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YOUNG AND OLDER ADULTS' READING OF DISTRACTERS

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Eye-tracking technology was employed to examine young and older adults' performance in the reading with distraction paradigm. Distracters of 1, 2, and 4 words that formed meaningful phrases were used. There were marked age differences in fixation patterns. Young adults' fixations to the distracters and targets increased with distracter length. This suggests that they were attempting to integrate the distracters with the sentence and had more and more difficulty doing so as the distracters

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increased in length. Young adults did have better comprehension of the sentences than older adults, and they also had better recognition memory for target words and distracters.

Based on a series of studies (Carlson, Hasher, Connelly, & Zacks, 1995; Connelly, Hasher, & Zacks, 1991), Hasher and Zacks have argued that older readers experience a breakdown of inhibition when confronted with texts with distracter words printed in different typefaces (see also Zacks & Hasher, 1997; Zacks, Hasher, & Li, 2000). These studies suggested that young adults are able to inhibit processing the distracting material, whereas older adults' inhibitory deficit results in slowing reading times and impairing comprehension as the older adults attempt to integrate the distracters with the text.

Hasher and Zacks (1988) postulated three functions of inhibition: preventing irrelevant information from entering working memory, deleting irrelevant information from working memory, and restraining probable responses until their appropriateness can be assessed. In a previous study (Kemper & McDowd, 2006), we used eyetracking to examine the first function of inhibition, blocking irrelevant information from entering working memory. We compared young and older adults' fixation patterns while reading single sentences containing distracters that were distinguished either by a change in color or a change in font and that varied in their relationship to the sentence. We found that older adults took longer to read sentences with distracters than did young adults, and older adults had poorer comprehension of the sentences. However, we also found both young and older adults were equally likely to fixate distracters and spent similar amounts of time fixating distracters. We interpreted these results as providing little support for inhibitory deficit theory since the fixation patterns of young and older adults were similar. We also found that distracters set off from the text by color were less likely to be fixated, were fixated for a shorter time, and triggered fewer regressions than distracters distinguished by font. And we found that distracters that were related to the meaning of the sentence produced more regressions and longer total fixation times than unrelated distracters, perhaps reflecting greater efforts to integrate the distracting text with the sentence. There were no age differences in the use of color or meaning to detect distracters, suggesting both young and older adults can use visual salience and semantic relatedness to block distracters from entering working memory.

In this experiment, we investigated the second function of inhibition by asking whether there are age differences in the ability to delete irrelevant information from working memory. Whereas the irrelevant distracters in our first experiment were cued visually, irrelevant information in this experiment was cued linguistically. The distracters appeared in the same roman font as the rest of the sentences, but they were unrelated to the meaning of the sentence and did not fit into its grammatical structure. Therefore, readers had to use linguistic information to detect the distracters. They then had to inhibit further processing of the distracters, deleting them from working memory, in order to fully comprehend the sentence. For example, the distracter in "To keep animals out of the garden, he put up a sweeps fence to block it off" violates a variety of linguistic rules: A verb ("sweeps") cannot follow an indefinite article ("a") and a "sweeps" cannot be erected. The reader must detect these violations in order to identify "sweeps" as a distracter but then inhibit it since "sweeps" cannot be integrated with the rest of the sentence.

We hypothesized an age-related breakdown in inhibition would affect the ability of older readers to inhibit processing the distracters. We thought this would result in more and longer fixations to the distracters and more regressions to the distracters as the older readers attempted to integrate the distracters with the rest of the sentence. We also varied the length of the distracters, creating 2- and 4-word phrases that did not fit in with the rest of the sentence. We hypothesized that by providing additional linguistic cues to the distracters we might benefit readers by enabling them to recognize they formed a discrete phrase that could be deleted from working memory. In contrast, a breakdown in the deletion function of inhibition might force older readers to spend additional time attempting to integrate these phrases with the rest of the sentence, further slowing reading and disrupting comprehension.

