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Pay Now or Pay Later: Aging and the Role of Boundary Salience in Self-Regulation of Conceptual Integration in Sentence Processing

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Previous research has suggested that older readers may self-regulate input during reading differently from the way younger readers do, so as to accommodate age-graded change in processing capacity. For example, older adults may pause more frequently for conceptual integration. Presumably, such an allocation policy would enable older readers to manage the cognitive demands of constructing a semantic representation of the text by off-loading the products of intermediate computations to long-term memory, thus decreasing memory demands as conceptual load increases. This was explicitly tested in 2 experiments measuring word-by-word reading time for sentences in which boundary salience was manipulated but in which semantic content was controlled. With both a computer-based moving-window paradigm that permits only forward eye movements, and an eye-tracking paradigm that allows measurement of regressive eye movements, we found evidence for the proposed tradeoff between early and late wrap-up. Across the 2 experiments, age groups were more similar than different in regulating processing time. However, older adults showed evidence of exaggerated early wrap-up in both experiments. These data are consistent with the notion that readers opportunistically regulate effort and that older readers can use this to good advantage to maintain comprehension.

Keywords: reading, resource allocation, comprehension, sentence processing, eye-tracking

Language processing undergoes a variety of changes with advancing age, with some aspects showing considerable decline and others showing relative preservation (Burke & Shafto, 2008; Thornton & Light, 2006; Wingfield & Stine-Morrow, 2000). Although age deficits in text memory are well documented, there are some conditions that mitigate this effect (Johnson, 2003). Some research indicates that strategies used by older adults can account for age differences in text memory, such that differential patterns of effort allocation (i.e., an "allocation policy") can allow older adults to adapt to cognitive changes (Stine-Morrow, Miller, Gagne, & Hertzog, 2008; Stine-Morrow, Miller, & Hertzog, 2006).

One well-documented aspect of a reader's allocation policy is an increase in reading time at the ends of syntactic boundaries (Rayner, Kambe, & Duffy, 2000; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989). The durations of these micro-pauses are sensitive to factors such as informational complexity, ambiguity, implicit intonation, and existing knowledge (Daneman & Carpenter, 1983; Haberlandt & Graesser, 1989a; Haberlandt, Graesser, Schneider, & Kiely, 1986; Hirotani, Frazier, & Rayner, 2006; Miller & Stine-Morrow, 1998; Sharkey & Sharkey, 1987; Wiley & Rayner, 2000), suggesting that this time reflects processing effort to create an integrated representation of a text's meaning. Hence, the term *wrap-up* (Just & Carpenter, 1980) that has been used to characterize this phenomenon is apt. Individual differences in wrap-up have also been shown to be related to subsequent performance (Haberlandt et al., 1986; Stine-Morrow, Milinder, Pullara, & Herman, 2001), so that it appears to have functional significance.

These peaks in reading time are closely related to the concept of the *input cycle* in discourse processing theory (e.g., Kintsch, 1988)—a notion that ultimately derives from William James's (1890) conception of consciousness. James compared the flow of consciousness with the life of a bird, consisting of "an alternation of flights and perchings" (p. 243). During the flight, "the rush of thought is . . . headlong" (p. 244); during the perching, which he also referred to as the *substantive part*, we reflect on the experiences of the flight (or the *transitive part*). James noted that "the rhythm of language" reflects this fundamental nature of human consciousness:

> Every thought is expressed in a sentence, and every sentence closed by a period. The resting-places are usually occupied by sensorial imaginations of some sort, whose peculiarity is that they can be held before the mind for an indefinite time, and contemplated without changing; the places of flight are filled with thoughts of relations, static or dynamic, that for the most part obtain between the matters contemplated in the periods of comparative rest. (p. 243)

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Much like grasping any experience, then, text comprehension depends on segmenting the input into coherent pieces that can be reflected upon and integrated. Features of word meanings are accessed promiscuously on the fly, and meaning is constructed incrementally (Pickering & van Gompel, 2006); at the end of the input cycle, the surface form decays as the representation of meaning is consolidated (Jarvella, 1971). Our focus in the current research study was an investigation into the nature of age differences in this rhythm of "flights and perchings."

Research on age differences in wrap-up has sometimes shown that older adults allocate less time to wrap-up at the ends of syntactic boundaries, which is related to poorer comprehension and memory (Stine, 1990). However, in cases in which older adults have engaged in wrap-up more often or for longer durations, age-equivalence in subsequent memory has been found (e.g., Stine, 1990; Stine-Morrow et al., 2001). Older adults are also sometimes found to wrap up more frequently (Miller & Stine-Morrow, 1998; Stine, 1990), a pattern that may be compensatory in allowing text to be processed in smaller chunks within a smaller working memory. However, this interpretation is predicated on the assumption that more frequent wrap-up can conserve effort in the long run by reducing the effort needed to construct the semantic representation.

Early research on wrap-up suggested that input cycles are defined by syntactic boundaries and that the duration depends on the semantic complexity of the text (Aaronson & Scarborough, 1976; Haberlandt & Graesser, 1989a, 1989b; Haberlandt et al., 1986; Just & Carpenter, 1980). One implication of this research is that wrap-up may be highly stimulus driven; that is, it may be an automatic process that is strictly governed by the computational demands of the language itself. Age differences in wrap-up, however, suggest that to some extent, wrap-up may be opportunistically self-regulated to accommodate individual differences in processing capacity. In the current research, we explicitly tested that assumption. In other words, do readers' "perchings" reflect automatic processes that are strictly driven by the demands to create a semantic representation, or is there some choice in the locations and durations of these perchings that are more pragmatic? Millis and Just (1994) compared reading times for two independent sentences with those when the sentences were combined into one with a connective. They found that wrap-up for the first independent clause was exaggerated when it was a sentence relative to when it was conjoined to a subsequent sentence with a connective (see also Rayner et al., 1989).

