ADULT AGE DIFFERENCES IN INFORMATION FORAGING
IN INTERACTIVE READING ENVIRONMENTS

BY

XIAOMEI LIU

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science in Educational Psychology
in the Graduate College of the
University of Illinois at Urbana-Champaign, 2014

Urbana, Illinois

Adviser:

Professor Elizabeth A. L. Stine-Morrow

Abstract

When learning about a single topic in natural reading environments, readers are confronted with multiple resources varying in type and amount of information. In this situation, readers are free to select the resources and allocate time for study, but there may be costs in exploring and switching between resources. Thus, two experiments were conducted to investigate age differences in the selection and study time allocation in learning about a topic from multiple texts. Younger and older adults explored texts that varied in information richness (i.e., sentence elaboration) and under different conditions of switch cost (i.e., time delay in switching). In both experiments, participants selected less informative sentences first, and then moved progressively towards more informative sentences. Switch cost did not have any effect on selection and time allocation when there was no time pressure on learning. However, under moderate time pressure, increased switch cost led to a greater likelihood of selecting more informative texts first, more time allocation in studying, and better text memory. Older adults were more adaptive to the switch cost as shown by their earlier selection of more high-elaboration sentences in the large-switch-cost condition than in the small-switch-cost condition, whereas younger adults did not behave differently across switch cost conditions. The results indicated that both younger and older readers follow similar self-regulated strategies to gain information from texts, but these strategies can be influenced by the factors in search environment and learner's age.

*To my beloved parent*s

Acknowledgments

I want to thank my committee members, Dr. Elizabeth A. L. Stine-Morrow, Dr. Daniel G. Morrow, and Dr. Kiel Christianson, for their critical comments and suggestions on my thesis. I would like to express the deepest appreciation to my adviser, Dr. Elizabeth A. L. Stine-Morrow, from whom I received invaluable academic training. Without her persistent guidance, support, and insight this thesis would not have been possible. I also want to thank my friends and colleagues for their encouragement and feedback in the progress of conducting this project: Brennan Payne, Jessie Chin, Xuefei Gao, Laura Giffin, and Renato Azevedo. I wish to thank my lab manager, Mary Terese Campbell, for her endless help and administrative support. Lastly, I would like to thank my lab mates and research assistants for their direct help on the development of this project, and testing: Thomas Deegan, Andy Battles, Verlisa Shanklin, Jonathan Hoke, David Morrow, and Allison Steen.

Table of Contents

Chapter 1

Introduction and Literature Review

Reading is a critical activity throughout the life span, and is a positive predictor of cognitive resilience in later adulthood. People read not only for pleasure, but also to learn new things. With the development of the Internet, people often turn to the Web to gain knowledge. However, the problem is that when facing the huge amount of information sources available on the Internet, the learner cannot study all the information. For example, suppose a person is planning a trip to a new city and he or she wants to learn about the place in advance. A search on the Internet would likely yield multiple texts on the history, points of interest, local culture, and so forth. Because it is unrealistic to learn all the information, he or she must make decisions about which ones to learn and in what order, how long to spend with each text, and when to move on to the next one. These decisions are likely based on several factors, such as the learner's interests, the length of the texts, amount of new information, and the amount of available study time. In this circumstance, because the individual can control his or her learning process, he or she is engaged in the process of self-regulated learning.

However, in the dominant paradigm for investigating reading for gaining knowledge, texts are usually presented by the experimenters under controlled conditions. Less is known about how learners gain information from reading when they can freely select the texts they want to read. Adult age differences in reading comprehension and memory are well established in the existing literature, but it is unclear whether there is an aging effect on reading behaviors when readers can choose among multiple texts on a particular topic. Therefore, the purpose of this research was to understand the effect of age on how readers learn about specific topics in a self-regulated learning environment.

Cognitive Aging and Reading

Aging is accompanied by changes in cognitive capacities that influence learning and memory. Research has demonstrated age-related declines in fluid abilities such as working memory (Bopp & Verhaeghen, 2005) and processing speed (Salthouse & Ferrer-Caja, 2003), but at the same time, a growth in crystallized abilities, such as vocabulary (Verhaeghen, 2003). Both of these changes can affect learning and remembering. Compared to younger adults, older adults typically show a memory deficit on tasks of paired associate or serial learning (see review in Salthouse, 2004).

Age deficits are also found in text memory (see meta-analysis in Johnson, 2003). Moreover, Hartley, Stojack, Mushaney, Annon, and Lee (1994) showed that older readers are less efficient in encoding individual ideas from text than younger readers, as indicated by a longer time reading a sentence in order to recall the same amount of information as younger adults do. Nevertheless, these age deficits in text memory and processing efficiency tend to be reduced or even eliminated when texts are connected discourse relative to single sentences (Johnson, 2003; Stine-Morrow, Miller, Gagne, & Hertzog, 2008). The argument is that discourse or longer sentences are rich in elaboration, which provides contextual support for the encoding of individual ideas. Johnson (2003) also showed that age differences are smaller when reading is self-paced, which implies that older adults may use different strategies from younger adults.

Shake, Noh, and Stine-Morrow (2009) suggested that there are two distinct but coordinated representational forms in the language processing system, the textbase and discourse representations (see also Stine-Morrow et al., 2008; Stine-Morrow, Shake, Miles, & Noh, 2006). To establish textbase representations, readers encode associations between concepts that are explicitly provided by the text; whereas, at the same time, readers construct discourse representations that combine information from text and self-generated inferences. The former processing is heavily reliant on working memory, which tends to decline with age, but the latter is more dependent on knowledge and experience, which is preserved with age. Shake et al. (2009) presented younger and older adults with texts that were about a single topic (e.g., Connecticut), and were varied in the level of elaboration from simple factoids to highly elaborated texts. Older readers were more likely to recall information from the highly elaborated texts, while younger readers tended to recall more from the factoids. This implies that older adults are more likely to benefit from greater elaborative content in terms of text memory compared to younger adults. Of interest in the current studies was whether older adults would give preference to highly elaborated texts in selection, and still show memory benefits from those texts when they are free to pick what they want to read. To introduce this issue, I first review theories of self-regulated learning.

Aging and Self-Regulated Learning

Self-regulated learning (SRL) refers the learning process during which learners actively take control of and evaluate their own learning and behaviors (Zimmerman, 2001). In order to self-regulate, learners need to monitor the effectiveness of their learning strategies and respond to the feedback generated from monitoring in various ways, such as changing study strategies. Theories of SRL predict how people select items, allocate study time, and decide when to stop studying.

Discrepancy reduction model. The discrepancy reduction model (DRM; Nelson & Narens, 1990; Dunlosky & Thiede, 1998) argues that learners allocate effort to reduce the discrepancy between the current knowledge level and desired knowledge level. Nelson and Narens (1990) called the desired degree of learning outcome the *norm of study*. When an item is presented for study, the learner needs to assess the degree to which it has been learned and compares the assessment to his or her own norm of study. If the learner perceives his or her current degree of learning as equal to or exceeding the norm of study, the person will stop studying the current item and proceed to the next one. However, if there is still discrepancy between the current and desired degree of learning, the learner continues studying until the norm of study has been reached.

From the DRM perspective, because the discrepancy between the current learning state and the norm of study is greater for the difficult or less-well learned items than the easy or well-learned items, learners will allocate more attention to the more difficult items by selecting them more often and spending more time studying them (Thiede & Dunlosky, 1999). Several studies have supported the DRM in self-paced learning tasks, and developmental changes have been investigated. Dunlosky and Hertzog (1997) presented lists of word pairs to younger and older learners, and the participants made judgments of learning (JOLs) after studying each paired-associate, that is, how confident they were that they would be able to recall the item in 10 minutes. Immediately after learning the list, the participants were asked to recall the items, and then they were given the options to selectively restudy some items. The results indicated that both younger and older adults utilized their JOLs by selecting those items that they believed had been least-well learned items for restudy. Furthermore, there was no age difference in the accuracy of JOLs, shown by the similar gamma correlations for younger and older adults between JOLs and subsequent recall performance after the first study trial, which suggested that younger and older adults were equally able to correctly assess their learning state (Dunlosky & Hertzog, 1997). Dunlosky and Conner (1997) used a similar paradigm to test the DRM, and they also found there was no age difference in the accuracy of predicting recall from JOLs. In addition, they found a negative correlation between JOLs and study time in restudy trials, suggesting that participants were more likely to allocate more time to the less-well learned items. However, older adults demonstrated a weaker negative correlation, which implied that older adults utilized the assessment of learning to a lesser degree than their younger counterparts in regulating study.

Collectively, these findings support the DRM, suggesting that both younger and older learners achieve their goals by firstly determining the degree of knowledge discrepancy for each item, and then selecting to study the difficult items initially and allocating most of their study time to them. Although older adults can assess their learning states accurately to the same degree as younger adults can, they may not optimally utilize the output of the monitoring process to adopt effective study methods and strategies.

Region of proximal learning. Metcalfe and her colleagues developed an alternative model for SRL. According to the region of proximal learning (RPL) model (Metcalfe, 2002), people allocate effort to a perceived RPL, which is neither too easy nor too hard. Items that are already mastered and items that are too difficult are not good candidates for learning because investing time and effort into them produces less return and may cause opportunity cost. Thus, the model predicts that when learners are given the options to choose among items for study, they select the least difficult items, as far as they are not learned yet, and then shift progressively to more difficult items (Metcalfe & Kornell, 2003). The model also suggests that people allocate most of their study time to the items that have the highest learning return, in other words, a considerable amount of time is devoted to the easy or less difficult items.

Although the DRM and RPL models provide opposing expectations on choice and study time allocation, Metcalfe and Kornell (2005) reconciled these views empirically by examining studies in which participants studied only unlearned materials. They argued that for those items that people have mastered, they are less likely to be selected for re-study (Dunlosky & Conner, 1997; Dunlosky & Hertzog, 1997). The allocation to "difficult" items could be accounted for by the fact that people do not study what they already know. However, if learners are given study items with the elimination of the already-known items, they select and allocate time to study just like RPL predicts.

Son and Metcalfe (2000) conducted three experiments with three types of materials that differed in overall complexity and length, very short haikus, medium-length sonnets, and long biographies. The results indicated that participants allocated most of their time to the difficult items only when they were studying the short haikus, whereas when they were given the more complex forms, biographies or the sonnets, they allocated more time to the judged-easy items. However, under low time pressure, they shifted more of their time to study the difficult items. It implies that learners realize that when there is insufficient study time, spending time on the difficult items may be inefficient because with the same amount of time and effort, learners can easily master more of the less difficult items. Findings from several other studies have also supported the RPL model among younger adults by using paired-associate items (Kornell & Metcalfe, 2006; Metcalfe, 2002; Metcalfe & Kornell, 2003). No obvious age differences are typically found in initial learning selection and study behaviors, but older adults are more likely to restudy and allocate more of their time to easy items than younger adults (Price, Hertzog, & Dunlosky, 2010; Price & Murray, 2012).

Information foraging. Information foraging (IF) theory (Pirolli & Card, 1999) offers another theoretical framework for understanding resource allocation in learning information. Pirolli and Card (1999) suggested that humans actively search and gather information for learning, decision-making and problem solving, and also adapt their information-seeking strategies based upon the environment through which they search. From an evolutionary ecological perspective (Hills, 2006), these strategies are analogous to food-foraging strategies used by animals in the wild to gain energy. According to the IF model, certain properties of food foraging can be applied to how humans search for information. For instance, food is distributed in the wild, typically in clusters or "patches," and the available resources in each patch are finite and unknown before the exploitation of the patch. The patches may also vary in the amount of resources they contain or the potential gain, and there may be "scent cues" that provide hints on the potential gain from the patches. With the time spent in exploiting a patch, the rate of gaining food decelerates because of the limited nature of the resources within the patch. Optimal foraging theory (Stephens & Krebs, 1986) describes the heuristics that animals use to forage for food in the wild in order to maximize the rate of gain of energy. According to this theory, animals need to balance the gain from exploitation within a food patch and the costs of exploration (moving between patches) in the wild to find new patches.

From the IF perspective, just as animals forage habitats for sources of energy (i.e., calories), human search through memory (Hills, Jones, & Todd, 2012) and explore the physical environment (e.g., the Web) to acquire information (i.e., ideas; Fu & Pirolli, 2007). In environments through which people seek information, like the Web, different information sources can be considered "patches." Like an animal foraging for food in the wild, human foragers must trade off between exploitation of a particular patch and exploration for others. Thus, they are unlikely to stay at one information patch. Because the amount of information that can be gained from a single source is not infinite, foragers switch to new sources when the rate of gain decreases and the amount of possible information diminishes. Pirolli and Card (1999) presented a mathematical model of foraging. The cumulative amount of information gained is represented as a function of within-patch time, t_w. Because the rate of gain decelerates, the slope of within-patch gain function, $g(t_w)$, decreases (see Figure 1). Assuming that the human forager's goal is to maximize acquired knowledge (Pirolli & Card, 1999), according to Charnov's (1976) marginal value theorem, the forager should remain in a patch as long as the rate of marginal gain (i.e., the slope of $g(t_w)$) is greater than the average rate of gain, R, in the environment. As soon as the rate of marginal gain equals the average rate of gain, the forager should stop exploiting the current patch and switch to another patch in order to optimize overall gain. In other words, the theorem defines the optimal time to persist in a particular patch for maximizing information extracted from the whole ecology. Figure 1a shows the graphical representation of the marginal value theorem under the basic condition in which there is just one kind of patch-gain function. On the horizontal axis, t_B denotes the average between-patch travel time, which is the duration of finding a new patch. To determine the optimal within-patch foraging time, one draws a line from t_B, and the line runs tangent to the gain function, $g(t_w)$. The slope of the tangent is the average rate of gain, R, within that patch given a particular between-patch travel time. At the point of tangency, the slope of $g(t_w)$ (i.e., the marginal value) is the same as the slope of the tangent line (i.e., the average rate of gain, R). Therefore, according to the theorem, the corresponding time point is the optimal within-patch time, t^*.

