Age Differences in Learning from Text:

Evidence for Functionally Distinct Text Processing Systems

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Abstract

We investigated the influence of sentence elaboration on self-regulated learning in order to examine age differences in resource allocation to the construction of textbase and discourse-level representations. Older and younger adults learned about a topic by reading a series of sentences varying in elaboration (from simple factoids to highly elaborated text) and manner of presentation (progressive change in elaboration vs. random change in elaboration). Younger readers were more likely to recall information from factoids; older adults, from highly elaborated text. Relative to young, older readers showed an advantage in the progressive presentation condition, which minimized frequent changes between textbase and discourse-level processing. Older adults showed poorer memory monitoring for factoids and less elaborated discourse relative to young, but when passages were highly elaborated or presented progressively, age differences were eliminated. Results support the idea that textbase and discourse-level encoding arise from functionally distinct systems whose regulation depends on text properties and reader age.

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While elaboration in text adds complexity, it also provides contextual support for the encoding of individual ideas. This fact becomes particularly important as we age: though older adults frequently show poorer memory for text relative to younger adults, elaboration often reduces or eliminates this age deficit (Johnson, 2003; Zelinski & Gilewski, 1988). The time needed to encode individual ideas is also differentially reduced by context among older readers (Stine-Morrow, Miller, Gagne, & Hertzog, 2008). This may be due to the fact that such contextual support allows for development of a discourse-level representation of the text (Radvansky, Zacks, & Hasher, 1996; Wingfield & Stine-Morrow, 2000; Graesser, Millis, & Zwaan, 1997), which can bootstrap encoding and organization of the ideas, thereby improving recall of the content (Miller, Cohen, & Wingfield, 2006; Miller & Stine-Morrow, 1998; Stine-Morrow, Gagne, Morrow, & DeWall, 2004). Indeed, successful text comprehension and memory depend on the operation of a multifaceted language processing system (e.g., Kintsch, 1998) regulated by an overarching metacognitive system, and the manner in which this system operates has important implications for age differences in learning (Stine-Morrow, Miller, & Hertzog, 2006). The current study investigated the degree to which younger and older readers' language processing and metacognitive systems are differentially affected by (a) the amount of elaboration, and (b) frequent changes in encoding demands evoked by unpredictable variation in elaboration. These factors are particularly relevant for contexts of applied learning in which real-world texts (unlike "factoids" often used in reading research) are likely to vary from moment to moment in elaborative content, requiring flexibility in the manner in which the reader allocates effort to meet text demands. In the following paragraphs, we describe components of the language processing system and highlight a model that makes predictions about the effects of elaboration and frequent changes in encoding demands.

The language processing system is often conceptualized as constructing two distinct (but coordinated) representational forms. On the one hand, readers construct meaning as interrelationships among concepts that are explicitly provided by the text, forming a network of ideas (or "propositions") that are organized to achieve coherence (the "textbase," Kintsch, 1994; 1998). Establishing textbase representations, then, involves encoding associations among core concepts, as in the case of decontextualized factoids (e.g., "The state flower of Rhode Island is the violet."). At the same time, however, readers may also construct higher-level discourse representations that incorporate information from prior text and self-generated inferences to describe the situation suggested by the discourse (e.g., a "situation model," Zwaan & Radvansky, 1998). The development of an accurate discourse-level representation, then, depends on the ability to track a much larger network of background context and circumstances (e.g., "Observation Tower, a 100-foot high wooden tower at Hannah Robinson Park, sits on a natural wooded hill, providing a panoramic view of Narragansett Bay and the rugged uneven shoreline of Rhode Island"). Thus, while factoids and elaborated sentences each rely on both textbase and discourse-level mechanisms, they draw differentially on resources from these levels; while the textbase representation depends on the encoding of specific associations, the situation model depends more on knowledge-based and perceptual processes (Radvansky & Dijkstra, 2007). Research investigating the selective allocation of resources to construct these two representations suggests that readers are generally sensitive to the inherent moment-to-moment demands of the text, with reading processes at each level operating to define the reader's "allocation policy" (i.e., the manner in which the reader's attention is engaged to construct the text representation). A successful allocation policy allows the reader to seamlessly create an integrated understanding of the information through textbase- and discourse-level computations; however, there is large interindividual and age-related variation in the extent to which resources are recruited for these computations (Stine-Morrow et al., 2006; Stine-Morrow et al., 2008).

These variations are due to functions of both the metacognitive system (e.g., to monitor the current mental representations and to recruit resources to where they are needed) and the cognitive-level implementation of the computations. The factors contributing to individual differences in the ability to self-regulate learning within these metacognitive and cognitive systems are a source of interest in the literature, with considerable research examining the conditions that moderate how items are chosen for study (e.g., Dunlosky & Thiede, 2004; Metcalfe & Kornell, 2005) and the degree to which metacognitive and regulatory capacities affect allocation policies and memory outcomes (e.g., Dunlosky & Connor, 1997; Miles & Stine-Morrow, 2004; Stine-Morrow, Shake, Miles, & Noh, 2006; Thiede & Dunlosky, 1999). Some have argued that the self-regulation of learning is in itself resource-consuming (Kanfer & Ackerman, 1996), such that it may be constrained by working memory, particularly the central executive which controls cognitive resources and monitors information processing (Baddeley, 1986; Thiede & Dunlosky, 1999; Dunlosky & Thiede, 2004). In summary, then, a reader's allocation policy is guided by limited intrinsic, individual cognitive and metacognitive resources, which direct effort in response to extrinsic demands such as text elaboration.

Given the considerable evidence for aging effects on applied learning, language comprehension, and reading (Meyer & Pollard, 2006; Thornton & Light, 2006), it has been suggested that such age differences are driven by these cognitive/linguistic and metacognitive systems. The self-regulated language processing model (SRLP; Stine-Morrow et al., 2006) is a theoretical framework describing these systems in terms of a series of feedback loops in which time is allocated to construct different facets of the text representation (word-, textbase-, and discourse-level). According to the SRLP model, resource allocations to these levels of text representation are independently regulated and are differentially vulnerable to aging (Stine-Morrow et al., 2004). For example, older adults do not always successfully allocate effort to construct the textbase representation, especially when demands are high (most notably for decontextualized sentences, informationally dense text, or stringent goals for memory accuracy; Johnson, 2003; Stine & Wingfield, 1990; Stine-Morrow, Shake, Miles, & Noh, 2006; Zabrucky & Moore, 1994), but are exceptionally attuned to discourse and situational representations (Radvansky, Zwaan, Curiel, & Copeland, 2001; Radvansky & Dijkstra, 2007).

