper names) and memory load (matched sentence NP type, mismatched, none) across lists. Ten different examples of each combination of cleft type, sentence NP type, and memory load occurred in each list. Individual sentences and NP proper names and descriptions were not repeated within a list. The items were blocked into an initial warm-up block of 24 filler items followed by two experimental blocks each containing 60 experimental items (5 from each condition) and 60 filler items. The items within a block were presented in a different random order for each participant.

The trial event sequence is shown in Figure 1. Using EPRIME (Schneider, Eschman, & Zuccolotto, 2002), participants were presented first with a memory-load set: the words were all in capital letters, centered on a computer monitor. The participants were instructed to read the three memory load items aloud twice, saying “Xs” if no memory load was presented, and to remember the memory load. Following this, they read a single sentence presented one word at a time in the center of the screen using self-paced reading time methodology. They were instructed to read the sentences at a natural pace, not to hurry but not to linger longer than necessary before pressing the space bar to see the next word. Immediately after they read the last word of the sentence a true/false comprehension statement was presented, and the participants responded by pressing the “z” key for “true” and the “/” key for “false.” After the comprehension statement, the participants were prompted to recall the three memory load items aloud, repeating the proper names or descriptions or saying “Xs.” The participant’s response was recorded and later scored for accuracy of recall.

Results

Results of the comprehension probes are presented first, followed by the memory load recall findings, and then the on-line processing results. The primary analysis of all dependent measures was performed with a 2 (age group) X 2 (sentence complexity [subject-extracted clefts, object-extracted clefts]) by 2 (sentence NP [descriptions, names]) by 3 (memory load [matching sentence NP type, mismatching, none]) ANOVA. Both an analysis with subjects as random, *F*1, and an analysis with items as random, *F*2, are reported. The final section presents a series of regression analyses examining how individual differences in age, vocabulary, working memory, and inhibition affect comprehension, on-line processing, and memory load recall.

Comprehension

The proportion of incorrect answers to probe questions was analyzed. The main effect of age was significant $F1(1, 38) = 4.549$, p = .047, $\eta^2 = .209$; $F2(1, 119) = 1.1770$, $p = .187$, $\eta^2 = .018$. Older adults answered fewer probe questions correctly than young adults (see Figure 2). Both young and older adults made more errors on questions about object-extracted clefts than subject-extracted clefts, $F1(1, 38) = 35.174$, $p < .001$, $\eta^2 = .474$, $F2(1, 119) = 3.546$, $p = .063$, $\eta^2 = .462$. No other effects were significant in either the F1 or F2 analysis.

Recall

The proportion of errors for recall of the memory loads was analyzed. The main effect of age group was significant, $F1(1, 38) = 10.382$, $p < .001$, $\eta^2 = .417$; $F2(1, 119) = 2.704$, $p = .025$, $\eta^2 = .353$. Older adults had significantly worse recall of the memory loads than young adults (see Figure 2). Recall by both groups was worse following object-extracted cleft sentences than following subject-extracted cleft-sentences, $F1(1, 38) = 11.199$, $p = .002$, $\eta^2 = .196$; $F2(1, 119) = 2.612$, $p = .109$, $\eta^2 = .027$. The recall data supports both the comprehension data in showing that object-extracted clef sentences impose higher processing demands than subject-extracted cleft sentences, impairing recall of the memory load NPs.

On-line processing

Only reading times from trials on which the participants correctly answered the comprehension probe and recalled the memory load correctly were analyzed. Sentence comprehension and recall of the memory loads were highly correlated across conditions, $r(39) \geq .85$; therefore, the number of valid trials included in the reading time analysis varied with condition, parallel to the comprehension and recall results: there were more valid trials for young adults ($M = 7.8$ per condition) than for older adults ($M = 6.3$ per condition) and more for subject-extracted cleft sentences ($M = 7.3$ per condition) than for object-extracted cleft sentences ($M = 5.8$) per condition. Because the reading times were highly positively skewed, log-transformed reading times were used in all analyses. Word-by-word reading times were averaged within 3 critical regions. Region 1 included the sentence initial cleft and was the same for both subject-extracted and object-extracted cleft sentences; Region 2 included a NP and verb and the word order varied between the 2 types of sentences; Region 3 included the sentence final prepositional phrase and was the same for both types of sentences.