We examined this issue by measuring wrap-up for texts in which the conceptual load was constant across all conditions, but the salience of syntactic boundaries was manipulated, as in the example in Table 1. All versions of each passage were lexically identical through the first target word (T1; e.g., *candy*), which varied across condition in terms of its prominence as a syntactic boundary. In the unmarked (UnM) boundary condition, T1 was not marked with punctuation, and it was followed by a prepositional phrase, a prepositional phrase with gerund, an adverbial phrase, a purpose infinitive, a relative infinitive, a reduced relative clause, or a restrictive relative clause. In the weakly marked (WkM) boundary condition, a comma marked the T1 boundary, and the passage continued with a coordinating conjunction and another independent clause. In the strongly marked (StrM) boundary condition, a period marked the end of the sentence at T1, and another sentence completed the passage. The continuation after T1 always ended with the same target word (T2; e.g., *closet*). If readers are opportunistic in segmenting text, they would be expected to show greater wrap-up at T1 with stronger marking of the boundary. To the extent that this resulted in a consolidated semantic representation that could then be more easily accessed at the subsequent boundary, the stronger marking at T1 would be expected to result in reduced processing time at T2. If this were true, it would provide evidence for conceptual integration as a self-regulated process and explain why older readers are often found to wrap-up more frequently.

Table 1
Sample Passages

Condition	Passage
Unmarked boundary	After doing her chores, Susan wanted the *candy* her mom had kept hidden in the hall *closet*. Susan looked all over the house for it.
Weakly marked boundary	After doing her chores, Susan wanted the *candy*, but her mom kept it hidden in the *closet*. Susan looked all over the house for it.
Strongly marked boundary	After doing her chores, Susan wanted the *candy*. Her mom had hidden it all in the *closet*. Susan looked all over the house for it.

Experiment 1: Moving Window Method

Our first experiment relied on the moving window method of self-paced reading, in which readers press a computer key to reveal each word of the text. This approach provides a relatively straightforward measure of processing time, is sensitive to processing difficulty in a wide array of circumstances, and often shows effects similar to those found in more naturalistic eye-movement data (Just, Carpenter, & Wooley, 1982). Because readers in the prototypical moving window method paradigm cannot reread, processing difficulty is measured as the processing time on the first word on which the reader is aware of the problem; however, the reader cannot reread the prior text, so that it is possible that comprehension difficulties may not be fully resolved. This method has been used to reveal age differences in reading (e.g., Miller & Stine-Morrow, 1998; Stine-Morrow et al., 2001, 2008).

Method

Participants. Twelve older adults (M_O = 65.7 years, SD = 3.9) and 12 younger adults (M_Y = 22.9 years, SD = 5.6) were recruited from the community to participate in this experiment. Prior to participation, all individuals were screened to ensure they were native speakers of English and did not have any severe neurological or medical impairment (e.g., macular degeneration, stroke, or inability to use both hands). Older and younger participants did not differ in educational level (M_O = 15.2 years, SD = 3.2; M_Y = 15.6 years, SD = 1.5), $t(22) = 0.33$; forward digit span (M_O = 6.8, SD = 0.9; M_Y = 7.5, SD = 1.2), $t(22) = 1.72$; or backward digit span (M_O = 4.8, SD = 1.2; M_Y = 5.2, SD = 1.8), $t(22) = 0.68$. Older participants had higher vocabulary scores than the younger participants on the Wechsler Adult Intelligence Scale–Revised (Wechsler, 1981; M_O = 51.2, SD = 7.1; M_Y = 32.2, SD = 4.4), $t(22) = 7.94$, $p < .01$. Younger participants had higher working memory spans as assessed by mean reading and listening span tasks (Stine & Hindman, 1994), (M_O = 4.1, SD = 0.9; M_Y = 5.6, SD = 1.1), $t(22) = 3.78$, $p < .001$. All participants had at least 20/20 corrected vision as measured with a Snellen eye chart.

Stimulus materials. Thirty-six passages, as described earlier, were used for this study, with one version of each passage constructed for each of the three boundary conditions (see Table 1). The text in each condition was identical through T1 (i.e., *candy*) and almost identical in content and length through T2 (i.e., *closet*). Within each group, one passage contained an unmarked boundary (i.e., not marked by any punctuation), one passage contained a weakly marked boundary (i.e., marked by a comma), and one passage contained a strongly marked boundary (i.e., marked by a period). The text following T1 was as similar across conditions as possible while maintaining grammaticality and adhering to the following constraints. First, the word immediately following the boundary of interest was approximately the same length for all three conditions. Second, the distance (as measured by number of syllables) between T1 and T2 was held constant. No proper nouns were introduced following the boundary of interest, and the number of noun concepts was held constant for all conditions. Each experimental passage was followed by a short filler sentence, related to the first, which helped ensure that reading time estimates obtained at T2 would represent comprehension and encoding processes, rather than preparation to respond to the upcoming question. Materials were counterbalanced across condition to create three stimulus sets. Sentences in different sets were randomly arranged for presentation with the restriction that no more than three sentences within a single boundary condition appeared consecutively. A simple yes/no question was constructed for each passage to check for comprehension.

Procedure. Passages were presented one word at a time in a moving window display (Just et al., 1982). Reading times were recorded with PowerLab software (Chute, Westall, & Barisa, 1996) on a Macintosh G3 running OS 9. Text was displayed in black in nonproportional Courier 36-point font on a white background. Words not in view were replaced with underlines, marked with punctuation appropriate to the upcoming text. T1 and T2 always appeared within a contiguous line of text and never at the end of a line. Participants were seated in front of the computer in a quiet room. Participants advanced from one word to the next by pressing the space bar.

