Age Differences and Similarities in the Shift From Computation to Retrieval During Reading Comprehension

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Abstract:
One of the most robust effects in psychology is the finding that practice yields a negatively accelerated decrease in the time required to perform a task. Speed-ups with practice have been shown in a wide range of cognitive tasks, from mental arithmetic to air traffic control to reading comprehension, and in a wide range of age groups (e.g., Ackerman, 2007; Anderson & Lebiere, 1998; Jenkins & Hoyer, 2000; Logan & Klapp, 1991; Rawson, 2004; Touron & Hertzog, 2004a). The primary goal of the present research was to examine age-related differences in one of the cognitive mechanisms thought to underlie speed-ups with practice during reading comprehension.

Articles:
Several different mechanisms have been proposed to explain speed-ups in task performance with practice, including increasing selective attention to task-relevant information (e.g., Haider & Frensch, 1996), improvements in the efficiency of computational processing (e.g., Anderson, 2007; Anderson & Lebiere, 1998), and increasing reliance on retrieval rather than on computation during task performance (e.g., Logan, 1988; Palmeri, 1997; Rickard, 1997). These mechanisms are not mutually exclusive, and each may contribute to practice effects to different degrees in various tasks. For present purposes, we focus on the latter class of theories, which we refer to as memory-based accounts of automaticity.

Although the various memory-based accounts differ in some auxiliary assumptions, they share the core assumption that speed-ups with practice reflect a shift away from slower computational processing of stimulus interpretation to faster retrieval of interpretations computed on previous trials. For example, according to instance theory (Logan, 1988), algorithmic processes compute an interpretation the first time a particular stimulus is encountered. This interpretation is then stored as an instance in long-term memory, which may be retrieved if that stimulus is encountered again. On subsequent encounters of a stimulus, the computation and retrieval routes race to produce an interpretation, and stimulus interpretation is based on the output of whichever process finishes first. With increasing amounts of practice, an increasing number of instances for a given stimulus are stored in memory. Instance theory assumes that each instance of a prior interpretation races against the other instances to be retrieved, with normally distributed finishing times for each instance. Accordingly, the likelihood that at least one instance will be retrieved quickly increases with the number of instances in the race, and thus retrieval is increasingly likely to finish before computation over the course of practice.

Although most of the empirical evidence for memory-based accounts has come from studies that used relatively simple cognitive tasks, recent research has established the contribution of memory-based processing to young adults' speed-ups with practice in syntactic and semantic processes involved in reading comprehension (Rawson, 2004; Rawson & Middleton, 2009). Extending beyond this initial work, the present research addresses the following key question: To what extent do older and young adults differ in the contribution of memory-based processing to practice effects in reading comprehension? Whereas previous research has examined age-related differences in memory-based processing in various other cognitive tasks, the extent to which young and older adults differ in the contribution of memory-based processing to practice effects during reading comprehension is currently unknown.

Basic research on memory deficits in older adulthood suggests that older adults may be slower to shift from computation to retrieval during reading comprehension practice. Age differences in simple associative learning occur during both encoding and retrieval (Dunlosky, Hertzog, & Moman-Powell, 2005; Naveh-Benjamin, 2000; Old & Naveh-Benjamin, 2008), which both involve greater attentional demands in older adulthood (Anderson, Craik, & Naveh-Benjamin, 1998). These findings suggest that older adults may have poorer encoding of instances during reading or may have greater difficulty retrieving those instances on subsequent encounters of repeated stimuli. Furthermore, in tasks that involve a transition from computation or visual search for solutions to memory-based retrieval of solutions, older adults are typically slower to rely on memory retrieval (e.g., Touron & Hertzog, 2004a; 2004b; Touron, Hoyer, & Cerella, 2004; Touron, Swaim, & Hertzog, 2007).

However, other findings suggest that older adults may not show pronounced deficits in memory-based practice effects during reading comprehension. First, previous research generally has found age-related deficits for intentional episodic memory but not for implicit memory or repetition priming (Fleischman & Gabrieli, 1998; Fleischman, Wilson, Gabrieli, Bienias, & Bennett, 2004) as in the bottom-up resonance-based activation of associated information assumed by instance theory and by theories of reading comprehension more generally (e.g., Kintsch, 1988, 1998; McKoon & Ratcliff, 1998; Myers & O'Brien, 1998). Second, substantial evidence exists for preservation of some comprehension and verbal abilities in older adulthood, with older adults even outperforming young adults on some measures of crystallized intelligence including vocabulary (for a review, see Park, 2000). So it is not a foregone conclusion that age differences in the contribution of memory-based processing to practice effects shown in other tasks will also manifest in reading comprehension.

To examine age differences in the contribution of memory-based processing to practice effects in reading comprehension, we adapted the method and materials used by Rawson and Middleton (2009). Young and older adults read short stories that each contained an unfamiliar noun–noun combination (e.g., bee caterpillar; see Appendix for sample stories). Each combination had more than one possible meaning, and the target sentence that followed the combination contained disambiguating information that indicated the intended meaning. Combinations were disambiguated with either their dominant meaning (the meaning most often generated in norming studies, e.g., a caterpillar that looks like a bee) or a subordinate meaning (a plausible alternative meaning, e.g., a caterpillar that buzzes like a bee). In the repeated dominant condition, stories with the dominant meaning were presented repeatedly across blocks of practice. In the repeated subordinate condition, stories with the subordinate meaning were presented repeatedly across practice blocks. In the unrepeated subordinate condition, stories with the subordinate meaning were each presented only once at some point in practice. The dependent variable of interest was reading time in the disambiguating region of the target sentences (see examples in Appendix).

Evidence for the contribution of memory-based processing to speed-ups with practice comes from comparison of reading times in the repeated subordinate condition to reading times in the other two conditions. First, the memory-based accounts predict that reading times will be longer in the repeated subordinate versus repeated dominant condition at the beginning of practice, whereas reading times in these two conditions will converge in later blocks of practice. This prediction is based on the assumption that the first time an unfamiliar combination is encountered, no prior interpretations are available to be retrieved, and thus an interpretation must be computed. In both conditions, the dominant meaning is presumably computed (given that it is the one most frequently generated by participants when no prior context is presented). When the subsequent disambiguating region is reached, the initial meaning will be consistent with the intended meaning in the dominant condition but not in the subordinate condition. Thus, reanalysis will be needed in the subordinate condition, which will inflate reading times in the disambiguating region (i.e., a semantic garden path effect). In contrast, in later blocks of practice, the correct interpretations stored on previous trials can be retrieved in both conditions, and thus the need for reanalysis in the subordinate condition is avoided.

Second, the memory-based accounts predict that reading times will be faster in the repeated subordinate versus unrepeated subordinate condition. On the basis of the logic presented earlier, the correct interpretations of repeated subordinate items stored on previous trials can be retrieved on subsequent encounters of those items, thus avoiding the need for reanalysis in the disambiguating region in this condition. In contrast, unrepeated combinations must rely on computation for their interpretation, which is most likely to output the normatively preferred but contextually inappropriate dominant meaning. Thus, reanalysis will be needed in the disambiguating region in the unrepeated subordinate condition.

Both of these patterns predicted by the memory-based accounts have been shown in previous research with young adults (Rawson, 2004; Rawson & Middleton, 2009). The key question here concerns the extent to which young and older adults differ in the extent or time course of (a) the convergence of reading times in the repeated subordinate and repeated dominant conditions and (b) the divergence of reading times in the repeated subordinate and unrepeated subordinate conditions.

Experiment 1

Method

Participants and design

Participants included 65 young adults (30 women and 35 men) and 52 older adults (31 women and 21 men). 1 Young adults were students enrolled in General Psychology at Kent State University who participated for course credit. Older adults were community residents from the Boone, North Carolina, area recruited from the registry of the Adult Cognition Laboratory at Appalachian State University who received a $40 honorarium for their participation. In the main reading comprehension task, text condition (unrepeated subordinate, repeated subordinate, repeated dominant) and practice block (1–10) were within-participant manipulations.

Materials

Materials for the main task included 25 experimental texts and 4 filler texts. Each experimental text was a short narrative containing two critical sentences (see Appendix). The first critical sentence introduced a novel noun–noun combination. In a prior norming study, 16–33 participants read each critical text up to and including the combination sentence and then wrote down the most likely meaning of the combination. For each combination, the meaning most frequently generated by participants was selected as the dominant meaning (across texts, 83% of participants generated the dominant meaning). A plausible alternative meaning for each combination was selected as the subordinate meaning (across texts, 5% of participants generated the subordinate meaning). The full set of materials is available from Katherine A. Rawson.

