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The Allocation of Memory Resources During Sentence Comprehension: Evidence from the Elderly[1]

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Two experiments were carried out to examine the ability of elderly subjects to establish syntactically governed dependency relations during the course of sentence comprehension. The findings reveal the manner in which memory constraints operate during syntactic processing.

INTRODUCTION

The work reported here tries to demonstrate the way in which memory constraints influence sentence comprehension. Like many previous inquiries of this general sort, we focus on performance in the elderly.

It is well established that elderly subjects fare significantly worse than young subjects in understanding syntactically complex sentences (Emery, 1985; Kemper, 1986, 1988). It is also accepted that in some manner this difference implicates diminished memory capacity (Wingfield, Stine, Lahar, & Aberdeen, 1988; and see Light, 1990, for a review of relevant work). What we seek to detail here is where in the chain of sentence comprehension the age-related memory bottleneck occurs. By locating this bottleneck, we can highlight how memory resources are allocated and how they impose constraints.

To our knowledge, the techniques that have been used to study syntactic processing in the elderly have been "off-line": viz., object manipulation (Feier & Gerstman, 1980), question answering (Emery, 1985), grammatical judgment (Kemper, 1988), and sentence recall (Norman, Kemper, Kynette, Cheung, & Anagnopoulos, 1991). All of these techniques conflate two sources of memory demands: those that arise transiently during the temporal course of constructing an interpretation with those that accrue to a later stage at which the form and content of the sentence must be examined for an appropriate response. So we cannot tell whether age-related memory problems limit performance during or immediately after sentence interpretation; and we cannot tell how aging affects the allocation of memory resources in the first instance-that is, as syntactic analysis actually takes place and comprehension unfolds.

Recognizing these general limitations, investigators focusing on college-aged populations have sought to apply on-line techniques to the study of language comprehension. Based mostly on reaction time or reading time measures, these techniques are intended to reveal the characteristics of processing operations at different levels (lexical, syntactic, semantic, and discourse), the time course of their various interactions, and the degree to which they each depend on memory resources (Swinney & Fodor, 1989, 1991, 1993).

The possibilities offered by these techniques have not, however, been fully explored by researchers in the field of cognitive aging. Rather, such on-line studies of age-related comprehension changes as presently exist have tended to focus on processing at the discourse level (e.g., Hasher & Zacks, 1988; Light & Capps, 1986). Although a number of important descriptive generalizations have emerged-particularly with respect to memory capacity and inference formation in old age-such generalizations will not likely be relevant to our understanding of syntactic processing per se. Fitting words and sentences into a discourse structure, although largely an unconscious

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process, seems, nevertheless, to be under the "cognitive control" of strategies tied to general knowledge, knowledge of discourse conventions, and statistical bias (Corbett & Dosher, 1978; Cutler & Swinney, 1978; Fodor, 1983; Swinney & Osterhout, 1990).

By contrast, syntactic operations during the course of sentence comprehension seem to be automatic and mandatory (Fodor, 1989; Garnsey, Tanenhaus, & Chapman, 1989; McElree & Bever, 1989; Nicol & Swinney, 1989; Swinney, Ford, Frauenfelder, & Bresnan, 1988), and most importantly they seem not to be influenced by any rational considerations-not even by the semantics of the sentence that is being parsed (Hickok, Canseco-Gonzalez, Zurif, & Grimshaw, 1992; Swinney, 1991; Swinney & Osterhout, 1990). It seems reasonable to expect, therefore, that "reflexive" syntactic mechanisms create fewer demands on memory capacity than do operations involved in searching through and evaluating information at the discourse level, where age-related memory limitations clearly do apply (Stine & Wingfield, 1990). This granted, it seems entirely possible that the relative inability of elderly subjects to process complicated syntax is more apparent than real--more the consequence of task-imposed memory demands following sentence interpretation than the result of memory demands imposed by syntactic processing during comprehension. It is this possibility that impelled the present study.