Based on this optimization model (Pirolli & Card, 1999), there are at least two variables, between-patch enrichment and within-patch enrichment, which can influence the optimal persistence time on a patch (i.e., the optimal time to stop and switch to a new patch). Between-patch enrichment is defined as resources that increase the easiness of switching patches, which can be operationalized as the time cost in exploration between patches. An increase in the between-patch enrichment reduces the average cost of getting from one patch to another, whereas, a reduction in enrichment increases the cost of time and energy to switch. Figure 1b illustrates the effect of increased switch cost on optimal foraging time within a patch. Assuming a consistent rate of gain across patches in the ecology, as the between-patch switch cost increases from t_{B1} to t_{B2}, the average rate of gain decreases from R_1 to R_2. Therefore, in order to optimize the overall outcome with t_{B2}, it would be better to persevere in the current patch for a longer time before moving on to a new patch, so the optimal within-patch time increases from t_1* to t_2*. This implies that high switch cost should lead to longer persistence within patch.

There has been some evidence supporting the effect of switch cost on within-patch perseverance. For example, Dennis and Taylor (2006) found that when people read information on a browser for a decision making task, longer time delay between browsing pages led to longer time spent within a page and less switching between pages. The findings support hypothesis that increased switch cost lead to longer persistence in within-patch exploitation. However, it is unclear whether the same results can be found in a reading task.

On the other hand, within-patch enrichment can be defined as set of factors that improve the possible rate of information gain from a patch (Pirolli & Card, 1999). High within-patch enrichment means that the rate of information gain is fast and foragers can leave the patch earlier but with more information learned. As shown in Figure 1c, assuming the between-patch switch cost is fixed, when the within-patch rate of gain is decreased from g_1 to g_2, the overall rate of gain in the ecology decreases from R_1 to R_2. The outcome is optimized by persisting longer, so that optimal within-patch time increases from t_1* to t_2*.

Besides decisions on persistence and switching, foragers also make decisions on which particular patches they select and the order of selecting. In the IF model, this is described as information scent cues that can inform the value or potential gain of the patches. Scent cues can be operationalized as a title or key words, and can help foragers to estimate the value of the patch without actually sampling the patch. Otherwise, foragers need to sample the patch, for example, skimming the texts first. In any case, learners make their selection decisions in order to reach the goal of learning (Fu & Pirolli, 2007).

Very few studies have investigated adult age differences using the IF model. Chin et al. (2012) used a word search puzzle task to examine the age differences in ability on information foraging. Younger and older adults were asked to maximize the number of words found in a set of four puzzles by freely searching within a puzzle or switching between them. The results indicated that younger adults had a faster rate in finding words from individual puzzles, but their rate decelerated more than older adults during the search. There were also age differences in the patterns of switching and persistence with older adults showing fewer switches among puzzles and longer time spent persevering a puzzle without finding a word before switching to another puzzle, which indicated that older adults are less explorative and suboptimal in switching. Similar age differences were also found in studies using a virtual fishing task and an anagram task (Mata, Wilke, & Czienskowski, 2009, 2013). However, these aging differences in information foraging have not been studied in reading.

The Current Research

Collectively, the reviewed SRL studies have found some similarities and also differences in the strategies used in SRL between younger and older adults, but these studies have mostly used non-reading tasks. Of interest in the current studies was whether in a self-regulated reading environment, younger and older adults would use different strategies to gain information from texts. I was also particularly interested in testing implications from the IF model that between-patch enrichment can influence readers' behaviors in learning from multiple texts. The prediction from the IF model that increased switch cost impacts persistence in learning contradicts common sense. This is not predicted by other theories of SRL, and suggests a possible approach for instructors to help their learner to improve learning.

To test these ideas, a reading task was designed to simulate the learning environment on the Web, where readers can freely explore several texts to learn about specific topics in order to prepare for a memory test. Between-patch switch cost was operationalized as the time to switch between texts, which was implemented as a time delay after selecting a text. Within-patch enrichment was operationalized as the different amounts of information in texts (i.e., text elaboration), and participants were given "scent cues" indicating the elaboration level of each text that they could use to make selections.

According to the IF model, increased switch cost should lead to longer persistence in studying texts. Neither the RPL model nor DRM make any predictions about such effects from the reading ecology. The IF model also predicts that learners will select the less informative sentences first, and then increase the difficulty and complexity of the selected sentences step-by-step. The RPL model would make the same prediction on text selection, while the DRM would predict that learners select the more elaborative and complex sentences first. Older adults may give preferences to selecting more informative texts and use different time allocation strategies from younger adults as implied by studies on the aging effects on text memory and SRL.

Chapter 2

Experiment 1

The first experiment was a pilot study aiming to test the feasibility of the reading task described above. In order to examine how people study when they had considerable freedom to explore among multiple texts, there were no constraints on which texts should be selected or the time limits for study.

Method

Participants. Twenty-five participants were recruited for this experiment. All individuals were native speakers of English, had normal vision, and were screened for severe neurological or medical conditions, such as Parkinson's, Alzheimer, and stroke. One younger adult's data was excluded because of a failure to comply with the instructions. Older adults were also screened for mild cognitive impairment using the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005), and none of them was excluded based on the test. Data for the remaining participants, 12 younger (19-22 years of age) and 12 older (62-68 years of age) adults, were retained for analysis. Younger adults were undergraduate students in an Educational Psychology course at the University of Illinois at Urbana-Champaign and received course credits for participating this study. Older adults were recruited from the surrounding community and were paid for their participation. On average, older adults were college-educated, while younger adults were college students. Hence, younger adults had fewer years of education than older adults (see Table 1).

All participants were administered several cognitive measures. Table 1 shows that the age difference in the level of vocabulary measured by the Advanced Vocabulary Test (Ekstron, French, & Harmon, 1976) was not significant. Younger adults showed higher levels of speed of processing (Salthouse, 1991) and working memory (Stine & Hindman, 1994), whereas older adults demonstrated a higher level of print exposure (Author Recognition Test; Stanovich & West, 1989) as a measure of reading habits and experience.

Materials. Reading materials consisted of 24 factual sentences about Connecticut (CT) and 24 about Rhode Island (RI), adopted from the stimuli used by Shake et al. (2009). The sentences were all related to CT or RI, but there was no contextual overlap between the sentences for each state. The sentences varied in the number of propositions or "idea units," which are the relationships or networks between concepts within a sentence (Kintsch & van Dijk, 1978). Sentences about each state were studied together so that participants learned about a single topic at a time. The low-elaboration condition contained eight sentences with 2-4 propositions, the medium-elaboration condition contained eight sentences with 6-8 propositions, and the high-elaboration condition had eight sentences with 10-12 propositions. Sample sentences from each elaboration level are shown in the Table 2, and the complete set of materials is shown in Appendix A.

To ensure the equality of texts across states, the materials were analyzed based on three characteristics, number of propositions, number of syllables, and number of new concepts. The number of proposition ($M_{\text{CT}} = 7.00$, $SE = 0.71$; $M_{\text{RI}} = 6.88$, $SE = 0.69$), the number of syllables ($M_{\text{CT}} = 31.96$, $SE = 3.20$; $M_{\text{RI}} = 31.83$, $SE = 3.22$), and the number of new concepts ($M_{\text{CT}} = 6.71$, $SE = 0.59$; $M_{\text{RI}} = 6.50$, $SE = 0.64$) did not differ across material set, $t(46) = .13$, $p = .90$, $t(46) = .03$, $p = .98$, and $t(46) = .24$, $p = .81$ respectively. Also, there were no State × Elaboration interactions for these three material characteristics, all $F(2, 42) < 1$.

Design. The experiment followed a 2 × 2 × 3 mixed factorial design with one between-subject variable, age (young vs. old), and two within-subject variables, switch cost (small vs. large) and sentence elaboration (low vs. medium vs. high). The switch cost was manipulated by introducing a random loading time after the selection of a sentence. In the small-switch-cost condition, sentences were presented after 0-1 seconds, and in the large-switch-cost condition, sentences were presented after 5-8 seconds. To make sure that variation in the switch-cost condition was salient, sentences in each condition were blocked for presentation, with each block containing sentences about CT or RI. Materials were counterbalanced across switch-cost conditions, and the order of switch-cost block was counterbalanced across subjects, which created four stimuli lists.

Procedure. The testing session took about 1.5 hour. First, background demographics were collected, and older adults were administered the MoCA. Then, all the participants completed the Advanced Vocabulary Test, and Letter and Pattern Comparison Tasks to assess processing speed, followed by the reading task on iPad. Lastly, participants were administered the loaded working memory test and Author Recognition Test. Participants were also asked about their previous experience with RI or CT area, whether they had visited these two states or whether they were familiar with the materials used in the reading task. Only four older adults mentioned they had travelled to the states, but the trips was 30 to 40 years ago. They confirmed that they were not familiar with the information of the two states in the reading task. Thus, none of the participants was excluded from subsequent analysis.

During the reading task, participants sat in front of an iPad set up in portrait orientation with a wireless keyboard. The task was programmed on a second-generation iPad, and sentences were presented in Calibri 18-point font (see Figure 2). Participants were given instructions to learn about CT and RI so that they would be able to later type all they had learned about each state. They were told that the texts about each state were single sentences, which varied in the amount of information. Instructions were to "select how much information you want to learn by pressing buttons on the screen, where each button corresponds to one sentence." Participants were told that there were three sizes of the buttons, small, medium, and large, and the size indicated the amount of the information available in a sentence, meaning the bigger the button, the more information in the sentence. Once participants selected a sentence, the screen momentarily turned gray. From the participant's perspective, the gray screen was the result of the iPad loading the sentence, however, the duration of "loading" was the manipulated variable for switch cost. Participants could read as long as they wanted, and when they finished learning a sentence, they were instructed recall the sentence aloud immediately by pressing a read circle button at bottom right of the screen. The verbal recall was signaled by the disappearance of the sentence and the appearance of a question mark. Participants were asked to recall as many of the ideas as they could after reading in order to help them better remember the information for subsequent test, but there was no need to recall the exact words of the original sentence. The iPad recorded the recall in a audio file that was saved for transcribing and scoring. When participants were done with the recall, they terminated the recording by pressing a black square button, which returned the participants back to the selection page. Participants did not have the option to re-study the sentences, therefore, once a sentence had been selected, the corresponding button disappeared from the selection page.

Three sentences about Louisiana of the three elaboration levels were given for demonstration and practice. Then, the participants proceeded to learn about CT and RI. For each state, the 24 sentences resulted in 24 buttons in three different sizes, and the buttons were displayed in random orders in four columns.

There was no time limit on reading or recall. Participants were told they could read as much as they liked but that they needed to read at least half of the sentences for each state (i.e., they could choose to skip to the next stage without reading all the sentences). After reading, participants played a matching card game on the iPad for 1 minute and 30 second as a distraction task, followed by the free recall test that asked participants to type everything they could remember about the information they learned during the reading section on the iPad. The process (i.e., read and immediate recall, play a game, then free recall test) was repeated for the two states.

Results

Unless otherwise stated, dependent variables were analyzed with a 2 (Age) × 2 (Switch Cost) × 3 (Elaboration) repeated measures analysis of variance (ANOVA). Only statistically significant results are reported.

Item selection behaviors. Not all participants chose to read all the sentences. The mean number of sentences selected a function of Switch Cost and Elaboration is shown as in Table 3. The analysis revealed a main effect of Elaboration on the number of sentences ($M_{\text{LOW}} = 7.7$, $SE = 0.1$; $M_{\text{MED}} = 6.1$, $SE = 0.3$; $M_{\text{HI}} = 3.9$, $SE = 0.7$), $F(2, 44) = 25.99$, $p < .001$, which indicated that the participants selected fewer sentences to read as the elaboration level increased. Neither the main effect of Age ($F(1, 22) < 1$) nor Switch Cost ($F(1, 44) = 3.14$, $p = .09$) was significant.

Following the procedure used by Metcalfe and Kornell (2005), each sentence was assigned a numerical value representing its level of elaboration condition. The sentences in the low elaboration condition were assigned the value “1,” the ones in the medium condition were assigned the value “2,” and the ones in the high condition were assigned the value “3.” Because all participants read at least 12 of the sentences, only the first 12 sentences selected from each state were included in the analysis of selection behaviors. The 12 sentences were grouped into four groups of three for statistical analysis. Elaboration ranking was analyzed in a 2 (Age) × 2

(Switch Cost) × 4 (Order) repeated measures ANOVA. As shown in Figure 3, there was a main effect of Order, $F(3, 66) = 8.94$, $p < .001$, and participants in both age groups selected sentences that were short and containing less information first, and then moved to sentences that were relatively longer and containing more information. There was no main effect of Age ($F(1, 22) = 1.01$).

Reading time. Because participants had a choice in how much time they allocated to the task and the types of sentences they selected, I was interested in how the total reading time that participants spent studying the two states was distributed to sentences of different elaboration levels. On average, younger adults spent a total of 9.0 minutes (*SE* = 1.5; range = 3.3 - 20.5), and older adults spent a total of 9.8 minutes (*SE* = 1.1; range = 4.3 - 16.9). This age difference was not significant, $t(22) < 1$.