The second critical sentence in each text followed immediately after the combination sentence and included information that disambiguated the meaning of the combination. Specifically, the disambiguating region of the second critical sentence was the phrase containing the information that indicated the intended meaning of the novel combination in the preceding sentence. Two versions of the disambiguating region were written for each critical sentence, one supporting the dominant meaning and one supporting the subordinate meaning. The disambiguating regions in the dominant and subordinate versions of each critical sentence were matched as closely as possible for number of syllables and mean word frequency. Materials also included 10 yes/no comprehension questions for each story.

Procedure

Prior to completing the experimental tasks, participants completed a questionnaire collecting basic demographic information (e.g., education level, health status). Demographic information for each age group is reported in Table 1. Participants were then instructed that the goal of the experiment was to examine how practice in a reading task influences how efficiently people can learn from text. They were instructed to read each story carefully and to answer as many comprehension questions correctly as possible.

Table 1
Demographic Information and Performance on Baseline Cognitive Measures for Each Age Group in Experiment 1

Variable	Young adults			Older adults		
	M	*SE*	Range	*M*	*SE*	Range
Demographics						
Age (years)*	20.4	0.3	18–34	67.5	0.6	60–76
Education (years)*	13.0	0.2	11–17	16.5	0.4	12–23
Health rating*	1.8	0.1	1–3	1.5	0.1	1–4
Health conditions*	0.3	0.1	0–3	1.0	0.2	0–5
Baseline cognitive measures						
Digit–Symbol*	62.9	1.4	28–89	39.3	1.5	10–57
Digit–Symbol Recall*	8.3	0.2	2–9	6.2	0.4	0–9
Names recall*	7.0	0.5	0–15	4.9	0.5	0–15
Vocabulary*	26.6	0.5	19–35	33.6	0.6	20–39

Note. Education = self-reported number of years of formal education. Health rating = self-reported rating of overall health, from 1 (*very good*) to 5 (very poor). Health conditions = self-reported number of moderately serious or very serious health conditions, out of 35 queried. Digit–Symbol, Digit–Symbol Recall, Names Recall, and Vocabulary are reported as the number of questions answered correctly; see text for descriptions of these tasks.
* Differences between young and older adults significant at $p < .05$.

Demographic Information and Performance on Baseline Cognitive Measures for Each Age Group in Experiment 1

Each text was presented with a moving window procedure that presented one region of each sentence (1–7 words) at a time. The first region was presented in the upper left of the computer screen. When the participant pressed the space bar, each of the characters of the first region was replaced with dashes, and the next region was presented to the right of the first and so on for each subsequent region. Participants were not permitted to move backward to reread previously viewed regions. To discourage skimming during text presentation, if the mean reading time for 10 consecutive regions was less than 200 ms, the program temporarily removed the text from the screen and displayed the following warning for 4 s: “TOO FAST!! Please read each text carefully. The story will continue in a moment.” Text presentation then resumed at the same point as before the warning. The computer recorded the position and number of warnings for each participant. The mean number of “TOO FAST” warnings totaled across blocks of practice was 4.5 for young adults and 0.6 for older adults.

After the end of a text, the computer displayed a yes/no comprehension question based on the content of the story just read. For repeated texts (described later), a different comprehension question was presented after each trial. Each question tapped understanding of nontarget material within the text. Comprehension questions were included to support the cover task instructions that the experiment was about text learning and to encourage participants to read each text carefully. Performance on these questions was relatively high for young and older adults (M = 90.6% and 92.0%, respectively) and will not be discussed further, given that it is not of theoretical interest for present purposes.

In addition to two short practice texts presented during the instructions to familiarize participants with the moving window procedure, the first four texts presented in the main task were filler texts. The experimental texts were then presented in 10 blocks of trials. For each participant, five texts included the dominant version of the disambiguating sentence. Each of these texts was presented 10 times, once in each block of trials (the repeated dominant condition). Five texts included the subordinate version of the disambiguating sentence and were also presented once in each block of trials (the repeated subordinate condition). The remaining 15 texts also included the subordinate version of the disambiguating sentence, but each of these was only presented once (the unrepeated subordinate condition). Three of the unrepeated subordinate texts were presented in each of Blocks 2, 4, 6, 8, and 10. Assignment of text to condition was counterbalanced across participants in both age groups. Assignment of text to practice block in the novel subordinate condition was also counterbalanced across participants. The order of text presentation within each block was random.

After each block of practice trials, participants were offered a short break. Additionally, baseline cognitive measures were administered after Blocks 2, 4, and 7. In the digit–symbol task (adapted from Wechsler Adult Intelligence Scale Digit Symbol Subtest, Wechsler, 1981), the digits 1–9 were paired with symbols at the top of the screen. On each trial, a symbol was shown, and participants responded with the corresponding number as quickly as possible. Participants had 90 s to answer as many questions as they could. In the digit-symbol recall task administered immediately afterwards, the nine symbols were presented alone, and participants recalled which digit went with each symbol. In the names recall task (adapted from First and Last Names Test, French, Price, & Thurstone, 1962), participants were given 3 min to study 15 first name–last name pairs. They were then shown the last names and asked to type in the first name for each one. The vocabulary test was adapted from the Shipley Vocabulary Test (Zachary, 1986). Participants had 4 min to answer 40 questions. Performance on the baseline measures for each age group is reported in Table 1.

Results and Discussion

To foreshadow, the overall pattern of results indicated that both young and older adults shifted from computation to retrieval with practice in the reading comprehension task. However, results also indicated that young and older adults differed in how quickly that shift took place. Below, we first consider results bearing on the similarities between the two age groups. We then turn to the results concerning differences between the two groups.

For each participant, we computed mean reading time in the disambiguating region within each block of trials for each condition. For this and all other reading time measures reported, reading times for individual trials less than 100 ms or more than 4 standard deviations (SDs) above the mean were removed from analyses (< 1% of trials in each age group). Mean reading times across participants in each age group are shown in Figure 1. Results of an omnibus 2 (age group) × 2 (repeated subordinate vs. repeated dominant) × 10 (practice block) mixed-factor analysis of variance (ANOVA) are reported in Table 2. Although the Age × Meaning × Practice interaction did not reach significance, we report appropriate paired comparisons because the results of previous research motivate a priori directional predictions.

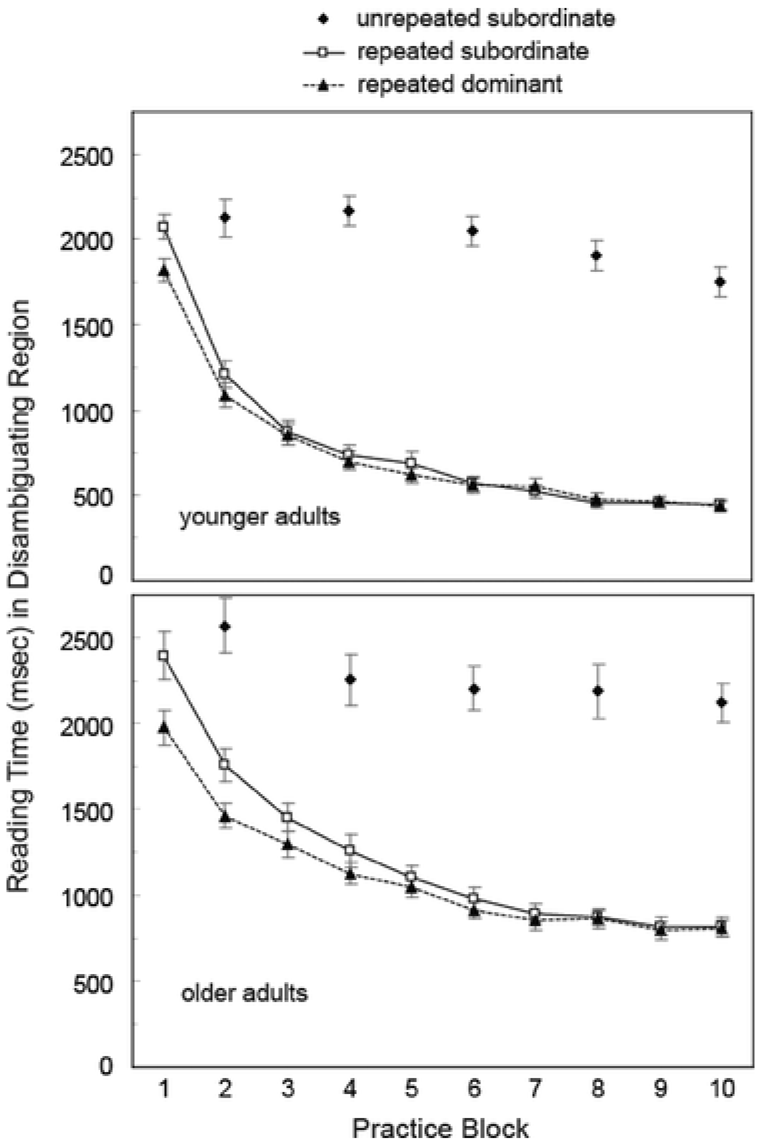

Figure 1. Mean reading time (in milliseconds) in the disambiguating region of target sentences for young adults (top panel) and older adults (bottom panel), as a function of the disambiguated meaning of the combination, repeated or unrepeated condition, and practice block in Experiment 1. Error bars represent standard error of the mean.