The Present Approach

In our effort to isolate an aspect of syntactic processing that emphasizes memory storage, we have focused on a within-sentence bookkeeping operation termed *gap-filling.* Some background: In order to understand the sentence

> The tailor hemmed the cloak that the actor from the studio needed for the performance

the noun phrase *(NP) the cloak* must be understood as the object of the verb *needed.* One way linguistic theory represents this fact is to posit (1) a place holder-a phonologically empty NP-within the phrase headed by the verb *needed* (i.e., immediately following it) and (2) a link between this empty NP and its "moved" antecedent. The place holder or empty NP is referred to in some formal models (e.g., Chomsky, 1981) as a trace (t), and the dependency relation between it and its antecedent is usually indicated by a subscript, as in the following:

> The tailor hemmed the $cloak_i$ that the actor from the studio needed (t_i) for the performance.

This, or some close variant, is a standard analysis given to such sentences in most current versions of syntactic theory. Indeed, traces are held to be crucial for the assignment of thematic roles in a sentence (e.g., agent, goal, and so on), such roles being assigned to hierarchically structured sentence positions regardless of the identity of the assignee. If a thematic position is filled with a lexical NP (e.g., a noun), then it receives its thematic role directly; but if a thematic position contains a trace (an empty NP), then the trace is assigned the thematic role and the constituent that was moved (leaving the trace) gets its role indirectly, by being coindexed to the trace (Chomsky, 1981). In our example, the trace receives the role of theme-the role of the object affected by the verb (the "thing needed")-and *the cloak* is assigned this role only through its link to the trace.

The sentence used for our illustration is an object-relative construction--the moved constituent has been extracted from the object position of the subordinate clause. We employ this type of construction in the work reported here. We also employ a subject-relative construction of the following sort:

> The gymnast loved the $professor_i$ from the northwestern city who (t_i) complained about the bad coffee.

Following Clements, McCloskey, Maling, & Zaenen (1983), among others, we hypothesize that movement occurs from subject position in this example: The subscript (i) indicates that the head of the moved constituent, *professor*, must be linked to the trace in the subject position in order to receive its thematic role of agent.[8,9]

To this point, we have been discussing representational theories. Of particular importance here, however, is the fact that these representations have been found to reflect real-time processing operations: It has been shown that the antecedent is directly and immediately recovered by the processing system at the gap indexed by the trace. That is, for young adults the "moved" constituent appears to be reactivated so that it "fills" the position left by its "movement." (See Swinney & Fodor, 1989, 1993, and Swinney & Osterhout, 1990, for reviews of the relevant studies.) Such gap-filling is what we focus upon.

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[8] Technically, it is the Wh element (*who*) that has been moved from the subject position of the relative clause, but since *who* and *professor* corefer, *who* inherits the semantics of *professor.* The same technical consideration holds also for object-relative sentences. Thus, in our earlier example, the antecedent of the trace is not *cloak* but the relative pronoun *that*. Again, we conventionally assume that since *that* and *cloak* corefer, the semantics of *cloak* are passed on to *that*.

[9] The hypothesis of movement from subject position is referred to as string-vacuous movement (e.g., Clements et al., 1983). This is because (in contrast to the object-relative situation), the movement does not reorder the elements in the string.

As with studies performed with young adults, our examination of this phenomenon turns on a measure of lexical priming employed during sentence comprehension. By *priming* we refer to facilitation in the processing of one word (the target or probe word) due to the prior processing of a related word (the prime word). This facilitation is standardly taken to indicate that activating the related prime lowers the recognition or processing threshold for all words within its semantic or associative sphere via the propagation of activation within a network of mental representations (Meyer, Schvaneveldt, & Ruddy; 1975).

In our study, we assess the presence or absence of priming between, on the one hand, a word (the prime) in an auditorily presented sentence and on the other hand, a visually presented target word (the probe). By presenting the probe at different times during the delivery of the sentence, we chart when the prime is active during the course of sentence comprehension. More to the point, by choosing a probe related to the moved constituent-or put the other way around, by making the moved constituent the prime-we can determine if elderly adults reactivate this constituent at the gap.

We lay out the details of our assessment of gap-filling in the Methods section. Here, we want only to forecast two of its critical features-one having to do with our manipulation of memory load, and the other with subject selection.