The proportion of total time allocated to reading sentences from the three elaboration levels under the two switch-cost conditions was calculated for each participant based on individual total reading time. The main effect of Elaboration was significant, $M_{\text{LOW}} = .11$, $SE = 0.01$; $M_{\text{MED}} = .24$, $SE = 0.01$; $M_{\text{HI}} = .15$, $SE = 0.02$, $F(2, 44) = 11.18$, $p < .001$. Follow-up tests showed that participants allocated more of their time to study sentences in the medium elaboration level than the low elaboration ($t(23) = 12.33$, $p < .001$) and high elaboration level ($t(23) = 2.69$, $p = .01$), whereas, there was no significant difference in the proportion of time allocated between the low and the high elaboration level ($t(23) < 1$). As shown in Figure 4, although the main effect of Switch Cost was not significant ($F(1, 22) < 1.3$), the effect of Elaboration interacted with Switch Cost, $F(2, 44) = 3.52$, $p = .04$, suggesting that relatively less time was allocated to the medium elaboration level under the large-switch-cost than the small-switch-cost condition.

To test the hypothesis that switch cost would increase perseverance, mean sentence reading time was analyzed for the participants who had read at least one sentence from each elaboration condition ($N_Y = 9$; $N_O = 8$).[1] As indicated in Figure 5, there was no effect of Switch Cost ($M_{\text{SMALL}} = 19.0$, $SE = 1.9$; M_{LARGE} 18.3, $SE = 1.3$; $F(1, 15) < 1$) nor Age nor an interaction between Switch Cost and Age. However, the results showed that reading times (in seconds) increased with sentence elaboration level, $M_{\text{LOW}} = 6.7$, $SE = 0.5$, $M_{\text{MED}} = 21.5$, $SE = 2.0$, $M_{\text{HI}} = 27.8$, $SE = 2.3$, $F(2, 30) = 87.73$, $p < .001$, but this effect did not vary with Age or Switch Cost.

Recall performance. Immediate recall was transcribed and then scored based on the propositional units. Delayed free recall was also scored using the same propositional scoring method. The recall score for each sentence was calculated as the total number of propositions recalled, and also the proportion of correct propositions recalled out of the available propositions. Interrater scoring was reliably similar, with correlations of .93 and .91 for immediate and delayed recall.

Immediate recall. There was variation in the total number of propositions recalled (range: 96 - 290). Although younger adults recalled numerically more propositions overall than older adults, $M_{\text{Y}} = 176.4$, $SE = 25.0$; $M_{\text{O}} = 151.8$, $SE = 15.7$, this age difference was not significant, $t(22) < 1$.

To find out whether there were age differences in recalling information from different elaboration conditions, an ANOVA was conducted on the proportion of number of propositions recalled out of the total in an individual protocol. There was a main effect of Elaboration, $M_{\text{LOW}} = .16$, $SE = 0.01$; $M_{\text{MED}} = .21$, $SE = 0.01$; $M_{\text{HI}} = .13$, $SE = 0.02$, $F(2, 44) = 2.77$, $p = .04$, indicating that participants recalled more information about sentences in the medium elaboration level than the low and the high level. This pattern is similar to the one found in the analysis on proportion of total reading time. A non-significant interaction between Age and Elaboration ($F(2, 44) < 1$) suggested that both younger and older adults recalled more ideas from medium-elaboration sentences.

Finally, the mean proportion of propositions recalled from sentences that was selected was analyzed based on the partial sample with data from each elaboration condition. The main effect of Elaboration was significant, $F(2, 30) = 77.55$, $p < .001$, such that participants produced almost perfect recall of low-elaboration sentences, but showed decreased performance as the sentence elaboration increased ($M_{\text{LOW}} = .93$, $SE = 0.01$; $M_{\text{MED}} = .75$, $SE = 0.03$; $M_{\text{HI}} = .65$, $SE = 0.03$). Again, a main effect of Age was found, $F(1, 15) = 6.01$, $p = .027$, with younger adults recalling more information from sentences they read than older adults ($M_{\text{Y}} = .82$, $SE = 0.03$; $M_{\text{O}} = .73$, $SE = 0.03$). The effect of Switch Cost was not significant.

Delayed recall. Similar to the results on immediate recall, younger adults recalled numerically more propositions overall than older adults at the end of each block, $M_{\text{Y}} = 49.5$, $SE = 8.8$; $M_{\text{O}} = 41.9$, $SE = 8.3$, but this age difference was not significant, $t(22) < 1$. The ANOVA on the total number of propositions recalled in delayed recall test showed that younger and older adults did not differ statistically ($M_{\text{Y}} = 8.2$, $SE = 1.4$; $M_{\text{O}} = 7.0$, $SE = 1.4$; $F(1, 22) < 1$). The main effect of Elaboration, $F(2, 44) = 5.71$, $p = .01$, suggested that participants recalled more information about sentences from the medium and high levels than the low-elaboration level ($M_{\text{LOW}} = 4.4$, $SE = 0.6$; $M_{\text{MED}} = 9.7$, $SE = 1.2$; $M_{\text{HI}} = 8.8$, $SE = 2.0$), but the difference between the medium and high levels was not significant, $t(23) < 1$. There was also a main effect of Switch Cost, $F(1, 22) = 4.64$, $p = .04$, suggesting that participants recalled more information about the topic they read when the texts were presented under the large-switch-cost condition than the small-switch-cost condition ($M_{\text{SMALL}} = 6.9$, $SE = 0.9$; $M_{\text{LARGE}} = 8.3$, $SE = 1.2$).

To investigate how much information was retained from what had learned, conditional recall for each participant was calculated as the mean proportion of propositions recalled out of the available propositions for the sentences that had been selected. Because not all participants selected sentences from the high elaboration level, the analysis was conducted on the partial sample consisting of participants who had read sentences from all elaboration levels. Consistent with the findings with the raw total score of propositions recalled, there was no significant age difference in the amount of information retained ($F(1, 15) < 1$), and participants retained more when they read texts in the large-switch-cost condition compare to the small-cost condition, $M_{\text{SMALL}} = 0.19$, $SE = 0.03$, $M_{\text{LARGE}} = 0.25$, $SE = 0.03$, $F(1, 15) = 9.00$, $p = .01$. However, as shown in Figure 6, this effect of Switch Cost was entirely due to the performance in the older group. The Age by Switch Cost interaction was marginally significant, $F(1, 15) = 4.07$, $p = .06$, such that older adults tended to retain more information from reading texts in the large-cost condition ($F(1, 7) = 16.85$, $p = .005$), whereas the Switch Cost had no effect on recall among younger adults ($F(1, 8) < 1$).

Relationships between the number of sentences selected, reading time, and recall performance. Taking advantage of this free foraging paradigm in which there were no constraints on which texts should be selected or the time limits for study, I was interested in whether there were positive relationships between the number of texts selected, time allocated to read, and the amount of information learned. Pearson product-moment correlation coefficients were computed, and results are shown in Table 4. The participants who selected more sentences allocated more time to read, and they recalled more information in the immediate recall and delayed recall test. People who recalled more information immediately after reading also retained more information. However, there was no significant correlation between the total reading time and the amount of information retained in delayed recall test.

Discussion

This study used a novel paradigm to examine how younger and older readers learn from multiple texts under no task constraints. The paradigm allowed to test two key ideas: (a) whether readers selected texts and allocated their study time as the RPL model suggested and (b) whether increasing switch cost led to longer perseverance in reading texts.

First of all, younger and older adults used similar strategies in selecting texts and allocating their time to study. Consistent with the RPL and IF model, people tended to select shorter and less informative sentences to read first, and then moved progressively to the more elaborative texts for information gain. It suggested that people were attempting to select texts that were within their region of proximal learning and also fitted their learning goals.

Participants also allocated relatively more of their study time to sentences in medium elaboration level compared to the ones in the low and high elaboration level, which implied that participants used the Goldilocks principle to allocating time to their perceived RPL, which is studying texts that are not too easy, not too difficult, but just right. The sentences in the low elaboration level were simple factoids that were easy to learn and memorize, which was supported by the findings on immediate recall that most participants produced almost perfect recalls on the simple sentences. On the other hand, sentences in the high elaboration level were long and contained large amount of information that required building multiple associations between idea units. Although the large passage of discourse certainly provide rich context, readers were slow in extracting ideas from the highly elaborative texts and were less likely to produce perfect recalls. Therefore, it could be argued that medium elaboration level sentences were at the “just right” level of difficulty, because they definitely required more time and effort to master than the low elaborative sentences, but they were easier than the high elaborative sentences and could get better payoff if the same amount of time was invested. In addition, the non-significant age differences also suggested that both younger and older readers perceived the medium-elaboration texts as their RPL, and allocated most of their time and effort to study those texts.

According to the IF model, when switch cost increases, learners should persist longer in reading texts compared to low switch cost environment in order to optimize their information gain. However, contrary to the hypothesis, switch cost did not have any effect on study time allocation or information gain. One possible reason could be the introduced time delay was not actually perceived as a cost. Dennis and Taylor (2006) argued that response time delay is common when using computer system and the Internet, and it takes away times that can be devoted to the actual accomplishment of a task. At the same time, delay increases the cost of doing a task by extending the time required to complete it. A noticeable point is that Dennis and Taylor (2006) developed these arguments based on the premise that time must be considered as a limited resource. Nevertheless, in the current experiment, the participants could spend as long as they wanted in learning about the topics, which may make them feel they had “infinite” time for study. Therefore, the time delay may not have created a cost for switching texts, and when the delay increased, the participants might not think the cost of information search increased.

Interestingly, large switch cost was found to help participants retain more of what they learned in the delayed free recall test than small switch cost, and older adults benefited more from this switch cost effect. Although the IF model cannot explain this finding, it could be argued that the participants may use the time delay as an opportunity to rehearse the previously learned information. The longer time delay during texts presentation might "force" the participants to slow down their learning pace and to rehearse what they had learned before learning a new piece of information.

Collectively, both younger and older adults behaved similarly in selecting and allocating time for studying texts, and these SRL behaviors were in line with RPL and IF model's predictions. Despite the possibility that the introduced time delay may not be perceived as a switch cost, results found in delayed recall suggested that the switch cost could still potentially impact the SRL behaviors. I wondered if the manipulation of switch cost became salient, whether learners adapt their selection and time allocation strategies to different switch costs. This was the focus of the second experiment.

Chapter 3

Experiment 2

The first experiment indicated that the foraging task with texts was feasible to investigate the age differences in SRL from reading. The goal of Experiment 2 was to further test the effect of switch cost. Based upon the findings in Experiment 1, five major modifications to the study design were made: (a) in order for the time delay to be perceived as a switch cost, a total study time limit was added for learning about the each topic; (b) to make it clear that the iPad had a "loading time" after selecting a text (i.e., the time delay), an animated sign was added to the "loading screen"; (c) the amount of time delay in that small- and the large-switch-cost condition was slightly changed to make sure the time range was the same; (d) the material set was reduced to lower the possible impact of fatigue during experiment so that participants could be more focused on learning; and (e) the delayed free recall test was changed to a cued recall test, because it was relatively easy to take and score.

Method

Participants. Fifty participants were recruited for this experiment. Two older adults were excluded from the analysis because they scored below the cutoff point of 26 out of 30 on MoCA test. The remaining participants were 24 younger (18-35 years of age) and 24 older (61-81 years of age) adults. The criteria for inclusion were the same as the ones used in Experiment 1, however both younger and older adults were recruited from the community and were paid for their participation. This recruiting method produced a sample of younger and older adults with a similar level in education (see Table 1). Just as in the first experiment, younger adults showed faster processing speed, higher level of working memory capacity, but lower level of print exposure than older adults. There was a marginally significant age difference in vocabulary, with older adults showing higher scores than younger adults. A notable finding was that even through there was no age difference in the level of education, older adults still outperformed on the test of print exposure as an indicator of being more experienced readers than younger adults.

Materials. The new set of materials consisted of 21 sentences about CT and 21 about RI, where for each state, each elaboration condition had seven sentences. Materials were the same as the ones used in Experiment 1 except that one sentence from each elaboration condition was deleted from each set, and one sentence in the medium elaboration level of CT was replaced with a new sentence. The deletion and replacement was based upon the immediate recall performance in Experiment 1 by deleting and replacing the ones that had the lowest recall score.

The number of proposition ($M_{CT} = 7.14$, $SE = 0.75$; $M_{RI} = 6.81$, $SE = 0.71$), the number of syllables ($M_{CT} = 32.19$, $SE = 3.53$; $M_{RI} = 31.57$, $SE = 3.22$), and the number of new concepts ($M_{CT} = 6.76$, $SE = 0.63$; $M_{RI} = 6.57$, $SE = 0.69$) did not differ across the new material set, $t(40) = .32$, $p = .75$, $t(40) = .13$, $p = .90$, and $t(46) = .20$, $p = .84$ respectively. Also, there were no State × Elaboration interactions for these three material characteristics, all $F(2, 36) < 1$.

Procedure. The sequence of events in the testing session was identical to that of the Experiment 1. However, as mentioned earlier, there were a number of changes made to the reading task. First of all, a time limit of 11 minutes was added to the reading session for each topic. This decision on the length of the time limit was based upon the performance of participants in Experiment 1. Among the nine participants who read at least 20 sentences from each set in Experiment 1 (five younger adults and four older adults), the total time on reading and immediate recalling ranged from 8.5 to 19.1 minutes ($M = 13.1$, $SE = 0.65$). The time limit of 11 minutes was chosen to accommodate to the new materials with three sentences fewer for each topic and to ensure that participants could read most of texts. The timer started as soon as participants pressed the start button and saw the selection page with 21 buttons, which represented the sentences for one state. Loading time (i.e., switch cost) and time spent on immediate recall was also counted in the time limit. Participants were asked to use their time to learn about the states until the time ran out. However, if the participant finished reading all the sentences within the time limit, the time left was shifted to the distraction task. In the small-switch-cost condition, 16 younger and 14 older adults finished learning all the sentences before the timer ran out, which was 62.5% of the total sample. Whereas in the large-switch-cost condition, nine younger adults and only one older adult finished earlier than the time limit, which was 20.8% of the participants.