Table 2
Results of Analyses of Variance For Main Task Reading Time Measures In Experiment 1

Region/items	*df*	*F*	*MSE*	*p*
Disambiguating region, repeated subordinate and repeated dominant items (Blocks 1–10)				
Main effect of age	1, 115	40.99	2214405	<.001
Main effect of meaning	1, 115	27.20	147485	<.001
Main effect of practice block	9, 1035	276.12	172060	<.001
Age × Meaning	1, 115	5.97	147485	.016
Age × Practice Block	9, 1035	2.16	172060	.023
Meaning × Practice Block	9, 1035	11.52	59908	<.001
Age × Meaning × Practice Block	9, 1035	1.10	59908	.361
Spillover region, repeated subordinate and repeated dominant items (Blocks 1–10)				
Main effect of age	1, 115	43.15	1268609	<.001
Main effect of meaning	1, 115	<1.00		
Main effect of practice block	9, 1035	209.68	89798	<.001
Age × Meaning	1, 115	<1.00		
Age × Practice Block	9, 1035	4.64	89798	<.001
Meaning × Practice Block	9, 1035	2.41	33892	.011
Age × Meaning × Practice Block	9, 1035	1.64	33892	.100
Disambiguating region, repeated and unrepeated subordinate items (Blocks 2, 4, 6, 8, 10)				
Main effect of age	1, 115	16.00	2380661	<.001
Main effect of repetition	1, 115	594.66	730256	<.001
Main effect of practice block	4, 460	48.95	295688	<.001
Age × Repetition	1, 115	3.46	730256	.065
Age × Practice Block	4, 460	1.34	295688	.254
Repetition × Practice Block	4, 460	11.24	234210	<.001
Age × Repetition × Practice Block	4, 460	1.75	234210	.137
Repeated–unrepeated comparison values (Blocks 2, 4, 6, 8, 10)				
Main effect of age	1, 115	6.61	999	.011
Main effect of practice block	1, 115	75.04	731	<.001
Age × Practice Block	1, 115	2.27	731	.267

Results of Analyses of Variance For Main Task Reading Time Measures In Experiment 1

Replicating earlier research, practice effects were evident in both young adult (YA) and older adult (OA) groups. Reading times were significantly faster during the 10th block versus the first block of trials in the repeated subordinate condition[YA: $t(64) = 21.78$, $p < .001$; OA: $t(51) = 12.92$, $p < .001$]and in the repeated dominant condition [YA: $t(64) = 20.50$, $p < .001$; OA: $t(51) = 12.26$, $p < .001$]. 2 Several key comparisons provide evidence that these practice effects reflected increasing involvement of memory-based processing across trials. First, in the first block of practice, reading times were significantly slower in the repeated subordinate versus repeated dominant condition for both age groups [YA: $t(64) = 3.92$, $p < .001$; OA: $t(51) = 4.15$, $p < .001$]. Given that all items were still novel at this point, this difference presumably reflects initial computation of the dominant meaning in both conditions, necessitating reanalysis in the subsequent disambiguating region in the subordinate condition. In contrast, by the end of practice (Block 10), reading times in the two repeated conditions did not significantly differ [YA: $t(64) = 0.50$; OA: $t(51) = 0.30$]. Presumably, reading times in the two repeated conditions converged because participants shifted away from computation to retrieval of the appropriate interpretation in both conditions. Most important, young and older adults were similar to the extent that both groups shifted from computation to retrieval by the end of practice.

Concerning age differences, comparisons of reading times for the two repeated conditions during intermediate blocks of practice suggested that older adults were slower than young adults to shift from computation to retrieval. For young adults, reading times for subordinate versus dominant items differed significantly in Block 2, $t(64) = 1.99$, $p = .026$, but not in any other block of practice; the difference in Block 5 was marginal, $t(64) = 1.58$, $p = .059$. In contrast, for older adults, reading times for subordinate versus dominant items differed significantly in Blocks 2, 3, and 4 [$t(51) = 4.03$, $p < .001$; $t(51) = 3.34$, $p < .001$; $t(51) = 2.05$, $p = .023$, respectively] with a marginal difference in Blocks 5 and 6 [$t(51) = 1.49$, $p = .071$; $t(51) = 1.40$, $p = .084$, respectively]. Thus, older adults required more practice trials for reading times in the two repeated conditions to converge, suggesting a slower shift from computation to retrieval for older adults than for young adults.

An alternative interpretation is that young and older adults shifted from computation to retrieval at similar rates, but that young adults were more likely to complete reanalysis in the subsequent region (i.e., the spillover region) rather than in the disambiguating region. If so, the garden path effect associated with computation's initial misinterpretation of the subordinate items would be expected in the spillover region in intermediate blocks of practice for young adults but not for older adults. Mean reading times in the spillover region for each age group are presented in Figure 2, and results of an omnibus ANOVA are reported in Table 2. Inconsistent with this alternative interpretation, young adults' reading times in the spillover region were only significantly longer for subordinate versus dominant items in Block 1, $t(64) = 2.33$, $p = .012$. Reading times in the spillover region for subordinate versus dominant items did not differ significantly in Blocks 2–10 for either age group (YA: $ts < 1.33$; OA: $ts < 1.50$).

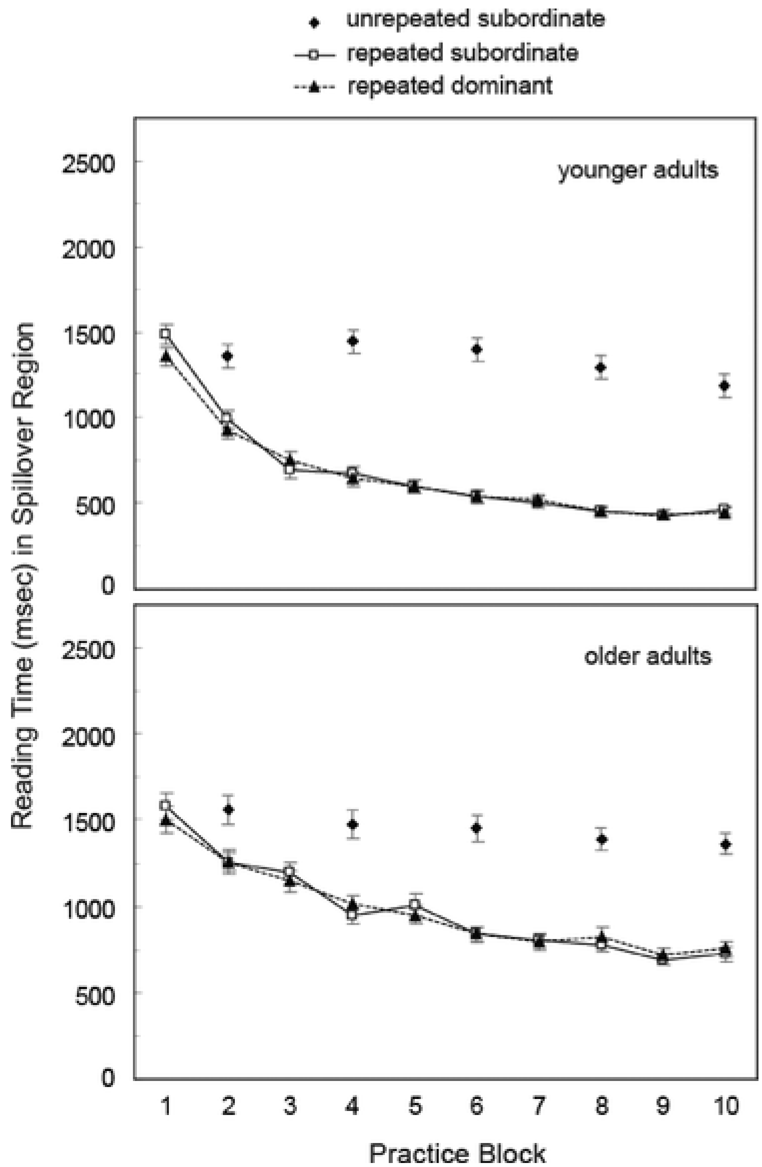

Figure 2. Mean reading time (in milliseconds) in the spillover region of target sentences for young adults (top panel) and older adults (bottom panel), as a function of the disambiguated meaning of the combination, repeated or unrepeated condition, and practice block in Experiment 1. Error bars represent standard error of the mean.