Before beginning the experiment, participants read instructions on the computer screen, and they were told to read as naturally as possible so that they would understand the passage enough to be able to answer a question about it immediately afterward. They read three practice passages to familiarize themselves with the procedure.

Results and Discussion

The first analysis focused on whether wrap-up was demonstrated at the early boundary site (i.e., whether processing time was longer at T1 relative to the mean reading time for nonboundary [NB] words up to that point) and whether this effect varied with age and boundary salience. Word reading times were analyzed in a 2 (Age: Young, Old) × 2 (Location: NB, T1) × 3 (Boundary Salience: UnM, WkM, StrM) repeated measures analysis of variance (ANOVA) in which the latter two variables were manipulated within subject. All main effects were highly reliable. Older adults' reading times were longer than those of younger adults (M_Y = 476, SE = 62; M_O = 724, SE = 62), $F_1(1, 22) = 7.91$, $p < .01$, η^2 = .264; $F_2(1, 35) = 109.31$, $p < .001$, η^2 = .758. Reading times at T1 (M_{T1} = 731, SE = 67) were longer than those for NB words (M_{NB} = 469, SE = 30), $F_1(1, 22) = 23.17$, $p < .001$, η^2 = .513; $F_2(1, 35) = 121.11$, $p < .001$, η^2 = .776. Even though semantic content was identical across condition, Boundary Salience increased reading time (M_{UnM} = 503, SE = 35; M_{WkM} = 620, SE = 46; M_{StrM} = 677, SE = 63), $F_1(2, 44) = 10.65$, $p < .001$, η^2 = .326. Finally, the Location effect was exaggerated by Boundary Salience, $F(2, 44) = 11.76$, $p < .001$, η^2 = .348; $F_2(2, 70)$ = 21.89, $p < .001$, η^2 = .385. This interaction, shown in the left panel of Figure 1, suggests that the more strongly marked the boundary was, the longer the reader spent in wrap-up at this point.

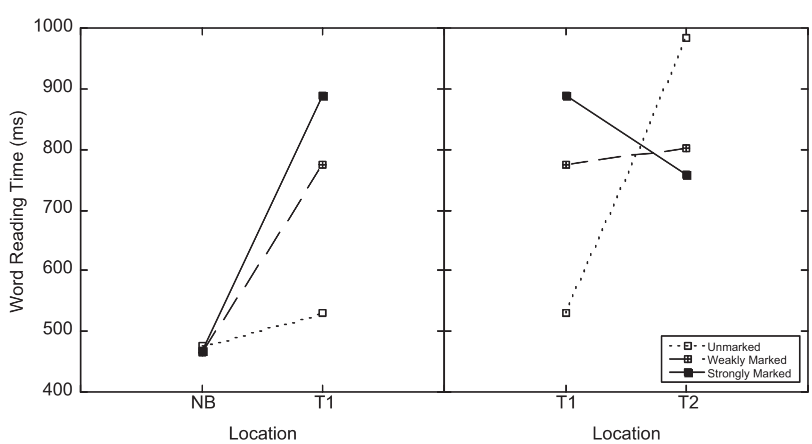

Figure 1. Word reading time (in milliseconds) as a function of location in the passage and boundary marking. The left panel shows wrap up at the early boundary site (i.e., longer times at first target word [T1] than nonboundary [NB]). The right panel shows tradeoff in processing time between earlier boundary sites (T1) and later boundary sites (continuation after T1 ending with the same target word [T2]) as a function of marking.

None of the remaining interactions reached significance—for all, $F_1 < 1$; $F_2 < 1.44$.

The next analysis—a 2 (Age: Young, Old) × 3 (Location: T1, T2) × 3 (Boundary Salience: UnM, WkM, StrM) repeated measures ANOVA—focused on whether there was any evidence that the salience-induced wrap-up at the early boundary facilitated wrap-up at the later boundary. As predicted, there was a reliable Location × Boundary Salience interaction, $F_1(2, 44) = 10.52$, $p < .001$, $\eta^2 = .323$; $F_2(2, 70) = 29.02$, $p < .001$, $\eta^2 = .453$. This interaction, shown in the right panel of Figure 1, illustrates the "pay now or pay later" effect: When wrap-up was induced at the early boundary, sentence-final wrap-up at which the content was collectively consolidated was relatively less effortful. This interaction was not moderated by age, $F_1 < 1$; $F_2(2, 70) = 1.66$, $p = .20$. Thus, these data support the notion that there can be tradeoffs in the time course of conceptual integration and that these effects are very similar for younger and older readers.

In light of earlier findings showing that older readers are more likely to wrap up at more minor (frequent) boundaries (e.g., Miller & Stine-Morrow, 1998; Stine, 1990), we specifically examined wrap-up times only in the UnM condition. The logic here was that age differences in wrap-up patterns have been demonstrated before with naturalistic texts in which minor boundaries are typically not marked (or weakly marked). If older adults' more frequent segmentation is driven more by sensitivity to syntactic structure than by explicit marking (Stine-Morrow, Noh, & Shake, in press), then we might have missed this effect (depending on the three-way interaction to detect a subtle effect at UnMs relative to the much exaggerated wrap-up in the marked boundary conditions). Thus, we examined wrap-up at T1 for passages in the UnM condition in a 2 (Age) × 2 (Location: NB, T1) repeated measures ANOVA. In fact, the Age × Location interaction was reliable, $F_1(1, 22) = 6.10$, $p < .03$, $\eta^2 = .22$; $F_2(1, 35) = 8.74$, $p < .001$, $\eta^2 = .200$. For these earlier unmarked boundaries, older readers showed a greater wrap-up effect ($M_{NB} = 588$, $SE = 43$; $M_{T1} = 684$, $SE = 57$) than younger readers ($M_{NB} = 371$, $SE = 43$; $M_{T1} = 376$, $SE = 57$). Thus, these data are very much in line with earlier demonstrations of age differences in wrap-up patterns. Wrap-up at the two marked conditions, in which readers were explicitly cued, was very similar for younger and older adults, $F_{1 \text{ and } 2} < 1$ for the interactions.