In addition, an animated spinning wheel was added to the center of the "loading screen" after participants selected a sentence, in order to make the loading process on iPad salient. The time delay under the small-switch-cost condition was 0-2 seconds, and 6-8 seconds under the large-switch-cost condition. Because the study time limit was the same in both switch-cost conditions, participants had relatively less time to study when the sentences were presented under the large-switch-cost condition compared to the small-cost condition. To contextualize the difference, if a participant read all of the sentences, the functional time available was 10.65 minutes in the small-cost condition, and 8.55 minutes in the large-cost condition.

In contrast to the delayed free recall test in the first experiment, participants completed a fill-in-the-blank test after reading sentences about each state. The complete test can be found in Appendix B.

At the end of the testing, participants were also asked about whether they noticed the differences in the loading time of the iPad. If the participants did not notice, they gave general ratings on acceptability and annoying level without differentiating between the switch-cost conditions. If the participants said they noticed the differences, they were asked to explain how the loading times were different before rating the acceptability and annoying level of the loading times separately. Only five participants correctly figured out the differences in the loading time, which was that the loading time was differed between blocks but not within blocks. Whereas, the others thought the differences were results of longer texts taking longer time to load, which was an incorrect perception. Although the long time delay was rated as being less acceptable, $t(47) = 3.78$, $p < .001$ and more annoying than the short time delay, $t(47) = 3.32$, $p < .001$, the ratings might just reflect the participants' view on loading time generally existed in daily life's computer use, but not specific to the one manipulated in this experiment.

Results

Unless otherwise specified, data analysis was conducted in the same way as in the first experiment with a 2 (Age) × 2 (Switch Cost) × 3 (Elaboration) repeated measures ANOVA. Only statistically significant results are reported.

Item selection behaviors. Not all participants read all the sentences for each state, but every participant read some sentences in each elaboration condition. The mean number of sentences selected as a function of age, switch cost, and elaboration are shown in Table 5. The analysis revealed a main effect of Elaboration ($M_{\text{LOW}} = 6.6$, $SE = 0.1$; $M_{\text{MED}} = 6.8$, $SE = 0.1$; $M_{\text{HI}} = 5.8$, $SE = 0.2$), $F(2, 92) = 15.80$, $p < .001$, and a main effect of Switch Cost ($M_{\text{SMALL}} = 6.7$, $SE = 0.1$; $M_{\text{LARGE}} = 6.1$, $SE = 0.1$), $F(1, 46) = 58.65$, $p < .001$, indicating that the participants selected fewer sentences as the elaboration level increased, and read more sentences when the switch cost was small. The Elaboration × Switch Cost interaction, $F(2, 92) = 6.38$, $p = .003$, showed that the effect of sentence elaboration was more pronounced under the large-switch-cost relative to the small-switch-cost condition. Although the main effect of Age was not significant,

$F(1, 46) = 2.16$, the analysis yielded an Age × Switch Cost interaction, $F(1, 46) = 6.19$, $p = .016$, which suggested that older adults selected fewer sentences under the large-switch-cost condition than younger adults, $t(46) = 2.05$, $p = .04$, but not under the small-cost condition, $t(46) < 1$.

Using the same procedure of assigning numerical values to elaboration levels as in Experiment 1 to analyze the order of selection, the first 15 sentences selected by each participant were used to study the order of selection. The 15 sentences were grouped into five groups of three for statistical analysis. Elaboration ranking was analyzed in a 2 (Age) × 2 (Switch Cost) × 5 (Order) repeated measures ANOVA. As shown in Figure 7, there was a main effect of Order, $F(4, 184) = 16.85$, $p < .001$, which was consistent with the findings from Experiment 1 that participants selected shorter and easier sentences first, and then moved to longer and harder sentences, and this effect did not differ between age groups ($F(1, 46) < 1$). Different from Experiment 1, a marginally significant effect of Switch Cost $F(1, 46) = 3.61$, $p = .06$, indicated that participants were more likely to choose more informative sentences among their first 15 selections under large-switch-cost condition compared to small-cost condition ($M_{SMALL} = 1.80$, $SE = 0.03$; $M_{LARGE} = 1.84$, $SE = 0.04$). The Switch Cost effect was moderated by Age such that the Age × Switch Cost interaction, $F(1, 46) = 4.18$, $p = .04$, showed that older adults selected more highly elaborative sentences to read first in the large-switch-cost condition than in the small-cost, whereas younger adults did not behave differently across switch-cost conditions (Figure 8). This interaction suggested that older adults were more adaptive than younger adults in the large-switch-cost condition in seeking out richer patches.

Reading time. Recall that in contrast to the first experiment, there was a time limit in this experiment, and participants were asked to use their time to learn about the topics until the time ran out. Analysis on the total reading time spent learning about two states (reported in minutes) indicated that older adults (M_O = 7.7, SE = 0.4, range = 5.5 – 12.6) spent more time reading than younger adults (M_Y = 6.5, SE = 0.2, range = 4.5 – 8.1), $t(46) = 2.69$, $p = .01$. It is important to note that the number of younger adults who finished reading before the time limit was larger than the one of older adults, particularly in the large-switch-cost condition. This was probably the reason to the age difference in total reading.

Because of the difference in the functional time available between the small- and large-switch-cost conditions, the proportion of total time allocated to reading sentences from the three elaboration levels was calculated in each switch-cost condition. A main effect of Elaboration, M_{LOW} = .19, SE = 0.005, M_{MED} = .40, SE = 0.01, M_{HI} = .41, SE = 0.01, $F(2, 92) = 173.9$, $p < .001$, suggested that the proportion of time allocated to read sentences in the low-elaboration level was significantly smaller than in both the medium-, $t(47) = 25.88$, $p < .001$, and the high-elaboration condition, $t(47) = 16.34$, $p < .001$, whereas there was no difference between the medium- and high-elaboration conditions ($t(47) < 1$). As shown in Figure 9, the significant interaction between Switch Cost and Elaboration, $F(2, 92) = 10.79$, $p < .001$, indicated that participants allocated more of their time in reading the low- and medium-elaboration sentences under the large-switch-cost condition relative to the small-cost condition ($t(47)$s > 2.7, $p < .01$), but they allocated relatively less of their time to read high-elaboration sentences in the large-switch-cost than the small-cost condition ($t(47) = 3.80$, $p < .001$). This interaction implied that the large switch cost might create a larger time pressure for study than the small switch cost did, which made learners to shift their RPL to texts that were less difficult.

To examine the effect of switch cost on perseverance, an ANOVA was conducted on the mean sentence reading time. Mean reading time of younger and older adults for the three elaboration conditions is reported in seconds in Table 6. Reading time increased with sentence elaboration level, $F(2, 92) = 138.93$, $p < .001$. There was also an age difference, $F(1, 46) = 6.85$, $p = .01$, with older adults spending more time in reading a single sentence. This age difference marginally varied with Elaboration, $F(2, 92) = 2.69$, $p = .07$, showing that the difference was more pronounced as sentence elaboration increased.

Figure 10 shows that a main effect Switch Cost, indicating that participants spent longer time reading each sentence under the large-switch-cost condition compared to the small-switch-cost condition, $M_{SMALL} = 11.20$, $SE = 0.46$; $M_{LARGE} = 11.92$, $SE = 0.56$, $F(1, 46) = 5.95$, $p = .02$. Indeed, large switch cost led to numerically longer persistence in reading sentences at each elaboration level. The effect Switch Cost did not vary with Age, suggesting that both younger and older adults persisted longer when sentences were presented in the large-switch-cost condition than the small-switch-cost condition.

Recall performance. As in the first experiment, immediate recall was transcribed and then scored based on the propositional units. When scoring the fill-in-blank test as a measure of delayed cued recall, every blank was worth two points. Perfect recall or recall of the equivalent meaning was given the full score, and partially correct answer was given a score of one point. To study how much information was retained from learning, the delayed recall for each participant was calculated as the mean conditional recall based on the sentences selected during reading. Interrater reliability of scoring was .95 for immediate recall and .98 for delayed recall.

Immediate recall. Younger adults demonstrated better text memory in terms of the total number of propositions recalled, $M_Y = 204.9$, $SE = 5.0$, $M_O = 167.1$, $SE = 5.8$, $t(46) = 4.91$, $p < .001$.

The analysis on the proportion of propositions recalled out of the total in an individual protocol yielded a main effect of Switch Cost, $M_{SMALL} = .17$, $SE = 0.002$, $M_{LARGE} = .16$, $SE =$

0.002, $F(1, 46) = 4.74$, $p = .035$, suggesting participants recalled more information under the small-switch-cost condition than the large-cost condition. There was also a significant age difference, with younger adults recalled more from each sentence than older adults did, $M_{\mathrm{Y}} = .82$, $SE = 0.02$, $M_{\mathrm{O}} = .72$, $SE = 0.02$, $F(1, 46) = 19.68$, $p < .001$. A main effect of Elaboration, $M_{\mathrm{LOW}} = .10$, $SE = 0.002$, $M_{\mathrm{MED}} = .19$, $SE = 0.003$, $M_{\mathrm{HI}} = .21$, $SE = 0.005$, $F(2, 92) = 132.1$, $p < .001$, suggested that the number of propositions recalled increased as the sentence elaboration level increased, and an interaction between Switch Cost and Elaboration, $F(2, 92) = 12.22$, $p < .001$, indicated that the effect of Switch Cost was significant only for recalling sentences from the high-elaboration condition, $M_{\mathrm{SMALL\_HI}} = .22$, $SE = 0.005$, $M_{\mathrm{LARGE\_HI}} = .19$, $SE = 0.008$, $t(47) = 3.90$, $p < .001$, whereas there were no differences in recalling sentences from the low- and medium-elaboration between the two switch-cost conditions ($M_{\mathrm{SMALL\_LOW}} = .10$, $SE = 0.003$; $M_{\mathrm{LARGE\_LOW}} = .10$, $SE = 0.003$; $M_{\mathrm{SMALL\_MED}} = .19$, $SE = 0.004$; $M_{\mathrm{LARGE}} = .19$, $SE = 0.003$; ts < 1).

Because participants read fewer sentences when the switch cost was large, to investigate the information gain from individual texts, the mean proportion of propositions recalled from sentences that were selected was analyzed. Mean proportional immediate recall of younger and older adults for the three elaboration levels is shown in Table 7. There was a main effect of Elaboration, $F(2, 92) = 311.08$, $p < .001$, where less of the information was recalled from a sentence as its elaboration level increased. Participants showed better recall performance when sentences were displayed with a large switch cost ($M_{\mathrm{LARGE}} = .79$, $SE = 0.01$) than the small switch cost ($M_{\mathrm{SMALL}} = .75$, $SE = 0.02$), $F(1, 46) = 9.21$, $p = .004$. A main effect of Age was found, $F(1, 46) = 19.68$, $p < .001$, with younger adults recalling more of the information from a sentence. This age effect varied with Elaboration in an Age × Elaboration interaction, $F(2, 92) =$

5.11, $p = .01$, such that recall performance among older adults was more compromised than younger adults as the sentence elaboration level increased.

Delayed recall. In terms of the raw score from the delayed fill-in-the-blank test, whose maximum score was 82, younger adults performed better than older adults, $M_Y = 51.3$, $SE = 2.0$, $M_O = 43.9$, $SE = 2.0$, $t(46) = 2.62$, $p = .01$. Because some participants did not read all the sentences, I calculated the conditional delayed recall for each participant based on only the sentences that were selected. The analysis revealed a main effect of Elaboration, $F(2, 92) = 5.29$, $p = .007$, indicating participants retain relatively better memory of high elaborative sentences than low and medium elaborative sentences ($M_{LOW} = .60$, $SE = 0.02$; $M_{MED} = .61$, $SE = 0.02$; $M_{HI} = 0.66$, $SE = 0.02$), and this effect did not vary with Age, $F(2, 92) < 1$. The benefit of Switch Cost in immediate recall was sustained, $F(1, 46) = 14.17$, $p < .001$; that is, the large-switch-cost condition during sentence presentation produced better delayed memory performance ($M_{SMALL} = .59$, $SE = 0.02$; $M_{LARGE} = .67$, $SE = 0.02$). Older adults performed a little bit worse than younger adults, $M_Y = .66$, $SE = 0.03$, $M_O = .59$, $SE = 0.03$, $F(1, 46) = 3.58$, $p = .065$, but as indicated in Figure 11, there was a significant interaction between Age and Switch Cost, $F(1, 46) = 4.61$, $p = .04$. The follow-up *t* tests indicated that older adults retained more information from reading texts in the large-cost condition, $t(23) = 4.13$, $p < .001$, whereas the Switch Cost had no effect on recall among younger adults ($t(23) = 1.16$). Furthermore, the age difference in recall was eliminated when texts were presented under the large-switch-cost condition, $t(46) = 2.76$, $p = .01$.

Discussion

Similar to the first experiment, the results supported the RPL and IF model in terms of selection behavior. What differed from the previous experiment was that the switch cost had a strong effect on study time allocation and immediate recall of texts, which supported the hypothesis formed based on IF model. Consistent with the model, increased switch cost led to increased perseverance and decreased number of text selection. This suggested that a time pressure did make people perceive the time delay in getting a text as a switch cost when they selected to read multiple texts. It also indicated that people adjusted their time allocation strategy to compensate the increased switch cost by investing more time in learning and less switching among information sources. The findings that increased switch cost led to better text memory further implied that learners were not simply slowed down by the high switch cost, but they gained more information from individual texts, suggesting that learners were adaptive in trying to maximizing their information gain with increased switch cost.