Region 1—Included in this region were the first clause of the sentence and the relative pronoun (i.e. “It was NP that…”). Region 1 was constant across cleft types. There was a significant main effect of age group; young adults had faster reading times than older adults, ($M_y = 393.7$, $SD = 10.9$ ms; $M_o = 686.4$, $SD = 15.1$ ms) $F1(1, 38) = 37.889$, $p < .001$, $\eta^2 = .452$; $F2(1, 119) = 32.849$, $p < .001$, $\eta^2 = .444$. No other significant effects or interactions were found for Region 1 in either the *F*1 or *F*2 analysis.

Region 2—This region was the critical region for the cleft manipulation. It contained the same words, NP and verb, for the two cleft types, with a difference in word order. Word order for subject-extracted cleft sentences was verb-NP, while word order for object-extracted cleft sentences was NP-verb. A main effect of age group was found such that young adults had faster reading times than older adults, (M_y = 411.3, *SD* = 31.1 ms; M_o = 682.0, *SD* = 49.4 ms) *F*1(1, 38)= 25.123, $p < .001$, $\eta^2 = .853$; *F*2(1, 119) = 25.258, $p < .001$, $\eta^2 = .887$. The main effect of sentence complexity was significant, *F*1(1, 38) = 24.454, $p < .001$, $\eta^2 = .385$; *F*2(1, 119) = 13.260, $p < .001$, $\eta^2 = .385$. As expected, reading times were longer for object-extracted clefts than subject-extracted clefts for both young and older adults.

The memory load main effect was significant, *F*1(2, 37) = 9.591, $p = .004$, $\eta^2 = .822$; *F*2(2, 118) = 12.346, $p = .129$, $\eta^2 = .288$ as was the age group by sentence complexity by memory load interaction, *F*1(2, 38) = 7.745, $p = .008$, $\eta^2 = .216$; *F*2(2, 118) = 3.399, $p = .072$, $\eta^2 = .439$. This interaction was decomposed to examine the sentence complexity by memory load NP interaction separately for each age group. For young adults, there were significant main effects of both sentence complexity and memory load, *F*1(1, 19) = 9.567, $p = .006$, $\eta^2 = .335$; *F*2(1, 119) = 9.628, $p = .003$, $\eta^2 = .170$ and *F*1(2, 19) = 8.803, $p = .008$, $\eta^2 = .317$; *F*2(2, 118) = 1.832, $p = .183$, $\eta^2 = .038$, respectively, as well as a significant sentence complexity by sentence NP interaction, *F*1(2, 19) = 6.8133, $p = .017$, $\eta^2 = .264$; *F*2(2, 118) = 2.155, $p = .149$, $\eta^2 = .045$. Young adults took longer to read object-extracted cleft sentences than subject-extracted cleft sentences; this effect of syntactic complexity was exacerbated when the type of NP used in the memory load matched that used in the object-extracted cleft sentence (see Figure 3). Object-extracted cleft sentences required an additional 76 ms (SD = 31) to process than subject-extracted cleft sentences when the NPs in sentence and memory load matched, an additional 62 ms (SD = 22) when the NPs did not match, and an additional 37 ms (SD = 21) when there was no memory load. The object – subject difference was greater in the matched condition than in the mismatched condition, *t*(19) = 4.142, $p = .001$, and greater in the mismatched condition than in the no-load condition, *t*(19) = 3.954, $p = .001$.In contrast, the main effect of sentence complexity was significant for older adults' Region 2 reading times, *F* (1, 19) = 15.197, $p = .001$, $\eta^2 = .432$; *F*2(1, 119) = 6.386, $p = .015$, $\eta^2 = .120$. Older adults required an additional 65 ms (SD = 31) to read Region 2 of object-extracted cleft sentences than Region 2 of subject-extracted cleft sentences (see Figure 3) regardless of memory load. In addition, the main effect of memory load was significant, *F* (2, 18) = 15.197, $p = .001$, $\eta^2 = .432$; *F*2(2, 118) = 6.386, $p = .015$, $\eta^2 = .120$). Both types of memory load NPs impaired older adults' Region 2 reading times, increasing reading times by 39 ms (SD = 26), compared to the no load condition, *t*(19) = 8.587, $p < .001$, and memory load interference was similar for both subject-extracted and object-extracted cleft sentences, both *t*(19) < 1.0, $p < .50$.

Region 3—The remainder of the sentence was included in this region; it was constant across all conditions. A main effect of age was found such that young adults had faster reading times than older adults, *F* (1, 38) = 23.789, $p < .001$, $\eta^2 = .352$; *F*2(1, 119) = 6.386, $p = .015$, $\eta^2 = .120$. No other significant main effects or interactions were observed in this region.