The second main pattern of results indicating that both age groups increasingly shifted from computation to retrieval—and that older adults did so more slowly—comes from comparison of reading times in the disambiguating region in the repeated subordinate and unrepeated subordinate conditions (Figure 1; results of an omnibus ANOVA are reported in Table 2). Regarding age similarities, both age groups exhibited item-specific practice effects, with reading times significantly faster for repeated items than for unrepeated items in Blocks 2, 4, 6, 8, and 10 (YA: $ts > 9.60$; OA: $ts > 6.23$). According to the memory-based processing account, when repeated subordinate items are encountered in later blocks of practice, the correct interpretations encoded on previous trials are retrieved, whereas interpretation of unrepeated subordinate items continues to involve computation.

In addition to examining overall means in these two conditions, we computed repeated–unrepeated comparison (RUC) values for each participant (Rogers & Gilbert, 1997; Rogers, Hertzog, & Fisk, 2000) as follows: In each block of practice that included unrepeated subordinate items (Blocks 2, 4, 6, 8, and 10), we identified the participant's fastest reading time in the disambiguating region from among those for the unrepeated subordinate items in that block (as an estimate of the lower boundary for computation completion time). We then computed the percentage of reading times in the disambiguating region for repeated subordinate items in that block that were faster than the participant's fastest unrepeated item reading time (as an estimate of the percentage of trials in which retrieval beat computation). Means across individuals in each age group for each block of practice are presented in Figure 3, and results of an omnibus ANOVA are reported in Table 2.

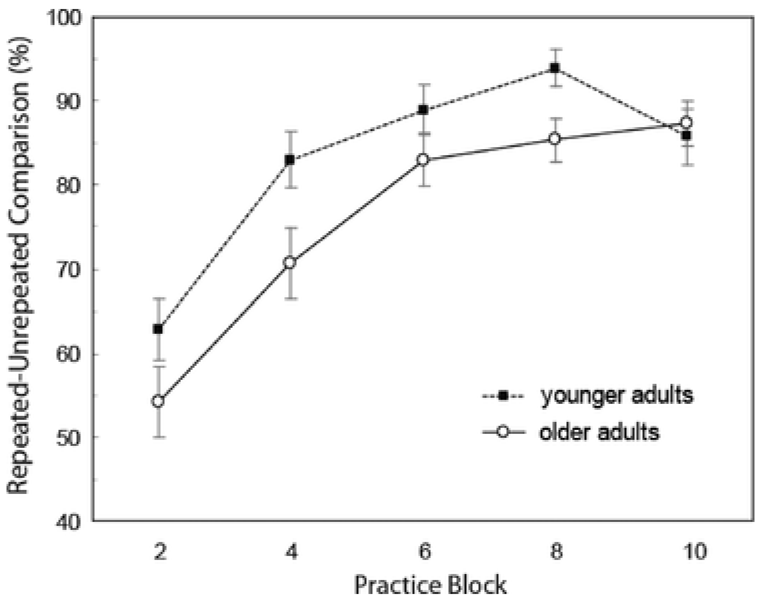

Figure 3. Mean repeated–unrepeated comparison (RUC) values across participants in each age group as a function of block of practice in Experiment 1. RUC is the percentage of disambiguating region reading times for repeated subordinate items that were faster than a participant's fastest reading time for unrepeated subordinate items in a given block of practice. Error bars represent standard error of the mean.

As would be expected, RUC values increased across blocks for both age groups, consistent with the assumption that the interpretation of repeated items increasingly involves retrieval rather than computation across blocks of practice. Regarding age differences, we found a consistent trend of lower RUC values for older versus young adults in early and intermediate blocks of practice [Block 2: $t(115) = 1.54$, $p = .064$; Block 4: $t(115) = 2.31$, $p = .012$; Block 6: $t(115) = 1.36$, $p = .089$; Block 8: $t(115) = 2.51$, $p = .007$]. This pattern suggests that interpretation of repeated items in early and intermediate blocks of practice was less dependent on retrieval for older adults than for young adults, providing further evidence for a slower shift from computation to retrieval for older adults.

Experiment 2

Why were older adults slower to shift from computation to retrieval during reading comprehension practice? To explore this question, we pretrained participants in Experiment 2 on the meanings for half of the combinations in each repeated condition prior to presentation of the stories in the main reading phase of the experiment. Pretraining involved an initial study trial for each combination along with the meaning that would be presented during the main reading phase, followed by subsequent cued recall and restudy until each item was learned to criterion.

According to the encoding deficit hypothesis, older adults are slower to shift from computation to retrieval due to poorer encoding of interpretations during practice. If older adults encode fewer or poorer instances, the retrieval route is less well equipped to produce an interpretation before computation. The encoding deficit hypothesis makes two key predictions for performance in the main reading task. First, neither age group will show a garden path effect in any block of practice for the pretrained items. This prediction follows from the idea that pretraining on the target meanings minimizes encoding differences between young and older adults. Thus, upon encountering a combination in the main reading task, both young and older adults can retrieve the intended meaning learned during pretraining. For the untrained items, however, older adults still will be at a learning disadvantage for these items and thus will be slower than young adults to shift from computation to retrieval during practice.

An alternative hypothesis of why older adults were slower to shift from computation to retrieval concerns biases in selecting the two possible processing routes to interpretation, above and beyond any differences in associative memory. In its most general form, the retrieval aversion hypothesis (Touron & Hertzog, 2004a) assumes that older adults are more likely to avoid retrieval-based processing. Greater retrieval aversion in older adults could reflect conscious reluctance to rely on retrieval due to lower confidence in memory accuracy (Touron & Hertzog, 2004a) or nonconscious age differences in response selection parameters within the processing system, although this distinction is not critical for present purposes. In either case, the claim of the retrieval aversion hypothesis is that older adults show greater bias against use of the retrieval route to interpretation.

The distinction of greater relevance concerns the extent to which older adults' bias against retrieval is persistent or modifiable. Touron and Hertzog (2004a) found evidence for persistent bias in a noun pair look-up task. Older adults continued to rely on visual search of a look-up table even when memory for the noun pairs was sufficient to support retrieval (as indicated by performance on item recognition probes). If retrieval aversion is persistent in the current reading task, (a) older adults will show a garden path effect at the outset of practice for pretrained items, whereas young adults will not, and (b) older adults will show more persistent garden path effects for untrained items than young adults, as in Experiment 1.

Regarding the modifiability of older adults' bias against retrieval, Touron and colleagues have reported conditions that reduce older adults' bias against retrieval (Touron & Hertzog, 2004a; Touron et al., 2007). In Touron and Hertzog's (2004a) noun pair look-up task, one group received intermittent recognition probe trials for half of the items (in which the look-up table was absent, thus requiring use of retrieval strategy), and another group received no recognition probes. Relative to the no-probe group, older adults in the probe group reported using retrieval on more trials and showed faster response times for both probed and unprobed items. Thus, probing memory modified older adults' bias against retrieval, with similar reductions in the bias for both probed and unprobed items. In the current reading task, pretraining may similarly modify older adults' bias against retrieval. If pretraining is sufficient to overcome retrieval aversion, (a) young and older adults will show similar patterns of reading times for the pretrained items, with neither group showing a significant garden path effect, and (b) young and older adults will also show similar shifts from computation to retrieval for untrained items. In sum, the encoding deficit hypothesis predicts that the pattern of reading times for young and older adults will be similar for pretrained items but different for untrained items. The retrieval aversion hypothesis predicts the pattern of reading times for young and older adults will be different for both pretrained and untrained items if older adults' bias is persistent or similar for both pretrained and untrained items if older adults' bias is modifiable.

Method

Participants and design

Participants included 53 young adults (37 women and 16 men) and 49 older adults (33 women and 16 men). 3 Young adults were undergraduate students at Kent State University who were given a $20 honorarium for participating. Older adults were community residents from the Greensboro, North Carolina, area recruited from the registry of the Adult Cognition Laboratory at the University of North Carolina at Greensboro who received a $30 honorarium. In the main reading comprehension task, text condition (unrepeated subordinate, repeated subordinate, repeated dominant) and practice block (1–8) were within-participant manipulations. The other within-participant manipulation was pretraining condition (pretraining or no pretraining of items prior to the main task). The design was not a full factorial, given that the pretraining manipulation was only applicable in the two repeated conditions.

Materials

Materials for the main task included 28 experimental texts and 3 filler texts. Twenty-three of the experimental texts were the same as in Experiment 1. The 5 new experimental texts were constructed and normed in the same manner as in Experiment 1 (the dominant meaning was generated by 78% of the 21 young adults in the norming study, and the subordinate meaning was generated by 5%).