This assumption of the SRLP model that textbase and discourse-level representations are created by distinct processors (Stine-Morrow et al., 2006) is consistent with recent neuroscience data. For example, sentence processing in adults appears to depend mostly on perisylvian regions (e.g., frontal operculum) of the left hemisphere, whereas more elaborative discourse-level text leads to a wide range of extrasylvian, bihemispheric recruitment (Xu, Kemeny, Park, Frattali, & Braun, 2005). In addition, high- and low-functioning older readers may be differentiated by their patterns of neural activation, with successful older readers developing neurological and/or cognitive compensatory mechanisms to offset age-graded declines in sentence-level processing regions in the brain (Wingfield & Grossman, 2006). This work suggests that the allocation of effort to different text representation levels is a dynamic process. For example, patterns of resource allocation often differ across multiple encounters with text (e.g., Raney, 2003; Zwaan et al., 1995), with younger readers generally give priority to textbase processes on the initial reading. Because these systems appear to be independently regulated (Stine-Morrow et al., 2006) and may rely on different neural substrates (e.g., Xu et al., 2005; Yang, Perfetti, & Schmalhofer, 2007), we wondered whether there may be some "cost" associated with engaging and disengaging these systems unpredictably.

The focus of the current investigation was on how readers of different ages manage the recruitment of resources as a function of natural variation in sentence elaboration. Syntactically coherent segments such as sentences can be thought of as "psychological moments" (James, 1890/1918) in which comprehension is monitored and allocation of effort regulated. We wondered how readers allocate resources to manage construction of the different facets of the text representation within those moments, which can show considerable variation from simple "factoids" (essentially simple associations of concepts that can be constructed within a single input cycle) to more elaborated sentences requiring integration of multiple associations across cycles that which also afford discourse-based representations. As noted earlier, this is routine in many types of applied naturalistic reading tasks, wherein content can vary dramatically in complexity from sentence-to-sentence. Of course, in such a situation, the larger discourse (i.e., the sentences that come before) certainly provides context, but we wondered about the effects of context *within* these moments, in which readers make implicit choices as to how to allocate effort. Assuming that less elaborated text requires the reader to focus more on textbase processing, while more elaborated text allows (and/or induces) more discourse-level processing, we tested the idea that such texts require different processing mechanisms that would also evoke costs evident in reading time, comprehension, and metacognition, whenever readers were frequently required to change resource allocation from textbase-level to discourse-level (or vice versa) processing.

In our experiment, participants read and reread a series of sentences about a single topic (either Connecticut or Rhode Island) with instructions to learn as much as they could about that topic. Sentences ranged from expressions of short and simple factoids to more elaborative, rich descriptions. This task, then, was fairly reflective of a real world situation in which a reader is learning about a new topic (e.g., flipping through a travelogue) and encounters varying types of sentences across multiple distinct domains (e.g., geography, history, business, etc.). We measured reading and rereading time to assess self-regulated effort to sentences at different levels of elaboration. We also examined judgments of learning (JOL; Nelson, Dunlosky, Graf, & Narens, 1994) using a paradigm wherein participants make judgments about how well they learned the text presented. This allowed for an explicit assessment of the metacognitive mechanisms, to see how they might also be affected by frequent switches between text processing mechanisms. Finally, we also examined subsequent memory for those sentences to gauge, both in a relative and absolute sense, the relationships between time allocation, perceived learning, and actual memory.

If older readers rely relatively more on discourse context to encode textbase content well, they would be expected to show poorer memory for simple factoids (i.e., text that contains simple facts with little to no instantiation within place, time, setting, etc.). On the other hand, older adults' memory should differentially benefit from more elaborated constructions that support encoding of textbase content. If the textbase and discourse-level processors are distinct and differentially resource-consuming in older vs. younger adults, frequent and unpredictable variations in the amount of elaboration across sentences would be expected to cause difficulty in switching between the two text processing systems, especially for the older adults. Text that is presented in progressive (i.e., incremental) order of elaboration (e.g., highest-to-lowest elaboration or vice versa), on the other hand, would be expected to reduce age effects in memory and metacognition because it would decrease the need to constantly switch between text processing systems, thus freeing up resources from self-regulatory executive control, reducing processing time, and improving learning and retention.

Method

Participants

Participants were 45 younger (M = 20.22 yrs., SE = .25, range 18-29) and 47 older (M = 65.78 yrs., SE = 1.05, range 55-82) adults. Older adults were recruited from the surrounding community and were paid a small honorarium for participating. Younger adults were recruited from courses at the University of Illinois at Urbana-Champaign and received course credit in exchange for participating. All individuals were native speakers of English, and were screened prior to participation for severe neurological or medical impairment (e.g., Parkinson's, inability to use both hands, macular degeneration, stroke, diagnosed neurological or learning disability) and acceptable visual acuity (i.e., 20/30 or better). The sample was 86.7% Caucasian, 5.6% African American, 4.4% Asian, 2.2% Hispanic, and 1.1% Alaska Native/American Indian.

Participants were administered the loaded reading and listening working memory span tasks (see Stine & Hindman, 1994; Daneman & Carpenter, 1980); younger adults' loaded working memory span (mean of reading and listening) was higher than that of the old (M_Y = 5.34, SE = .14; M_O = 4.55, SE = .20), $t(80) = 3.26$, $p < .01$. Older adults had more years of formal education than younger adults (M_O = 16.00, SE = .36; M_Y = 13.60, SE = .15), $t(87) = 6.19$, $p < .001$. On a five-point scale (1 = "excellent", 5 = "poor"), participants rated their overall health (M_O = 2.03, SE = .13; M_Y = 1.58, SE = .10), vision (M_O = 2.02, SE = .12; M_Y = 1.69, SE = .13), and hearing (M_o = 1.74, SE = .12; M_y = 1.40, SE = .08) as good to excellent. Younger adults self-reported better levels of health and hearing, $t(89) = 2.68$, $p < .01$; $t(89) = 2.32$, $p < .05$, and marginally better levels of vision, $t(89) = 1.86$, $p = .07$. Older and younger adults did not significantly differ on the WAIS-R (Wechsler, 1981) Vocabulary subtest ($M_O = 48.70$, $SE = 1.16$; $M_Y = 46.36$, $SE = .98$), $t(88) = 1.53$, $p = .13$. The age groups were also similar on the Forward ($M_O = 6.59$, $SE = .21$; $M_Y = 6.27$, $SE = .21$), $t(89) = 1.07$, $p = .29$, and Backward ($M_O = 5.31$, $SE = .21$; $M_Y = 4.84$, $SE = .21$), $t(88) = 1.57$, $p = .12$, Digit Span tasks.

