Aging and Resolution of Quantifier Scope Effects

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Two experiments were conducted to compare young and older adults’ processing of complex sentences involving quantifier scope ambiguities. Young adults were hypothesized to use a mix of syntactic processing strategies to interpret sentences such as Every actor used a prop. Older adults, particularly those with limited working memories, were hypothesized to rely on a simple pragmatic principle. Participants read the quantifier sentences and judged whether a continuation sentence “made sense.” Reading times for the quantifier sentences and decision times and continuation sentence acceptability judgements were analyzed. Whereas young and older adults exhibited similar patterns of reading times for the quantifier sentences, they preferred different continuations for the Every...a quantifier sentences. As predicted, both young adults and older adults interpreted a quantifier sentence such as An actor used every prop as referring to a single entity resulting in a preference for continuations such as The actor was on the stage. In contrast, young and older adults made different interpretations of a quantifier sentence such as Every actor used a prop; young adults preferred continuations postulating multiple entities such as The props were on the stage whereas older adults, particularly those with working memory limitations, preferred continuations with a single entity such as The prop was on the stage. These results support models of the effects of aging on language processing in which immediate syntactic analysis is not affected by aging or working memory limitations whereas postcomprehension processes are affected by aging and/or working memory limitations.

The effects of working memory limitations on adults’ comprehension of complex syntactic constructions has been the focus of recent psycholinguistic research. Working memory limitations have been shown to affect some aspects of language processing, especially those involving the analysis of complex or ambiguous syntactic structures (Just, Carpenter, & Keller, 1996; King & Just, 1991; MacDonald, Just, & Carpenter, 1992; Miyake, Just, & Carpenter, 1994; Pearlmuter & MacDonald, 1995), although effects of working memory span on language processing have not been observed consistently (Caplan & Waters, 1999; Waters, Caplan, & Hildebrandt, 1987; Waters & Caplan, 1996a, 1996b). Working memory limitations have also been assumed to affect older adults’ language processing (Kemper, 1997), although support for this hypothesis is also mixed (Just, Carpenter, & Keller, 1996; Caplan & Waters, 1999). Support for this hypothesis is primarily based on off-line measures of sentence imitation, sentence recall, and text comprehension (Kemper, 1992). Only a few studies have employed on-line measures of immediate sentence processing with young and older adults. Zurif, Swinney, Prather, Wingfield, and Brownell (1995) investigated whether working memory limitations affect older adults’ processing of complex syntactic constructions. They suggested that older adults might require additional processing time in order to analyze sentences involving so-called filler-gap constructions. For example, while processing “The tailor hemmed the cloak that the actor from the studio needed [t] for the performance,” a trace of “the cloak” must be retained in order to fill the gap [t] as the direct object of the verb “needed.” Zurif and colleagues reported that age-related deficits in working memory can limit older adults’ ability to retain such syntactic constituents while simultaneously processing the intervening material. However, more recent investigations have failed to find effects of age-associated working memory limitations on on-line syntactic processing.

Stine-Morrow, Loveless, and Soederberg (1996) decomposed reading times by young and older adults with regards to various word-, sentence-, and text-level factors; both young and older adults allocated extra reading time to complex syntactic constructions, suggesting that on-line processing at this level is age invariant. A similar conclusion was reached by Kemtes and Kemper (1997), who examined older adults’ comprehension of syntactically complex sentences using both an on-line measure of reading time and an off-line measure of comprehension. Kemtes and Kemper showed that older adults produce word-by-word reading time patterns for complex sentences that are equivalent to those of young adults; in contrast, off-line answers to probe questions about these same complex sentences by young and older adults differ. They concluded that working memory limitations do not affect the on-line interpretation of complex syntactic constructions but that older adults make more errors answering probe questions as a result of working memory limitations on postcomprehension processes.

In order to explore this issue further, we examined another type of complex syntactic construction, sentences involving quantifier scope ambiguities. The types of sentences studied by Kemtes and Kemper (1997) and Zurif and colleagues (1995) involve structural ambiguities in which alternative structures can be assigned to a phrase. Quantifier scope ambiguities do not arise from alternative syntactic structures but from alternative semantic interpretations that result when two or more noun phrases in a sentence are modified by a quantifier such as some, every, many, or few. Ambiguity arises from different logical or semantic interpretations of the scope of the quantifiers; scope refers to the relationships among the sets of individuals referenced by the quantified terms. Quantifier scope ambiguities

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have been the focus of extensive studies in linguistics and philosophy (Chierchia & McConnell-Ginet, 1990; Fodor, 1982; Kempton & Cormack, 1991).

Kurtzman and MacDonald (1993) extended the psycholinguistic study of ambiguity resolution by considering how young adults resolve quantifier scope ambiguities. Kurtzman and MacDonald required young adults to read a quantifier sentence and then evaluate whether a continuation sentence was consistent with the meaning of the quantifier sentence. Each continuation was consistent with only one interpretation of the quantifier sentence. We adopted their paradigm to investigate the possibility of age differences in ambiguity resolution. Our issue was not whether the time course of scope ambiguity resolution was the same for older and young adults. We expected to find few differences due to age or working memory span on the immediate processing of the quantifier sentences, as reflected in sentence reading times; however, we hypothesized that young and older adults might differ in their interpretations of the quantifier sentences. Consequently, they might prefer different continuations to the quantifier sentences, consistent with different resolutions of the quantifier scope ambiguities.

Consider the quantifier sentences in Table 1. Every kid climbed every tree is ambiguous. In one interpretation, the first noun phrase is accorded wide scope (WS1); this implies that there are multiple trees and each kid climbed a different tree. Alternatively, the second noun phrase can be accorded wide scope (WS2); this implies only that there is at least one tree, although there may be multiple trees, and that every kid climbed the same tree. The quantifiers can be reordered, producing A kid climbed every tree. According wide scope to the first noun phrase (WS1) produces an interpretation in which the same kid climbed every tree. According wide scope to the second noun phrase (WS2) produces an interpretation in which a different kid climbed every tree.