We also conducted another norming study to establish that our experimental items have similar normative properties for both young and older adults. In this study, 91 older adults (mean age, 69 years; 61% women and 39% men; mean length of education, 16 years) from northeastern Ohio communities completed the norming task in the context of a larger study (not the main experiment reported here). Each participant responded to approximately one third of the items, such that each item had 29–34 responses. The procedure was the same as in the norming study conducted with young adults, described in Experiment 1. Across items, older adults generated the dominant meaning 65% of the time and the subordinate meaning 6% of the time. 4

For the main task, 8 texts were assigned to the repeated dominant condition, 8 were assigned to the repeated subordinate condition, and 12 were assigned to the unrepeated subordinate condition. Half of the texts in each of the two repeated conditions were assigned to the pretraining condition, and the other half were assigned to the no-pretraining condition. Assignment of text to all conditions was counterbalanced across participants in each age group.

Procedure

Prior to completing the experimental tasks, participants completed a questionnaire collecting basic demographic information as in Experiment 1 (see summary statistics in Table 3). To allow participants to practice making speeded responses using the mouse and the keyboard, buttons appeared on the screen one at a time at different locations, and participants were instructed to move the mouse and click on each button as quickly as possible. Then, participants were shown letters and digits one at a time and were asked to press the corresponding key on the keyboard as quickly as possible.

Table 3

Demographic Information and Performance on Baseline Cognitive Measures for Each Age Group in Experiment 2

Variable	Young adults *M*	Young adults *SE*	Young adults Range	Older adults *M*	Older adults *SE*	Older adults Range
Demographics						
Age (years)*	21.7	0.2	19–26	67.3	0.6	60–75
Education (years)	15.1	0.2	13–20	15.6	0.4	12–21
Health rating†	1.8	0.1	1–3	1.6	0.1	1–3
Health conditions†	0.6	0.2	0–6	1.0	0.2	0–5
Baseline cognitive measures						
Digit–Symbol*	64.2	1.2	44–86	43.6	1.2	21–61
Digit–Symbol Recall†	8.0	0.2	4–9	7.6	0.2	4–9
Vocabulary*	28.7	0.6	22–39	34.8	0.5	22–40
Meaningful Memory Recall	13.5	0.6	4–20	14.3	0.5	6–20
Operation Span*	20.6	0.9	8–32	11.4	1.1	0–30

Note. Education = self-reported number of years of formal education. Health rating = self-reported rating of overall health, from 1 (*very good*) to 5 (*very poor*). Health conditions = self-reported number of moderately serious or very serious health conditions, out of 35 queried. Digit–Symbol, Digit–Symbol Recall, Vocabulary, Meaningful Memory Recall, and Operation Span performance are reported as the number of questions answered correctly; see text for descriptions of these tasks.
† $p < .08$. * $p < .05$.

Demographic Information and Performance on Baseline Cognitive Measures for Each Age Group in Experiment 2

Participants then completed the pretraining phase of the main experiment. Participants were informed that the noun phrases would be encountered again in another task later in the experiment and that learning them now would help them in that task. The 8 pretraining items were then presented one at a time for a self-paced study trial. Each item was then presented for a test–restudy trial. First, the noun phrase was presented with an empty textbox for participants to type in the definition. After participants had finished responding, the correct answer was presented on the screen along with their response. Participants were prompted to compare their response to the correct response and indicate with a button click whether they thought their response was not correct at all, partly correct, or completely correct. Next, the judgment information and their response were removed from the screen, and participants were prompted to restudy the correct definition at their own pace.

During the judgment portion of a trial, if the participant did not judge his or her response to be completely correct, the item was placed at the end of the practice list to receive another test–restudy trial later. If a response was judged as completely correct, the computer calculated whether the response was at least half the length (in characters) as the correct answer. If not, a pop-up box informed the participant that his or her judgment was not correct and encouraged the participant to make judgments more carefully on subsequent trials. The item was then placed at the end of the practice list for another test–restudy trial later. If the participant judged his or her response as correct and the response was at least half the length of the correct answer, the item was dropped from further practice during that block. After all 8 items had been correctly recalled once, they underwent a second block of test–restudy trials until they were correctly recalled a second time.

After pretraining, the main task was administered as in Experiment 1, with the following exceptions. The experimental texts were presented in eight blocks of trials, with repeated dominant and subordinate texts presented once in each block. Three of the 12 unrepeated subordinate texts were presented in each of Blocks 2, 4, 6, and 8. Across all blocks of practice, the mean number of “TOO FAST” warnings was 4.0 for young adults and 0.6 for older adults, and performance on the comprehension questions was relatively high for both young and older adults (M = 91.7% and 92.5%, respectively).

The baseline cognitive measures were administered after Blocks 2, 4, and 6. The digit–symbol task, digit–symbol recall, and the vocabulary task were the same as in Experiment 1. We replaced the names task from

Experiment 1 with the Meaningful Memory task (adapted from Hakastian & Cattell, 1976). Participants were given 75 s to study 20 word pairs consisting of a noun and a related adjective (e.g., street–empty). Participants then completed an operation span measure of working memory. Participants then completed the Meaningful Memory test in which they were to select a synonym of the adjective originally paired with each noun from among four distractor adjectives (e.g., street: faraway, near, deserted, broad, bustling). Performance on the baseline cognitive measures for each age group is reported in Table 3.

Results and Discussion

Pretraining phase performance

For each dependent measure of interest, we performed a 2 (age group) × 2 (item meaning) mixed-factor ANOVA. The results of these analyses are reported in Table 4, along with descriptive statistics for each condition. Given that age effects on pretraining performance are of greatest interest for present purposes, we collapsed across item meaning for paired comparisons reported in the following section and focus our discussion on comparison of performance in the two age groups.

Table 4

Pretraining Phase Performance as a Function of Age Group and Item Meaning in Experiment 2

	Young adults				Older adults			
	Subordinate		Dominant		Subordinate		Dominant	
Item meaning	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Mean no. of practice trials per item	3.18	0.18	3.04	0.16	4.95	0.34	4.68	0.26
Main effect of age: $F(1, 100) = 28.89$, $MSE = 82.02$, $p < .001$								
Main effect of meaning: $F(1, 100) = 2.80$, $MSE = 11.73$, $p = .097$								
Interaction: $F < 1$								
Mean no. of correct recalls per item	2.86	0.13	2.81	0.11	4.01	0.26	4.10	0.25
Main effect of age: $F(1, 100) = 24.48$, $MSE = 49.44$, $p < .001$								
Main effect of meaning: $F < 1$								
Interaction: $F < 1$								
Mean no. of trials to first correct recall	1.26	0.07	1.16	0.05	1.60	0.08	1.37	0.05
Main effect of age: $F(1, 99) = 13.93$, $MSE = 0.28$, $p < .001$								
Main effect of meaning: $F(1, 99) = 14.92$, $MSE = 0.10$, $p < .001$								
Interaction: $F(1, 99) = 2.23$, $MSE = 0.10$, $p = .139$								

Note. Subordinate = items trained with subordinate meaning; Dominant = items trained with dominant meaning.

Pretraining Phase Performance as a Function of Age Group and Item Meaning in Experiment 2

For each participant, we computed the mean number of practice trials per item during pretraining. Overall, older adults completed more practice trials per item than young adults (YA: M = 3.11, SE = 0.16; OA: M = 4.81, SE = 0.28). To revisit, each pretrained item was practiced until a participant judged the item to be correctly recalled on two separate trials. To ensure that both age groups actually reached the criterion of two correct recalls, we scored participants' pretraining recall responses. Correct responses included verbatim reproductions and close paraphrases of the original definition. Both age groups showed some underconfidence when judging their own pretraining responses, judging some correct responses (according to our scoring) as only partially correct. (On the basis of informal discussion with participants, we suspect that some may have believed that items had to be recalled verbatim to be judged as completely correct.) As a result, some items that had been correctly recalled twice continued to be presented for practice because the participant did not judge them as correct. Across dominant and subordinate items, the mean number of times items were correctly recalled was 2.83 (SE = 0.11) for young adults and 4.05 (SE = 0.23) for older adults. Most important, older adults were not at a disadvantage with respect to level of learning achieved during pretraining, with a significant difference in the opposite direction, $t(100) = 4.95$, $p < .001$.

For each participant, we also computed the mean number of practice trials needed to reach the first correct recall (according to our scoring; mean values for one older adult were more than 4 SDs above the group mean and were excluded from analyses here and in Table 4). The mean number of trials to first correct recall was 1.21 (SE = 0.05) for young adults and 1.49 (SE = 0.05) for older adults. Although the age effect was significant, t(99) = 3.73, p < .001, the difference was relatively small, and both age groups learned the correct meanings of the noun phrases in fewer than two trials. Expanding the analysis to include partially correct responses suggested that the initial study presentation was sufficient for most participants to learn some or all of the definition (mean number of trials to reach first partial or complete correct recall, YA: M = 1.02, SE = 0.02; OA: M = 1.17, SE = 0.03).