Regressions

A series of regression analyses were conducted to examine how individual differences in vocabulary, working memory, and inhibition affected comprehension, on-line processing, and recall of the memory loads. The predictor variables were the participants' age, score on the vocabulary test, working memory composite latent factor score, Digit Symbol score, and Stroop difference score. The Digit Symbol score was considered to be a measure of processing speed (Salthouse, 1992) and the Stroop difference score was considered to be a measure of inhibitory function (Dempster, 1992). Dependent variables were the comprehension scores for the object-extracted cleft sentences, Region 2 reading times (after first controlling for reading times for the subject-extracted cleft sentences), and memory load recall scores. All scores were averaged over sentence NP type manipulation. All predictor variables were entered simultaneously. None of the predictors was significant in the analysis of the condition in which no memory load was presented or in the conditions where the memory load NP type did not match the type of NP used in the sentence. However, in the interference condition when the memory load NP matched the type of NP used in the sentence, the working memory composite score accounted for 9% of the variance in comprehension of object-extracted cleft sentences, $R = .306$, $F(4,36) = 1.515$, $p = .24$, 23% of the variance in the Region 2 reading time, $R = .483$, $F(4,36) = 4.469$, $p = .008$, and 28% of the variance in memory load recall, $R = .526$, $F(4,36) = 7.427$, $p < .001$. Adding other predictors did not improve the fit of the regression models. These results support the interpretation that immediate syntactic processing of complex constructions is constrained by working memory capacity as measured by span scores.

Discussion

The results of this study support a single resource model of working memory. They parallel the finding by Gordon et al. (2002) that syntactic processes do rely on working memory resources that are also used for other non-syntactic processes: (1) Object-extracted cleft sentences were more difficult to comprehend than subject-extracted cleft sentences in that readers allocate additional processing time to Region 2 of object-extracted cleft sentences, compared to subject-extracted clefts, in order to correctly map the subject and verb relations. (2) Errors on the comprehension probes and the memory load recall test increased whenever complex object-extracted cleft sentences were read. (3) A working memory composite latent factor score, derived from the span measures, predicted 23% of the variance in Region 2 reading times for the complex object-extracted cleft sentences.

An additional finding was that older adults with more limited working memory resources exhibited a different pattern of on-line reading times across conditions than young adults. Overall, readers allocated additional processing time to Region 2 of the object-extracted cleft sentences compared to Region 2 of the subject-extracted clefts. This complexity effect was exacerbated for young adults when the type of NP used in the memory load matched that used in the object-extracted cleft sentence. This pattern suggests that the young adults experienced two forms of memory interference, one due to the reduction in working memory resources from the imposed memory load and a second more specific form of interference due to the confusability of the NPs used in the memory load and those used in the sentences. The effect of the memory load on older adults' reading times for Region 2 were constant regardless of whether the memory load NP matched or mismatched the type used in the sentence. This suggests that the older adults experienced only a general reduction in on-line processing due to the burden placed on working memory by the memory load task and did not experience additional memory interference from the confusability of the NPs.

These results pose problems for the Caplan and Waters (1999a, 1999b) SSIR theory. According to this theory, a memory load should not effect syntactic processing nor differentially effect syntactic processing by young and older adults. These findings suggest that working memory capacity, memory interference, and language processing are closely intertwined. As a consequence, increasing the complexity of a sentence, decreasing working memory capacity by imposing a memory load, or decreasing memory capacity as happens in normal aging will increase the difficulty of on-line language processing as well as impairing comprehension and recall.