Kurtzman and MacDonald (1993) reported that young adults apparently resolve these quantifier scope ambiguities by using syntactic principles that assign scope to the noun phrases. The relevant syntactic principles include the linear order principle, which holds that scope is assigned left-to-right such that the leftmost phrase has wide scope. Alternatively, wide scope may be assigned to either the surface structure subject or the deep-structure subject. Scope can also be determined by a formal syntactic relationship, that of c-command (Chomsky, 1986): one phrase, or node A, c-commands another phrase or node B, if A does not dominate B and every node C that dominates A dominates B. For active sentences, these syntactic principles all predict that the left-most phrase will have wide scope: the left-most phrase is both the surface structure subject and the deep structure subject, and the surface structure subject c-commands the other noun phrases in the sentence.

All of these syntactic principles predict that the WS1 interpretation of both Every... a and A... every quantifier sentences will be preferred. Further note that the WS1 interpretation of Every... a quantifier sentences postulates that there is a set of multiple entities refered to by the first noun phrase which is mapped onto the set of multiple entities referenced by the second noun phrase. The WS2 interpretation of Every... a quantifier sentences is simpler: each of the set of entities referred to by the first noun phrase is mapped onto the single entity referenced by the second noun phrase.

An alternative to interpreting the quantifier sentences using syntactic principles is to interpret the sentences using pragmatic principles. A variety of pragmatic principles have been proposed including the topic principle (Katz, 1980; Kempton, & Cormack, 1981), which would predict that the topic is assigned wide scope, and the thematic hierarchy principle (Grimshaw, 1991), which would hold that the phrase highest in the thematic hierarchy is accorded wide scope. The thematic hierarchy establishes preferences among thematic (or semantic) roles as: AGENT > EXPERIENCER > THEME. Hence, the agent will have wide scope over the theme. These pragmatic principles make similar predictions for quantifier scope assignment to those generated by the syntactic principles for active sentences. For active sentences, the first or left-most noun phrase is predicted to have wide scope regardless of quantifier order; it is the subject of the sentence as well as the topic, and it is typically an agent.

One principle, however, makes different predictions for Every... a and A... every quantifier orders. This principle, the principle of single reference, holds that a single entity is postulated whenever the quantifier a is encountered (Kurtzman & MacDonald, 1993; Fodor, 1982). Applied to Every kid climbed a tree, the single reference principle postulates that there is a single tree, consistent with the WS2 interpretation in which there are many kids and each kid climbed the same tree. For A kid climbed every tree, the principle of single reference also would postulate a single kid, which is consistent with the WS1 interpretation in which there is one kid and this same kid climbed each of the trees. Thus, for active sentences with A... every quantifiers, the principle of single reference predicts wide scope over the first noun phrase, as do the syntactic principles and the other pragmatic principles. For active sentences with Every... a quantifiers, the principle of single reference predicts wide scope for the second noun phrase, in contrast to the syntactic principles and the other pragmatic principles that predict wide scope for the first noun phrase.

We hypothesized that older adults might rely on the pragmatic principle of single reference, rather than the syntactic strategies, in order to interpret sentences with quantifiers. This hypothesis was motivated, in part, by the work of Kliegl and...
Mayr and their associates on sequential versus coordinative complexity (Kliegl, Mayr, & Krampe, 1994; Mayr & Kliegl, 1993; Mayr, Kliegl, & Krampe, 1996; Verhaeghen, Kliegl, & Mayr, 1997). Sequential complexity applies to task domains where the number of simple and independent processing steps determines task complexity; coordinative complexity applies to task domains that involve the coordination, scheduling, and switching between interrelated processing steps and the temporary storage of the results of intermediate processes. Whereas age-related changes in sequential processing appear to be proportional to the general slowing of cognitive processes, age-related deficits in coordinative complexity are disproportionate and reflect additional deficits involving the temporary storage of information in working memory so that the information can be integrated with subsequent processing operations. The syntactic processing principles for the resolution of quantifier scope ambiguities appear to involve coordinative complexity whereas the pragmatic principles, particularly the principle of single reference, appear to involve sequential complexity. Consequently, we hypothesized that older adults would have difficulty applying the syntactic processing principles due to working memory limitations and would rely, instead, on the pragmatic principle of single reference.

In order to apply the principle of single reference, the processor need only postulate a single entity referenced by the quantifier and a set of multiple entities referenced by the quantifier every. In the case of Every... a sentences, the set of multiple entities referenced by the subject must be mapped onto the single entity referenced by the direct object, a sequential mapping operation that will result in wide scope being assigned to the second noun phrase.

Application of any of the syntactic principles, in contrast, involves the coordination of intermediate processing stages. Parallel processing models (Gibson & Thomas, 1996; Gibson, Schutze, & Salomon, 1996; Gorrell, 1989; Lewis, 1996) and competition models (MacDonald, 1994; MacWhinney, 1987) differ in terms of how these multiple interpretations are resolved. A parallel model would imply that the multiple representations are simultaneously held in working memory and evaluated; the WS1 interpretation would be chosen as it is consistent with most of the processing principles. The demands of constructing and choosing among alternative representations is a form of coordinative complexity. Alternatively, a competition model would imply that these processing principles are applied simultaneously and compete for processing resources. Only the WS1 interpretation is constructed because it is favored by most of the processing principles. Coordinative complexity arises in a competition model from the simultaneous application of competing syntactic principles.

Coordinative complexity also arises from the many-to-many mappings of the set of entities referenced by the first noun phrase on to the set of entities referenced by the second noun phrase, for either quantifier order. The WS1 interpretation of Every... a sentences requires not only that the quantifier be interpreted as a set of many entities but that each be mapped on to the set of many entities referenced by the first noun phrase. The WS1 interpretation of A... every sentences also involves this form of coordinative complexity.

We hypothesized that older adults would favor sequential processing over coordinative processing, resulting in a bias for the WS2 interpretation of Every... a quantifier sentences whereas young adults would favor coordinative processing, resulting in a bias for the WS1 interpretation of Every... a quantifier sentences. Both young and older adults were expected to prefer the WS1 interpretation of the A... every quantifier sentences although for different reasons. Young adults should be biased toward the WS1 interpretation as a result of applying the syntactic and/or pragmatic processing principles whereas older adults should be biased toward the WS1 interpretation as a result of applying the principle of single reference.