Collectively, these data provide support for a pay-now-or-pay-later effect in which earlier wrap-up can facilitate downstream processing. Younger and older readers appeared to take similar advantage of boundary salience as a cue to opportunistically pause for conceptual integration. However, the demonstration of the pay-now-or-pay-later effect provides evidence that older readers' tendency toward more frequent wrap-up may have functional significance. At the same time, we replicated the finding that older readers do allocate especial effort to conceptual integration at relatively early points in sentence processing while also showing that this is only a reliable effect when boundaries are unmarked. When text is manipulated so that wrap-up sites are more salient, both younger and older adults pause briefly to integrate the meaning of the clause or the sentence; only older adults paused without such boundary marking. Our data suggest, then, that older readers rely on syntactic cues to elect wrap-up points. Importantly, the fact that readers (regardless of age) benefit downstream from exaggerated integration induced by boundary salience supports the notion that regulating effort in this way can be beneficial.

Experiment 2: Eye-Tracking

The measurement of eye movements to assess age differences in reading is a relatively recent paradigm in the cognitive-aging literature (Kemper, Crow, & Kemtes, 2004; Kliegl, Grabner, Rolfs, & Engbert, 2004; Kliegl, Nuthmann, & Engbert, 2006; Laubrock, Kliegl, & Engbert, 2007; Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006), largely because of the development of lighter weight head-mounted systems that are less invasive and relatively resilient in collecting data with vision correction. The advantage to this method is that readers can regress to earlier portions of the text, so that it enables the dissection of relatively early (first-pass) versus later reading processes (e.g., Rayner & Pollatsek, 2006; Rayner et al., 1989). Eye-tracking has revealed findings about age differences in reading that would not have been possible with the moving window method; for example, Rayner et al. (2006) have argued that older adults adopt a more risky reading strategy characterized by a greater likelihood of initially skipping words combined with a greater likelihood of regressing back to these words later (see also Kliegl et al., 2004; Laubrock et al., 2007). Reading time effects are typically replicated across the computer-based moving window approach and eye-tracking (Just et al., 1982; but see Rayner, 1998); there is also evidence that fixation duration and N400 amplitude show similar effects of predictability and word frequency (Dambacher & Kliegl, 2007). Collectively, these methods corroborate the notion that mental workload fluctuates in a way that is highly sensitive to online language demands that are measurable in different ways (Just, Carpenter, & Miyake, 2003). However, because reading is relatively slow in the moving window method, this paradigm may exaggerate estimates of wrap-up processes relative to measures obtained with eye-tracking (Magliano, Graesser, Eymard, Haberlandt, & Ghoulson, 1993). Thus, there is good reason to be interested in whether the pattern demonstrated in the first experiment would replicate with the more naturalistic eye movements.

Method

Participants. Eighteen older adults ($M_O = 70.4$ years, $SD = 6.9$) and 18 younger adults ($M_Y = 20.3$ years, $SD = 1.9$) participated in this experiment. An additional four younger and three older adults were recruited, but their data were excluded for various reasons (one because of health issues, one because of experimenter error, and five because of participant-related eye-tracking problems). The older adults were recruited from the surrounding community and received a small remuneration for their participation, whereas the younger adults received course credit for participation. Participants were screened for neurological and medical impairment as in the first study.

Older adults had slightly more years of education ($M_O = 15.6$, $SD = 2.9$; $M_Y = 14.1$, $SD = 1.3$), $t(34) = 1.99$, $p < .06$. However, the groups did not significantly differ in vocabulary level ($M_O = 46.3$, $SD = 10.3$; $M_Y = 50.6$, $SD = 5.8$), $t(34) = 1.56$, $p = .13$; forward digit span ($M_O = 6.9$, $SE = 0.3$; $M_Y = 7.4$, $SE = 0.3$), $t(34) = 1.03$, $p = .31$; or backward digit span ($M_O = 4.9$, $SE = 0.2$; $M_Y = 5.3$, $SE = 0.4$), $t(34) = 0.91$, $p = .37$.

On a 5-point scale (1 = *poor*, 5 = *excellent*), participants rated their own health ($M_O = 4.1$, $SE = 0.1$; $M_Y = 4.4$, $SE = 0.1$), vision ($M_O = 3.9$, $SE = 0.2$; $M_Y = 4.6$, $SE = 0.1$), and hearing ($M_O = 3.7$,

SE = 0.2; M_Y = 4.5, SE = 0.1). Young adults reported better levels of vision and hearing, $t(34) = 3.21$, $p < .01$, and $t(34) = 2.69$, $p < .05$, respectively; they also reported marginally better overall health, $t(34) = 1.74$, $p = .09$. Although younger adults reported better vision, tests of visual acuity showed that all participants' vision was 20/25 or better; all participants who wore glasses normally for reading also wore them during the experiment.

Materials and design. The materials and design for the study were identical to those of the first experiment, with the exception that there were 25 passages per condition (a total of 75 in each stimulus list, rather than 36).