Interestingly, only a small number of participants detected the differences in the switch cost when reading the two topics, which suggested that most people were not consciously aware of the reduced time available for reading the texts under the large-switch-cost condition. One possible reason could be that although the time delay in the large-switch-cost condition was longer relative to the small-switch-cost condition, the longer delay was still "acceptable" for the learners. In the literature of human-computer interaction, acceptable time delay in loading a webpage is defined as time cost that should not trigger web users' dissatisfaction (Dennis & Taylor, 2006). Several studies attempted to quantify the range of acceptable time delays, and on average, researchers agreed that the range is bounded by a short time delay of two seconds or less and a long delay of 8-10 seconds (Galletta, Henry, McCoy, & Polak, 2004; Nielsen, 1994). In the current study, the introduced time delay in the large-switch-cost condition was within that acceptable range. Therefore, participants tolerated the increased switch cost by adapting their information search behaviors.

Additionally, older adults were more likely than younger adults to change their selection strategies under different switch cost condition, in which they gave priority to learning texts with more information first in the large-switch-cost condition (cf. Figure 8). Although it is hard to produce perfect recall after reading highly elaborative texts, the texts contain more ideas units that can provide adequate contextual supports for readers to process at discourse level. Shake et al. (2009) found that after reading equal number of sentences in different elaboration levers, older adults were more likely to recall information from high elaborative sentences. They suggested that high elaborative texts were beneficial to older adults because discourse processing is relatively preserved with age and older adults show greater tendency to engage this processing. Although in the current study, both younger and older learners recalled more information from texts in high-elaboration condition, older people may still perceive high elaborative texts as being more beneficial. Therefore, when the switch cost increases, older readers are more likely to select more informative sentences first.

Consistent with Experiment 1, older adults were also found to have better retention when they learned in the large-switch-cost environment. Besides the possible mechanism discussed in the first experiment, it could also be the result of difference in the number of sentences selected during study session, which was that older adults selected significantly fewer sentences to read under large switch cost than their younger counterparts, but there was no age difference under the small-switch-cost condition. Assuming equal amount of cognitive resources was available, it could be easier to retain most of the learned information if fewer texts were studied initially. Another mechanism could be that the information pieces were better encoded and stored to memory during study session when they were presented in large switch cost. The prolonged study time led to better immediate recall of information from working memory, and it might also help rehearse and consolidate it into long-term memory.

Chapter 4

General Discussion

Taken together, the proposed paradigm was capable to investigate what strategies people used to learn from a free-exploring reading environment. As mentioned in the introduction, very few studies on reading and aging gave readers the options to select the texts they wanted to read. The paradigm used in this research allowed participants freely select and allocate their time to the texts based on the amount of information. More importantly, this paradigm tested the influence of switch cost on text selection and reading time allocation, which is a unique prediction from the IF perspective.

The results of the two experiments indicated that when learner were faced with multiple texts, they were able to adapt their selection and time allocation based on the amount of information in the texts and the switch cost in the learning environment. Consistent with earlier work in SRL (Price, Hertzog, & Dunlosky, 2010; Price & Murray, 2012), younger and older adults used the same strategy in selecting study items. More importantly, this research provided empirical evidence in applying the IF model to investigate learners' SRL behaviors, particularly how to gain information from reading. Metcalfe and Jacobs (2010) suggested a relation between people's SRL strategies and animal foraging. They also indicated that this analogy may allow future studies to explore the variables, which have been well investigated in animal foraging but not in human learning, in human study selection and time allocation. Specifically, the variable examined in this research was the switch cost.

Although the effects of switch cost were minimal in the first experiment, in the second experiment learners were able to adjust their strategies to different switch cost if their resources, for instance time, became limited. Despite people's feelings that large switch cost in information searching was less acceptable and more annoying than small switch cost, large switch cost was found to be beneficial to learning in terms of increasing perseverance and promoting text memory. Prior studies found that decision makers persisted longer in reading web pages in large switch cost relative to small switch cost (Dennis & Taylor, 2006; Taylor, Dennis, & Cummings, 2013), however, whether the amount of information gain was also increased in large switch cost was not measured in those studies. The findings from the current research helped to solve the question, indicating learners gained more information when persisted longer in reading.[2] In other words, learners followed the assumption of the IF model that information foragers act to maximize information gain (Pirolli & Card, 1999).

This effect of switch cost can potentially be used in educational settings to improve learning. For example, when students are learning a particular topic, instructors can intentionally make it longer for students to access the reading materials. It might encourage students to allocate more of their time and read the texts more carefully such that they can learn more information and gain better memory retention compared to the situation where students can easily access the learning materials.

More interestingly, it seems that compared to younger adults, older learners were more sensitive to the switch cost, shown by their earlier preference of selecting highly informative texts when there was a large switch cost. Also, large switch cost was particularly beneficial to older adults in terms of learning retention. It is possible that older adults were aware of their slowing in reading speed and disadvantage in text memory, so they might be more sensitive to the changes in the resources that can impact their learning. Therefore, older adults might perceive the reduction in the time available for learning by the increased switch cost as more salient than the younger adults did. In this case, it would be necessary for the older adults to adapt their strategies to select the texts that they may benefit more. Future studies are needed to further investigate the age differences in response to different switch cost in reading environments.

A limitation of this research was that the evidence could only speak to the point that readers were adaptive in selecting texts and allocating their study time, but it is not clear whether these decisions were optimal. In order to assess the optimality according to the IF model, information gain function must be gained from each learner. Hartley et al. (1994) controlled the presentation speed of texts so that they could measure the number of ideas recalled with given reading time for each individual, which allowed them to estimate the gain function of information learned by reading time. However, in this research, because of the nature of the free foraging task, I could not control the reading time allocated to each text, which made it impossible to estimate the information gain function for each reader. It would be interesting to test this idea in future studies in which the information gain function is calculated for each reader, and then to examine whether readers are optimal in switching texts and allocating their time in different switch-cost conditions.

Collectively, the results from the two experiments favor the RPL and IF model for people's selection behavior in studying an unfamiliar topic from exploring multiple texts. Only under a moderate time pressure, the time delay in getting information could be perceived as a switch cost, and learners could adapt their learning strategies in order to achieve the learning goals. Higher switch cost led to longer persistence in gaining information and better memory, and older adults reacted differently to the switch cost by selecting richer information pieces to learn first and retaining better text memory in large switch cost learning environment.

References

Bopp, K. L., & Verhaeghen, P. (2005). Aging and verbal memory span: A meta-analysis. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *60*, 223-233. doi: 10.1093/geronb/60.5.P223

Charnov, E. L. (1976). Optimal foraging: The marginal value theorem. *Theoretical Population Biology*, *9*, 129-136.

Chin, J., Payne, B., Battles, A., Fu, W. T., Morrow, D., & Stine-Morrow, E. (2012). Information foraging in the unknown patches across the life span. In *Proceedings of the 34th Annual Meeting of the Cognitive Science Society* (pp. 1404-1409). Sapporo, Japan: Cognitive Science Society.

Dennis, A. R., & Taylor, N. J. (2006). Information foraging on the web: The effects of "acceptable" Internet delays on multi-page information search behavior. *Decision Support Systems*, *42*, 810–824. doi: 10.1016/j.dss.2005.05.032

Dunlosky, J., & Connor, L. T. (1997). Age differences in the allocation of study time account for age differences in memory performance. *Memory and Cognition, 25*, 691-700. doi: 10.3758/BF03211311

Dunlosky, J., & Hertzog, C. (1997). Older and younger adults use a functionally identical algorithm to select items for restudy during multitrial learning. *The Journals of Gerontology Series B: Psychological Science and Social Science, 52*, 178-186. doi: 10.1093/geronb/52B.4.P178

Dunlosky, J., & Thiede, K. W. (1998). What makes people study more? An evaluation of factors that affect self-paced study. *Acta Psychologia*, *98*, 37-56. doi: 10.1016/S0001-6918(97)00051-6

Ekstrom, R. B., French, J. W., & Harmon, H. H. (1976*). Manual for the Kit of Factor-Referenced Cognitive Tests.* Princeton. NJ: Educational Testing Service.

Fu, W.-T., & Pirolli, P. (2007). SNIF-ACT: A cognitive model of user navigation on the World Wide Web. Human-Computer Interaction, 22, 355-412.

Galletta, D. F., Henry, R., McCoy, S., & Polak, P. (2004). Web site delays: How tolerant are users? *Journal of the Association for Information Systems*, *5*, 1-28.

Hartley, J. T., Stojack, C. C., Mushaney, T. J., Annon, T. A. K., & Lee, D. W. (1994). Reading speed and prose memory in older and younger adults. *Psychology and Aging*, *9*, 216–223.

Hills, T. T. (2006). Animal foraging and the evolution of goal-directed cognition. *Cognitive Science*, *30*, 3-41. doi: 10.1207/s15516709cog0000_50

Hills, T. T., Jones, M. N., & Todd, P. M. (2012). Optimal foraging in semantic memory. *Psycholological Review*, *119*, 431-440. doi: 10.1037/a0027373

Johnson, R. (2003). Aging and the remembering of text. *Developmental Review*, *23*, 261–346. doi: 10.1016/S0273-2297(03)00009-1

Kintsch, W., & van Dijk, T. A. (1978). Toward a model of text comprehension and production. *Psychological Review, 85*, 363-394.

Kornell, N., & Metcalfe, J. (2006). Study efficacy and the region of proximal learning framework. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*, 609-622. doi: 10.1037/0278-7393.32.3.609

Mata, R., Wilke, A., & Czienskowski, U. (2009). Cognitive aging and adaptive foraging behavior. *Journal of Gerontology*, *64B*, 474-481. doi: 10.1093/geronb/gbp035

Mata, R., Wilke, A., & Czienskowski, U. (2013). Foraging across the life span: Is there a reduction in exploration with aging? *Frontiers in Neuroscience*, *7*. doi: 10.3389/fnins.2013.00053

Metcalfe, J. (2002). Is study time allocated selectively to a region of proximal learning? *Journal of Experimental Psychology: General*, *131*, 349–363. doi: 10.1037//0096-3445.131.3.349

Metcalfe, J., & Jacobs, W. J. (2010). People's study time allocation and its relation to animal foraging. *Behavioural Processes*, *83*, 213–21. doi: 10.1016/j.beproc.2009.12.011

Metcalfe, J., & Kornell, N. (2003). The dynamics of learning and allocation of study time to a region of proximal learning. *Journal of Experimental Psychology. General*, *132*, 530–42. doi: 10.1037/0096-3445.132.4.530

Metcalfe, J., & Kornell, N. (2005). A Region of Proximal Learning model of study time allocation. *Journal of Memory and Language, 52*, 463-477. doi: 10.1016/j.jml.2004.12.001

Nasreddine, Z. S., Phillips, N. A., Bedirian, V., Charbonneau, S., Whitehead, V., Collin, I., Cummings, J. L., & Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of American Geriatrics Society*, *53*, 695-699.

Neilsen, J. (1994). *Usability engineering*. San Diego, CA: Academic Press.

Nelson, T. O., & Narens, L. (1990). Metamemory: A theoretical framework and some new findings. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 26, pp. 125-173). San Diego, CA: Academic Press.

Pirolli, P., & Card, S. (1999). Information foraging. *Psychological Review*, *106*, 643–675. doi:10.1037//0033-295X.106.4.643

Price, J., Hertzog, C., & Dunlosky, J. (2010). Self-regulated learning in younger and older adults: Does aging affect metacognitive control? *Neuropsychology, Development, and Cognition. Section B, Aging, Neuropsychology and Cognition*, *17*, 329-359. doi: 10.1080/13825580903287941

Price, J., & Murray, R. G. (2012). The region of proximal learning heuristic and adult age differences in self-regulated learning. *Psychology and Aging*, *27*, 1120-1129. doi: 10.1037/a0029860

Salthouse, T. A. (1991). Mediation of adult age differences in cognition by reductions in working memory and speed of processing. Psychological Science, 2, 179-183.

Salthouse, T. A. (2004). What and when of cognitive aging. *Current Directions in Psychological Science*, *13*, 140-144. doi: 10.1111/j.0963-7214.2004.00293.x

Salthouse, T. A., & Ferrer-Caja, E. (2003). What needs to be explained to account for age-related effects on multiple cognitive variables? *Psychology and aging*, *18*, 91. doi: 10.1037/0882-7974.18.1.91

Shake, M. C., Noh, S. R., & Stine-Morrow, E. A. L. (2009). Age differences in learning from text: Evidence for functionally distinct text processing systems. *Applied Cognitive Psychology, 23*, 561-578. doi: 10.1002/acp.1494

Son, L. K., & Metcalfe, J. (2000). Metacognitive and control strategies in study-time allocation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 204-221. doi: 10.1037/0278-7393.26.1.204

Stanovich, K. E., & West, R. F. (1989). Exposure to print and orthographic processing. *Reading Research Quarterly*, *24*, 402-433.

Stephens, D.W., & Krebs, J.R. (1986). *Foraging theory*. Princeton, NJ: Princeton University

Press.

Stine, E. A. L., & Hindman, J. (1994). Age differences in reading time allocation for propositionally dense sentences. *Aging and Cognition*, *1*, 2-16.