METHOD

Participants

There were 24 older participants and 24 young participants. All older participants were community-dwelling adults recruited from a registry of prior research participants. All young participants were college students recruited via postings on campus bulletin boards and class announcements. All participants were monolingual speakers of English. All were paid a modest honorarium for their participation. Data from 12 additional older adults and 8 additional young adults were lost due to excessive eye tracking failures; most of these individuals wore corrective lens such as lined bi- or tri-focal

Table 1. Characteristics of the participants

	Young	Older	$F(1, 46)$	$p <$
Age	22.2 (0.9)	73.4 (4.6)		
Reading leisure (hrs/wk)	2.5 (2.0)	14.5 (9.2)	36.910	.001
Reading work/school (hrs/wk)	8.2 (4.7)	0.8 (1.9)	51.234	.001
Vocabulary	30.9 (3.2)	34.6 (3.8)	13.806	.001
Digits forward	9.0 (1.7)	7.5 (2.1)	7.441	.010
Digits backward	7.0 (2.1)	6.5 (1.9)	0.885	.352
Reading span	3.6 (1.2)	3.0 (0.7)	3.935	.053

glasses or tinted contact lens that impeded eyetracking; these individuals were not otherwise distinguishable from the remaining 48 participants with regard to performance on the working memory and vocabulary tests.

The 48 participants are described more fully in Table 1. Based on a one-way ANOVA comparing age groups, the participants differed in reading habits as well as performance on the Digits Forward test (Wechsler, 1981) and the Daneman and Carpenter reading test (Daneman & Carpenter, 1980; Maylor & Lavie, 1998). The older participants also scored higher than the young participants on the Shipley Vocabulary test (Shipley, 1940). An α level of .05 was set for this and all subsequent t and F tests.

Materials

The materials used by Kemper and McDowd (2006) were modified for use in this experiment by inserting 1-, 2-, or 4-word distracters. Distracters were unrelated to the meaning of the sentence, and content words used in the distracters were not associated with content words in the sentences. These conditions were based on the Nelson, McEvoy, and Schreiber (1998) association norms. All content words used as distracters phrases were of high frequency, greater than 80 occurrences per million words (Kucera & Francis, 1967). Four-word distracters formed meaningful phrases. For example, the phrase "the very angry taxpayer" was inserted as a distracter into the sentence "The postman opened the package to inspect its contents" prior to the target word "contents." The 4-word distracter phrases were then shortened to 2-word distracters, e.g., "angry taxpayer," and to 1-word distracters, e.g., "taxpayer." The final step was to make sure that all distracters did not plausibly form a "good continuation" of the grammatical structure of the sentence. For example, the noun "taxpayer" cannot plausibly follow the phrase "The postman opened the package to inspect its . . . " since an (angry) taxpayer isn't a property of packages; and the 4-word phrase "the very angry taxpayer" also cannot fit into the grammatical structure of the sentence.

The resulting sets of sentences, therefore, consisted of a basic sentence with no distracters and versions with 1-, 2- or 4-word distracters. A group of three judges then evaluated these materials. The judges were graduate students in psychology or related disciplines, naïve with respect to the goals of the research. The judges were given a booklet containing sentence stems ending in 1-, 2-, or 4-word distracter phrases and asked to judge whether the stems "made sense." For example, the judges were asked whether "The postman opened the package to inspect its very angry taxpayer . . . " made sense or whether "The postman opened the package to inspect its taxpayer . . . " made sense. Only those items rejected by all three judges were used in the experiment. There were 36 sets of sentences with four variants of each sentence, differing in the length of the distracter (no distracter, 1-, 2-, or 4-words). Examples are provided in Table 2.

Sentences were assigned to stimulus lists such that each list contained nine examples of each experimental condition but only 1 sentence from each set. In each list, 9 sentences did not have distracters, 9 had 1-word distracters, 9 had 2-word distracters, and 9 had 4-word distracters. Another 72 sentences without distracters were added to each list as filler sentences. Five sentences from each experimental condition and 40 filler sentences were followed by a probe question. Two blocks of sentences were creating by randomly assigning experimental and filler sentences to blocks. Lastly, 16 practice trials were created that shared the same characteristics of the experimental sentences; 4 practice sentences had no distracters, 4 had 1-word distracters, 4 had 2-word distracters and 4 had 4-word distracters.