Kurtzman and MacDonald (1993) also investigated quantifier scope resolution for a variety of other types of constructions. Their work suggests that young adults have no consistent preference for passive sentences (e.g., A tree was climbed by every kid), but young adults use a mix of syntactic, semantic, and pragmatic principles to interpret individual sentences. Kurtzman and MacDonald also suggest that complex noun phrases, such as I saw every picture of an acrobat, are preferentially assigned wide scope "contrary to the predictions of all the principles under consideration" (p. 267). As a result, we did not test older adults using these types of constructions because we could not formulate clear predictions regarding age differences in quantifier scope resolution.

Our predictions were clear for active sentences involving Every... a and A... every quantifier orders. We expected to replicate Kurtzman and MacDonald's (1993) findings for young adults: a strong WS1 preference for both quantifier orders reflecting the convergence of the linear order, surface subject, deep subject, and c-command syntactic principles. Each principle favors the wide scope reading of the first noun phrase for the active sentences used in the present experiment. We also expected older adults would rely on a nonsyntactic principle, the principle of single reference (Fodor, 1982; Kurtzman & MacDonald, 1993). This nonsyntactic principle would yield a strong preference for assigning wide scope to the second noun phrase in Every... a quantifier sentences such that the sentences would be interpreted as referring to a single noun phrase direct object; this nonsyntactic strategy would also yield a strong preference for WS1 interpretation of A.. every quantifier sentences, interpreting the sentences as referring to a single noun phrase subject. Hence, older adults were expected to prefer WS2 interpretations of Every... a quantifier order but WS1 interpretations of A... every order. This reliance on a nonsyntactic strategy was expected to be more evident for low-span older adults than for high-span older adults. Experiment 1 replicated Kurtzman and MacDonald's (1993, Experiment 1) with young and older adults.

**Experiment 1**

In order to investigate whether both young and older readers interpret quantified sentences using syntactic principles, participants read an ambiguous quantifier sentence followed by a continuation that was consistent with only one interpretation of the quantifier sentence. The participants were asked to judge whether the continuation "made sense." Young adults were expected to prefer continuations consistent with the WS1 interpretation of either type of quantifier sentence; older adults were expected to prefer different continuations for the two types of quantifier sentences. In addition to the continuation preferences,
reading time latencies for the quantifier sentences and decision latencies for the continuation sentences were also collected. Preferences for continuations to unambiguous variants of the quantifier sentences were also collected as a check on the participants’ comprehension of the sentences; foil or catch trials in which the continuation was inappropriate were also included.

**Method**

**Participants**

Twenty-four younger (Y) adults ranging in age from 18 to 25 years ($M = 22.1$; 52% women) and 24 older (O) adults ranging in age from 65 to 85 years ($M = 73.5$; 71% women) participated in the study. Data from one young adult were lost due to a computer malfunction; thus data from 23 young participants were available for analysis. The younger sample consisted of graduate and undergraduate students recruited by posted signs. The older sample consisted of community-dwelling older adults recruited from a listing of previous research participants. Participants received a modest honorarium for their participation in the study. All participants were native speakers of English. Number of years of education did not differ between age groups ($MY = 15.3, SDY = 3.1, M0 = 16.0, SD0 = 3.0, t(45) = -1.05, p = .30$) nor did self-reports of hearing, vision, or overall health. Older adults’ scores on the 40-item Shipley (1940) vocabulary test were significantly higher than those of the younger adults ($M_Y = 35.8, SD_Y = 3.6; M_0 = 32.1, SD_0 = 3.1; t(45) = -3.78, p < .01$). Overall, younger adults’ composite working memory scores were significantly higher than those of the older adults ($M_Y = 21.7, SD_Y = 4.9; M_0 = 31.4, SD_0 = 4.7; t(47) = 5.55, p < .01$). Participants’ complete descriptive statistics appear in Table 2.

**Experimental Procedure**

Participants were tested individually in a session that lasted approximately 1 hour. Participants first responded to questions about their formal education and work status, and they rated their vision, hearing, and overall health. Participants next completed the 40-item Shipley vocabulary test (Shipley, 1940). Participants then completed the forward and backward digits and reading span working memory tasks. Next, participants completed the experimental task. Finally, participants completed the Waters and Caplan working memory tasks. The working memory tasks are described in detail in the next section.

**Table 2: Descriptive Information for Young and Older Adults Participating in Experiments 1 and 2 (Standard Deviations in Parentheses)**

<table>
<thead>
<tr>
<th>Experiment 1</th>
<th>Young Adults</th>
<th>Older Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Span</td>
<td>Low Span</td>
</tr>
<tr>
<td>Age</td>
<td>22.2 (2.8)</td>
<td>22.0 (2.4)</td>
</tr>
<tr>
<td>Education</td>
<td>15.2 (1.8)</td>
<td>15.4 (1.9)</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>33.0 (2.3)</td>
<td>31.2 (3.5)</td>
</tr>
<tr>
<td>WM&lt;sub&gt;Composite&lt;/sub&gt;</td>
<td>35.1 (1.7)</td>
<td>27.6 (3.4)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment 2</th>
<th>Young Adults</th>
<th>Older Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Span</td>
<td>Low Span</td>
</tr>
<tr>
<td>Age</td>
<td>20.4 (1.7)</td>
<td>23.2 (2.3)</td>
</tr>
<tr>
<td>Education</td>
<td>14.8 (2.2)</td>
<td>13.6 (2.1)</td>
</tr>
<tr>
<td>Vocabulary</td>
<td>34.5 (2.1)</td>
<td>29.7 (5.5)</td>
</tr>
<tr>
<td>WM&lt;sub&gt;Composite&lt;/sub&gt;</td>
<td>24.3 (4.1)</td>
<td>19.7 (4.8)</td>
</tr>
</tbody>
</table>

**Working Memory Measures**

Participants completed four span measures in the experiment: the forward and backward digits from the WAIS–R (Wechsler, 1981), commonly used as indexes of short-term memory processing; a reading span task reported in Kemtes and Kemper (1997), which was based on the original Daneman and Carpenter (1980) reading span task; and the version of the Waters and Caplan sentence span task reported in Waters and Caplan (1996a).