Materials and Design

Stimulus materials consisted of 45 factual sentences about Connecticut (CT) and 45 about Rhode Island (RI), covering an array of topics about nature, historical landmarks, individuals, and tourism. While the sentences were all related to CT or RI, each sentence provided unique information that was not based upon other sentence material; thus there was little or no local coherence between sentence trials. The sentences varied in the number of propositions or "idea units" they contained (Kintsch & van Dijk, 1978). Thus, sentences varied in terms of both surface form (length in number of syllables and words), and textbase elaboration (the number of ideas).[1]

We analyzed stimuli to assess equality on three characteristics across content groups: number of syllables, number of new concepts, and complexity (represented by the number of propositions). The number of syllables ($M_{CT} = 37.91$, $SE = 2.90$; $M_{RI} = 38.27$; $SE = 2.84$), the number of propositions ($M_{CT} = 8.20$, $SE = .63$; $M_{RI} = 8.33$, $SE = .63$), and the number of new concepts ($M_{CT} = 4.51$, $SE = .30$; $M_{RI} = 5.13$, $SE = .41$) did not differ across material set, $t(88) = .09$, $p = .93$, $t(88) = .15$, $p = .88$, and $t(88) = 1.21$, $p = .23$ respectively. There were also no State x Elaboration interactions for syllables, propositions or new concepts, $F(4,80) = 1.42$, $p = .23$, $F(4,80) = 2.03$, $p = .10$, and $F(4,80) = 1.92$, $p = .12$ respectively. In general then, sentence characteristics were similar across content groups, and showed consistent increases in complexity on the basis of syllables, propositions, and new concepts.

Sentences about a state were grouped for presentation such that subjects studied all the sentences about one state before beginning the task again with sentences about the other state. The 45 sentences within each state were created in groups of five proposition loads (nine in each) in order to provide a wide range of elaboration; this included a Factoid level, which contained sentences lacking any elaboration (2-3 propositions; N=9), two “Low Elaboration” levels, which contained sentences with a moderate amount of elaboration on the topic (5-6 and 8-9 propositions; N=9 each), and two “High Elaboration” levels, which contained sentences with a high amount of elaborative content (11-12 and 14-15 propositions; N=9 each). Examples of sentences from each state (CT or RI) and Elaboration level are shown in the Appendix.

To manipulate the degree to which readers had to switch between textbase and discourse-level processing, sentences were either blocked or unblocked by Elaboration condition for presentation in a within-subject design. For each state, the blocked sentences occurred in either ascending order of elaboration (i.e., from factoids to high elaboration) or in descending order of elaboration (i.e., high elaboration to factoid). The blocked condition then was presented in ascending order of elaboration for half the subjects in each age group, and descending order for the other. In contrast, unblocked sentences appeared in random order with sentences of different elaboration intermixed. Each set of state materials was counterbalanced across blocking conditions and the order of blocking conditions was counterbalanced across subjects for presentation. This created a design with eight conditions, such that text about each state appeared equally often in each blocking condition and in each ordinal position.

Procedure

Each session lasted approximately two hours. First, background demographics were collected, including questions about any previous experience with the New England, Rhode Island, or Connecticut area. We also asked participants to rate their familiarity with the three regions on a scale from 1 (“know virtually nothing about it”) to 7 (“highly familiar with it”). In general, participants rated their familiarity with the states and the New England area to be very low (M_{CT} = 1.59, *SE* = .09; M_{RI} = 1.55, *SE* = .10; M_{NE} = 2.22, *SE* = .15), and no participants were excluded because of high familiarity with the content. Participants then completed the WAIS-R vocabulary task and the Digit Span tasks, followed by the sentence-learning task. Finally, at the end of the session, the loaded verbal working memory span tasks were administered.

Before reading the sentences, participants were given information on-screen about the nature of the task, that they would be reading two sets of sentences, one about Rhode Island and one about Connecticut. Instructions to were to “… read each sentence carefully and then to estimate (0 to 100%) how well you feel that you have learned this information…” Participants were given explicit instructions (and opportunity for practice) both with how sentences were presented and the nature of the JOL task. Sentences were presented one at a time on a Macintosh G3 computer using PowerLaboratory software (Chute & Westall, 1996) in Courier New 36-point font. The sentence-learning task was self-paced; participants continued to each subsequent screen in the task by pressing the space bar on the keyboard. Each trial began with a “READY?” signal. This was followed by a screen displaying the target sentence, followed by a screen on which participants were asked “How well did you learn this information so that you will remember it later?” They responded by using the mouse to click somewhere along a vertical line representing a continuum, with the bottom indicating “Not At All” and the top indicating

"Complete Mastery." From the subject's perspective, this judgment was on a continuous scale. For programming purposes, however, JOLs were recorded in four-point increments on a scale of 0 to 100 (i.e., 0, 4, 8, 12, … 88, 92, 96, 100). This entire process (i.e., read, then make a JOL) was repeated for nine sentences of the set of 45. After this, the same set of nine sentences was presented again for rereading and JOLs, in a different random order (but in the same blocking condition). This process was repeated until all 45 sentences for that state had been presented twice, for a total of 90 reading-JOL trials for each state.

If participants (1) reported making any keyboard or mouse errors for any of the trials, or (2) engaged in some distracting behavior (e.g., sneeze, or talking to the experimenter) during reading, those trials were recorded by the experimenter and subsequently eliminated before data analysis (resulting in elimination of 0.7% of the total data points). In addition, a small number of trials were lost due to programming error (resulting in elimination of 1.4% of the total data points).