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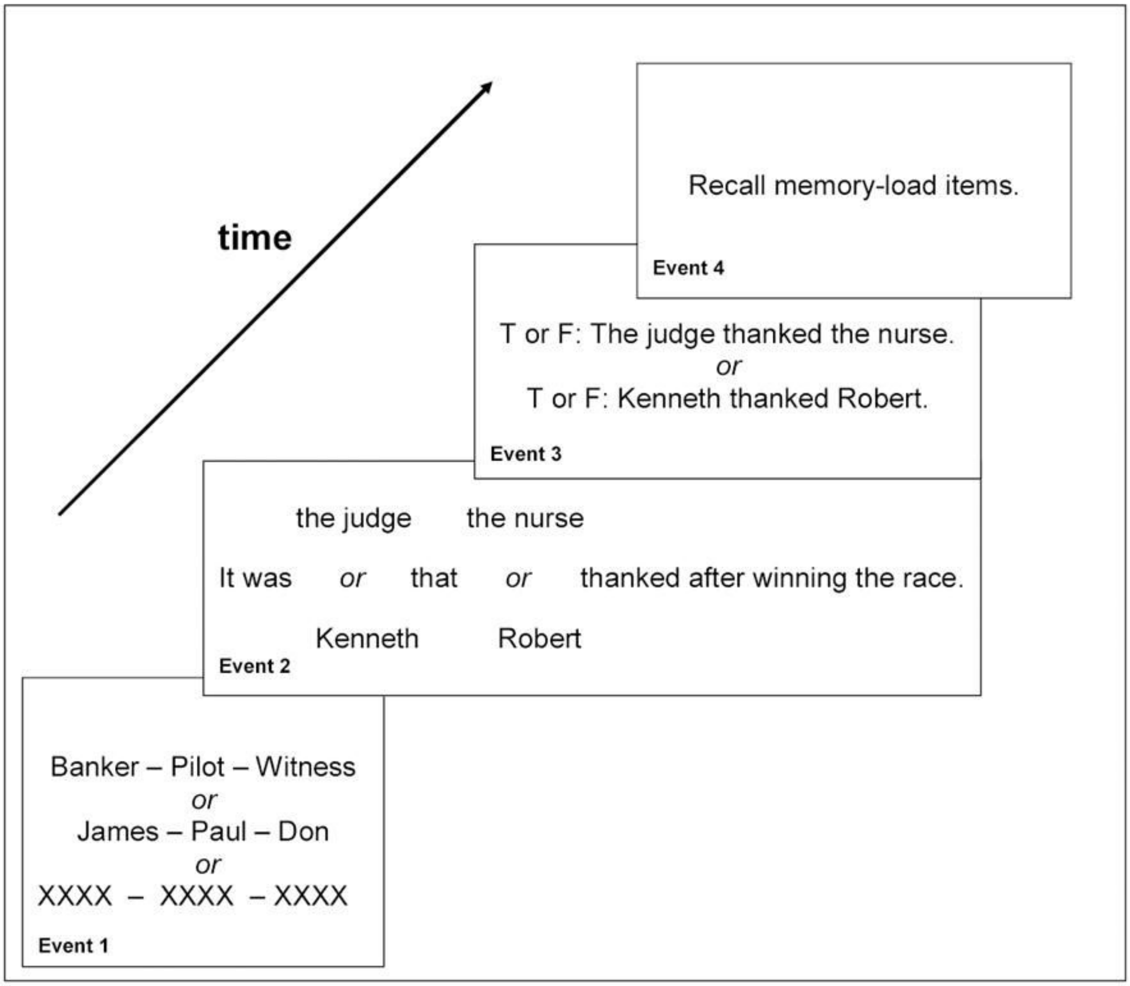

Figure 1.
Schematic illustration of trial event sequence. Participants read the memory load items aloud twice (Event 1), read the sentence one word at a time at their own pace (Event 2), responded to a true/false comprehension statement (Event 3), and finally recalled the memory-load items (Event 4).

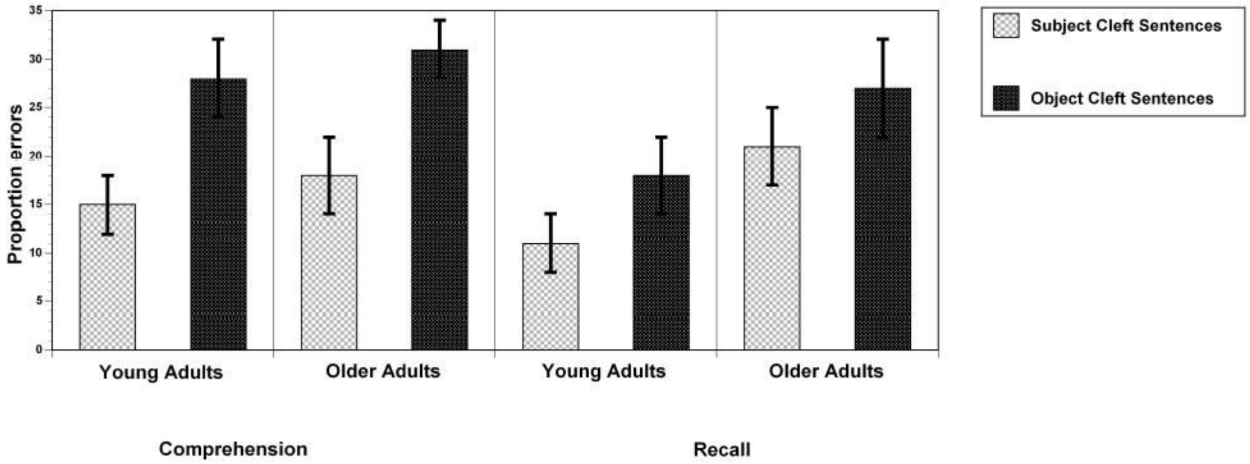

Figure 2.
Mean error rates (with standard deviations) for comprehension probes and for recall of the memory loads for subject-extracted and object-extracted cleft sentences.