Stine-Morrow, E. A. L., Miller, L. M. S., Gagne, D. D., & Hertzog, C. (2008). Self-regulated reading in adulthood. *Psychology and Aging, 23*, 131-153. doi: 10.1037/0882-7974.23.1.131

Stine-Morrow, E. A. L., Shake, M. C., Miles, J. R., & Noh, S. R. (2006). Adult age differences in the effect of goals on self-regulated sentence processing. *Psychology and Aging, 21*, 790-803. doi: 10.1037/0882-7974.21.4.790

Taylor, N. J., Dennis, A. R., & Cummings, J. W. (2013). Situation normality and the shape of search: The effects of time delays and information presentation on search behavior. *Journal of the American Society for Information Science and Technology*, *64*, 909-928. doi: 10.1002/asi.22782

Thiede, K. W., & Dunlosky, J. (1999). Toward a general model of self-regulated study: An analysis of selection of items for study and self-paced study time. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 1024-1037. doi: 10.1037/0278-7393.25.4.1024

Verhaeghen, P. (2003). Aging and vocabulary score: A meta-analysis. *Psychology and Aging*, *18*, 332-339. doi: 10.1037/0882-7974.18.2.332

Zimmerman, B. J. (2001). Theories of self-regulated learning and academic achievement: An overview and analysis. In B. J. Zimmerman & D. H. Schunk (Eds.), *Self-regulated learning and academic achievement: Theoretical perspectives* (pp. 1-36). Mahwah, NJ: Lawrence Erlbaum Associates.

Footnotes

[1]All the participants read at least some of the sentences in the low and medium elaboration conditions, but three younger adults and four older adults did not read any of the sentences in the high elaboration condition. Therefore, the ANOVA was conducted only with the data from the participants who had read at least one sentence from each elaboration condition.

[2]The efficiency of information gain, measured by the amount of reading time required to recall a proposition in immediate recall, was not affected by the switch cost, $F < 1$.

Tables and Figures

Table 1

Means (Standard Errors) of Sample Characteristics of Young and Older Adults in Experiment 1 and 2

	Experiment 1				Experiment 2			
	Young (N=12)	Older (N=12)	*t*-test (*df*=22)	p value	Young (N=24)	Older (N=24)	*t*-test (*df*=46)	p value
Age	19.83	64.75			24.08	68.96		
	(0.30)	(0.49)			(0.97)	(1.13)		
Education	14.17	16.17	-2.60	.02	15.71	15.06	1.30	.20
	(0.26)	(0.73)			(0.35)	(0.35)		
Vocabulary	15.20	19.90	-1.63	.12	16.89	20.31	-1.93	.06
	(1.70)	(2.32)			(1.23)	(1.27)		
Speed	13.42	9.08	5.79	< .001	12.92	9.33	5.21	< .001
	(0.63)	(0.40)			(0.45)	(0.42)		
WM	4.60	3.68	2.96	.01	4.58	3.65	2.96	.01
	(0.27)	(0.15)			(0.26)	(0.18)		
PE	3.92	11.58	-5.91	< .001	5.42	10.33	-4.84	< .001
	(0.53)	(1.18)			(0.61)	(0.82)		

Note. WM = Working Memory; PE = Print Exposure.

Table 2

Sample reading materials for Connecticut

Elaboration level	Sample sentence
Low	Samuel Colt was a gunsmith from Connecticut.
Medium	The cathedral of St. Joseph in Hartford is noted for its carillon bells, as well as 24 spectacular stained-glass windows that line the nave.
High	For 17 years, Mark Twain occupied a peach-colored Victorian Gothic house in Hartford, which is now open to the public and features personal items including an oak mantel brought back from Scotland.

Table 3

Mean (Standard Errors) Number of Sentences Selected as a Function of Sentence Elaboration and Age in the Small- and Large-Switch-Cost Condition in Experiment 1

	Elaboration condition						Overall	
	Low		Medium		High			
Age group	Small	Large	Small	Large	Small	Large	Small	Large
Younger	7.7	7.9	6.4	5.8	4.0	3.8	6.0	5.9
	(0.2)	(0.2)	(0.5)	(0.6)	(1.0)	(1.1)	(0.5)	(0.5)
Older	7.8	7.5	6.4	5.8	3.8	3.9	6.0	5.8
	(0.2)	(0.2)	(0.5)	(0.6)	(1.0)	(1.1)	(0.5)	(0.5)

Table 4

Summary of Intercorrelations, Means, and Standard Deviations for the TNSS, TRT, TPIR, and TPDR in Experiment 1

	Correlations			*M*	*SD*
	1	2	3		
1. TNSS				35.5	10.2
2. TRT	**.71**			563.8	267.1
3. TPIR	**.94**	**.65**		164.1	71.9
4. TPDR	**.63**	.29	**.74**	45.7	29.2

Note. SNT = total number of sentences selected; TRT = total reading time; TPIR = total number of propositions in immediate recall; TPDR = total number of propositions in delayed recall. Correlations in bold are significant at $p < .01$.

Table 5

Mean (Standard Errors) Number of Sentences Selected as a Function of Sentence Elaboration and Age in the Small- and Large-Switch-Cost Condition in Experiment 2

	Elaboration condition						Overall	
	Low		Medium		High			
Age group	Small	Large	Small	Large	Small	Large	Small	Large
Younger	6.9	6.5	6.9	6.7	6.4	5.8	6.7	6.5
	(0.1)	(0.2)	(0.1)	(0.2)	(0.3)	(0.4)	(0.1)	(0.1)
Older	6.8	6.3	7.0	6.6	6.3	4.8	6.7	5.9
	(0.1)	(0.2)	(0.1)	(0.2)	(0.3)	(0.4)	(0.1)	(0.1)
Overall	6.8	6.4	6.9	6.7	6.3	5.3		
	(0.1)	(0.2)	(0.1)	(0.1)	(0.2)	(0.3)		

Table 6

Mean Reading Time (seconds) for Young and Older Adults as a Function of Sentence Elaboration in Experiment 2

	Elaboration condition			
Age group	Low	Medium	High	Overall
Younger	5.50 (0.23)	11.05 (0.69)	14.26 (1.30)	10.27 (0.70)
Older	6.51 (0.23)	13.93 (0.69)	18.10 (1.30)	12.85 (0.70)
Overall	6.00 (0.16)	12.49 (0.49)	16.18 (0.92)	

Table 7

Mean proportion of immediate recall performance for Young and Older Adults as a Function of Sentence Elaboration in Experiment 2

	Elaboration condition			
Age group	Low	Medium	High	Overall
Younger	.96 (0.01)	.80 (0.02)	.69 (0.02)	.82 (0.02)
Older	.90 (0.01)	.69 (0.02)	.56 (0.02)	.72 (0.02)
Overall	.93 (0.01)	.74 (0.02)	.63 (0.02)	

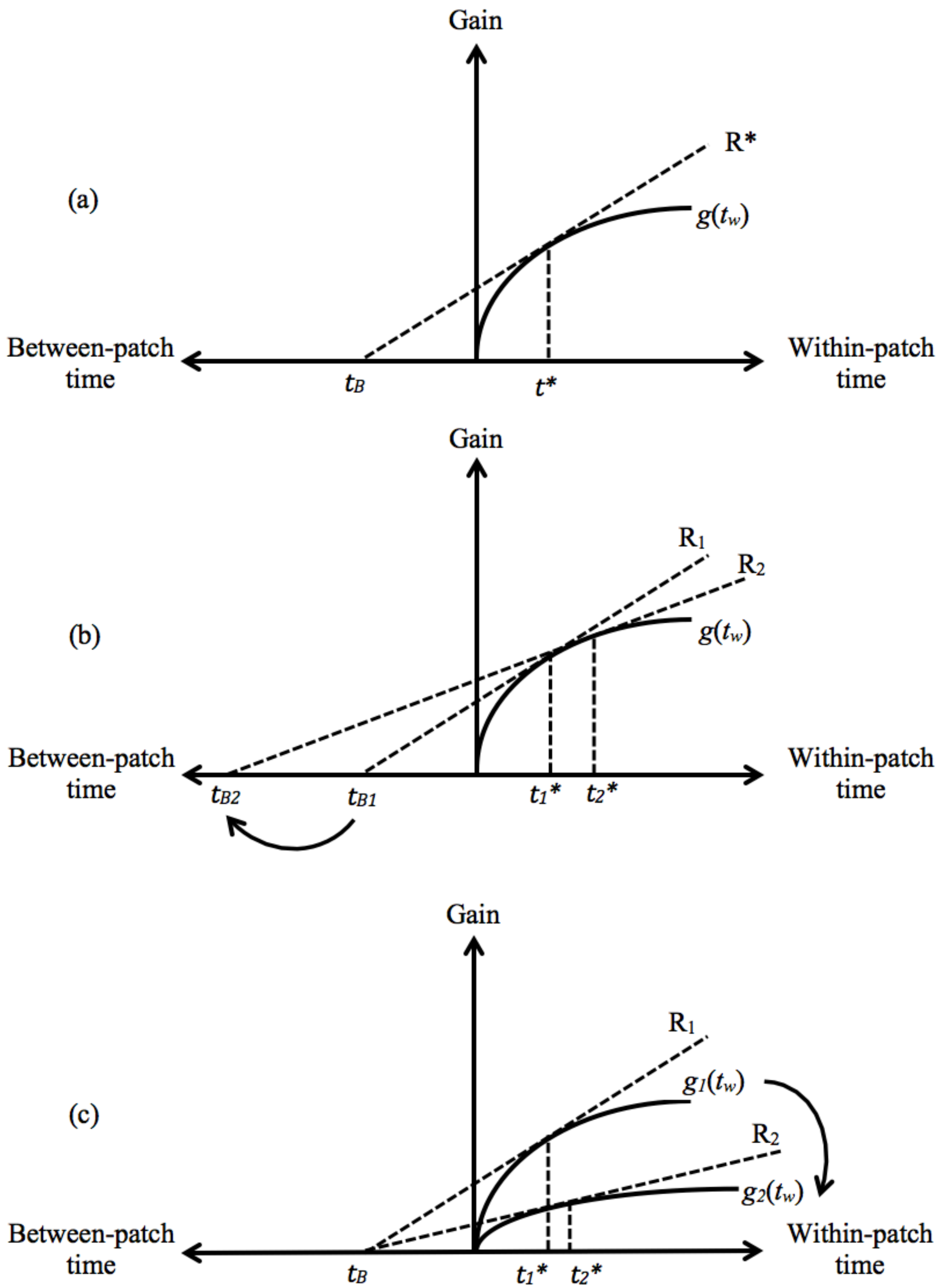

Figure 1. Demonstration of Charnov's marginal value theorem that suggests (a) the optimal within-patch foraging time, t^*, under basic situation, (b) the effect of between-patch switch cost, t_B, on t^*, and (c) the effect of within-patch gain, g, on t^* (adapted from Pirolli & Card, 1999).

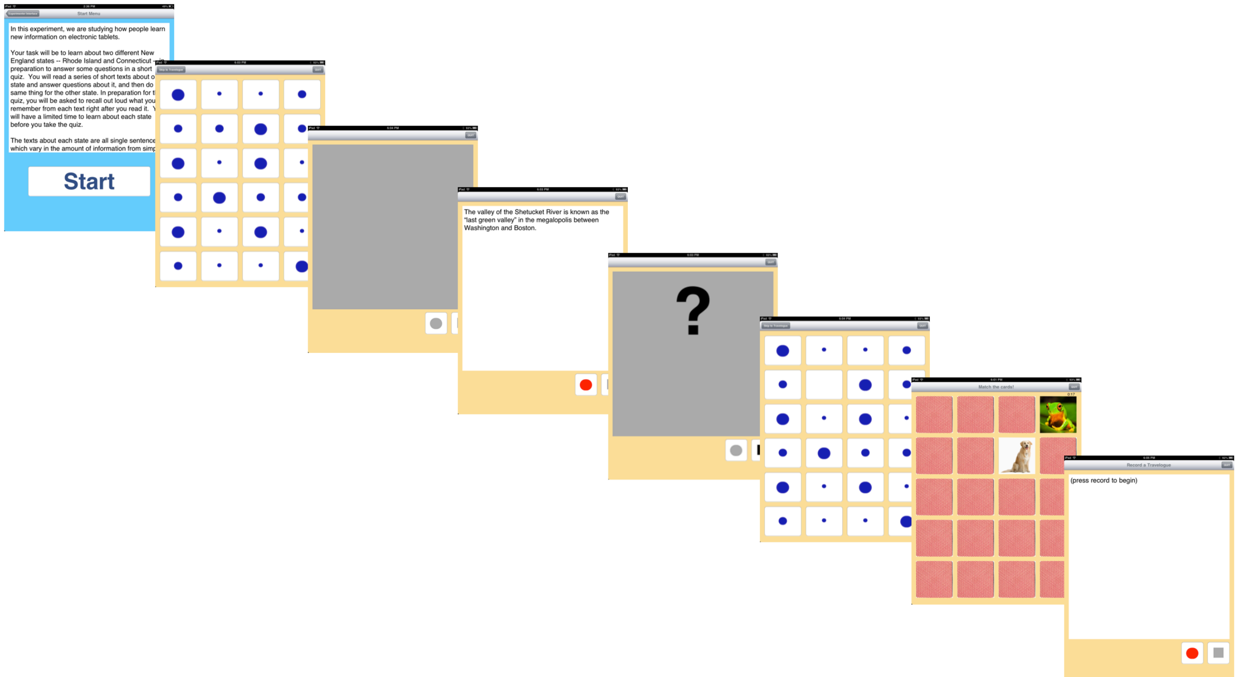

Figure 2. Procedure of reading task on iPad

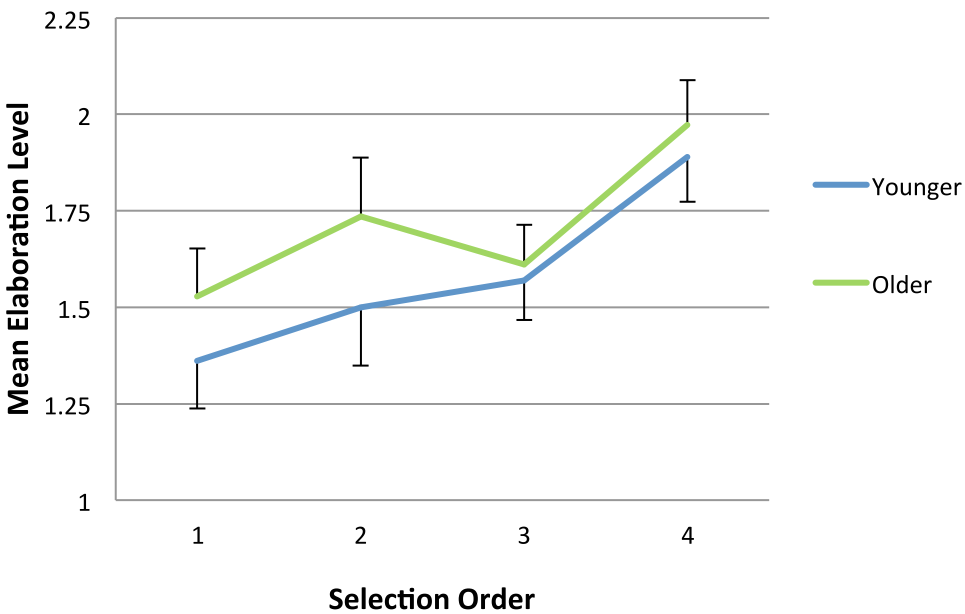

Figure 3. Mean elaboration level of younger and older readers' first 12 selections grouped into 4 groups, collapsed across switch-cost conditions in Experiment 1. Error bars represent standard errors.