After completing all sets of sentences about a state, participants were given a brief distracter task (2 minutes in length) in which they were presented a set of letter-number sequences to be rearranged into proper alphanumeric order. Participants were then asked to tell the experimenter everything they had learned about that state. Recall was recorded and later transcribed. After free recall for the first state, participants repeated the process with the next group of 45 sentences for the other state. At the completion of the second set, participants were presented key words from a subset (N = 20) of the sentences, and were asked to recall everything they could from that sentence, as well as what state the sentence was about (i.e., RI or CT; source memory). This cued recall was also recorded and later transcribed.

Results and Discussion

Residual Reading Times

To assess resource allocation to sentences of varying elaboration, raw reading times are uninformative since the amount of elaborative content is obviously confounded with sentence length. To control for this, we regressed the sentence reading times of each individual onto the number of syllables, to calculate unstandardized residuals. This residual reading time (RRT) measures the over- or under-allocation of attention relative to what would be expected from the demands of orthographic decoding alone. All RRTs are reported in milliseconds (ms). Analysis of variance (ANOVA) on the y-intercepts and slopes showed that slope (i.e., RT per syllable) was higher for the first reading than for rereading (cf. Stine-Morrow et al., 2004), $F(1,90) = 241.00$, $p < .001$, $\eta^2 = .73$. However, there was not a main effect of age nor any age interactions. The average regressions equation predicting raw reading time (y) from number of syllables (x) was similar for older adults (T_1: $y=229x+3354$; T_2: $y=86x+4184$) and younger adults (T_1: $y=218x+3377$; T_2: $y=98x+3412$), showing similar slopes and y-intercepts (all $p > .05$).

To investigate our main question, we examined RRTs within a 2 (Age) x 2 (Trial: Reading vs. Rereading) x 2 (Blocking: Unblocked vs. Blocked) x 3 (Elaboration: Factoid vs. Low Elaboration vs. High Elaboration) repeated measures ANOVA, with Age as a between-subjects variable and the others within-subjects. Means and standard errors are shown in Table 1. A main effect of Elaboration, $F(2,90) = 52.92$, $p < .001$, $\eta^2 = .37$, indicated that (even controlling for length) participants tended to process factoids more quickly relative to the more discourse-like sentences. However, within the two elaborated text conditions, participants allocated more time for the sentences containing less elaboration (all pairwise comparisons $p < .05$). An Elaboration x Trial interaction, $F(2,90) = 28.82$, $p < .001$, $\eta^2 = .24$, showed that the effect of elaboration on the first reading (M_{FCT} = -1033, *SE* = 87; M_{LO} = 470, *SE* = 67; M_{HI} = 20, *SE* = 48) was more pronounced relative to rereading (M_{FCT} = -191, *SE* = 104; M_{LO} = 76, *SE* = 80; M_{HI} = 151, *SE* = 32).

Consistent with our hypothesis about the effect of frequent and unpredictable changes between textbase and discourse-level processors, the main effect of Blocking showed that participants allocated more time when reading required frequent switching between text processing systems (i.e., unblocked; *M* = 543, *SE* = 162) relative to when sentences were blocked by level of elaboration (*M* = -713, *SE* = 149), $F(1,90) = 16.31$, $p < .001$, $\eta^2 = .15$. This effect interacted with Trial, $F(1,90) = 37.61$, $p < .001$, $\eta^2 = .30$, such that the blocking effect was significant at rereading, but not reliable for the first reading, $t(92) = .62$, $p = .54$. However, these interactions were subsumed by a reliable three-way Blocking x Trial x Elaboration interaction, $F(2,90) = 5.80$, $p < .01$, $\eta^2 = .06$ (see Figure 1). Figure 1 shows that during the initial encounter with the text, there was no influence of blocking on encoding time (all pairwise comparisons $p > .05$). During rereading, however, the unblocked condition consistently led to greater allocation of effort than the blocked condition did, though elaboration moderated this effect: in the unblocked presentation, elaboration had no effect on time allocation (all pairwise comparisons, $p > .05$), but when materials were blocked, there were successive increases in allocation as elaboration increased (all pairwise comparisons, $p < .05$).

These data are consistent with our hypothesis that interspersing encounters with factoids and elaborated texts produced a switch cost in strategic resource allocation, with the effect localized to rereading. This is not altogether surprising when you consider the reader's tendency to give priority to textbase processing on the initial encounter with the text (Millis et al., 1998), since at least some rudimentary textbase representation is necessary to scaffold situational understanding (cf. Radvansky et al., 2001). Consequently, on the initial encounter there may have been very little switching among text processors (though we note that at the highest level of elaboration, which may afford textbase neglect to some extent, there was a trend toward the predicted blocking effect). During rereading, however, readers processed the factoids according to the associationist principles of the textbase processor, but the elaborated sentences according to the schematic/situation-level principles of the discourse processor. The demand to engage and disengage these processors on the fly in the unblocked condition engendered a clear processing cost. Processing efficiency during rereading was not only much better in the blocked condition, but also more reflective of the inherent demands of text complexity, presumably because this switching between processors was not needed.

No main effect of Age was evident, nor did Age interact with Elaboration, Trial, or Blocking. Rather, young and old allocated reading time similarly in all three elaboration levels (all $p > .19$), suggesting age-equivalence in sensitivity to text demands from factoids and elaborated sentences. Overall, the reading times suggested that both older and younger readers benefit from predictability of text elaboration during encoding, particularly during rereading.

Recall Performance

Memory performance was measured in two ways: free recall and cued recall. The free recall task was scored using a 1/0 system, such that if a participant recalled any information from a sentence, 1 point was scored, while a 0 indicated no information recalled for that sentence.[2] This system allowed us to assess the proportion of sentences from which any information at all was remembered. Cued recall was also scored on the 1/0 system, as well as for whether the participant could accurately identify the state the keyword was from (i.e., CT or RI). Thus, cued recall could be analyzed not just for presence of recall for a sentence, but also for participants' source memory (Johnson, 1993). To ensure consistency in scoring, two raters who were blind to participant age scored a subset of both the cued and free recall protocols (N=9 and N=18, respectively). Interrater scoring of the recall was reliably similar, with correlations of .98 and .94 for cued and free recall.