We manipulated the transient memory demands associated with the syntactic operation of gap-filling (across two different experiments) simply by varying the distance between the moved constituent-the antecedent-and the gap indexed by the trace. This distance was defined by the number of words intervening between the two elements of the dependency relation. The intervening words always fit syntactically and semantically; there was never any incongruity. Still, we assumed that the greater this distance, the longer the listener had to keep track of the moved constituent and associate it with its trace-in other words, the greater the memory demand.

With respect to subject selection, we restricted our analyses to elderly subjects. We deemed it unnecessary to include a young adult group. Young adults reliably show gap-filling; more pointedly, they reliably show gap-filling for antecedent-gap distances at least as long as the longest used here (Swinney & Fodor, 1989, 1993; Swinney et al., 1988; Swinney & Osterhout, 1990). Also, even were there to be an age-related difference in the magnitude of the priming effect that signals gap-filling, it would be uninterpretable: At present, this priming effect admits only an "existence" proof-either there is priming at the gap, in which case reactivation of the antecedent at the gap is heeld to have occurred, or there is no priming and no assumption of reactivation. In these theoretically delimited circumstances, there is really only one question: Do diminished memory resources affect gap-filling? And this

question can be answered just by testing elderly subjects. Our aim, after all, was not to chart yet another age-related performance deficit. Rather, as noted at the outset, we sought to capitalize on a change in memory performance already documented in elderly subjects in order to advance our understanding of the role of memory in sentence comprehension.

EXPERIMENT 1

In Experiment 1 we used both subject-relative and object-relative constructions. This allowed us to assess the generality of gap-filling-to assess gap-filling in quite different structural contexts and under different computational demands, assuming, that is, that string-vacuous movement from subject position is computationally less expensive than is movement from object position (see footnote 9). We note, too, that in the present study the subject- and object-relative constructions were also different with respect to the number of words intervening between antecedent and gap. For the subject-relative sentences, about half had five words appearing between the moved constituent and the trace position, and half had six. For the object-relative sentences, the number of intervening words was either seven or eight. Thus, the subject- and object-relative sentences used in this first experiment differed from each other both in terms of computational *and* storage demands.

We loaded the contrast in this way to test processing in the elderly in as severe a manner as possible without having to introduce multiply embedded constructions hardly ever found in conversation. Even so, we felt that the elderly would show gap-filling in all circumstances-whether for the more difficult object-relatives with, in addition, long antecedent-gap distances or for "short-distance" subject-relatives. In effect, we started by supposing that earlier demonstrations of syntactic limitations in the elderly had more to do with postcomprehension task demands than with sentence processing per se.

Methods

Subjects

Twenty community-dwelling elderly adults participated in our first experiment. The mean age for this group was 68 years and their ages ranged between 60 and 75 years. All of these participants had adequate hearing and normal or corrected vision, none had any history of neurological disease, and all were native speakers of English. As for their educational levels, six had completed high school, four had completed junior college, and 10 had Bachelor's or Master's degrees.

Stimulus Materials

The experimental material consisted of 48 auditorily presented object-relative sentences and 48 auditorily presented subject-relative sentences.

To use our earlier illustration, the 48 object-relatives were all of the following form:

> The tailor hemmed the cloak$_i$ that the actor from the studio[1] needed[2] (t_i) for the performance.

By hypothesis, and as indicated by the subscript (i), *the cloak* has been moved from its position as object of the relative clause leaving a trace (t_i) behind; again, the trace is assigned the thematic role (the role of "thing needed") and *the cloak* gets this role only indirectly, by being coindexed to the trace.

For each experimental object-relative sentence, a set of two words was created to be used as visual probes for the examination of priming. One of the words-the experimental probe-was semantically related to the moved constituent (the antecedent). The other word-the control probe-was unrelated to the antecedent. It was, however, matched to the experimental probe in frequency and length (Francis & Kucera, 1982). For the above example, the experimental probe was *robe* (related to the antecedent *cloak*) and the control probe was *goat*. The semantically related (experimental) probes were selected, in each instance, by combining data from published norms (Jenkins, 1970; Keppel & Strand, 1970; Postman, 1970) with data obtained by polling college-age and elderly adults for their first associates to the words that were later incorporated in the sentences as "moved" constituents.