In the reading span task, participants read aloud progressively longer sets of sentences without pausing and then recalled the sentence-final word from each sentence in the set. The reading span score was defined as the highest level at which participants correctly recalled all of the words from two of the three sets. Participants received an additional half point if they correctly recalled one of the three sets from the next highest level.

The Waters and Caplan sentence span task has three primary components: (a) the processing component, which requires individuals to read sentences on a computer monitor; (b) the semantic decision component, which requires individuals to decide whether or not the sentence “makes sense” and (c) the recall component, which requires individuals to recall the sentence-final words at the end of each set. The Waters and Caplan (1996a) version is composed of two subtests, which correspond to two sentence types that differ in terms of syntactic and propositional complexity: cleft subject sentences, such as It was the gangsters that broke into the warehouse, and subject-object sentences, such as The meat that the butcher cut delighted the customer. The measure of working memory processing is the average reaction time to the sentence decision task; capacity is indexed by the highest level of sets correctly completed (ranging from Levels 2 to 6 with five sets per level) and by the total number of items correctly recalled. A composite score was calculated by computing standard scores for each of the constituent tasks for each participant and then averaging the standard scores across tasks.

**Materials and Tasks**

**Stimuli.**—The 32 quantifier-scope sentence frames used in the experiment were taken from Kurtzman and MacDonald (1993, Experiment 1); examples are shown in Table 3. Different versions of each sentence frame were constructed by varying quantifier order (Every . . . a vs A . . . every), ambiguity (ambiguous vs unambiguous), and continuation. The continuation sentences were consistent with either a wide scope reading over the first noun phrase (WS1) or a wide scope reading over the second noun phrase (WS2) in the quantifier sentences. The unambiguous sentences were included to provide a means to evaluate any overall stylistic preference for one continuation or the other. The ambiguous quantifier sentences were disambiguated by inserting same or different to clarify the scope of
either the first or second noun phrase. Thus, *A kid climbed every tree* is ambiguous, whereas *The same kid climbed every tree* resolves the ambiguity in favor of the WS1 interpretation. In all, there were eight types of experimental items constructed from each sentence frame by varying quantifier order, ambiguity, and continuation.

Twenty items were constructed to serve as foils. These items consisted of unambiguous quantifier sentences paired with continuation sentences that were inappropriate. For example, the quantifier sentence might refer to *different* dogs whereas the continuation sentence would describe one specific dog. Examples are shown in Table 3. Thirty-two additional items were constructed to serve as filler items. Each consisted of a quantifier sentence headed by quantifiers such as *all, none, few, many,* or *some* followed by continuation sentence. For these fillers, one-half of the continuation sentences were inappropriate.

The experimental items were divided into eight stimulus sets such that for each set, there were four instances of each of the eight types varying in quantifier order, ambiguity, and continuation; however, a particular sentence frame occurred only once within a set and the eight versions were assigned to different stimulus sets. Participants were randomly assigned to one of the eight stimulus sets. Each participant read a total of 32 experimental items, 20 foils, 32 fillers, and 10 practice items.

<table>
<thead>
<tr>
<th>Table 3. Example Materials Used in Experiments 1 and 2 Illustrating Alternative Quantifier Orders, Continuation Sentences Varying in Scope, Foils, and Context Sentences (Experiment 2 Only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Every... a Quantifier Order</td>
</tr>
<tr>
<td>Ambiguous, Wide Scope over the first noun phrase (WS1)</td>
</tr>
<tr>
<td>Quantifier Sentence: Every kid climbed a tree.</td>
</tr>
<tr>
<td>Continuation: The trees were full of apples.</td>
</tr>
<tr>
<td>Ambiguous, Wide Scope over the second noun phrase (WS2)</td>
</tr>
<tr>
<td>Quantifier Sentence: Every kid climbed a tree.</td>
</tr>
<tr>
<td>Continuation: The tree was full of apples.</td>
</tr>
<tr>
<td>Unambiguous, Wide Scope over the first noun phrase (WS1)</td>
</tr>
<tr>
<td>Quantifier Sentence: Every kid climbed a different tree.</td>
</tr>
<tr>
<td>Continuation: The trees were full of apples.</td>
</tr>
<tr>
<td>Unambiguous, Wide Scope over the second noun phrase (WS2)</td>
</tr>
<tr>
<td>Quantifier Sentence: Every kid climbed the same tree.</td>
</tr>
<tr>
<td>Continuation: The tree was full of apples.</td>
</tr>
<tr>
<td>A... every Quantifier Order</td>
</tr>
<tr>
<td>Ambiguous, Wide Scope over the first noun phrase (WS1)</td>
</tr>
<tr>
<td>Quantifier Sentence: A kid climbed every tree.</td>
</tr>
<tr>
<td>Continuation: The kids was full of energy.</td>
</tr>
<tr>
<td>Ambiguous, Wide Scope over the second noun phrase (WS2)</td>
</tr>
<tr>
<td>Quantifier Sentence: A kid climbed every tree.</td>
</tr>
<tr>
<td>Continuation: The kids were full of energy.</td>
</tr>
<tr>
<td>Unambiguous, Wide Scope over the first noun phrase (WS1)</td>
</tr>
<tr>
<td>Quantifier Sentence: The same kid climbed every tree.</td>
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<tr>
<td>Continuation: The kids was full of energy.</td>
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<tr>
<td>Unambiguous, Wide Scope over the second noun phrase (WS2)</td>
</tr>
<tr>
<td>Quantifier Sentence: A different kid climbed every tree.</td>
</tr>
<tr>
<td>Continuation: The kids were full of energy.</td>
</tr>
<tr>
<td>Foils</td>
</tr>
<tr>
<td>Quantifier Sentence: Every teacher praised a different principal.</td>
</tr>
<tr>
<td>Continuation: The principal was diligent and smart.</td>
</tr>
<tr>
<td>Contexts (Experiment 2)</td>
</tr>
<tr>
<td>Context 1: The kids were in the park.</td>
</tr>
<tr>
<td>Context 2: The trees were in the park.</td>
</tr>
</tbody>
</table>