Free Recall. To investigate our hypothesis that elaboration and switching between text processors would differentially impact age-related deficits in text memory, we conducted a 2 (Age) x 2 (Blocking) x 3 (Elaboration) repeated measures ANOVA was used to analyze the proportion of sentences recalled, with Age as a between-subjects variable. The main effect of Elaboration was significant, $F(2,89) = 41.58$, $p < .001$, $\eta^2 = .32$, such that memory for factoids > high elaborated sentences > low elaborated sentences ($M_{FCT} = .41$, $SE = .02$; $M_{LO} = .27$, $SE = .01$; $M_{HI} = .33$, $SE = .02$), all pairwise comparisons $p < .05$. Interestingly, factoids were both encoded the most quickly and more likely to be retained. While the main effects of Age and Blocking did not reach significance, $F(1,89) = 2.37$, $p = .13$, and $F(1,89) = .10$, $p = .75$, respectively, these variables did show a series of two-way interactions.

Figure 2 shows recall as a function of age and blocking condition (collapsed across elaboration). Consistent with our hypothesis, older adults derived differential benefit from sequential organization that minimized changes in allocation policy; the Blocking x Age interaction was significant, $F(1,89) = 4.39$, $p < .05$, $\eta^2 = .05$. This interaction showed that older adults' recall was enhanced when text was blocked, $t(45) = 2.33$, $p < .05$, while the younger adults' recall was not, $t(44) = 1.51$, $p = .14$.

Table 2 presents the mean proportion of sentences recalled by each age group as a function of elaboration condition collapsed across blocking. The Elaboration x Age interaction was reliable, $F(2,89) = 21.17$, $p < .001$, $\eta^2 = .19$, so that recall among younger and older readers was differentially affected by variation in elaboration. Younger adults were especially likely to recall information presented in factoids relative to more elaborated sentences. While they recalled almost half of the factoids, they recalled less than a third of the sentences containing elaboration. Older adults, on the other hand, showed nonlinear effects of elaboration, recalling more information from factoids (though with a much lower likelihood relative to the young) and highly elaborated passages. In the fact, in absolute terms, older adults showed better recall of the highly elaborated sentences than the young, $t(90) = 1.98$, $p = .05$. None of the remaining interactions reached significance.

Collectively then, despite age-equivalence in allocation of effort, factors affecting the relative engagement of the textbase and discourse processing systems had strong influences on age differences in text memory. First, high sentence elaboration was particularly beneficial to older adults in terms of text memory. We argue this is due to the relative preservation of the discourse processor with aging and hence a tendency to engage this system when possible (Radvanksy & Dijkstra, 2007; Stine-Morrow et al., 2006; Stine-Morrow et al., 2004). The differentially poor memory among older adults for factoids is likely due to the fact that there was inadequate context to enable engagement of the discourse-level processor, so that older adults were forced to rely on the association-driven textbase processor, creating demands which they are less able to meet (see, for example, Naveh-Benjamin, Brav, & Levy, 2007; Stine-Morrow et al., 2006). Second, text memory was more disrupted with age when frequent changes in allocation policy were required in the unblocked condition. We argue that this is in essence a switch-cost effect in which reduced attentional resources made it more difficult for older readers to engage and disengage these distinct language processors on the fly (Stine-Morrow et al., 2006).

Cued Recall. We also examined cued recall in a 2 (Age) x 2 (Elaboration) repeated measures ANOVA, excluding Blocking as a variable because of the small number of cues used (N=20). The main effect of Elaboration was significant, $F(2,88) = 16.98$, $p < .001$, $\eta^2 = .16$, showing that for cued recall, Factoids = High Elaboration > Low Elaboration ($M_{FCT} = .69$, $SE = .02$; $M_{LO} = .58$, $SE = .02$; $M_{HI} = .70$, $SE = .02$). The main effect of Age was also reliable, $F(1,88) = 9.08$, $p < .01$, $\eta^2 = .09$, showing that overall, younger adults had greater cued recall than old ($M_Y = .70$, $SE = .02$; $M_O = .61$, $SE = .02$). The Elaboration x Age interaction, $F(2,88) = 4.81$, $p < .01$, $\eta^2 = .05$, showed that younger adults (as with free recall) showed especially good memory for factoids ($M_{FCT} = .77$, $SE = .03$; $M_{LO} = .60$, $SE = .03$; $M_{HI} = .73$, $SE = .03$) as compared to the old ($M_{FCT} = .60$, $SE = .03$; $M_{LO} = .56$, $SE = .03$; $M_{HI} = .67$, $SE = .03$), $t(88) = 4.38$, $p < .001$, but older adults did not differ from the young in cued recall for the Low Elaboration, $t(88) < 1$, and High Elaboration, $t(88) = 1.73$, $p = .09$, conditions.

Source memory, i.e., whether participants could correctly identify the state associated with each cue (RI or CT), was assessed in a 2 (Age) x 2 (Elaboration) ANOVA. Findings were similar findings to those of free and cued recall. There were main effects of Elaboration, $F(2,88) = 8.95$, $p < .001$, $\eta^2 = .09$, and Age, $F(1,88) = 7.36$, $p < .01$, $\eta^2 = .08$, as well as an Elaboration x Age interaction, $F(2,88) = 5.85$, $p < .01$, $\eta^2 = .06$, which showed that younger adults were more accurate than older adults in remembering the source of the cue for factoids ($M_Y = .75$, $SE = .03$; $M_O = .58$; $SE = .03$), $t(88) = 3.69$, $p < .001$, and low elaboration text ($M_Y = .65$, $SE = .03$; $M_O = .56$, $SE = .03$), $t(88) = 2.17$, $p < .05$. However, older adults' source memory was equivalent to the young for the highly elaborative sentences ($M_Y = .71$, $SE = .03$; $M_O = .70$, $SE = .03$), $t(88) < 1$.

Synopsis of Memory Performance. Collectively then, both elaboration and blocking exerted reliable influences on age differences in memory performance. Older adults' recall appears to have benefited from the highly elaborated sentences in all measures of memory, again suggesting relative preservation of the discourse processor and a benefit from greater contextual cues. At the same time, older adults also differentially benefited from a presentation that was highly predictable (i.e., blocked) in terms of the relative engagement of the textbase and discourse processors, suggesting that switching between these two systems evoked some cost for text memory.

The Role of Metacognition

Given the literature suggesting metacognition may play a role in study time allocation when reading (Hertzog & Dunlosky, 2004) and recent conflicting work about the interaction of aging and memory monitoring (e.g., Dunlosky, Baker, Rawson, & Hertzog, 2006; Lin, Zabrucky, & Moore, 2002; Miles & Stine-Morrow, 2004), we examined whether JOLs were related to older and younger adults' time allocation and memory outcomes, and whether these effects were moderated by elaboration, blocking, or both.