As indicated by the superscripts I and 2 in the above example, priming was examined for each sentence at two points-at the gap indexed by the trace (superscript 2) and at a pregap position (superscript 1). We assessed priming at position 2 in order to measure whether the moved constituent was reactivated, or filled, at the gap (thus providing the prime). The pregap position (position 1) served as a baseline; it allowed us to measure any residual activation from the earlier appearance of the antecedent; that is, it enabled an examination of any nontrace-governed priming effects. Of course, at each position priming was determined by comparing the lexical decision time for the experimental probe to that for the control probe.

The 48 subject-relative sentences were prepared in the same way as the object-relatives. We illustrate with our earlier example and note that all of our subject-relatives were of this structural type:

> The gymnast loved the professor$_i$ from the northwestern city[1] who[2] (t_i) complained about the bad coffee.

Again, we enter the placeholder (t) to indicate the site of extraction-the gap-and we use the subscript (i) to indicate coindexation-to show that, by hypothesis, the role of "complainer" is assigned to the trace and the "professor" gets this role by being linked to the trace.

Priming was assessed in the same way for subject-relatives as for object-relatives. So, for each subject-relative sentence there were two accompanying visual probe words-an experimental probe and a control probe (respectively, *teacher* and *address* for our example); and there were two probe sites-at the gap indexed by the trace (superscript 2) and at a pregap baseline position (superscript 1).

Apparatus and Stimulus Construction

The sentences were presented auditorily on a Sharp Cassette Recorder (RD-771 AV) with an internal tone decoder, the recording having been made by a female speaker, speaking at a normal rate. The letter-string probes were presented visually, appearing either on a Zenith 287 video monitor connected to a Zenith 286 computer or on a Sony monitor (SSM-121) connected to a Compaq Portable II computer. Both monitors had amber phosphor and, as we detail below, both computers had the same clock card that the software accessed. So, in all relevant respects, the situations were the same.

Coordination of the visual and auditory components for the experimental sentences was accomplished as follows: The sentences were digitized at a sampling rate of 22 kHz, with the waveforms of the sentences displayed on a Macintosh Ilci microcomputer. This allowed determination of relevant word positions and boundaries within the sentences by visual inspection of the waveform and confirmation by auditory monitoring. A tone was then placed to coincide with either the pregap position or the gap position. This material was then transferred to the stereo cassette-the sentences to one channel, the tone to the other channel. The tone for each sentence-inaudible to the subjects-served to trigger (via the tone decoder) the visual presentation of the letter string probe so that the string appeared at the center of the monitor either at the offset of the word preceding the pregap position or at the offset of the word preceding the gap position. The tone simultaneously initiated timing for the lexical decision which, when made, removed the letter string from the screen (otherwise it remained on the screen for 2750 msec).

RTLAB software (V9.0) controlled the experiment. With the aid of a software-accessible clock card (Metrobyte CTM05), RTLAB enables the synchronization of stimulus presentation with monitor raster position so that lexical decision timing is accurate beginning from stimulus onset.

Design

Two scripts were created. Each script was composed of one-half (24) of the experimental object-relative sentences, one-half (24) of the experimental subject-relative sentences, and 77 filler sentences. Each sentence in a script had an associated visual probe word. So, for the 24 object-relatives, 12 were presented in conjunction with a visual probe word appearing at the gap and 12, with a visual probe appearing at the pregap position. Six of the 12 gap probes were experimental probes (letter strings forming words semantically related to the antecedent) and six were control probes. Likewise, six of the 12 pregap probes associated with each script were experimental and six were control. Moreover, there were two probe lists for each script such that half the subjects saw an experimental probe in a given location for a given sentence and half saw the control probe for that location in that sentence.

The same arrangements held for the 24 subject-relative sentences within each script. Twelve were conjoined with a probe at the gap, and 12 with a pregap probe. And in each of these two positions, six of the 12 were experimental words and six were control words.

Two versions of each script were prepared, the two differing from one another only in the matter of probe location (as determined by tone placement)-where one version contained a particular sentence with a gap probe, the other contained that sentence with the same probe at the pregap position. Equal numbers of pregap and gap locations appeared within each version.