Apparatus. The sentences were presented on a 19-in. (48.26-cm) ViewSonic P225f monitor set to a resolution of 1,024 × 768 pixels, controlled by a Pentium 3.20 GHz computer set up solely for the SR Research EyeLink II head-mounted eye-tracking system. The EyeLink II system has good spatial and temporal resolution, and it samples at a rate of 500 Hz. Passages were displayed in white font on a black background. Participants read passages binocularly; however, at the beginning of the session, the most accurately tracked eye was chosen for recording (on the basis of EyeLink calibration and validation tests). Participants were seated 96.5 cm from the monitor, with text presented in Times New Roman 30-point font, such that three letters represented about 1° of visual angle. Materials were positioned on the screen such that target regions T1 and T2 never appeared within two words of the beginning or end of a line of text on the screen. Although the EyeLink system is capable of adjusting for some head movement, we asked participants to remain still and place their head on a chin rest to ensure maximal accuracy.

Procedure. After first completing the background demographic questionnaire and the individual difference measures (as in Experiment 1), the participant was asked to read instructions on the computer screen about the upcoming reading task. Instructions were to read each passage normally for comprehension and to answer a yes/no question that would follow each passage with a button press on a keypad. Participants were informed that reading would be self-paced and that they could continue to each subsequent screen by pressing a different button on the keypad. After reading the instructions, the eye-tracker was placed on the participant, and the system was calibrated (this process is unique to each individual and generally takes 3–5 min). Calibration accuracy of the system was assessed by having the participant visually fixate on white circles appearing at various places on the computer screen. After the experimenter determined that calibration was adequate, participants began the reading task. Before reading each passage, a drift correction was performed to ensure that the eye-tracker was still accurately recording gaze position of the eyes. If at any time the experimenter determined that accuracy was poor, the participant was recalibrated; if the participant made any extreme movements or became distracted during any trial, the experimenter made a note to remove it from the data analysis. Less than 1% of all data points were lost or removed this way before subsequent analysis.

Results and Discussion

Prior to analysis, fixation data were cleaned and trimmed. Consecutive fixations that were less than 80 ms in duration and less than .5° of visual angle apart were merged and treated as a single fixation. Other fixations that were less than 80 ms and greater than 800 ms were deleted.

The probability of fixating the words at the two boundary sites (M_{T1} = 0.73, SE = 0.02; M_{T2} = 0.69, SE = 0.02) was greater than that at NB sites (M_{NB} = 0.55, SE = 0.01), $F_1(2, 68) = 36.93$, $p < .001$, $\eta^2 = .52$.[1] There was not an age difference in fixation probability (M_Y = 0.63, SE = 0.02; M_O = 0.68, SE = 0.02), $F_1(1, 34) < 1$. For all other effects and interactions, $F < 1$. Thus, younger and older readers were similar in their tendency to fixate on the boundary words, and probability of fixation did not vary with boundary salience, making it fairly straightforward to interpret the effects of age and boundary salience on the durations of fixations.

We next consider the temporal properties of these fixations using the same analytic approach that was used for the first experiment. Reading time measures included (a) first fixation durations (FFDs) and (b) gaze durations (GDs; the sum of all fixation durations on a word before moving to another word)—which reflect relatively early reading processes—as well as (c) regression path duration (also called go-past time, the sum of fixation times on a word including time spent rereading earlier parts of the text before moving ahead to read new parts of the text)—which reflect later, more integrative processing of the text. Unless otherwise noted, only effects reliable by participants and by items are reported.

Wrap-up at T1. First, we examine processing at the site at which boundary salience was manipulated (T1). Each eye-tracking measure was analyzed in a 2 (Age: Young, Old) × 2 (Location: NB, T1) × 3 (Boundary Salience: UnM, WkM, StrM) repeated measures ANOVA.

Early measures of processing (FFD, GD). First fixations of older readers were longer than those of younger readers (M_Y = 216, SE = 6; M_O = 250, SE = 6), $F_1(1, 34) = 14.46$, $p < .001$, $\eta^2 = .30$. First fixations were also longer at T1 than at NB sites (M_{NB} = 229, SE = 5; M_{T1} = 238, SE = 4), $F_1(1, 34) = 13.54$, $p < .001$, $\eta^2 = .29$. However, this Location effect was moderated by age, $F_1(1, 34) = 6.12$, $p < .02$, $\eta^2 = .15$, such that the increase in fixation durations for T1 was reliable for older readers (M_{NB} = 243, SE = 7; M_{T1} = 258, SE = 6), $t(17) = 4.31$, $p < .001$, but not for younger readers (M_{NB} = 215, SE = 7; M_{T1} = 218, SE = 6), $t(17) < |1|$. This interaction did not vary as a function of boundary salience, $F_1(2, 68) = 1.13$, $p = .33$, for the three-way interaction. GDs were also longer for older than for younger readers (M_Y = 244, SE = 7; M_O = 280, SE = 7), $F_1(1, 34) = 13.13$, $p < .001$, $\eta^2 = .28$, and for T1 words than for NB sites (M_{NB} = 252, SE = 6; M_{T1} = 271, SE = 5), $F_1(1, 34) = 15.65$, $p < .001$, $\eta^2 = .32$. In this case, the Location × Age interaction did not reach significance, $F_1(1, 34) = 2.02$, $p = .16$, $\eta^2 = .06$, but was of the same form as the reliable interaction for FFD: For older readers (M_{NB} = 267, SE = 8; M_{T1} = 292, SE = 7), $t(17) = 3.51$, $p < .01$; for

[1] Analyses in this experiment were conducted by-participants (F_1) and by-items (F_2) for analyses involving target words at boundaries (T1 and T2). The by-items analysis was not conducted for analyses involving NB words. There was some variation in the lexical items in the NB positions across conditions, and readers skipped about half of these words, so that the by-items analysis was not feasible. In these cases, only the by-participant analysis is reported.

younger readers (M_{NB} = 238, SE = 8; M_{T1} = 250, SE = 7), $t(17) = 1.97$, $p = .07$. These measures of early processing provide evidence that both younger and older readers showed wrap-up at T1, but that at this stage, wrap-up was not affected by boundary salience. There was also some evidence that at the earliest stage of processing older adults allocated more time at this boundary site.