Table 2. Example sentence materials.

Sentence	4-word distracter	Question
The postman opened the package to inspect its (distracter) *packing* before sending it.	the very angry taxpayer	What did the postman inspect?
To keep animals out of the garden, he put up a (distracter) *fence* to block it off.	the broom rapidly sweeps	How did he keep animals out of the garden?

Note. Pre- and post-target flankers and the 1-word distracter are underlined, the target word is italicized, and the position of the distracter [if any] before the target word is indicated. All words were presented in Roman font during eyetracking.

Procedure and Apparatus

Participants were first given the test battery and then seated before the eyetracker computer monitor. Participants sat in an adjustable chair with a headrest. They wore reading glasses if they normally did so. The chair could be raised or lowered to accommodate to bi- or tri-focal glasses. The participants also wore a visor with a small magnetic sensor attached. Each trial consisted of a fixation point centered on a blank screen for 500 milliseconds followed automatically by the presentation of a sentence. The participants controlled presentation rate by pressing the mouse when they had completed reading the sentence. The sentences were presented on a 17-inch flat panel computer screen at a viewing distance of 16 inches. The fixation point and stimulus items were presented in white (125.5 lux) on a black background (0.03 lux) to maximize pupil size. Text was presented in Arial typeface with a mean size for individual letters of 0.57° (horizontal). The participants held a computer mouse in their preferred hand, which was used to control presentation. Participants were instructed to read the sentences for meaning. They were told that approximately half of the sentences would be followed by a probe question, and they should try to answer each question based on the preceding sentence. Participants were advised that some sentences contained distracters that did not fit in with the meaning of the sentence; they were instructed to ignore the distracters. Participants answered the probe questions aloud, and their responses were recorded by the experimenter.

An Applied Sciences Laboratories eye tracker (Model 504) with a magnetic headtracker was used to record eye movements. Eye movements were sampled 60 times per sec with an accuracy rating of 0.5° visual angle. This translates to approximately 0.5 to 1 cm accuracy at 16 in. The headtracker noted displacements of the sensor attached to the readers' visor relative to a base unit and corrected the record of eye movements for head movements. Head movements were sampled 100 times per sec with an accuracy of 0.03° at 12 in. Stimuli were presented using GazeTracker software (Lankford, 2000) which also analyzed the eye movement data. The eyetracker was calibrated at the start of each session and between blocks for each participant. One microcomputer controlled the eye tracker; it was interfaced with a second microcomputer running the GazeTracker software for presentation and analysis.

Eye movement parameters were analyzed for the following critical regions in each sentence: (a) the target word; (b) the distracter, if present; (c) 1–3 words preceding the target (and distracter if present) as the pretarget flanker; and (d) 1–3 words following the target as a post-target flanker. Target words were analyzed to determine if the readers attempted to integrate the distracter with the sentence, which was expected to result in an increase in fixation times for the target words. The flankers were analyzed to determine if the presence of the distracter disrupted normal reading by affecting fixations to these words. In many cases, these flankers were short function words, e.g., *of*, *a*, *the*, which are often not fixated by skilled readers (Rayner & Duffy, 1986); in these cases, the flanker was extended to include a content word.

Three measures were computed for each flanker, distracter, or target word: the probability the word (or phrase in the case of 2- or 4-word distracters) was fixated at least once, the duration of the first pass fixation to the word, and the total duration of all fixations to a word. Fixations were defined as a minimum of two successive eye positions occurring within a fixation diameter of .5° of visual angle (approximately one character), or with a minimum duration of 100 milliseconds.

First-pass fixation duration, or gaze duration, is the summed duration of all fixations to a word beginning with the initial fixation to a word and ending with either the first fixation leftward to a previous word or rightward to a successive word; first pass fixations were contingent on there being at least one fixation to a word. Total fixation duration is the sum of all fixations to a word; it included all first-pass fixations as well as any fixations resulting from regressions or subsequent refixations after a leftward or rightward fixation to another word, again contingent on there being at least one fixation to a word. In addition, we computed the total number of leftward regressions to distracters from subsequent targets or posttarget flankers; over 80% of all regressions were leftward regressions to distracters. Two approaches were used to analyze the number of regressions to the distracters. First, all regressions were identified and the average number of such regressions per sentence was computed. Second, the number of regressions per distracter word was computed. Both approaches yield equivalent age by distracter length interactions but only those based on the total number of regressions per sentence are reported. Finally, total sentence reading time and overall accuracy in answering the probe questions were determined. Data from 3% of the experimental sentences were lost due to eye blinks, large head movements, or other eye tracking failures.