Main task performance for pretrained items

Mean reading times in the disambiguating region of target sentences in the main task for the pretrained items are displayed in Panels A and B of Figure 4, for young and older adults, respectively. Results of mixed-factor ANOVAs are reported in Table 5. Practice effects were evident in both age groups, with faster reading times during the eighth block versus the first block of trials in the repeated subordinate and repeated dominant conditions (YA: ts > 12.92; OA: ts > 10.08).

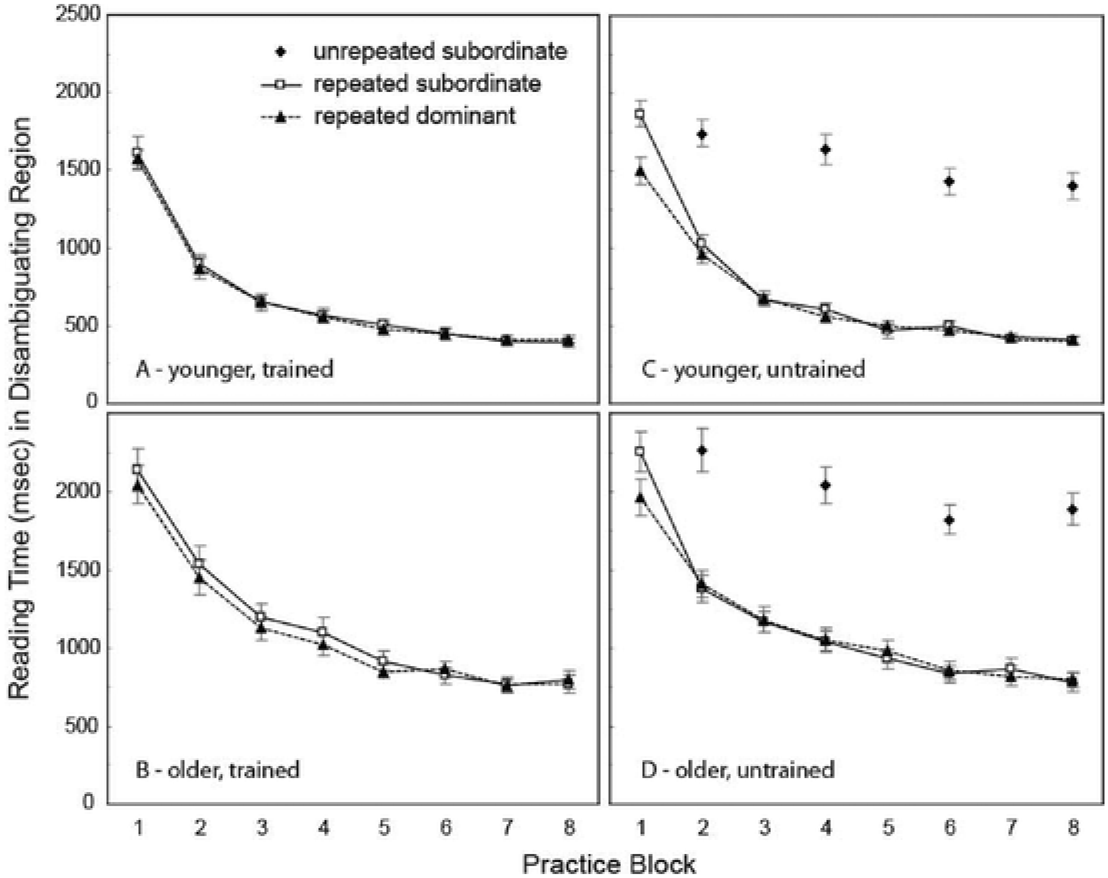

Figure 4. Mean reading time (in milliseconds) in the disambiguating region of target sentences for young adults (top panels) and older adults (bottom panels) for pretrained items (left panels) and untrained items (right panels) in Experiment 2. Error bars represent standard error of the mean.

Table 5
Results of Analyses of Variance for Main Task Reading Time Measures in Experiment 2

Region/items	*df*	*F*	*MSE*	*p*
Pretrained and untrained repeated items				
Disambiguating region, subordinate and dominant items (Blocks 1–8)				
Main effect of age	1, 96	59.94	2688977	<.001
Main effect of meaning	1, 96	6.65	120973	.011
Main effect of practice block	7, 672	246.65	295494	<.001
Main effect of training	1, 96	1.73	341902	.191
Age × Meaning	1, 96	<1.00		
Age × Practice Block	7, 672	<1.00		
Age × Training	1, 96	<1.00		
Meaning × Practice Block	7, 672	7.33	66292	<.001
Meaning × Training	1, 96	<1.00		
Practice Block × Training	7, 672	<1.00		
Age × Meaning Practice Block	7, 672	<1.00		
Age × Meaning Training	1, 96	2.14	111657	.146
Age Practice Block × Training	7, 672	2.49	86162	.016
Meaning × Practice Block × Training	7, 672	4.15	68700	<.001
Age × Meaning × Practice Block × Training	7, 672	<1.00		
Pretrained items				
Disambiguating region, subordinate and dominant items (Blocks 1–8)				
Main effect of age	1, 97	56.10	1521517	<.001
Main effect of meaning	1, 97	2.34	109447	.129
Main effect of practice block	7, 679	179.00	197473	<.001
Age × Meaning	1, 97	1.11	109447	.295
Age × Practice Block	7, 679	2.10	197473	.042
Meaning × Practice Block	7, 679	<1.00		
Age × Meaning × Practice Block	7, 679	<1.00		
Spillover region, subordinate and dominant items (Blocks 1–8)				
Main effect of age	1, 98	59.04	700222	<.001
Main effect of meaning	1, 98	<1.00		
Main effect of practice block	7, 686	174.77	103796	<.001
Age × Meaning	1, 98	<1.00		
Age × Practice Block	7, 686	<1.00		
Meaning × Practice Block	7, 686	1.53	37628	.157
Age × Meaning × Practice Block	7, 686	<1.00		
Untrained items				
Disambiguating region, repeated subordinate and repeated dominant items (Blocks 1–8)				
Main effect of age	1, 99	51.20	1476300	<.001
Main effect of meaning	1, 99	5.31	121469	.023
Main effect of practice block	7, 693	215.10	180461	<.001
Age × Meaning	1, 99	<1.00		
Age × Practice Block	7, 693	<1.00		
Meaning × Practice Block	7, 693	10.66	67052	<.001
Age × Meaning × Practice Block	7, 693	<1.00		
Spillover region, repeated subordinate and repeated dominant items (Blocks 1–8)				
Main effect of age	1, 100	50.82	736921	<.001
Main effect of meaning	1, 100	6.39	63931	.013
Main effect of practice block	7, 700	170.51	88302	<.001
Age × Meaning	1, 100	<1.00		
Age × Practice Block	7, 700	1.79	88302	.087
Meaning × Practice Block	7, 700	5.46	32889	<.001
Age × Meaning × Practice Block	7, 700	1.68	32889	.110
Disambiguating region, repeated and unrepeated subordinate items (Blocks 2, 4, 6, 8)				
Main effect of age	1, 100	26.96	1297343	<.001
Main effect of repetition	1, 100	340.30	546155	<.001
Main effect of practice block	3, 300	59.02	173179	<.001
Age × Repetition	1, 100	<1.00		
Age × Practice Block	3, 300	<1.00		
Repetition × Practice Block	3, 300	5.13	131817	.002
Age × Repetition × Practice Block	3, 300	<1.00		
Repeated–unrepeated comparison values (Blocks 2, 4, 6, 8)				
Main effect of age	1, 100	<1.00		
Main effect of practice block	1, 100	85.84	509	<.001
Age × Practice Block	1, 100	<1.00		

Results of Analyses of Variance for Main Task Reading Time Measures in Experiment 2

More important, reading times for repeated subordinate and repeated dominant items did not significantly differ at the outset of practice in either age group [Block 1, YA: $t(51) = 1.12$, OA: $t(48) = 0.81$; Block 2, YA: $t(52) = 0.50$, OA: $t(48) = 0.78$] nor in any block of practice thereafter [YA: ts < 1.12; OA: ts < 1.48]. The elimination of a garden path effect in the disambiguating region early in practice indicates that both young and older adults were retrieving the meanings of the combinations learned in pretraining, and thus no reanalysis was necessary in the disambiguating region in the subordinate condition. Ruling out the possibility that the absence of a garden path effect reflected completion of reanalysis in the subsequent region (i.e., the spillover region) rather than in the disambiguating region, Panels A and B of Figure 5 clearly indicate no garden path effects in the spillover region for either age group at the outset of practice [Block 1, YA: $t(52) = 0.69$, OA: $t(48) = 1.72$, with the trend in the opposite direction; Block 2, YA: $t(52) = 0.02$, OA: $t(48) = 0.56$].