Each subject was presented with *one* version of each of the *two* scripts. Thus, each subject heard each experimental sentence *once on/v*. *As* a result, each subject contributed only one data point for any one experimental sentence-one lexical decision time for either the experimental or control probe in either the gap or pregap position. So across all 48 object-relative sentences (over the two scripts), each subject contributed 12 data points per condition--12 reaction-time entries for the pregap experimental probe condition, 12 reaction-time entries for the pre-gap control probe condition, and the same number of entries for each of these two conditions at the gap location. In identical fashion, each subject also contributed 12 data points per condition across all 48 subject-relative sentences.

As for the 77 filler sentences in each script, 14 were coupled with visually presented real words and 63 with visually presented pronounceable nonwords. These filler sentences were syntactically similar to the experimental sentences. But to diminish the possibility of a "position set," the

visual probes associated with the filler sentences were placed at different positions in the sentence from those associated with the experimental object- and subject-relative sentences.

Procedure

Subjects were tested individually in two sessions not less than 1 week apart. They were fitted with headphones and seated at a table containing the video monitor and the lexical decision keys. They were instructed on both the auditory and visual aspects of the task.

With respect to the former, they were told that they would hear a series of sentences over the headphones and that their task was to listen carefully to each sentence. To encourage attention to the sentences, for each subject, we stopped the tape 14 times over the two sessions to ask a question about the sentence that was just presented.

Subjects were also told that there would be a second simultaneous task that they would have to perform: They would see a string of letters appear on the screen in front of them at some point during the presentation of each sentence, and they would have to decide as quickly and accurately as possible whether the letter string formed a word. They were instructed on the use of the response keys to indicate their decision-on pressing the *yes* key for a word and the *no* key for a nonword.

Each session consisted of 10 practice trials followed by the run-through of one version of one script.

Results

As will be seen, we have treated object- and subject-relative sentences separately in our analyses in order to provide more precise information concerning the generality of any observed priming effects.

Only the reaction times for the experimental sentences-not for the fillers-were analyzed. As a first step, a data screen was applied to remove errors and outliers. Errors consisted of trials on which the subjects had incorrectly identified a probe word as a nonword and trials on which they had failed to respond within the maximum allotment of 2750 msec; they also included computer errors. Outliers were defined on an individual subject basis as reaction times that were more than 2 standard deviations above the subject's overall mean reaction. The percentage of errors and outliers were calculated for each of the two syntactic types separately and within each syntactic type, for each condition separately. For each subject, errors and data excised were replaced by the subject's mean reaction time for that condition.

For the subject-relative sentences, the average percentage of errors and outliers was 5.7; this covered a range of from 4.5% for antecedent-related probes in the pregap position to 7% for control probes in the gap position. For object-relatives, the percentage of errors and outliers for the 2-standard-deviation screen was slightly higher: Data from 9% of the trials being removed on average, the extremes being 6% for antecedent-related probes at the gap and 13% for control probes at the gap.

The means of these screened data are presented separately for object- and subject-relatives in Table I. For each sentence type we performed two planned comparisons, using in each instance the error term for the specific contrast. In one we compared experimental and control probe reaction times at the pregap position, where no reliable difference was expected; in the other we compared experimental and control probe reaction times at the gap site, where a significant priming effect was expected.

The planned comparisons reveal that the elderly subjects could fill gaps for the subject-relative sentences but not for the object-relative sentences. For the former, they showed significant priming for the experimental probes at the gap site [$F(1, 19) = 5.09$, $p < .04$, $MS_e = 604$]; there was no indication of priming at the pregap location ($F < 1.0$, $MS_e = 1{,}395$). By contrast, for the object-relatives, subjects did not show priming for the experimental probes at either location [gap site: $F < 1.0$, $MS_e = 1{,}658$; pregap location: $F(1, 19) = 1.64$, $p = 0.22$, $MS_e = 2{,}869$].

Discussion

Contrary to our expectations, the elderly adults did not show reactivation at the gap for the object-relative sentences. This contrasts with young adults who do show gap-filling for this construction-in the same cross-modal paradigm and for comparable (if not greater) antecedent-gap distances (e.g., Swinney et al., 1988).

Table I. Experiment I Mean Reaction Time (msec)

	Visual probes			
	Pregap position		Gap position	
	Experimental	Control	Experimental	Control
Object-relatives	681	703	669	678
Subject-relatives	663	673	665[a]	682[a]

[a] Significant difference between reaction time for experimental probe and reaction time for control probe [$F(1, 19) = 5.09$, $p < .04$].