Selective allocation of effort to unlearned items. We computed Goodman-Kruskal gamma correlations between the JOL after the initial reading and the RRT for rereading. This allowed us to assess whether either of the age groups demonstrated use of a discrepancy reduction heuristic in their study efforts (i.e., greater allocation of effort during rereading to items which were perceived to be poorly learned on the initial reading; see Dunlosky & Connor, 1997; Miles & Stine-Morrow, 2004). A 2 (Age) x 2 (Blocking) x 3 (Elaboration) repeated measures ANOVA revealed a marginal effect of Age, $F(1,84) = 3.72$, $p = .06$, reflecting the fact that younger adults employed discrepancy reduction to a somewhat greater extent ($M_O = -.04$, $SE = .02$; $M_Y = -.09$, $SE = .02$)[3]; however, there were no reliable main effects or interactions with the text manipulations.

Relative accuracy of memory monitoring. Gamma correlations were computed between JOLs at rereading and free recall (these correlations represent, relatively speaking, the degree to which perceived learning matched actual recall). JOLs tended to be positively correlated with actual recall, suggesting good memory monitoring. This was true for both younger and older participants, as demonstrated by mean gamma correlations ($M_Y = .43$, $SE = .03$; $M_O = .31$, $SE = .04$) significantly greater than zero ($p < .001$, for both).

We examined the correlations in a 2 (Age) x 2 (Blocking) x 3 (Elaboration) repeated measures ANOVA. A significant main effect of Age, $F(1,65) = 5.64$, $p < .05$, $\eta^2 = .08$, showed that younger adults were more accurately monitoring the contents of their memory than the old. A significant main effect of Blocking, $F(1,66) = 9.32$, $p < .01$, $\eta^2 = .12$, indicated that participants' memory monitoring was better when text was blocked for presentation ($M_{BL} = .43$, $SE = .03$; $M_{UB} = .32$, $SE = .03$). These main effects were subsumed by a reliable Blocking x Age interaction (see Figure 3), $F(1,66) = 7.45$, $p < .01$, $\eta^2 = .10$, analogous to that found for recall, which showed that when text was unblocked for presentation, older adults' ability to monitor their learning was poorer than that of the young, but when text was blocked in a sequential elaboration order, there was age-equivalence in monitoring. Finally, there was a main effect of elaboration, $F(2,132) = 4.27$, $p < .05$, $\eta^2 = .06$, which showed that the relative accuracy of monitoring was better for factoids than for elaborated sentences ($M_{FCT} = .45$, $SE = .04$; $M_{LO} = .33$, $SE = .04$; $M_{HI} = .34$, $SE = .03$; both pairwise comparisons $p < .05$), however, elaboration did not interact with either age or blocking.

The Role of Working Memory

Findings thus far suggest that both age groups allocated more effort during rereading when text was arranged so as to evoke the need to switch unpredictably between textbase and discourse systems (cf. right panel of Figure 1), but this age-equivalence in response to the blocking manipulation did not lead to equality in text memory or memory monitoring. It is possible that the effects of Blocking and Elaboration on age differences in text memory (despite similar allocation of effort) may be due to age differences in working memory. We examined this possibility by examining how individual differences in working memory (as measured by loaded verbal working memory span) related to recall performance under different encoding conditions.

Collapsed across age, WM was reliably correlated with free recall in nearly all cases (all $p < .05$, except for High Elaboration/Blocked Presentation, where $p = .09$). Furthermore, Fisher's *R*-to-*Z* transformations showed that under a Blocked presentation, WM-Recall correlations became weaker as contextual support (i.e., elaboration) increased ($R_{FCT} = .50$, $R_{LO} = .27$, $R_{HI} = .19$), $z(78) = 1.70$, and $z(78) = 2.23$, $p < .05$ for the factoid-low and factoid-high comparisons, respectively (correlations did not reliably differ in the low and high elaboration conditions, $p > .05$). In the Unblocked condition, correlations were all reliably greater than zero (all $p < .05$), but there were no differences as a function of level of elaboration ($M_{FCT} = .34$, $M_{LO} = .24$, $M_{HI} = .36$; all pairwise comparisons, $p > .05$).

This relationship between WM and text recall was primarily localized to the older group: while younger adults showed no significant correlations (ranging from .07 to .25; all correlations, $p > .05$), older adults showed strong and reliable correlations between WM and free recall for all levels of elaboration and blocking (ranging from .37 to .67; all correlations, $p < .05$). Furthermore, for sentences under the Blocked presentation, correlations became weaker as contextual support (i.e., elaboration) increased ($R_{FCT} = .66$, $R_{LO} = .49$, $R_{HI} = .38$), though a Fisher's R-to-*Z* transformation showed only the difference between factoids and high elaboration reached significance, $z(35) = 1.64$, $p = .05$. This finding is consistent with previous work suggesting that context reduces the attentional resources needed to process text (Miller et al., 2006; Stine & Wingfield, 1990). For sentences in the Unblocked condition, correlations were smaller overall ($R_{FCT} = .49$, $R_{LO} = .37$, $R_{HI} = .38$) and were not significantly different from each other, all pairwise comparisons, $p > .05$. The fact that correlations in the Unblocked condition were somewhat lower and invariant across elaborative context supports the idea that the random elaboration presentation order strained the older adult's self-regulatory language processing system to its limits.

Conclusions

This study was motivated by the question of whether there are age differences in readers' engagement of distinct text processing systems to encode and remember text in an applied learning task. We examined readers' allocation of effort toward text demands both as a function of the amount of elaborative content as well as the predictability with which they had to switch between textbase- and discourse-level processing mechanisms.

Younger adults had good memory for simple factoids. Older adults, on the other hand, performed quite well when text contained highly elaborated content, but showed difficulty (compared to the young) in remembering unelaborated factoids, supporting the idea that the textbase processor is associationist in nature and that its effectiveness declines in efficiency with advancing age (see Naveh-Benjamin et al., 2007; Stine-Morrow et al., 2006).