**Sentence Presentation**

Sentences were presented on a 14" noninterlaced VGA monitor in a line-by-line format. The Micro Experimental Laboratory software (MEL; Schnieder, 1996) was used to control the presentation of the stimuli and collect reading times, as measured by a key press, to the nearest millisecond. At the beginning of each trial, participants read the following cue, which was presented in the middle of the monitor’s screen: PRESS THE + KEY TO BEGIN. Participants pressed the response key to clear the display and then pressed the key again to display the quantifier sentence. Participants were instructed to read this sentence and then press the continuation response key after they had finished. This key press cleared the quantifier sentence from the screen and displayed the continuation sentence. As in Kurtzman and MacDonald (1993), participants were instructed to read this sentence and decide whether it made sense and was a natural continuation of the first sentence and to indicate their response using the appropriate keys on the keyboard. After the acceptability decision had been made, the monitor display was cleared and the cue PRESS THE + KEY TO BEGIN appeared on the screen to indicate the start of a new trial. A practice block consisting of 10 sentences was presented in a fixed order for all participants followed by the experimental and filler sentences, which were presented in random order. At the start of the trials, participants were instructed to read each sentence quickly, but carefully, so as not to compromise their comprehension.

**Results**

**Working Memory Span**

As in Kemtes and Kemper (1997), participants’ composite working memory scores were formed using the four span measures, forward and backward digit span, reading span, and Waters and Caplan span. Separate median splits were performed on the younger and older adults’ distributions of working memory composite scores in order to form high- and low-span groups. Composite scores based on the four WM measures are summarized in Table 2.

**Reading Time Analyses**

Separate analyses were performed on the log-transformed reading times for quantifier and decision latencies for the continuation sentences. Reading times for the quantifier sentences were analyzed with 2 (age group) × 2 (span group) × 2 (quantifier order) × 2 (ambiguity) analysis of variance (ANOVA).
There were no main effects of span group, ambiguity, or quantifier order; however, the main effect of age group was significant: $F(1,43) = 9.8, p = .003, \eta^2 = .187$. Young adults’ reading times (in milliseconds) were faster than those of older adults ($M_Y = 2.955; M_O = 4.054$).

Reading times for the continuation sentences were analyzed with a $2 \times 2 \times 2 \times 2$ (quantifier order) ANOVA. The main effects of span group, quantifier order, ambiguity, and scope were not significant; however, the main effect of age group was significant, $F(1,43) = 30.1, p = .000, \eta^2 = .422$. Young adults’ reading times were faster than those of older adults ($M_Y = 2.837; M_O = 4.421$).

**Continuation Decisions**

Continuation sentences following unambiguous quantifier sentences were judged to be acceptable with greater frequency than continuation sentences following ambiguous quantifier sentences, resulting in an overall effect of ambiguity, $F(1,43) = 5.373, p = .025, \eta^2 = .107$ ($M_{Ambiguous} = 71\%$, $M_{Unambiguous} = 82\%$). Separate 2 (age group) $\times 2$ (span group) $\times 2$ (quantifier order) ANOVAs were conducted on the continuation judgments following unambiguous and ambiguous quantifier sentences because our predictions concerned continuations following ambiguous quantifiers only. The dependent variable was a difference score computed by subtracting, for each participant, the number of WS2 continuations found to be acceptable from the number of WS1 continuations found to be acceptable because Kurtzman and MacDonald (1993) reported an overall preference for WS1 interpretations. A positive score indicates a bias for the WS1 interpretation; a negative score indicates a bias for the WS2 interpretation.

For unambiguous quantifier sentences, there were no significant effects or interactions, all $F(1,43) < 2.20, p > .20$. For ambiguous quantifier sentences, there was a significant effect of quantifier order, $F(1,43) = 9.506, p = .007, \eta^2 = .156$, as well as a significant interaction of quantifier order and age group, $F(1,43) = 8.508, p = .006, \eta^2 = .154$. Young adults preferred the WS1 continuations for the Every... a quantifier sentences ($M_{WS1-WS2} = 8.6, SD = 9.2$); their preference for the WS1 continuations differed significantly from zero, or no preference, $p < .05$. Young adults had no preference for either WS1 or WS2 continuations for the A... every quantifier order ($M_{WS1-WS2} = -1.5, SD = 15.8$), $p > .10$. Older adults had a slight preference for WS2 continuations for the Every... a quantifier order ($M_{WS1-WS2} = 5.7, SD = 12.5$); their preference was marginally different from zero, $p = .06$. Older adults had no preference for either WS1 or WS2 continuations for the A... every quantifier order ($M_{WS1-WS2} = 1.7, SD = 21.1$), $p > .10$.

**Foil Sentences**

Fois were analyzed in a separate 2 (age group) $\times 2$ (span group) $\times 2$ (quantifier order) ANOVA. Young and older adults and high- and low-span individuals correctly rejected foils with equal accuracy following both Every... a and A... every quantifier sentences; all main effects and interactions were non-significant, all $F(1,43) < 2.2, p > .20$.

**Discussion**

In contrast to Kurtzman and MacDonald (1993) who reported a strong preference for WS1 continuations for Every... a and A... every quantifier sentences, young participants in the present study had only a weak preference for WS1 continuations for the Every... a quantifier sentences and no preference for A... every sentences. Older adults tended to prefer WS2 continuations for Every... a sentences but had no preference for WS1 or WS2 continuations to A... every sentences. Reading times for both types of quantifier sentences and for ambiguous and unambiguous sentences were similar as were reading and decision times for the continuations. Participants accurately rejected 72% of the foils involving inappropriate continuation sentences. These findings suggest that participants were not processing the stimulus materials deeply. They may have been responding on the basis of surface cues such as lexical overlap and repetition rather than by determining the meaning of the quantifier sentences. These cues were sufficient to yield different biases for young and old adults to the Every... a quantifier sentences but insufficient to bias either young or older adults’ interpretations of the A... every quantifier sentences. However, to the extent that participants were able to evaluate the continuation sentences on the basis of surface cues, they may not have fully processed the quantifier sentences and assigned wide or narrow scope to each noun phrase. A second study was conducted to examine this issue in more detail.