Later processing. Like the early measures, go-past times showed main effects of Age (M_Y = 353, SE = 14; M_O = 404, SE = 14), $F_1(1, 34) = 7.07$, $p < .02$, $\eta^2 = .17$, and of Location (M_{NB} = 345, SE = 9; M_{T1} = 411, SE = 13), $F_1(1, 34) = 42.41$, $p < .001$, $\eta^2 = .56$. The Age × Location interaction was not significant, $F_1 < 1$. For this measure of later processing, however, the main effect of Boundary Salience was reliable (M_{UnM} = 360, SE = 11; M_{WkM} = 367, SE = 10; M_{StrM} = 408, SE = 12), $F_1(2, 68) = 14.17$, $p < .001$, $\eta^2 = .29$. The Location × Salience interaction, $F_1(2, 68) = 13.52$, $p < .001$, $\eta^2 = .28$, was similar to the pattern shown in the first experiment, in that boundary salience increased wrap-up (see the left panel of Figure 2); also as in the first experiment, this interaction did not vary as a function of age, $F_1(2, 68) = 1.26$, $p = .29$.

Recap. Collectively, the analysis of the first wrap-up point (T1) suggests that earlier processes may be more driven by syntactic and semantic demands of the language but that boundary marking that increases the salience of potential wrap-up sites induces more integrative processing at later stages of processing. Thus, there was evidence that older readers' tendency toward more frequent wrap-up (Miller & Stine-Morrow, 1998; Stine, 1990) was a consequence of relatively early processing. Boundary salience affected only go-past times, suggesting that opportunistic integration engendered by pragmatic factors was a relatively later process that was exploited similarly by younger and older readers.

The pay-now-or-pay-later effect. Next, fixation measures for the target words at the early and late boundaries were examined to investigate potential age differences in downstream effects of boundary salience. These variables were analyzed in 2 (Age: Young, Old) × 2 (Location: T1, T2) × 3 (Boundary Salience: UnM, WkM, StrM) repeated measures ANOVAs.

Early measures of processing (FFD, GD). Older adults showed longer FFD at the two boundary sites than younger adults, $F_1(1, 34) = 18.56$, $p < .001$, $\eta^2 = .35$; $F_2(1, 148) = 212.43$, $p < .001$, $\eta^2 = .59$. There was no Location effect for FFD, $F_1(1, 34) = 1.77$, $p = .19$; $F_2(1, 148) = 2.20$, $p = .14$, but an interaction between Age and Location, $F_1(1, 34) = 3.59$, $p = .07$, $\eta^2 = .10$; $F_2(1, 148) = 7.42$, $p < .01$, $\eta^2 = .05$. Reflecting older adults' tendency toward wrap-up earlier in the sentence, their FFD tended to be longer at T1 than T2 (M_{T1} = 258, SE = 7; M_{T2} = 247, SE = 7; SE_{diff} = 6), $t_1(17) = 2.01$, $p = .06$; $t_2(148) = 2.59$, $p < .01$. Younger readers did not differ in FFD for T1 and T2 (M_{T1} = 218, SE = 5; M_{T2} = 220, SE = 5; SE_{diff} = 4), $t_1(17) < |1|$; $t_2(148) < |1|$.

GDs showed a main effect of age, $F_1(1, 34) = 14.92$, $p < .001$, $\eta^2 = .31$; $F_2(1, 148) = 133.88$, $p < .001$, $\eta^2 = .48$. The Age ×

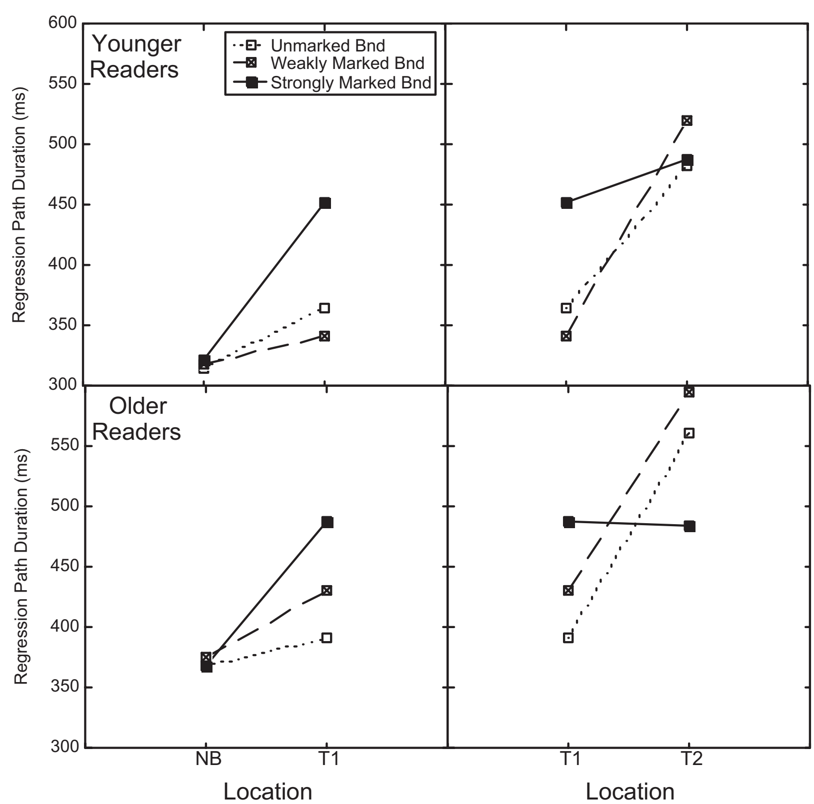

Figure 2. Regression path durations (in milliseconds) as a function of location in the passage and boundary (Bnd) salience for younger (upper) and older (lower) readers. NB = nonboundary; T1 = first target word; T2 = continuation after T1 ending with the same target word.