Older adults' text memory was particularly hampered by random variation in text elaboration between sentences. The switch-cost evoked by frequent changes between textbase and discourse-level processing in the current study explicates the nature of older adults' reading processes in understanding naturalistic text. Considering that skilled reading requires one to smoothly adjust encoding strategy on the basis of dynamically changing text demands, these results have important implications for explanations of frequently documented age deficits in text memory. For example, the majority of research on aging and text memory has used text that is uniform in complexity across sets of learning trials (as was the case in our Blocked condition). Real-world learning, however, is rarely so sequential or incremental; rather, it often changes dynamically from sentence to sentence in the degree to which it demands attention from textbase and situation model processing.

Finally, our findings are also informative with respect to metacognition and the factors that affect age differences in metacognition. Interestingly, while good memory monitoring of learned sentences has been previously demonstrated (Miles & Stine-Morrow, 2004; Stine-Morrow, Shake et al., 2006), gamma correlations are typically weaker than those observed in the literature using paired associate (i.e., non-sentence) learning (e.g., Dunlosky & Connor, 1997). In the current study, we found reliable differences in monitoring accuracy between simple factoids (which are more akin to paired-associates) and elaborated sentences. Thus, it may be that it is relatively difficult to monitor memory accuracy when materials are more semantically complex, in part because it becomes more difficult to assess what it means to have "learned the information" relative to a reference value that will undoubtedly vary with a reader's conception of what constitutes learning (Stine-Morrow et al., 2006). In short, it may be easier to monitor memory accuracy for simple associations than for more complex text (see also Dunlosky et al., 2006). This may contribute to the typically modest gamma correlations in the sentence-memory studies. In addition, older adults' monitoring accuracy was disproportionately impacted in the unblocked condition, which required frequent and unpredictable switching between text processors. This finding is also interesting in light of the inconsistency in the literature with respect to whether there are age differences in monitoring accuracy (e.g., Dunlosky et al., 2006;

Miles & Stine-Morrow, 2004; Stine-Morrow et al., 2006; Hertzog & Dunlosky, 2004). Our findings suggest that age deficits in memory monitoring may be most evident in reading scenarios where working memory limits are taxed (see also Dunlosky & Thiede, 2004), as in the case when text elaboration varies widely from sentence to sentence, forcing constant readjustment of the allocation policy. Age constancy in monitoring has been typically noted in paired-associate learning (e.g., Dunlosky & Connor, 1997; Hertzog & Dunlosky, 2004), but in those cases the allocation policy can presumably be entrained over trials; the interaction between age and blocking in the current study may suggest one class of moderators for age differences in monitoring accuracy. Also in the arena of age differences, our findings replicated work from paired associate learning which shows age deficits in use of a discrepancy reduction heuristic (Dunlosky & Connor, 1997). To the extent that older learners were less likely to target unlearned items on the rereading trial for more intense study, that may have contributed to age deficits in memory.

In summary, our findings provide support for the distinction between different text representation processing systems, and that older adults derive benefit not only from greater elaborative content, but also a relatively homogeneous and incremental amount of elaboration that minimizes frequent switches between distinct levels of text processing. These benefits are apparent in performance even in the case where both older and younger adults' allocate effort similarly. These findings provide some support for the notion that textbase and discourse-level representations are dissociable processors (Xu et al., 2005; Stine-Morrow, Miller et al., 2006; Wingfield & Grossman, 2006) and suggest that differential engagement of these processors with age may be important in understanding age differences in text comprehension. Our results offer implications for methods of designing real-world text in ways that can potentially reduce age deficits in text processing and comprehension.

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Appendix

Sample Sentence Stimuli Materials

Elaboration Level	*Sample Sentence*
<u>Connecticut</u>	
No elaboration/Factoid	The cotton gin was invented in Connecticut.
Low Elaboration	The Mountain Laurel is a popular flower because it swathes the hills in pink and white, mostly in the spring.
High Elaboration	The low, eroded hills of western Connecticut begin in the far north as rugged bedrock with dramatic, glacier-cut ravines where streams rush through the clefts.
<u>Rhode Island</u>	
No elaboration/Factoid	The Hasbro Toy Company was founded in Rhode Island.
Low Elaboration	Although there are older carousels in America, none are as stunning as the Crescent Park Carousel in East Providence, which features 62 hand-carved figures.
High Elaboration	In Bristol, Rhode Island, the state’s largest aquarium, which is sponsored in part by the Audubon Society, features a life-size model of a right whale, a tide pool tank with a rare blue lobster, and nature trails.

Author Notes

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Footnotes

[1] Note that this design necessitated a confound between surface length and semantic information, as is typical in everyday learning form text. While it is possible to control length and manipulate informational density within a small range (e.g., Kintsch & Keenan, 1973; Stine, Wingfield & Poon, 1986; Stine-Morrow, Shake, Miles, & Noh, 2006), our goal was to vary elaboration in a more extreme way than would be possible by controlling the surface form. Consequently, we controlled for syllable length in our analyses of reading time and measured recall in terms of the probability of remembering any ideas from that trial.

[2] An alternative would have been to measure propositional recall. However, we were more interested in how the level of elaboration enabled readers to retrieve any information at all from each "psychological moment" of the text. In fact, propositional scoring was relatively uninformative in this case. A preliminary analysis on a subset of the subjects suggested that (a) propositional recall was difficult to score reliably because participants combined content across different sentences, and that (b) to the extent we could score this, participant elaboration of recall, as one might expect, did not keep pace with stimulus elaboration, with subjects recalling at most three or four propositions from sentences regardless of the level of elaboration.

[3] The discrepancy reduction gammas in this data set are smaller than in some previously published research (though, we note, still reliably different than zero, all $p < .05$ for both age groups); however, this may be due to the nature of the JOL used in the current study, in which the scale is based on 4-point increments. Most previous studies used 10 or 20-point increments on a scale of 100, and frequently result in "constant" (i.e., no variation) JOLs, which cannot be used to compute a gamma and thus are not used in subsequent analyses. In contrast, the current

study showed more diverse JOLs and was, from the participant’s perspective, non-numeric and continuous in nature.

Table 1.

Means (M) and standard errors (SE) of residual reading times (RRT) for Reading and Rereading as a function of Age, Elaboration, and Blocking presentation.