The materials from Experiment 1 were revised for use in a second experiment. A context sentence was written to accompany each quantifier sentence plus continuation. The context sentences referred to either the first or the second noun phrase in the quantifier sentence and were intended to promote deeper processing of the quantifier sentence. The instructions were also revised to emphasize reading comprehension and the need to evaluate the appropriateness of the continuation sentence with reference to the preceding two sentences that established a setting or situation.

**Experiment 2**

Participants were asked to read a sequence of three sentences and to judge whether the sequence “made sense.” The context sentence referred to either the first or second noun phrase of the quantifier sentence. The context sentence was intended to provide a framework for interpreting the quantifier sentences. We expected the context sentences would promote deeper processing of the materials, improving rejection rates for the foils.

The design of Experiment 2 also permitted a test of an alternative processing account. The context sentences referred to either the first noun phrase (Context 1) or the second noun phrase (Context 2) of the quantifier sentence. The noun phrases used in the context sentences were plural in order to be consistent with either interpretation of the quantifier sentence. However, the quantifier sentences could also be interpreted with reference to a mental model (Moxey & Sanford, 1993) established by the context sentence. If so, there should be a strong bias for the interpretation of the quantifier sentences involving multiple entities, reflecting the plural noun phrases used in the context sentences. Thus, the WS1 interpretation of Every... a quantifier sentences should be preferred following Context 2, e.g., The trees were in the park. Every kid climbed a tree. The trees were full of apples, but not following Context 1 referring to the kids. In contrast, the WS2 interpretation of A... every quanti-
fier sentences should be preferred following Context 1, *The kids were in the park. A kid climbed every tree. The kids were full of energy*, but not following Context 2, referring to the *trees*.

This account contrasts with the account based on syntactic processing principles, which predicts a strong bias for the WS1 interpretation of both *Every... a* and *A... every* quantifier sentences, regardless of context. It also differs from the pragmatic processing account, which predicts a bias for the WS2 interpretation of *Every... a* quantifier sentences and a bias for the WS1 interpretation of *A... every* quantifier sentences, regardless of context.

**METHOD**

**Participants**

Thirty-two younger (Y) adults ranging in age from 18 to 25 years (*M* = 21.8; 53% women) and 32 older (O) adults ranging in age from 63 to 84 years (*M* = 75.1; 74% women) participated in the study. The younger sample consisted of graduate and undergraduate students recruited by posted signs. The older sample consisted of community-dwelling older adults recruited from a listing of previous research participants. All participants were native speakers of English. None of the participants had taken part in Experiment 1. Younger adults received $10 for their participation and older adults received $20 for their participation in addition to travel expenses for the trip to the university laboratory. Number of years of education did not differ between age groups (*M* Y = 14.2, *SD* Y = 2.0; *M* O = 13.0, *SD* O = 2.7; *t*(61) = 2.0, *p* = .06) nor did self-reports of hearing, vision, or overall health. Young and older adults’ scores on the 40-item Shipley (1940) vocabulary test did not differ significantly: *M* Y = 32.1, *SD* Y = 3.9; *M* O = 33.4, *SD* O = 4.8; *t*(61) = 1.1, *p* = .30. Overall, younger adults’ composite working memory scores were significantly higher than those of the older adults: *M* Y = 22.0, *SD* Y = 4.3; *M* O = 11.9, *SD* O = 4.2; *t*(61) = 9.4, *p* < .000. Participants’ complete descriptive statistics appear in Table 2.

**Experimental Procedure**

Participants were tested individually in a session that lasted approximately one hour. Participants first responded to questions about their formal education and work status, and they rated their vision, hearing, and overall health. Participants next completed the 40-item Shipley vocabulary test. Participants then completed the forward and backward digit span tests and the reading span test. Finally, participants completed the experimental task that is described below. Participants did not complete the Waters and Caplan working memory tasks as in Experiment 1 due to time constraints.

To investigate how the inclusion of the Waters and Caplan working memory measure affected the identification of high- and low-span individuals, composite working memory scores were recomputed for the participants in Experiment 1 based on only forward and backward digit spans and reading spans. The resulting high- and low-span groups identified on this basis were nearly identical to those identified originally, affecting the classification of only four young adults and two older adults, and the alternative composite scores were strongly correlated, *r*(32) = .82 for young adults and *r*(32) = .76 for older adults. Inclusion of the Waters and Caplan measure increases the range of composite working memory scores, particularly for young adults without significantly affecting the identification of high- and low-span individuals based on a median split.

**Materials and Task**

Experiment 2 used experimental items, foils, and fillers prepared for Experiment 1. The experimental items consisted of quantifier sentences that varied in terms of quantifier order (*Every... a vs A... every*) and ambiguity (ambiguous vs unambiguous) and a continuation sentence that was consistent with either a wide scope reading over the first noun phrase (WS1) or a wide scope reading over the second noun phrase (WS2) in the quantifier sentences. Thus, there were eight types of experimental items, varying in quantifier order, ambiguity, and continuation. Fillers consisted of an unambiguous quantifier sentence followed by an inappropriate continuation sentence. Fillers consisted of quantifier sentences using *some, few, all*, and *any* followed by either an appropriate or an inappropriate continuation sentence.

A context sentence was written for each item. The context sentences were designed to introduce either the subject noun phrase of the quantifier sentences (Context 1) or the object noun phrase (Context 2). Plural nouns were used to be consistent with either the WS1 or WS2 interpretation of experimental sentences. The experimental sentence frames were divided into eight subsets such that for each subset, there were four instances of each of the eight types; however, a particular sentence frame occurred only once within a subset. The foil and nonfoil filler items were identical across sets. Thus, each participant read a total of 32 experimental items, 20 foils, 32 fillers, and 10 practice items.

**Design**

Quantifier sentence reading times were analyzed in a mixed-design analysis of variance with context, quantifier order, ambiguity as within-subject factors and age group and span group as between-subject factors. Acceptability decisions and response latencies for the continuation sentences were analyzed separately in mixed-design analyses of variance with context, quantifier order, ambiguity, and scope as within-subject factors and age group and span group as between-subject factors. For the post hoc comparisons, Type I error was controlled using the Modified Shaffer procedure (Shaffer, 1995). The log-transformed sentence reading times and response latencies were analyzed because the untransformed times did not meet the assumption of homogeneity of variance.