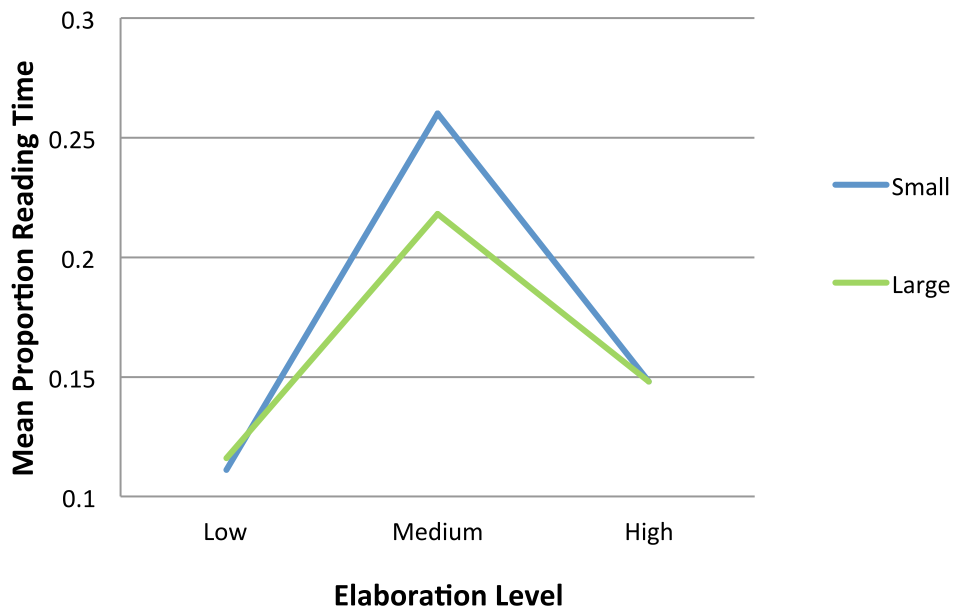

Figure 4. Mean proportion of total reading time allocated to reading sentences from the three elaboration levels in the small- and large-switch-cost condition in Experiment 1.

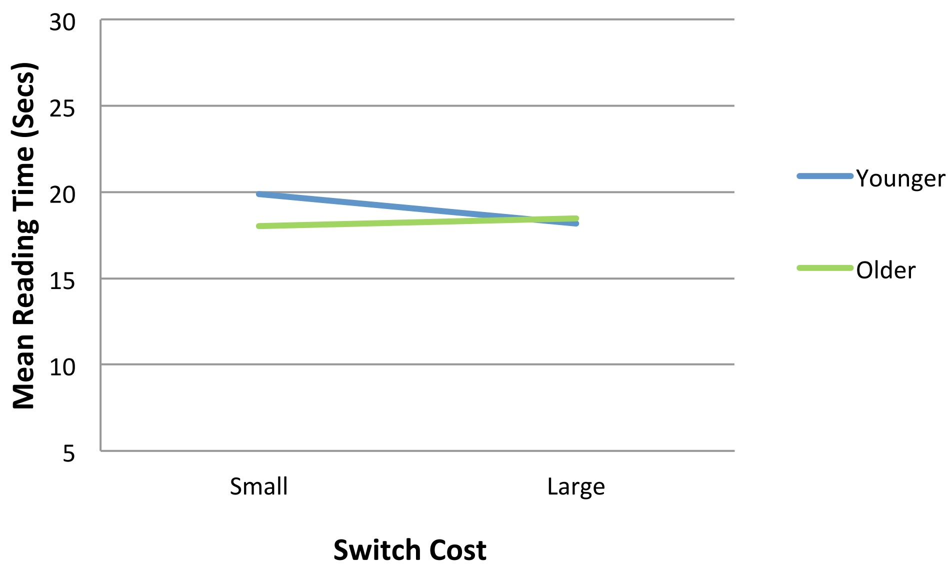

Figure 5. Mean reading time of younger and older readers as a function of switch cost, collapsed across elaboration conditions in Experiment 1.

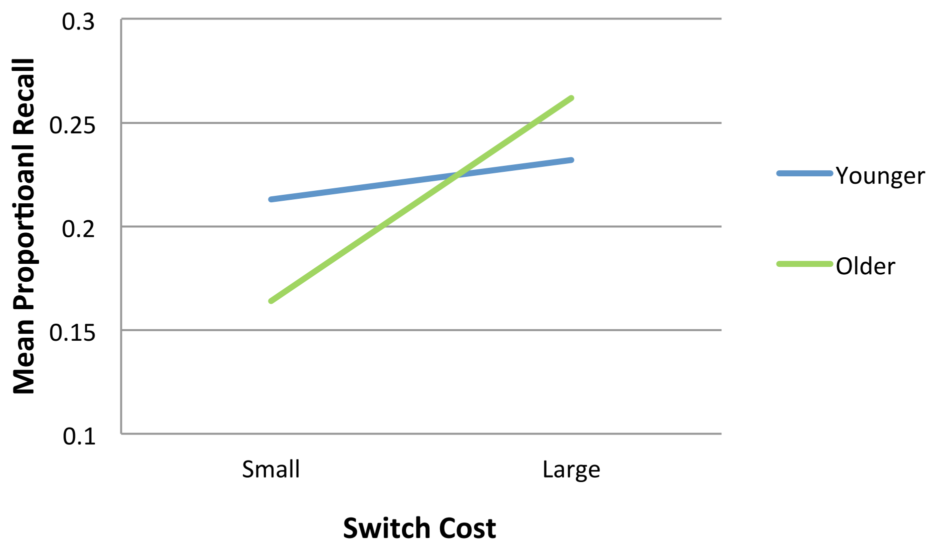

Figure 6. Mean proportion of conditional delayed recall of younger and older adults as a function of switch cost, collapsed across elaboration conditions in Experiment 1.

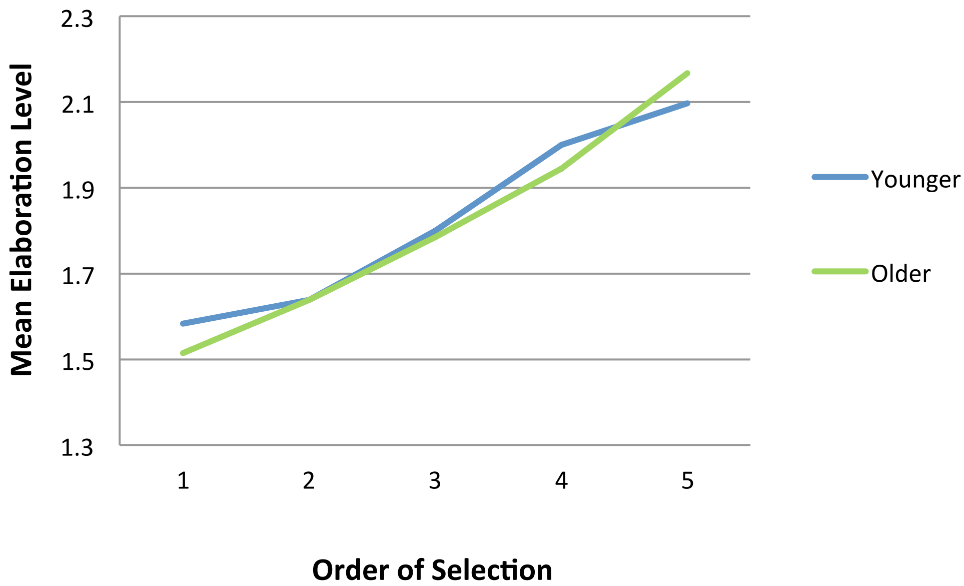

Figure 7. Mean elaboration level of younger and older readers' first 15 selections grouped into 5 groups, collapsed across switch-cost conditions in Experiment 2.

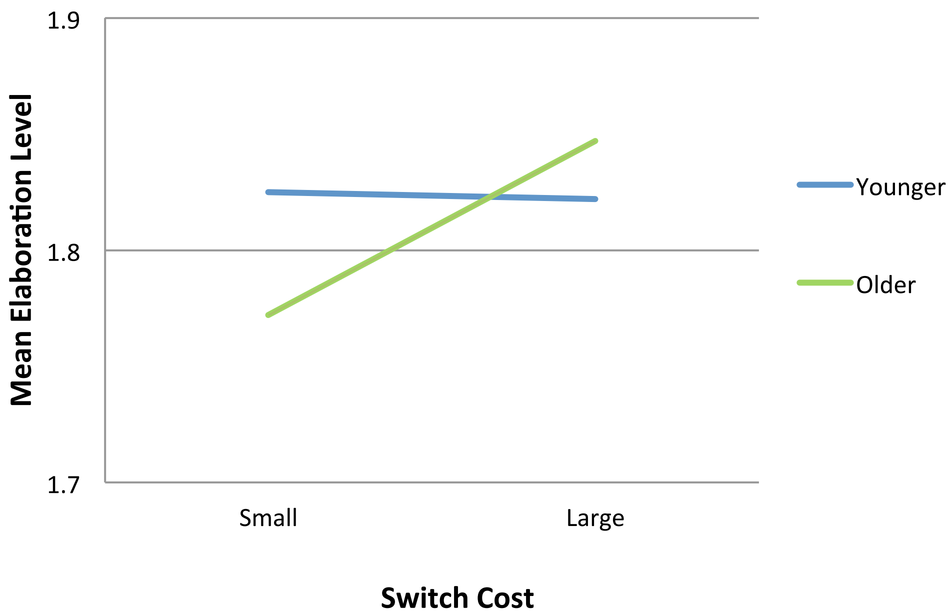

Figure 8. Mean elaboration level of sentences for the first 15 sentences selected as a function of age and switch cost in Experiment 2.

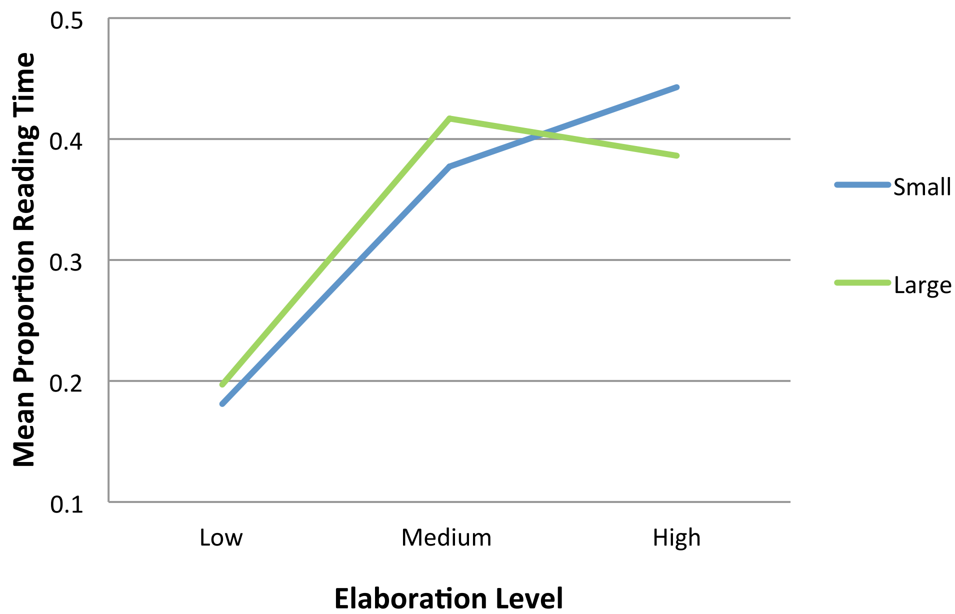

Figure 9. Mean proportion of reading time allocated to reading sentences from the three elaboration levels in the small- and large-switch-cost condition in Experiment 2.