Location interaction was of the same form as that observed for FFD, but it was reliable only by items, $F_1(1, 34) = 1.40$, $p = .25$; $F_2(1, 148) = 6.84$, $p < .01$, $\eta^2 = .48$ (for old: $M_{T1} = 292$, $SE = 6$; $M_{T2} = 279$, $SE = 6$; for young: $M_{T1} = 245$, $SE = 6$; $M_{T2} = 250$, $SE = 5$).

Measures of early processing, then, did not strongly distinguish between the two wrap-up sites, though there were trends toward older readers showing a preference for early over late boundaries for wrap-up. Importantly, boundary salience had no influence on these first-pass reading processes.

Later processing. Unlike the first pass measures, regression path durations showed reliably more processing at T2 than T1 ($M_{T1} = 411$, $SE = 13$; $M_{T2} = 522$, $SE = 22$), $F_1(1, 34) = 43.86$, $p < .001$, $\eta^2 = .56$; $F_2(1, 148) = 30.82$, $p < .001$, $\eta^2 = .17$. In addition, this measure of later processing also revealed reliable moderation of the location effect by boundary salience in a Location × Salience interaction, $F_1(2, 68) = 13.91$, $p < .001$, $\eta^2 = .29$; $F_2(2, 296) = 4.10$, $p < .02$, $\eta^2 = .03$, as shown in the right panel of Figure 2. The three-way interaction was not significant,[2] $F_1(2, 68) = 1.15$; $F_2 < 1$. However, at T2, older readers showed facilitation in the StrM condition relative to both the WkM condition—reliable by participants only—$t_1(17) = 2.40$, $p < .03$; $t_2 < |1|$, and to the UnM condition, $t_1(17) = 2.12$, $p < .05$; $t_2 < |1|$. No facilitation was found for younger readers' sentence wrap-up, $t_{1 \text{ and } 2} < |1|$, for both comparisons.

Regressions. Given that boundary salience had effects on regression path durations, but not on FFDs and GDs, it seemed likely that boundary salience was inducing rereading. Indeed, boundary salience contributed to how readers regulated regressive eye movements. As shown in the left panel of Figure 3, the more salient the boundary was at T1, the more likely it was to be used as a launching point for first-pass regressions, $F_1(2, 68) = 18.01$, $p < .001$, $\eta^2 = .35$; $F_2(2, 148) = 15.74$, $p < .001$, $\eta^2 = .18$. This effect of boundary salience did not differ as a function of age, $F_1 < 1$; $F_2(2, 148) = 1.78$, $p = .17$, for the Age × Salience interaction. This pattern suggests that boundary marking was a factor in the choice of when to end the input cycle. Readers initiated regressions from more StrMs to earlier parts of the sentence, suggesting that conceptual integration was accomplished in part by scanning earlier parts of the surface form. Wrap-up, then, may be thought of not only as purely mental reflection but also at a point at which the reader scans for information to augment integration (cf. Hegarty, 1992).

Marked boundaries at T1 were also less likely to be a landing site for regressions launched from later parts of the text, $F_1(2, 68) = 9.96$, $p < .001$, $\eta^2 = .23$; $F_2(2, 148) = 24.68$, $p < .001$, $\eta^2 = .25$, for the main effect of Boundary Salience, so that once the semantic representation was consolidated at wrap-up, the reader was less likely to revisit. As shown in the right panel of Figure 3, this effect was also similar for young and old, $F_{1 \text{ and } 2} < 1$, for the Age × Salience interaction.

Finally, when the boundary at T1 was salient, T2 was less likely to be a launching site for regressions ($M_{UnM} = 0.37$, $SE = 0.03$; $M_{WkM} = 0.37$, $SE = 0.03$; $M_{StrM} = 0.32$, $SE = 0.03$), reliable by participants, $F_1(2, 68) = 3.72$, $p < .03$, $\eta^2 = .10$, but not by items, $F_2(2, 148) = 1.20$, $p = .30$. This effect did not vary with age, $F_{1 \text{ and } 2} < 1$. These findings suggest that once the semantic representation of a segment is consolidated at the end of the input cycle, readers are less likely to regress to retrieve information about the surface form.

Recap. Readers showed evidence of a pay-now-or-pay-later effect in the patterns of their eye movements. Strongly marked boundaries engendered more thorough processing of the current input cycle, primarily measurable in terms of time allocated to rereading (i.e., regression path duration and probability of launching a regressive eye movement). Under these conditions, both younger and older adults were less likely to revisit the boundary site. In addition, older adults' wrap-up downstream from the strongly marked boundary was facilitated. Thus, having paid extra attention to conceptual integration early in the sentence enabled facilitated processing later (they "paid less later").

General Discussion

As they move through text, readers periodically consolidate the semantic representation, which is more enduring relative to the surface form (e.g., Kintsch, Welsch, Schmalhofer, & Zimny, 1990). One consequence of such a system is that the surface form can decay without loss of comprehension. Reflection (wrap-up) then creates a more enduring representation that better prepares the reader to interpret subsequent text. Assuming that older adults have particular difficulty in retaining the surface form relative to the semantic representation (Cohen & Faulkner, 1984; Radvansky, Zwaan, Curiel, & Copeland, 2001), more frequent wrap-up is plausibly a strategy that would enhance the experience of coherence in reading. Thus, in terms of James's (1890) metaphor, older readers perch more often to reflect on the events of the flight. We have found this in reading, and to the extent that these rhythms also apply to decomposing and finding meaning in experience itself (James, 1890; Zacks, Tversky, & Iyer, 2001), one may be tempted to wonder whether this principle of "more frequent perches" applies more broadly as well.