		Overall		Younger		Older	
		Reading	Rereading	Reading	Rereading	Reading	Rereading
Elaboration:	Blocking:						
Factoid	Unblocked						
	M	-994	1161	-1060	1335	-931	995
	SE	146	294	173	447	235	387
	Blocked						
	M	-1068	-1542	-1191	-1831	-951	-1265
	SE	135	146	189	192	194	213
Low Elaboration	Unblocked						
	M	462	1321	645	1159	287	1475
	SE	179	205	239	267	266	311
	Blocked						
	M	475	-1168	419	-1047	528	-1285
	SE	168	208	219	349	256	237
High Elaboration	Unblocked						
	M	304	1009	238	783	367	1226
	SE	325	236	415	392	500	271
	Blocked						
	M	-265	-707	-178	-471	-348	-933
	SE	302	243	434	417	424	259

Note. The residual reading times in the table do not sum to zero because the low and high elaboration conditions were created by averaging two levels of elaboration within each (see methods section).

Table 2.

Means (M) and standard errors (SE) of proportion of sentences recalled by Age group as a function of Elaboration.

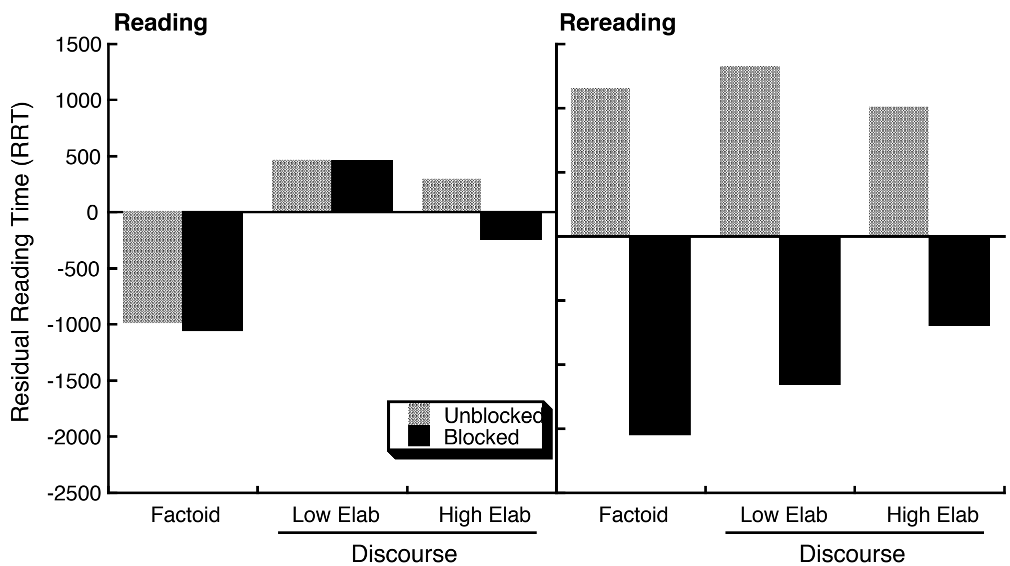
	Younger	Older
Elaboration:		
Factoid		
M	0.47	0.34
SE	0.02	0.02
Low Elaboration		
M	0.30	0.25
SE	0.02	0.02
High Elaboration		
M	0.30	0.36
SE	0.02	0.02

Figure Captions

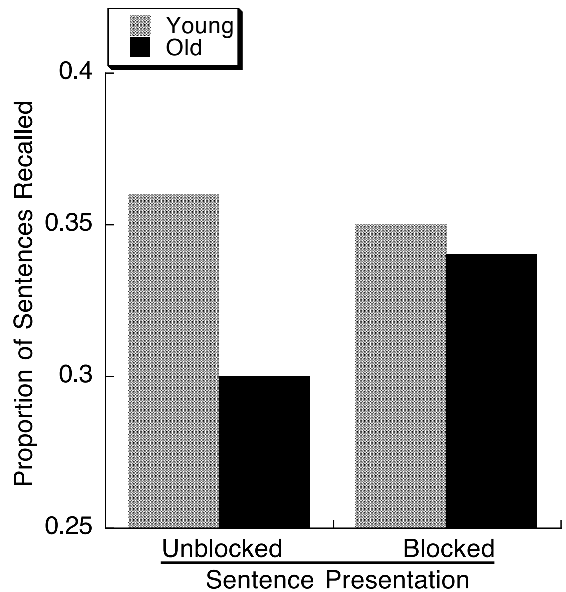
Figure 1. Residual reading times (RRT) for Reading (left) and Rereading (right) in milliseconds (msec), as a function of elaboration and blocking presentation.

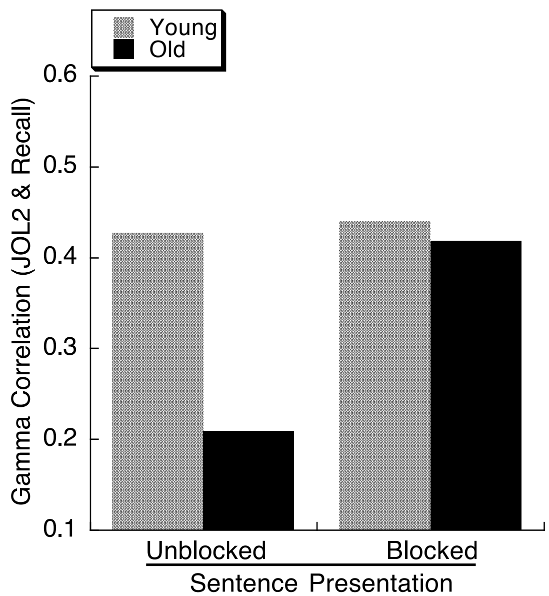
Figure 2. Mean proportion of sentences recalled for younger and older adults as a function of blocking presentation.

Figure 3. Mean gamma correlation between the Rereading JOL and subsequent Recall, for younger and older adults as a function of blocking presentation.



Reading
Rereading
Residual Reading Time (RRT)
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
Unblocked
Blocked
Factoid
Low Elab
High Elab
Discourse
Factoid
Low Elab
High Elab
Discourse


Young
Old
0.4
0.35
0.3
0.25
Proportion of Sentences Recalled
Unblocked
Blocked
Sentence Presentation


Young
Old
0.6
0.5
0.4
0.3
0.2
0.1
Gamma Correlation (JOL2 & Recall)
Unblocked
Blocked
Sentence Presentation