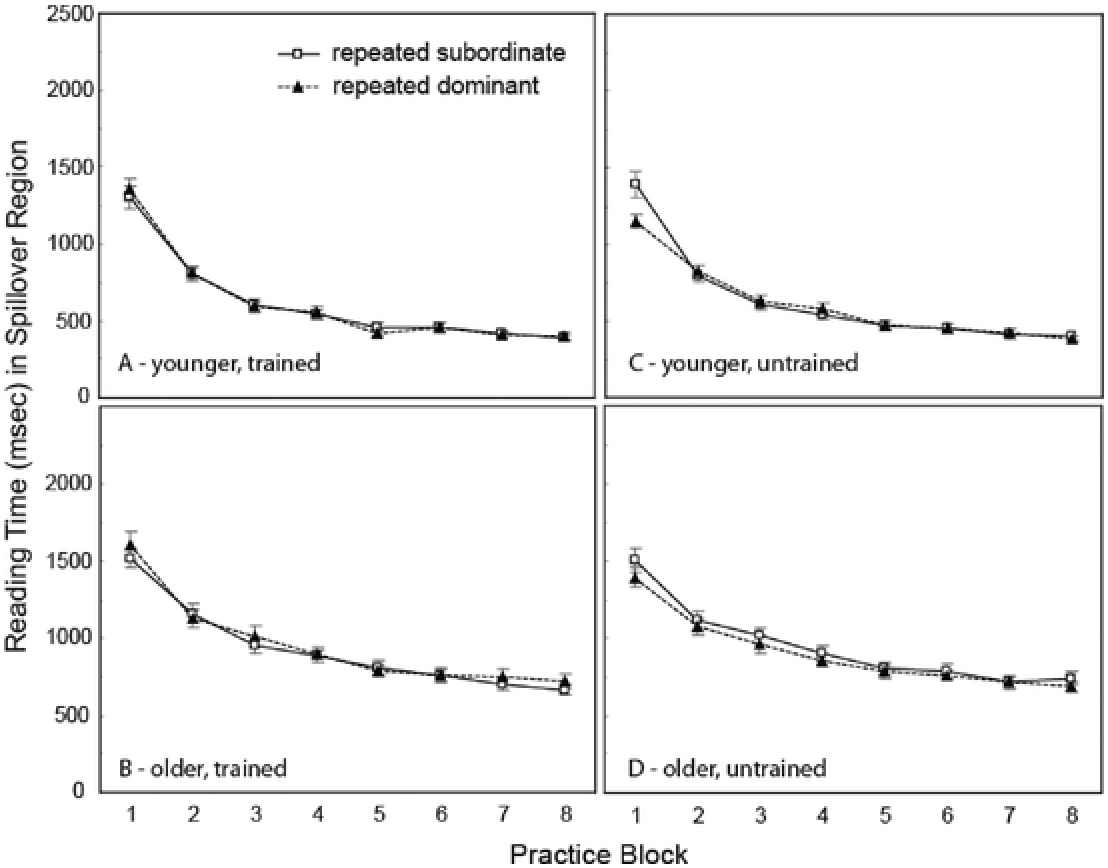

Figure 5. Mean reading time (in milliseconds) in the spillover region of target sentences for younger adults (top panels) and older adults (bottom panels), for pretrained items (left panels) and untrained items (right panels) in Experiment 2. Error bars represent standard error of the mean.

These results weigh against the possibility of persistent retrieval aversion in the current task. However, the results are consistent with both the encoding deficit hypothesis and the modifiable retrieval aversion account. To adjudicate between these two hypotheses, we turn to results for the untrained items.

Main task performance for untrained items

Mean reading times in the disambiguating region for each age group are displayed in Figure 4, and results of mixed-factor ANOVAs are reported in Table 5. Practice effects were evident in both age groups, with faster reading times during the eighth block versus the first block of trials in the repeated subordinate and repeated dominant conditions [YA: ts > 14.00; OA: ts > 10.54]. 5

In both age groups, reading times for untrained items were significantly slower in the repeated subordinate versus repeated dominant condition during the first block of practice [YA: $t(52) = 4.48$, $p < .001$; OA: $t(48) =$

3.27, p = .001]. Given that all of the untrained items were still novel at this point, this difference presumably reflected initial computation of the dominant meaning in both conditions, necessitating reanalysis in the subsequent disambiguating region in the subordinate condition. In contrast, by the end of practice (Block 8), reading times in the two untrained repeated conditions did not significantly differ [YA: t(52) = 0.28; OA: t(48) = 0.36]. Presumably, reading times in these two conditions converged because participants shifted away from computation to retrieval of the appropriate interpretation in both conditions.

Most important, older and young adults showed similar shifts from computation to retrieval during intermediate blocks of practice. Reading times in the two untrained repeated conditions did not significantly differ in Blocks 2–7 for either young or older adults [YA: ts < 1.27; OA: ts < 1.17]. Thus, older adults did not require more practice trials than young adults for reading times in the two untrained repeated conditions to converge. This pattern of results is inconsistent with the encoding deficit hypothesis and instead supports the retrieval aversion hypothesis. Furthermore, older adults' retrieval aversion was clearly modifiable—pretraining on a subset of items was sufficient for older adults to overcome any conscious or nonconscious bias against use of the retrieval route to interpretation.

Further results rule out the alternative interpretation that older adults completed reanalysis in the subsequent spillover region rather than in the disambiguating region on intermediate trials. Although reading times in the spillover region (see Figure 5) were significantly longer for subordinate versus dominant untrained items in Block 1 for both age groups [YA: t(52) = 2.96, p = .002; OA: t(48) = 2.11, p = .020] reading times in the spillover region for these two conditions did not differ significantly in Blocks 2–8 for either age group [YA: ts < 1.28; OA: ts < 1.54, except for Block 8, t = 1.93].

The second main pattern of results indicating that the two age groups were similar in their shift from computation to retrieval comes from comparison of reading times in the disambiguating region for the repeated subordinate and unrepeated subordinate conditions. Both age groups exhibited item-specific practice effects, with reading times significantly faster for repeated versus unrepeated items in Blocks 2, 4, 6, and 8 [YA: ts > 7.76; OA: ts > 8.67]. In addition to examining overall means in these two conditions, we computed repeated–unrepeated comparison (RUC) values for each participant, as in Experiment 1. Means across individuals in each age group for each block of practice are presented in Figure 6. In contrast to the consistent trend of lower RUC values for older versus young adults in Experiment 1, RUC values did not differ significantly for older versus young adults in any block of practice (ts < 1.23).

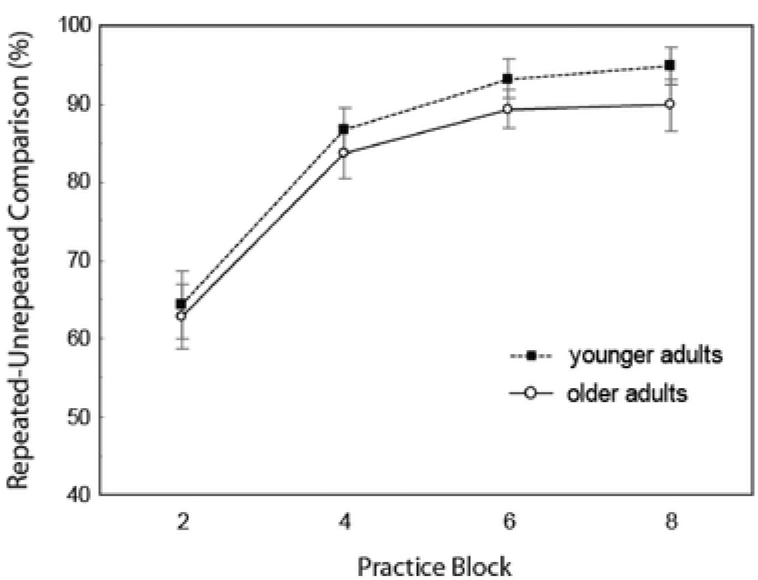

Figure 6. Mean repeated–unrepeated comparison (RUC) values across participants in each age group for pretrained and untrained items in Experiment 2. RUC is the percentage of disambiguating region reading times

for repeated subordinate items that were faster than a participant's fastest reading time for unrepeated subordinate items in a given block of practice. Error bars represent standard error of the mean.

General Discussion

In Experiments 1 and 2, both young and older adults shifted from computation to retrieval with practice during reading comprehension. However, in Experiment 1, young and older adults differed in how quickly that shift took place. Older adults required more blocks of practice than young adults for reading times to converge in the repeated subordinate and repeated dominant conditions, and older adults also showed less divergence of reading times in the repeated subordinate and unrepeated subordinate conditions. Note that the age difference in the timing of the shift from computation to retrieval during reading comprehension was likely one of degree rather than discrete (see Touron, 2006). That is, the conclusion that older adults were slower to shift does not mean that they processed all items via computation until making a relatively abrupt shift to retrieval-based processing of items at a point later in practice than young adults. Rather, in early and intermediate blocks of practice, interpretation was likely based on retrieval on some proportion of trials for both young and older adults (based on the significantly faster reading times for repeated versus unrepeated subordinate items even in Block 2 for both age groups). Our claim is that in Experiment 1, the proportion was greater for young versus older adults in early and intermediate blocks of practice.