**Sentence Presentation**

Sentences were presented as described in Experiment 1, with the addition that in Experiment 2, individuals read sets of three sentences: a context sentence, a quantifier sentence, and a continuation sentence. As in Experiment 1, participants were instructed to read the continuation sentence and decide whether it made sense and was a natural continuation of the first two sentences and to indicate their response using the appropriate keys on the keyboard. A practice block consisting of 10 sentences was presented in a fixed order for all participants, followed by the experimental and filler sentences, which were presented in random order. At the start of the trials, participants were instructed to read each sentence quickly, but carefully, so as not to compromise their comprehension.
RESULTS

Working Memory Span
Participants' composite working memory scores were formed using the three span measures. Separate median splits were performed on the younger and older adults' distributions of working memory composite scores in order to form high- and low-span groups (e.g., Kemtes & Kemper, 1997). Span scores for the WM composite measures are summarized in Table 2.

Reading Time Analyses
Separate analyses were performed on the log-transformed reading times for the quantifier sentences and decision latencies for the continuation sentences. A 2 (age group) × 2 (span group) × 2 (context) × 2 (quantifier order) × 2 (ambiguity) ANOVA was used to analyze the reading times for the quantifier sentences. There were no main effects of context or working memory span group; however, the main effect of age group was significant: $F(1,54) = 29.5, p = .000, \eta^2 = .367$. Young adults' reading times (in milliseconds) were faster than those of older adults ($M_Y = 2,191; M_O = 3,498$).

Continuation Decisions
Continuation sentences preceded by ambiguous quantifier sentences were judged to be acceptable with greater frequency than continuation sentences preceded by unambiguous quantifier sentences, resulting in a main effect of ambiguity, $F(1,54) = 6.958, p = .011, \eta^2 = .107$. Because our predictions concerned ambiguous quantifier sentences only, separate analyses were conducted on the continuation judgments for unambiguous and ambiguous quantifier sentences. A 2 (age group) × 2 (span group) × 2 (context) × 2 (quantifier order) ANOVA was used to analyze the continuation decisions (see Table 4). As in Experiment 1, a difference score was computed for each participant by subtracting the percentage of WS2 continuations found to be acceptable from the percentage of WS1 continuations found to be acceptable. A positive score indicates a bias for the WS1 interpretation, a negative score a bias for the WS2 interpretation (see Figure 1).

For unambiguous quantifier sentences, there were no significant effects or interactions, all $F(1,54) < 2.2, p > .20$. Young and older participants and high- and low-span individuals found WS1 and WS2 versions of the unambiguous sentences to be equally acceptable.

For ambiguous quantifier sentences, there was a main effect of quantifier order, $F(1,54) = 5.843, p < .023, \eta^2 = .086$, as well as a significant interaction between quantifier order, age group, and span group, $F(1,54) = 5.596, p = .021, \eta^2 = .088$. Context did not affect continuation decisions and did not interact with

Table 4. Percentage of Continuations Judged to “Make Sense” That Were Consistent With Either the WS1 or WS2 Interpretation of the Ambiguous Quantifier Sentences by High- and Low-Span Participants in Experiment 2

<table>
<thead>
<tr>
<th>Quantifier Order</th>
<th>Scope</th>
<th>Young Adults</th>
<th>Older Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High Span</td>
<td>Low Span</td>
<td>High Span</td>
</tr>
<tr>
<td>$A...a$</td>
<td>WS1</td>
<td>86%</td>
<td>75%</td>
</tr>
<tr>
<td></td>
<td>WS2</td>
<td>56%</td>
<td>65%</td>
</tr>
<tr>
<td>$A...every$</td>
<td>WS1</td>
<td>63%</td>
<td>69%</td>
</tr>
<tr>
<td></td>
<td>WS2</td>
<td>40%</td>
<td>48%</td>
</tr>
</tbody>
</table>

Figure 1. Bias for WS1 or WS2 continuation sentences following ambiguous quantifier sentences for Experiment 2 as a function of age group. Positive values correspond to a bias for WS1 continuations whereas negative values correspond to a bias for WS2 continuations.
any age group or span group. The Context × Quantifier Order interaction for the ambiguous sentences was not significant, F(1,54) < 1.0, p > .50. Figure 1 summarizes the results.

High-span young adults found the WS1 continuations to the Every... a quantifier sentences to be preferable to the WS2 continuations, (M_{WS1−WS2} = +20.0, SD = 33.2) as did low-span young adults (M_{WS1−WS2} = +17.4, SD = 27.5), t(30) < 1.0, p > .50. High-span young adults found the WS1 continuations to the A... every quantifier sentences also to be preferable to the WS2 continuations (M_{WS1−WS2} = +22.0, SD = 18.2) as did low-span young adults (M_{WS1−WS2} = +21.4, SD = 24.1), t(30) < 1.0, p > .50. In contrast, high-span older adults tended to prefer the WS2 continuations for the Every... a quantifier sentences (M_{WS1−WS2} = −5.2, SD = 9.1); this difference did not differ statistically from zero, or no preference, t(14) > 2.20, p > .50, and low-span older adults had a stronger preference for WS2 continuations for the Every... a quantifier order (M_{WS1−WS2} = −11.2, SD = 12.3); this difference did differ significantly from zero, t(16) = 2.90, p < .05. High-span older adults preferred the WS1 interpretations of the A... every quantifier sentences (M_{WS1−WS2} = +19.8, SD = 12.3); low-span older adults had an equally stronger preference for the WS1 continuations of the A... every quantifier sentences, (M_{WS1−WS2} = +21.5, SD = 11.9), t(30) = 4.43, p < .01.

**Foil Sentences**

Foils were analyzed with a 2 (age group) × 2 (span group) × 2 (quantifier order) ANOVA. Young adults were more accurate rejecting foils than older adults (M_t = 92%, M_o = 84%) resulting in a main effect of age group, F(1,54) = 3.98, p = .051, η^2 = .051. High-span young adults responded with greater accuracy than low-span young adults (M_{HighSpan} = 96%; M_{LowSpan} = 88%), p < .05, whereas high- and low-span older adults' accuracy did not differ (M_{HighSpan} = 86%; M_{LowSpan} = 82%), p > .50. This resulted in a significant interaction between age group and span group, F(1,54) = 6.485, p = .027, η^2 = .070. There were no other significant effects or interactions.