To the extent that eye-tracking allows us to distinguish between first-pass, automatic, and obligatory reading processes—as opposed to later, integrative processes (Rayner & Pollatsek, 2006)—our eye-tracking data suggested that the increased tendency with age toward more frequent wrap-up may reside in reading processes that are relatively early; that is, older readers showed evidence of exaggerated wrap-up at the first boundary (T1), primarily in FFDs, but not at all in patterns of regressions or in regression path duration that reflects later processing. Thus, the eye-tracking data augment accounts of age differences in wrap-up patterns by suggesting that older adults' tendency toward more frequent conceptual integration may be regulated through the monitoring of syntactic structure and semantic load that occurs relatively quickly in the reading process.

Our data showed that readers could be induced to wrap-up by making syntactic boundaries more salient. This is interesting for at least a couple of reasons. First, our salience manipulation did not substantively change the semantic content of the text (certainly, up to the boundary, the surface form of the text was identical across conditions), and yet, the extent of wrap-up showed systematic change in response to salience. Contrary to accounts of wrap-up that are explained in terms of the inherent demands of resolving the semantic representation (Ditman, Holcomb, & Kuperberg, 2007; Haberlandt et al., 1986; Just & Carpenter, 1980), this finding provides evidence for

[2] The lack of a significant interaction here is not an issue of power; in fact, the patterns of the Location × Salience interactions for younger and older readers are virtually identical.

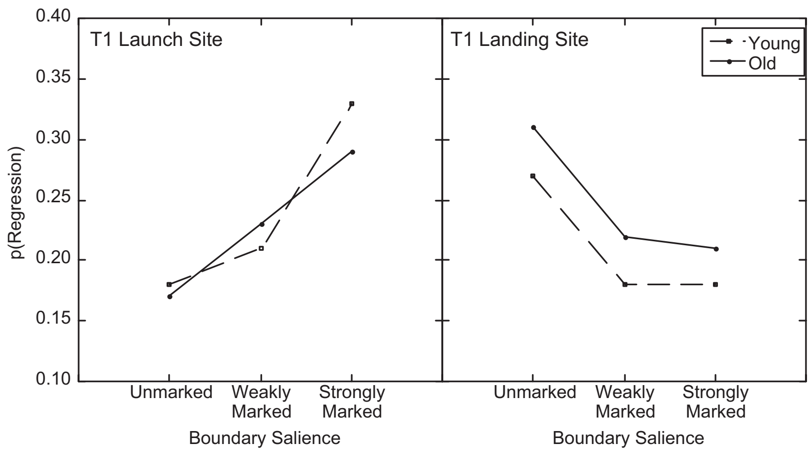

Figure 3. The probability of the first target word (T1) being a launch site (left panel) and a landing site (right panel) as a function of age and boundary salience.

opportunistic self-regulation of how thoroughly linguistic computations are conducted on the fly (Christianson, Hollingsworth, Halliwell, & Ferreira, 2001; Stine-Morrow et al., 2006). This opportunistic self-regulation of reading was evident not only in computer-based reading times, which are relatively slow, but also in eye movements in which we could distinguish relatively early and relatively late processes. At the same time, it is important to note that the wrap-up processes that were differentially stimulated by boundary salience were evident only in regressions (physically moving the eyes back). Boundary salience appeared to have no effect on early first-pass measures of reading time (which might be thought of as more obligatory and language driven). Rather, boundary salience increased the probability of scanning back in the text, thus, increasing the overall processing time before the reader moved forward in the text (regression path duration). Second, we found evidence that this opportunistic shift in resource allocation to wrap-up had downstream effects on the resources required for integration. The pay-now-or-pay-later effect—that greater allocation of resources to consolidate the semantic representation early yields savings in allocation downstream—suggests that the opportunistic effort toward integration may be effective in managing comprehension.

We found very little evidence for age differences in these effects. Boundary salience did not differentially impact the older readers' likelihood of regressing backward in the text (see Figure 3, left panel) or in the time allocated for processing (see the left panels of Figures 1 and 2). There was evidence that for both younger and older readers, an increase in conceptual processing induced by boundary salience reduced the likelihood of regressions to earlier text (see Figure 3, right panel) and reduced processing time downstream (see Figure 1, right panel); there was some evidence that older readers may have garnered special benefit from early wrap-up (see Figure 2, right panel), but these were somewhat weak effects that need to be interpreted with caution at this point.

Our findings replicate some prior work suggesting older adults may show longer initial fixation durations and more regressive eye movements (Kemper et al., 2004; Kliegl et al., 2004, 2006; Laubrock et al., 2007; Rayner et al., 2006). In contrast to some studies (cf. Kliegl et al., 2004; Laubrock et al., 2007; Rayner et al., 2006), we found no evidence for age differences in probability of fixation (not skipping). There is some evidence that age differences in skipping rates are moderated by word frequency (Rayner et al., 2006) and predictability (Kliegl et al., 2004), but these effects are not consistently found, so that the age difference in probability of fixation may have not been apparent given that the effects of these moderators were not examined.

Finally, these data have replicated earlier studies showing age differences in patterns in wrap-up (Miller & Stine-Morrow, 1998; Stine, 1990), under conditions with greater control over linguistic materials than had been achieved before (both experiments) and with eye-tracking (Experiment 2), which tends to show smaller wrap-up effects (Magliano et al., 1993). By examining the consequences for downstream processing, we have augmented these earlier results by considering the function of early wrap-up in the ecology of reading. Age differences in the response to boundary salience were minimal; however, at the same time, we found that older readers showed a downstream processing advantage that was at least as strong as that shown by the young, suggesting that more frequent wrap-up may serve older readers well in allowing the consolidation of the semantic representation to engender a more fluent reading experience.

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