At the conclusion of the reading experiment, participants were administered a single word recognition test. The words included 24 foils (content words that did not appear in any of the experimental sentences or filler sentences), 24 target words, 24 distracters (the 1-word distracters), and 24 words from filler sentences. The words were randomly ordered for each participant. Participants made a yes/no recognition judgment for each word.

RESULTS

The results of the eye tracking analysis are presented first, followed by the results for the probe comprehension questions and then the word recognition test. Since the probability of fixation was uniformly high, averaging more than $p \geq .95$ ($SD = .03$), and did not vary with region, age group, or distracter length, this measure was not analyzed further. All significant main effects and interactions are reported.

Flankers

Fixations to flankers were compared to determine if the distracters disrupted normal reading patterns. First-pass and total fixation durations to flankers were analyzed with age group by 4 distracter length (none, 1-word, 2-words, and 4-words) by 2 flanker location (pre-versus posttarget) ANOVAs. There were no significant effects of age, distracter length, or flanker location for first pass fixation times for the flankers. A significant effect of age was found for total fixation duration to the flankers, $F1(1, 46) = 39.82$, $p < .001$, $\eta^2 = .46$, $F2(1, 7) = 17.72$, $p < .001$, $\eta^2 = .42$. Older adults had longer total fixation times ($M = 291$ ms, $SD = 13$) to the flankers than younger adults ($M = 184$ ms, $SD = 12$). Fixations to flankers were not affected by the distracters.

Distracters

Fixations to distracters were compared to determine if the readers could inhibit processing of the distracters. Since distracters differed in length, the analyses of first pass fixations and total fixation durations used ms-per-character as the dependent variable. Since the distracters differed in length, the fixation durations to the distracters and the overall sentence reading rates were analyzed in two ways. First, following Frazier and Rayner (1982), they were converted to ms-per-character (letters and spaces), yielding first pass fixation times, total fixation time, and sentence reading times in ms-per-character. Second, as introduced by Ferreira and Clifton (1986), the fixation durations and reading rates for each participant were first regressed on the number of characters (letters and spaces) in each

Table 3. First-pass fixation times in milliseconds per character, the total number of regressions, and total fixation durations in milliseconds per character to distracters as a function of distracter length

	First-pass fixations		Regressions		Total fixations	
Distracter length	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young adults						
1-word	40	12	3.8	2.1	80	14
2-words	55	11	6.1	2.4	98	14
4-words	73	20	7.6	3.8	113	18
Older adults						
1-word	64	13	2.7	2.4	121	16
2-words	65	14	2.9	2.4	119	16
4-words	69	13	2.2	2.2	123	15

region and then the residuals, reflecting length-corrected reading times, were used in a second analysis. Both approaches yielded equivalent results but only those using the ms-per-character times are presented. First-pass fixations, regressions, and total fixation durations to distracters were analyzed with two age group by three distracter length (1-word, 2-words, and 4-words) ANOVAs. The results are summarized in Table 3. Older adults' first pass fixations were longer than young adults', $F1(2, 45) = 37.28$, $p < .001$, $\eta^2 = .32$; $F2(2, 6) = 6.21$, $p < .05$, $\eta^2 = .11$. Leftward regressions to the distracters were common and accounted for more than 80% of all regressions. Young adults made more leftward regressions to the distracters than older adults, $F1(1, 46) = 17.5$, $p < .001$, $\eta^2 = .25$; $F2(1, 7) = 5.92$, $p < .05$, $\eta^2 = .15$. Total fixation durations for older adults were longer than those for young adults, $F1(1, 46) = 28.48$, $p = .001$, $\eta^2 = .25$; $F2(1, 7) = 8.23$, $p > .01$. Finally, there was a significant interaction of age group and distracter length for total fixation durations, $F1(3, 44) = 16.94$, $p < .001$, $\eta^2 = .23$; $F2(3, 5) = 8.63$, $p < .05$, $\eta^2 = .12$. Young adults' total fixation durations increased with distracter length, all $t(46) > 3.172$, $p < .01$, whereas older adults' total fixations did not vary with distracter length, all $t(46) < 2.00$, $p > .05$.