**Discussion**

The context sentences successfully promoted deeper processing of the stimulus materials. This was evident in the increased rejection rates for foil sentences which were inconsistent with the preceding quantifier sentences. Although the context sentences did promote deeper processing, the participants appeared to be processing the quantifier sentences using processing principles rather than with reference to a mental model established by the context sentence. Consequently, context did not affect reading times for the quantifier sentences or for the continuation sentences and preferences for the continuation sentences were unaffected by context.

The results from the young participants in Experiment 2 matched those reported by Kurtzman and MacDonald (1993): young adults had a strong preference for the WS1 continuations of both Every... a and A... every quantifier sentences. Young participants preferentially assigned wide scope to the first noun phrase, or the subject, of these active sentences. Although formally the quantifier sentences are ambiguous, young adults tend to interpret them unambiguously, consistent with various syntactic processing principles. It appears that syntactic subjects, at least for active sentences, are assigned wide scope by young adults regardless of the order of the quantifiers and regardless of context. This bias for the WS1 interpretation of Every... a sentences is robust, emerging even in Experiment 1, whereas the WS1 interpretation of A... every sentences is somewhat weaker, emerging only in Experiment 2 when deeper processing of the materials was encouraged.

In contrast, the older participants, particularly those with limited working memory spans, exhibited a different pattern of preferences. Older adults assigned different interpretations to Every... a and A... every quantifier sentences. Every... a sentences, such as Every actor used a prop, were interpreted with wide scope assigned to the second noun phrase; hence, a WS2 continuation, such as The prop was on the stage, was preferred. Like young adults, older adults interpreted a sentence such as An actor used every prop with wide scope assigned to the first noun phrase resulting in a preference for WS1 continuations, such as The actor was on the stage. Older adults' preferences, like those of young adults, were not affected by context, suggesting that they were not relying on a mental model established by the first sentence. This bias for the WS2 interpretation of Every... a sentences, like young adults' bias for the WS1 interpretation, is robust as it emerged in Experiment 1 as well as Experiment 2, whereas the older adults' WS1 bias for A... every sentences is somewhat weaker and emerged only in Experiment 2.

A nonsyntactic processing principle can account for this pattern of preferences for older adults. If older adults adopt the single reference principle, they will assign wide scope to the second noun phrase for Every... a sentences such that only a single entity is postulated, consistent with the WS2 continuation. If a single entity is assumed, A... every sentences will also be interpreted with wide scope assigned to the first noun phrase in order to maintain reference to a single entity, consistent with the WS1 continuation.

These results are similar to prior findings by Kemptes and Kemper (1997): young and older adults make different interpretations of complex constructions despite similar on-line reading time patterns. In the present case, young and older adults interpret sentences involving quantifier scope ambiguities using different processing principles. Young adults use syntactic principles in order to interpret the quantifier sentences and, therefore, assign wide scope to the first noun phrase, resulting in a preference for continuations consistent with this interpretation. Older adults appear to use a pragmatic principle of single reference in order to interpret the quantifier sentences; this principle assumes that a single entity is referenced by the quantifier a. As a result, wide scope is assigned to the second noun phrase of Every... a quantifier sentences in order to maintain this interpretation, resulting in a preference for WS2 continuations. The single reference principle also assumes that A... every quantifier sentences reference a single entity; hence, wide scope is assigned to the first noun phrase, resulting in a preference for WS1 continuations. Working memory limitations may be responsible for older adults' reliance on the single reference principle as the preference for WS2 continuations of Every... a quantifier sentences was stronger among low-span older adults than among high-span older adults.

These results are also consistent with demonstrations by Kliegl and Mayr and their colleagues (Kliegl et al., 1994; Mayr...
QUANTIFIER SCOPE EFFECTS

& Kliegl, 1993; Mayr et al., 1996; Verhaeghen et al., 1997) of an age-related dissociation between tasks requiring sequential complexity and tasks requiring coordinative complexity. Application of the single reference principle involves sequential complexity. Only a single representation of the quantifier sentence is constructed and a single entity is postulated and then mapped serially onto each member of the set of entities referenced by the other noun phrase. Application of the syntactic principles involves coordinative complexity: Two representations of the quantifier a are constructed, one specifying a single entity and one specifying multiple entities; each representation then is mapped onto the set of multiple entities specified by the other noun phrase; and each resulting interpretation is checked against the syntactic principles in order to select the preferred interpretation. Older adults may have difficulty with tasks involving coordinative complexity due to working memory limitations on simultaneous processing, the temporary storage of information during immediate processing steps, and the scheduling and evaluation of multiple processing steps.

Every...a sentences were read more rapidly than A...every sentences. A consistent, multiple-entity representation of the first noun phrase is maintained for every...a sentences regardless of whether wide scope is assigned to the first or second noun phrase. Alternative representations of the first noun phrase, corresponding to the WS1 and WS2 interpretations, are possible for every...a sentences. If the first noun phrase is initially interpreted as referring to a single entity, additional processing time to backtrack or re-read the sentence may be required whenever wide scope is assigned to the second noun phrase. These findings also suggest that on-line reading time tasks may be insensitive to many factors, such as working memory span, which may affect the immediate processing of complex constructions, a conclusion also suggested by Caplan and Waters (1999). On-line reading time may be more sensitive to working memory limitations on postcomprehension processes as low-span individuals did require longer to read and evaluate continuations following ambiguous quantifier sentences, continuations following every...a quantifier sentences, and WS1 continuations, regardless of quantifier order. These findings suggest that low-span readers may have difficulty with some postcomprehension decision tasks that involve sequential comparison operations.

Other measures derived from on-line reading tasks, such as evoked potentials or eye-movement reading patterns, may reveal subtle differences in the immediate processing of complex sentences due to working memory or syntactic or semantic ambiguity. The immediate sensibility judgment task of Boland (1997) evoked potentials or eye-movement reading patterns, may reveal comparison operations.

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