This null result for a marker of syntactic processing cannot be attributed to a generalized psychomotor slowing. The elderly group's failure to fill gaps was not, after all, global; and in any event, we charted relative reaction times, not absolute speed. And to our minds, the possible explanations all seem to implicate memory.

One possibility is that the memory "workspace" can no longer be used efficiently. The elderly subjects' relatively greater ability to fill gaps in subject positions is compatible with this notion. As already described, the computational requirements for subject-relatives reasonably seem to be fewer than for object-relatives-for example, movement does not reorder the elements of a subject-relative string as it does for an object-relative string (see footnote 9). So in the face of reduced processing efficiency in old age, the processing component of working memory maybe less able to deal with "difficult" object-relative constructions than with subject-relatives.

Another possibility is that the limitation charted here has more to do with storage than with parsing (structure building) considerations. The subject-relative versus object-relative comparison is again relevant. As already indicated, the distance between antecedent and gap was uniformly shorter for the subject-relatives than for the object-relatives. For the former, the number of intervening words was typically five or six; for the latter, seven or eight. In effect, the antecedent in an object-relative sentence had to be stored for a longer time and over more words than did the antecedent in a subject-relative sentence. And perhaps it was this storage factor that limited the elderly subjects' performance more strikingly for object- than for subject-relatives.

A second experiment was undertaken to evaluate these alternative explanations for the difference between subject- and object-relatives.

EXPERIMENT 2

To determine whether the pattern of results in the first experiment pointed to processing inefficiency or to a decreased storage 'capacity, we again assessed gap-filling for object-relatives-but this time for object-relatives with a "shorter" antecedent-gap distance. We reasoned that, if the syntactic problem had more to do with storage capacity than with computational expense, we could ensure reliable gap-filling for object-relatives simply by reducing the antecedent-gap distance. Indeed, from this mechanistic perspective, if five- and six-word distances yielded moderately reliable gap-filling for subject-relatives, then a maximum distance of five words ought to yield even more reliable gap-filling-even for the more difficult object-relative construction.

Methods

Subjects

Experiment 2 also used 20 community-dwelling elderly adults. Of these, nine had participated in the first experiment; but since 2 1/2 years separated our two experiments and since all of these nine subjects had appeared in many other studies during that time, we confidently exclude any order or practice effects. The mean age for the entire group of 20 was 69 years, with a range between 61 and 76 years. As in the first experiment, all subjects had adequate hearing and normal or corrected vision, all were free of any history of neurological disease, and all were native speakers of English.

Stinulus Materials

There were 48 auditorily presented object-relative sentences. These sentences were formed from the object-relatives used in Experiment 1. What was changed was the number of words appearing between antecedent and gap. More particularly, we dropped an adjunctive phrase that did not participate in the structural relations that we investigated. Whereas the object-relatives in Experiment I typically had seven or eight intervening words, those in Experiment 2 always had only five. In every other respect they were the same. To illustrate, we resurrect our earlier example: For Experiment I the sentence was

> The tailor hemmed the cloak$_i$ that the actor from the studio needed (t_i) for the performance.

For Experiment 2 it became

> The tailor hemmed the cloak$_i$ that the broadway actor needed (t_i) for the performance.

Since the antecedents remained the same across the two experiments, so, too, did the visual probes. The probe locations also did not change: The gap site appeared immediately after the verb in the subordinate clause; the pregap probe always appeared immediately before that verb. Again, the only change was the "shorter distance" between antecedent and gap.

Apparatus and Stimulus Construction

The equipment used for Experiment 2 was the same as that used in Experiment 1, and the method of stimulus construction was also the same.

Design

The same general design principles held across the two experiments. But whereas in Experiment I there were 96 experimental sentences (48 object-relatives and 48 subject-relatives), in Experiment 2 there were altogether only 48 experimental sentences. Accordingly, instead of two scripts, only one was necessary. This consisted of the 48 experimental object-relatives and 72 filler sentences. Of the 48 object-relative sentences, 24 were coupled with visual probe words appearing at the gap and 24 with visual probes at the pregap position. Twelve of the 24 gap probes were experimental (that is, semantically related to the antecedent) and 12 were control probes. This experimental-control distinction applied also to the pregap probes. And again there were two probe lists such that half the subjects saw an experimental probe in a given location for a given sentence and half saw the control probe for that location in that sentence.