Targets

Target words were analyzed to determine if the readers attempted to integrate the distracters with the sentences. First pass fixation times and total fixation durations to targets were analyzed with two age

Table 4. First-pass fixation times and total fixation durations to targets as a function of distracter length

	First-pass fixations		Total fixations	
Distracter length	M	*SD*	*M*	*SD*
Young adults				
none	177	87	1348	194
1-word	228	93	1583	283
2-words	228	75	1645	287
4-words	480	172	1736	375
Older adults				
none	379	185	1554	281
1-word	377	172	1561	265
2-words	372	163	1565	287
4-words	374	179	1574	295

group by four distracter length ANOVAs. The results are summarized in Table 4. The age and distracter length interaction for first pass fixation times to the targets was significant ($F1(3, 44) = 6.26$, $p < .001$, $\eta^2 = .08$; $F2(3, 5) = 1.03$, $p > .05$). Young adults' first pass fixations to targets in the no distracter condition were shorter than older adults' first pass fixations, $t(23) = 15.92$, $p < .001$; young adults' first pass fixation times to the targets increased with distracter length, all $t(23) > 22.42$, $p < .001$, whereas older adults' fixations to the target words did not vary with distracter length, all $t(23) < 1.0$, $p < .05$. The age by distracter length interaction was also significant for total fixation durations for the targets ($F1(3, 44) = 61.10$, $p < .001$, $\eta^2 = .56$; $F2(2, 6) = 12.42$, $p < .05$, $\eta^2 = .42$). Young adults' total fixations to targets in the no distracter condition were shorter than older adults' total fixations, $t(23) = 11.38$, $p < .01$, and for young adults, total fixation durations to the targets increased with distracter length, all $t(23) > 3.17$, $p < .01$. In contrast, older adults' total fixations to the target words did not vary, all $t(23) < 1.541$, $p < .05$.

Total Reading Time

Since sentences varied in length due to the distracters, sentence reading times were computed with ms-per-character as the dependent measure. Total reading times were analyzed with two age group by four distracter length ANOVA. Total reading times were longer for older adults than young adults ($F1(1, 46) = 155.78$, $p < .001$, $\eta^2 = .77$; $F2(1, 7) = 27.58$, $p < .001$, $\eta^2 = .38$).

Probe Questions

The percentage of probe questions answered correctly was analyzed with a two age group by four distracter length ANOVA. A significant effect of age group was found, $F(1, 46) = 10.32$, $p < .01$, $\eta^2 = .21$, as well as a significant age group by distracter length interaction, $F(3, 44) = 8.464$, $p < .001$, $\eta^2 = .37$. Overall, older adults ($M =$ 83.5%, $SD = .03$) answered fewer probe questions correctly than younger adults ($M = 97.42\%$, $SD = .03$). Young adults' comprehension did not vary with distracter length, all $t(23) < 1.50$, $p < .05$, whereas older adults had good comprehension of sentences without distracters (92.5% correct, $SD = .05$) and poor, but equivalent, comprehension of sentences with 1-, 2-, and 4-word distracters (75.6% correct, $SD = .04$), all $t(23) < 1.00$, $p < .05$.