Experiment 2 suggested that older adults' slower shift from computation to retrieval was primarily due to differences in retrieval aversion rather than to encoding deficits. After pretraining on the meanings for half of the combinations, older adults showed rates of shifting from computation to retrieval that were similar to those of young adults for both pretrained and untrained items. The finding that older and young adults showed similar shifts for untrained items weighs against the encoding deficit hypothesis, because pretraining would only have overcome encoding deficits for pretrained items. Performance during pretraining in Experiment 2 also suggests that older and young adults were relatively similar in encoding. During pretraining, the initial study presentation was sufficient for most participants to learn the definitions of the combinations, for both older and young adults. Overall, the results of Experiment 2 are most consistent with the retrieval aversion hypothesis and indicate that older adults' retrieval aversion in the reading comprehension task used here is relatively modifiable.

How do the results of the current research compare with findings in earlier work investigating age effects on shifts from computation to retrieval in other cognitive tasks? On one hand, the qualitative pattern observed in Experiment 1 is similar to those in many earlier studies showing that older adults are slower to shift from computation to retrieval during practice in cognitive tasks (Jenkins & Hoyer, 2000; Touron & Hertzog, 2004a;Touron et al., 2004). On the other hand, the present findings show some striking differences from previous research in the degree of age differences in the shift from computation to retrieval. For example, although older adults were slower than young adults to shift in Experiment 1, older adults resembled young adults after fewer than 10 presentations of repeated items. Previous work has typically found that age differences in strategy shifts persist despite extensive training (Rogers & Gilbert, 1997; Rogers et al., 2000; Touron & Hertzog, 2004a; Touron et al., 2007). Notably, Touron & Hertzog (2004a) found that age differences in retrieval use persisted after 60 item repetitions, even in a condition for which all items were pretrained. In stark contrast, age differences in retrieval use in the current study were eliminated early in training, even for untrained items. Touron and Hertzog (2004a) also found substantial age differences in their pretraining phase (older adults required nearly four times as many trials as young adults to reach criterion), whereas age differences in pretraining were minimal in the present study. Indeed, relative to most previous research using simpler and less familiar cognitive tasks, older and young adults showed somewhat surprising similarities in their overall patterns of performance in the reading comprehension task.

Thus, the present work represents a significant departure from much of the previous research and further suggests that age differences in the cognitive mechanisms that underlie practice effects may depend critically on the nature of the cognitive task. For example, we found minimal evidence that encoding deficits underlie age differences in the involvement of retrieval-based processing during practice in reading comprehension, in contrast to other tasks (Jenkins & Hoyer, 2000; Rogers et al., 2000). Additionally, we observed much less persistence of older adults' retrieval aversion than in previous research. These differences suggest that an important direction for future research will be identification of factors that moderate the involvement of encoding deficits and retrieval aversion as well as the persistence of retrieval aversion across tasks.

The present results have implications for theories of age-related differences in reading comprehension and may provide further insight into patterns of deficit and sparing in older adults' reading comprehension. For example, Stine-Morrow and colleagues (Stine-Morrow, 2007; Stine-Morrow, Miller, & Hertzog, 2006) have proposed a model of self-regulated language processing involving a coordinated system of negative feedback loops that each regulate a level of text processing (surface, text base, and situation model levels). The model assumes that the monitoring and control processes in each feedback loop require attentional resources, and the system's allocation policy reflects the relative amount of resources invested at each level of processing. On the basis of several studies showing differences in the allocation policies of young and older adults, they state that "(implicit or explicit) choices about attentional engagement predict performance. What is less clear is what drives the recruitment of resources for effective attentional engagement" (Stine-Morrow, 2007, p. 296).

In addition to factors that have recently been shown to influence allocation policy (e.g., reader goals, memory self-efficacy; Stine-Morrow, Shake, Miles, & Noh, 2006), the present results suggest that the allocation of attentional resources to different levels of processing may also be influenced by the extent to which processing at a given level involves retrieval versus computation. Previous research has shown that resource demands decrease with increasing shifts from computation to retrieval (Klapp, Boches, Trabert, & Logan, 1991). Additionally, recent research has found that increased resource demands at one level of text processing can interfere with processing at another level; Rawson (2007) showed that the resource demands of reanalyzing initial syntactic misinterpretations interfered with the processing of causal inferences. Taken together, these findings suggest that the investment of resources at the various levels of text processing (i.e., allocation policies) of young and older adults may differ in part due to differential reliance on retrieval versus computation. For example, if older adults are less likely to rely on retrieval during lower level text processing (e.g., syntactic parsing), more costly computational processing would require the allocation of additional resources. If so, the increased resource demands of lower level text processes may interfere with the successful functioning of higher level processes (e.g., causal inferencing).

The present work provides an important launching point for subsequent research to further explore age differences in the shift from computation to retrieval during practice in reading comprehension. A key direction will be the extension of the present findings to other component processes involved in reading comprehension, such as lexical processing and syntactic parsing (Rawson, 2004). Another important extension will be to examine age-related differences in memory-based processing with longer delays. Previous research with young adults has shown that instances stored during an initial practice session are retained and continue to support memory-based processing across delays of several days (Rawson, 2004; Rawson & Middleton, 2009). However, these studies also showed some forgetting across delays (see also Rickard, 2007). To the extent that older adults experience greater forgetting across delays (Giambra & Arenberg, 1993; Jenkins & Hoyer, 2000), age differences in the involvement of memory-based processing may be exacerbated with longer retention intervals. More generally, the present research provides important foundational work for further understanding age-related differences in the involvement of memory-based processing in reading comprehension.

Footnotes

1 Data from an additional 5 young adults and 2 older adults were excluded from analyses because participants either did not complete all experimental tasks or because they failed to comply with experimental instructions.

2 Practice effects were also evident in the unrepeated subordinate condition in both age groups, with faster reading times in Block 10 than in Block 2 [YA: $t(64) = 3.48$, $p < .001$; OA: $t(51) = 2.86$, $p = .003$]. Although not of primary interest for present purposes, these results suggest gains for both young and older adults in computational efficiency with practice (for relevant discussion, see Rawson, 2004; Rawson & Middleton, 2009).

3 Data from an additional 4 young adults and 5 older adults were excluded from analyses because participants did not complete all experimental tasks or because they failed to comply with experimental instructions; 1 additional older adult was dropped because he or she did not learn items to criterion during the pretraining phase of the main task.

4 Although older adults showed a clear bias for the dominant meaning, the percentage of dominant meanings generated was somewhat lower for older adults than for young adults. Informal inspection of the nondominant responses generated during the norming task suggested that older adults tended more than young adults to produce general definitions (e.g., bee caterpillar = "a type of insect"; cf. McGinnis & Zelinski, 2003) and more references to specific information that had been stated in the text (e.g., bee caterpillar = "an unusual insect species they found in the African Congo").

5 Practice effects were again evident in the unrepeated subordinate condition in both age groups, with faster reading times in Block 8 than in Block 2 [YA: $t(52) = 4.21$, $p < .001$; OA: $t(48) = 3.72$, $p < .001$].

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APPENDIX

APPENDIX A: Sample Stories Used in the Reading Comprehension Task

Below, the novel combination in each text is underlined and the disambiguating region is italicized for illustrative purposes. In the experiment, the disambiguating region contained either the dominant meaning (the first phrase in the bracket) or the subordinate meaning (the second phrase in the bracket).

Stanley was late to feed the animals that morning and jogged down to the primate lab, hoping his advisor hadn't made it in yet. However, as Stanley approached the door to the primate lab he knew something was wrong. It was eerily quiet, the normally raucous chatter of the animals notably absent. Stanley opened the door slowly and found the lab in disorder—the cages were empty, and the food was gone from the cupboards and refrigerators. He knew immediately they had been burgled by several monkey thieves. He quickly realized that [the activists who stole the monkeys/the monkeys who stole all the food] had escaped through the back room. He was so dumbfounded that it took him a minute to realize he should call his advisor.Marcia was starting to think that she was never going to finish her dissertation work. Even though her mentor had advised her against it, she had chosen to pursue one of the more difficult lines of research in marine biology. She was trying to identify the influence of pollution on the rate of aquatic diseases in tropical species. Her work was challenging because the particular species she had chosen to study was quickly moving toward the endangered species list, so there weren't many specimens to observe. As if she wasn't already having trouble finding enough animals to study, lately things had gotten even worse. The dolphin virus was really slowing her work down. She certainly had not expected [the virus that attacked the dolphins/to catch a virus from the dolphins] she was studying. She realized that she just might not finish her dissertation until next year.