Also as in the first experiment, two versions of each script were prepared such that the sentences were balanced with respect to probe location: If a given sentence in version 1 contained a gap probe, that same sentence appeared in version 2 with the same probe, but at the pregap position. Each subject was presented with one version, and in consequence, each subject provided 12 data points for each condition-exactly the same number of data points as in Experiment 1.

With respect to the 72 filler sentences, 12 were associated with visually presented real words and 60, with pronounceable nonwords.

Procedure

The sole procedural change was that only one testing session for each subject was required.

Table II. Experiment 2 Mean Reaction Times (msec)

	Visual probes			
	Pregap position		Gap position	
	Experimental	Control	Experimental	Control
Object-relatives	784	791	766[a]	809[a]

[a] Significant difference between reaction time for experimental probe and reaction time for control probe [$F(1, 19) = 5.74$, $p < .03$].

Results

As in Experiment 1, the reaction time data were screened for errors and outliers, which were defined as being 2 standard deviations above the subject's overall mean. Eight percent of the data were excised by this screen, the excisions being roughly equivalently distributed across conditions. Again, the errors and outliers were replaced on an individual-subject basis by the subject's mean reaction time in that condition. The means of these screened data are presented in Table II.

The data were examined by two planned comparisons using the error term for the specific contrast. In one contrast we compared experimental and control probe reaction times at the pregap location; in the other we compared experimental and control probe reaction times at the gap site.

These analyses show that there was reliable priming at the gap [$F(1, 19) = 5.74$, $p < .03$, $MS_e = 3{,}197$], but no pregap priming ($F < 1.0$, $MS_e = 3{,}682$).[10]

Discussion

With only five words separating antecedents and gaps in each of our object-relative sentences, elderly adults reliably filled these gaps-they reliably established the intrasentence dependency relations existing between moved constituents and phonologically empty elements (traces). It seems, therefore, that the ease with which elderly subjects could link antecedents and gaps on-line was more affected by the distance separating the two than by the nature of the syntactic representation that had to be constructed; difficulties arose for greater than five-word distances regardless of whether the antecedent had been extracted from an object or subject position.

GENERAL DISCUSSION

Our undertaking was driven by the notion that automatic syntactic processing is relatively resource free (Fodor, 1983; Forster, 1990; Frauenfelder Tyler, 1987; Swinney & Fodor, 1989). It seemed quite reasonable, therefore, to expect such processing to be impervious to memory constraints such

[10] We wanted to avoid any repetition priming artifacts (e.g., Monsell, 1985) and so each subject saw each sentence once only. This design feature and the highly constrained (i.e., nonrandom) selection of stimuli precluded any legitimate item analysis in either Experiment I or 2. Accordingly, and strictly speaking, our inferential tests apply only to the specific items used here. Still, the pattern of findings across the two experiments clearly demonstrates that elderly subjects are capable of gap-filling when the antecedent-gap distance is short.

as those associated with normal aging. Thus, we started by supposing that, contrary to past speculation on the matter, there really was no direct-link in the elderly between limitations in memory capacity and syntactic processing. We assumed that the difficulty elderly subjects had with complicated syntax had to do with task-imposed, postcomprehension memory demands *independent of* syntactic processing.

The data we have presented here fail, however, to support our initial assumptions concerning the effects of aging. These data indicate, rather, that age-related memory limitations apply *even as comprehension unfolds temporally*.

The data also suggest, however, that there are aspects of syntactic processing that are relatively insulated from the memory limitations that attend old age. In particular, when the antecedent-gap distance was within storage capacity, we saw no sign of inefficient use of the memory workspace. Gaps were filled not only for subject-relative sentences, but also for the more "difficult" object-relatives. Thus, with respect to these two constructions at least, the bottleneck applies, not to the system responsible for assigning phrase structure, but to that responsible for establishing dependency relations-for coindexing and coreferencing once the relevant syntactic configuration has been constructed.

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