Word Recognition

Young and older adults' recognition rates for the foils and fillers were analyzed with one-way ANOVAs. Young and older adults were equally able reject foils ($M = 83\%$ correctly rejected, $SD = 8$), $F(1, 46) = .06$, $p > .05$. Young adults correctly recognized more fillers ($M = 70\%$ correctly recognized, $SD = 19$) than the older adults ($M = 59\%$, $SD = 14$), $F(1, 46) = 6.89$, $p < .05$, $\eta^2 = .13$. An ANOVA with age group and distracter length (none, 1-word, 2-words, and 4-words) was used to examine recognition rates for the targets. Young adults correctly recognized more targets ($M = 79\%$ correctly recognized, $SD = 12$) than older adults ($M = 49\%$, $SD = 18$), $F(1, 46) = 5.01$, $p < .05$, $\eta^2 = .10$. An ANOVA with age group and distracter length (1-word, 2-words, and 4-words) was used to examine recognition rates for the distracters. The age by distracter length interaction was significant, $F(2, 45) = 6.79$, $p < .01$, $\eta^2 = .12$. Young adults' recognition of the distracters improved with distracter length (1-word distracters: $M = 42\%$, $SD = 29$; 2-word distracters: $M = 62\%$, $SD = 22$; 4-word distracters: $M = 74\%$, $SD = 19$); older adults' recognition of the distracters did not vary with distracter length ($M = 34\%$, $SD = 29$).

DISCUSSION AND CONCLUSIONS

We had hypothesized that there might be age differences in the deletion function of inhibition such that older adults would attempt to integrate distracters with the rest of the sentence. We further hypothesized that young adults would be able to use linguistic information to identify the distracters and then would inhibit further processing of the distracters by deleting them from working memory, resulting in shorter fixations and fewer regressions to distracters, especially as distracter length increased. Our results do not support this hypothesis. Rather, they suggest young adults were attempting to understand the distracters as well as the sentences whereas older adults were not. Young adults made more leftward regressions to the distracters as distracter length increased; consequently, their total fixation durations to distracters and target words also increased with distracter length. This pattern suggests that young readers were attempting to understand the distracters and evaluate their relationship to the sentences, encountering more and more difficulty doing so as the distracters increased in length. Older adults' reading appears to be nonstrategic in that they did not differentially allocate fixation times to distracters or targets as a function of distracter length. Older adults' insensitivity to the phrase structure of the 2- and 4-word distracters suggests that they were not forming a detailed semantic and syntactic representation of the distracters or sentences as they were reading but treating them as lists of words.

In many regards, our results parallel those reported by Connelly et al. (1991): older adults read more slowly with poorer comprehension than young adults. However, young adults spent more time fixating the distracters and the targets as distracter length increased, suggesting they, not older adults, were attempting to understand the distracter phrases as well as the sentences. Like the findings of Dywan and Murphy (1996), however, young adults in this study were apparently able to keep distracter information from interfering with comprehension, as their comprehension performance was nearly perfect (97.4% correct). And the young adults had better recognition memory for the distracters as well as for the target words than the older adults.

Rayner, Reichle, Stroud, Williams, and Pollatsek (2006) suggest that older adults not only read more slowly than young adults but also adopt a "risky" reading strategy, skipping over many words but being forced to make many regressions to skipped words when they encounter problems. Other studies (Kemper, Crow, & Kemtes, 2004; Kemper & Liu, 2007) observed that older adults also make many regressions while processing complex sentences with temporary syntactic ambiguities. In the present study, young adults made more regressions than older adults, suggesting they were reanalyzing the distracters as they attempted to make sense of them. Older adults in this study made few regressions, suggesting that they were not encountering problems making sense of the sentences, even those including 4-word distracter phrases. This again suggests that the older adults were not attempting to fully understand the sentences but treating them as word lists.

These age differences in fixation patterns to distracters are consistent with the perceptual load hypothesis (Lavie, 1995; Maylor & Lavie, 1998). This hypothesis suggests that selective processing only occurs if a task requires virtually all available processing capacity. Otherwise, all information available in the environment will be processed until the limits of capacity are reached. In the present case, older adults may have reached their capacity limits with regards to processing the to-be-read information sooner than the young adults and so did not fully process the distracters or sentences. Young adults, on the other hand, may have greater capacity to process the sentences and continued to process the distracters. This result not only in their increased attention to distracters as distracter length increased but also in their superior comprehension of the sentences and recognition memory for both targets and distracters. Older adults treat these sentences with distracters in a list-like fashion, due not a breakdown in inhibition but to due to capacity limits on their ability to simultaneously process sentences and distracters.

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