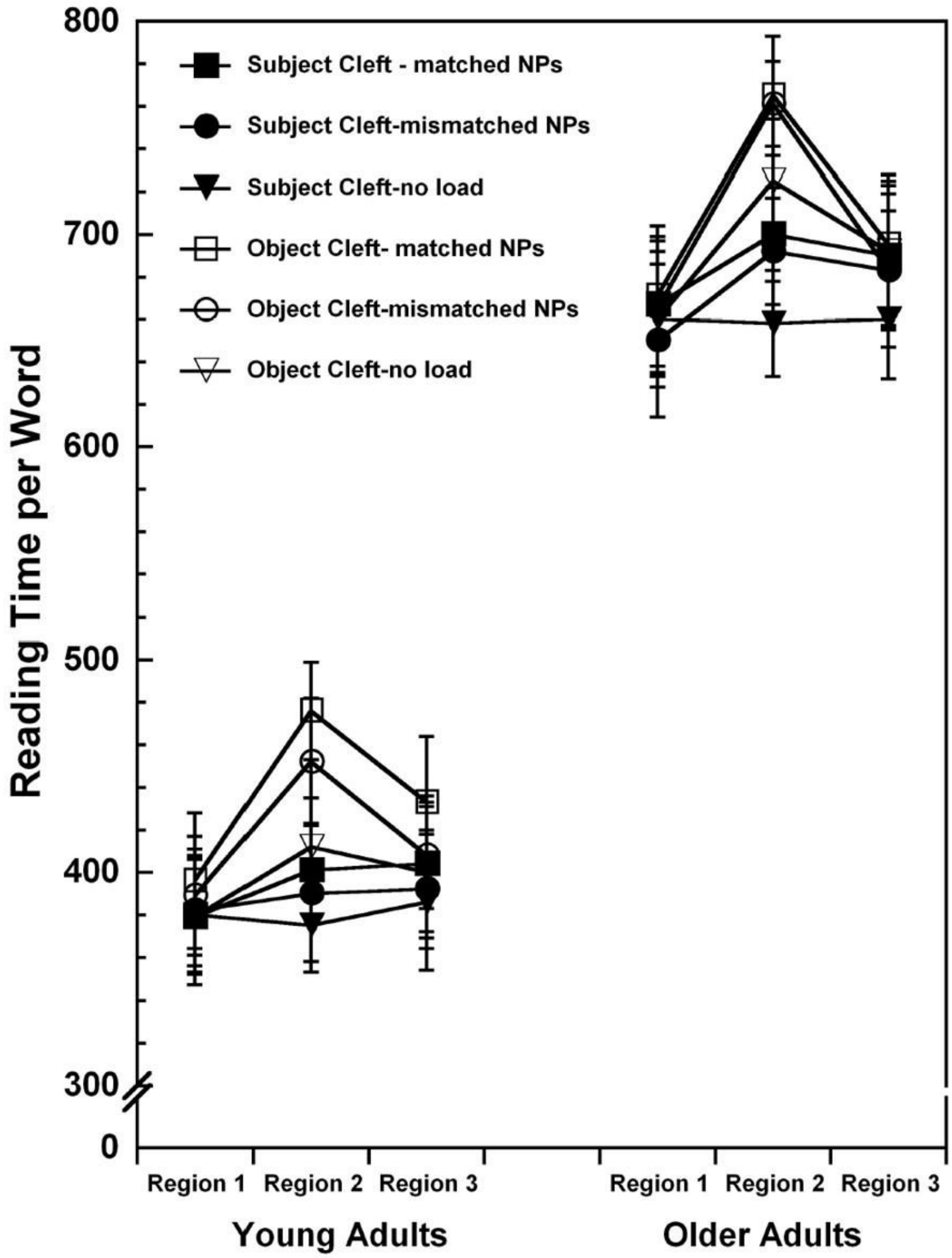

Figure 3.
Mean reading time in ms per word for the three sentence regions (with standard errors) for young and older adults for subject-extracted and object-extracted cleft sentences as a function of memory load NP.