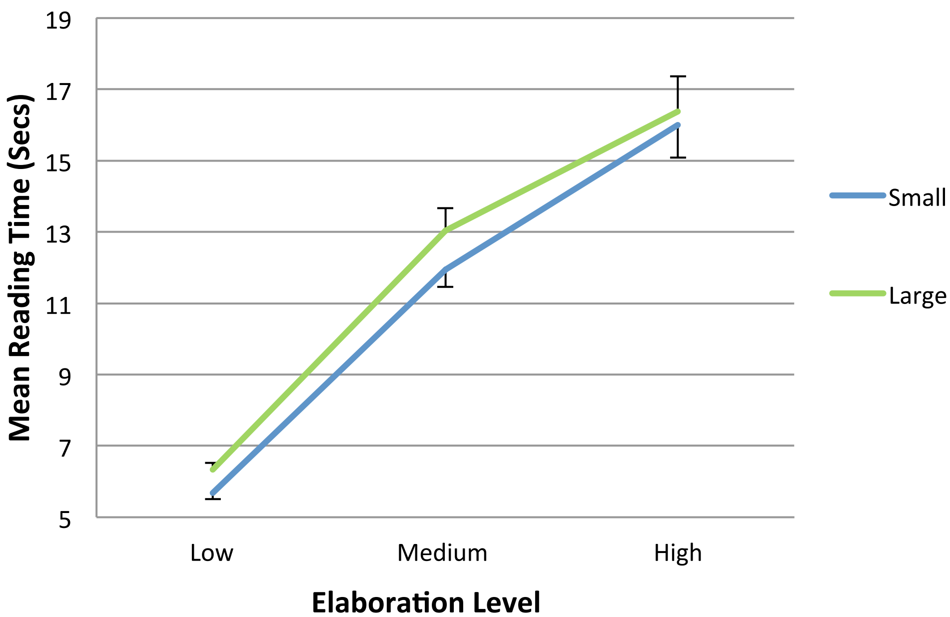

Figure 10. Mean reading time of sentences in elaboration levels under the small- and large-switch-cost condition in Experiment 2. Error bars represent standard errors.

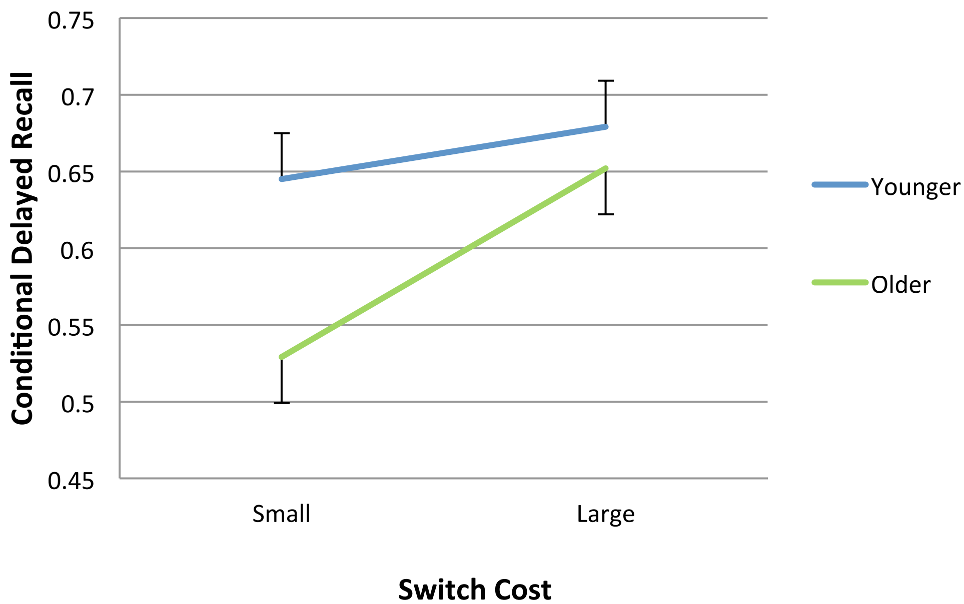

Figure 11. Mean proportion of conditional delayed recall of younger and older adults as a function of switch cost in Experiment 2. Error bars represent standard errors.

Appendix A

Reading Materials Used in Experiment 1 and Experiment 2

Connecticut	
Elaboration Level	Sentence
Low	Connecticut was made a state in 1788.
	Native son Charles Goodyear invented vulcanized rubber.
	Samuel Colt was a gunsmith from Connecticut.
	*The Eli Whitney Museum in Hamden offers invention workshops.
	The English established a settlement at Hartford in 1635.
	New Haven was designed as a planned city in the colonies.
	Endangered sperm whales can be seen off the coast.
	Wadsworth Atheneum is the oldest public art museum.
Medium	Connecticut is unofficially known as the "Nutmeg State," probably because sailors in the 18th century returned here from voyages with the valuable spice.
	*The Charter Oak, depicted on the state quarter, is where the state's charter was hidden by Captain John Wadsworth from the British in 1662.
	It was in New Haven in 1876 that Alexander Graham Bell set up the first telephone conversation with his assistant, Thomas A. Watson.
	The Eastern oyster, which is a bivalve mollusk, thrives naturally in Connecticut's rivers and embayments.
	The center of Connecticut state coat of arms depicts three grape vines that are bearing fruit.

The Mountain Laurel is a flower that swathes the hills in pink and white, mostly in the spring.

*Connecticut is named after the Connecticut River, which is the longest river in New England that approximately bisects the state and flows into Long Island Sound.

+The cathedral of St. Joseph in Hartford is noted for its carillon bells, as well as 24 spectacular stained-glass windows that line the nave.

The valley of the Shetucket River is known as the "last green valley" in the megalopolis between Washington and Boston.

High

In the early nineteenth century, Lambert Hitchcock from Cheshire was mass-producing hundreds of ornate rocking chairs called Boston Rockers, which are highly valued antiques today.

After the first exploration in 1614, Dutch fur traders sailed up Connecticut River and built a fort at Hartford, which was called "House of Hope."

Though Connecticut passed its first Abolition law in 1784, it lagged behind other states by neglecting to actually enforce the law until 1848.

Abandoning his lumberwork, Native-born Samuel Morey invented the internal combustion engine in 1792, which enabled an improved design of the commercially-used steamboat and, in the next century, the invention of the automobile.

The hillsides of the state yielded the first metal ores in the earliest days of the Colonies so that its craftsmen were fashioning metal while other colonies were whittling wood.

	For 17 years, Mark Twain occupied a peach-colored Victorian Gothic house in Hartford, which is now open to the public and features personal items including an oak mantel brought back from Scotland.
	The state of Connecticut is home to some interesting “firsts,” including the first medical diploma awarded in the U.S. by Yale University and the first U.S newspaper published in Hartford.
	*The low hills of Western Connecticut begin in north as rugged bedrock with glacier-cut ravines where streams rush through the clefts.

Rhode Island

Elaboration Level	Sentence
Low	Rhode Island is officially called the “Ocean State.”
	The state flower is the violet.
	*The state tree is the maple.
	The Hasbro Toy Company was founded in Rhode Island.
	During colonial times, Rhode-Islanders made rum from molasses.
	Some towns are only accessible by bridges.
	Roger Williams founded the first permanent settlement in 1636.
	Cumberlandite is a brown-black rock found only in Rhode Island.
Medium	The Narragansett Pacer, the first American-bred horse, contributed to Rhode Island prosperity in the Colonial era.
	In the Jamestown Penguin Plunge, 300 tuxedo-clad swimmers jump into Mackerel Cove on New Year’s Day.

When Anne Hutchinson was kicked out of the Massachusetts Bay colony for her beliefs about women's rights, she settled with her family on Aquineck Island.

On Block Island, which is twelve miles off the coast, visitors can see Settlers' Rock, which is inscribed with the names of the island's first inhabitants.

*The Stagecoach Tavern in Chepachet, built in the early 1700s with hand-hewn post-and-beam construction, is still serving customers.

Lime Rock Preserve features dolomitic marble which produce a special soil that nurtures rare plant species.

Although there are older carousels in America, none are as stunning as the Crescent Park Carousel in East Providence.

Rhode Island's economy is built upon three powerful industries: health services, tourism and manufacturing.

High

The Newport Casino, which is actually a country club rather than a place to gamble, is home to the International Tennis Hall of Fame that hosts the only grass-court tournament in the United States.

Visitors come to Blithewold, a 33-acre Victorian-era estate on the bay in Bristol, primarily for the spectacular display of daffodils.

*After the Revolutionary War, Rhode Island was a laughingstock and pariah because its legislature voted thirteen times not to ratify the Constitution before finally acquiescing in 1790.

Rhode Island boasts 21 lighthouses, but the most distinctive is the Beavertail Light, which was reconstructed in granite in 1856 after the original went up in flames.

The ship *Katy,* which was later named *Providence*, won the first battle of the Revolution in 1775 as part of the first Colonial Navy.

Since the mid 1980's, Providence has been transformed step-by-step from a gritty little city to one of *Newsweek's* top-ten cities in the United States, an accomplishment welcomed by both inhabitants and tourists.

Diners can sit on the deck overlooking the harbor-front at Vincent's restaurant, where they can savor delectable seafood dishes such as stuffed scrod.

Rough Point is a 49-room mansion overlooking the Atlantic Ocean that was once the home of Doris Duke, a tobacco heiress and prominent preservationist in the mid 1900's.

Note. * denotes the sentence used only in Experiment 1; + denotes the sentence used only in Experiment 2.

Appendix B

Delayed Cued Recall Test in Experiment 2

Connecticut		
No.	Question	Answer
1	Abandoning his lumberwork, Native-born Samuel Morey invented the internal combustion engine in 1792, which enabled an improved design of the _______________and, in the next century, the invention of the automobile.	commercially-used steamboat
2	The center of Connecticut state coat of arms depicts three ________________.	grape vines that are bearing fruit
3	Native son ____________ invented vulcanized rubber.	Charles Goodyear
4	For 17 years, Mark Twain occupied a peach-colored Victorian Gothic house in Hartford, which is now open to the public and features personal items including an oak mantel brought back from ___________.	Scotland
5	It was in ___________ in 1876 that Alexander Graham Bell set up the first telephone conversation with his assistant, Thomas A. Watson.	New Haven
6	The ____________, which is a bivalve mollusk, thrives naturally in Connecticut's rivers and embayments.	Eastern oyster
7	The state of Connecticut is home to some interesting "firsts," including the first medical diploma awarded in the U.S. by Yale University and the first U.S ____________ in Hartford.	newspaper published

8	Connecticut was made a state __________.	in 1788
9	Connecticut is unofficially known as the "___________," probably because sailors in the 18th century returned here from voyages with the valuable spice.	Nutmeg State
10	The English established a settlement at in ____________ 1635.	Hartford
11	The Mountain Laurel is a flower that swathes the hills in _______, mostly in the spring.	pink and white
12	___________was a gunsmith from Connecticut.	Samuel Colt
13	The hillsides of the state yielded the first metal ores in the earliest days of the Colonies so that its craftsmen were fashioning metal while other colonies were ____________.	whittling wood
14	The cathedral of St. Joseph in Hartford is noted for its __________, as well as 24 spectacular stained-glass windows that line the nave.	carillon bells
15	The valley of the Shetucket River is known as the "____________" in the megalopolis between Washington and Boston.	last green valley
16	Though Connecticut passed its first Abolition law in 1784, it lagged behind other states by __________________ the law until 1848.	neglecting to actually enforce
17	__________sperm whales can be seen off the coast.	Endangered
18	After the first exploration in 1614, Dutch fur traders sailed up Connecticut River and built a fort at Hartford, which was called "____________."	House of Hope
19	Wadsworth Atheneum is the oldest __________ museum.	public art

20	In the early nineteenth century, ___________from Cheshire was mass-producing hundreds of ornate rocking chairs called Boston Rockers, which are highly valued antiques today.	Lambert Hitchcock
21	___________was designed as a planned city in the colonies.	New Haven

Rhode Island

No.	Question	Answer
1	The _________ Toy Company was founded in Rhode Island.	Hasbro
2	Visitors come to Blithewold, a 33-acre Victorian-era estate on the bay in Bristol, primarily for the __________.	spectacular display of daffodils
3	Since the mid 1980's, Providence has been transformed step-by-step from a gritty little city to one of __________in the United States, an accomplishment welcomed by both inhabitants and tourists.	*Newsweek's* top-ten cities
4	Some towns are only accessible __________.	by bridges
5	Cumberlandite is a __________ found only in Rhode Island.	brown-black rock
6	Although there are older carousels in America, none are as stunning as the ___________ in East Providence.	Crescent Park Carousel
7	The Newport Casino, which is actually __________ rather than a place to gamble, is home to the International Tennis Hall of Fame that hosts the only grass-court tournament in the United States.	a country club
8	When Anne Hutchinson was kicked out of the Massachusetts Bay colony for her __________, she settled with her family on Aquineck Island.	beliefs about women's rights

9	Rough Point is a 49-room mansion overlooking the Atlantic Ocean that was once the home of Doris Duke, a ___________and prominent preservationist in the mid 1900's.	tobacco heiress
10	Rhode Island is officially called the "___________."	Ocean State
11	In the Jamestown Penguin Plunge, 300 __________ swimmers jump into Mackerel Cove on New Year's Day.	tuxedo-clad
12	On Block Island, which is twelve miles off the coast, visitors can see Settlers' Rock, which is inscribed with the ______________.	names of the island's first inhabitants
13	Diners can sit on the deck overlooking the harbor-front at ____________, where they can savor delectable seafood dishes such as stuffed scrod.	Vincent's restaurant
14	Rhode Island's economy is built upon three powerful industries: __________, tourism and manufacturing.	health services
15	During colonial times, Rhode-Islanders made rum from ________.	molasses
16	The ship *Katy,* which was later __________, won the first battle of the Revolution in 1775 as part of the first Colonial Navy.	named *Providence*
17	The state flower is the __________.	violet
18	Rhode Island boasts 21 lighthouses, but the most distinctive is the Beavertail Light, which was reconstructed _________in 1856 after the original went up in flames.	in granite
19	The ___________, the first American-bred horse, contributed to Rhode Island prosperity in the Colonial era.	Narragansett Pacer
20	__________founded the first permanent settlement in 1636.	Roger Williams

21	____________features dolomitic marble which produce a special soil that nurtures rare plant species.	Lime Rock Preserve