Published in final edited form as:

Psychol Aging. 2009 March ; 24(1): 63–74. doi:10.1037/a0014586.

Age Differences in the Effects of Domain Knowledge on Reading Efficiency

Lisa M. Soederberg Miller

University of California, Davis

Abstract

The present study investigated age differences in the effects of knowledge on the efficiency with which information is processed while reading. Individuals between 18 and 85 years of age, with varying levels of cooking knowledge, read and recalled a series of short passages within the domain of cooking. Reading efficiency was operationalized as time spent reading divided by the amount recalled for each passage. Results showed that reading efficiency increased with increasing levels of knowledge among older but not younger adults. Similarly, those with smaller working memory capacities showed increasing efficiency with increasing knowledge. These findings suggest that knowledge promotes a more efficient allocation policy which is particularly helpful in later life, perhaps due to age-related declines in working memory capacity.

The notion that knowledge is a powerful component of cognition is widely accepted (e.g., Feigenbaum, 1989). The advantages that experts display within their domain of expertise can be attributed, in part, to their vast and well-organized knowledge base (e.g., Chi, Glaser, & Farr, 1988), distinctive encoding processes (van Overschelde, Rawson, Dunlosky, & Hunt, 2005), chunking and template matching skills (Chase & Simon, 1973; Gobet & Simon, 1996), and retrieval structures that link the contents of working memory to long-term memory (Ericsson & Kintsch, 1995). Given these advantages which ultimately are thought to make processing faster and more efficient, some researchers have questioned whether knowledge and experience may also reduce demands on working memory (Hambrick & Engle, 2002, Hambrick & Oswald, 2005; Sohn & Doane, 2003; Taylor, O'Hara, Mumenthaler, Rose, & Yesavage, 2005).

Aging is associated with two areas of change that may increase the importance of knowledge in later life. First, aging is associated with declines in the efficiency of cognitive processes (Salthouse & Miles, 2002). Second, knowledge, representing the long-term products of processing, is relatively well-preserved in later life as reflected in stable levels of crystallized ability (e.g., Salthouse, 2000; Schaie, 1993). This multidirectional quality of cognitive change in adulthood has prompted researchers to ask whether knowledge can mitigate age-related losses in cognitive efficiency (Charness, 2000). Relatively few studies, however, have directly assessed age differences in the effects of knowledge on the efficiency of processing, reflecting how much individuals "get" from the time they have invested.

Address correspondence to: Lisa M. Soederberg Miller, Department of Human and Community Development, University of California, Davis, One Shields Avenue, Davis, CA 95616, 530-752-3955 (office), 530-752-5660 (FAX), lmsmiller@ucdavis.edu.

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Several studies have examined age differences in knowledge effects on various outcomes, in particular, memory performance. For example, Castel (2005) found age-related declines in memory for grocery prices when prices were unrealistically lower or higher but not when prices were within a realistic range. Similarly, Morrow and colleagues (1994) found that age differences among pilots were eliminated on a task that provided support to experts, but not on a task offering less support. On the other hand, Arbuckle and colleagues (Arbuckle, Vanderleek, Harsany, & Lapidus, 1990) found age differences were comparable within high- and low-knowledge groups. Still other studies have found that age differences remain within the high-knowledge group, but after controlling for knowledge, these differences are magnified (e.g., Meinz, 2000). This pattern suggests that older adults migrate into higher knowledge groups, which mitigates age-related declines in performance (Salthouse, 2003). Thus, the literature does not provide a uniform picture of how the effects of knowledge on cognition change with age.

The possibility explored in the present study was that, even if age differences in the effects of knowledge are not evident on measures of memory performance, they may be evident on assessments of processing efficiency. Knowledge may enable individuals to pay attention to relatively more salient aspects of the task, organize elements more quickly, and create more elaborate and effective retrieval structures in a time frame that is comparable to low-knowledge individuals. With more accomplished in less time, knowledgeable individuals would be more efficient. One way that knowledge could offer greater efficiency in later life is by reducing demands on working memory. This hypothesis is based on the assumption that older adults, due to working memory capacity limitations, are less able to process information efficiently relative to younger adults. However, when older adults have knowledge to draw upon, they may be able to use retrieval structures to increase efficiency, despite working memory limitations (Miller, Cohen, & Wingfield, 2006). The literature assessing working memory by knowledge (Hambrick & Oswald, 2005) and working memory by knowledge by age interactions (Hambrick & Engle, 2002) on memory performance, however, is inconsistent with this hypothesis. Nevertheless, it could be that when processing time is considered in conjunction with memory performance to create an assessment of efficiency, a different pattern emerges.

Self-Regulation and Reading Efficiency

The Self-Regulated Language Processing model (SRLP; Stine-Morrow, Miller, & Hertzog, 2006) proposes that readers allocate attention to text in such a way that enables them to construct a representation of the passage that is “good enough” relative to their current reading goals. That is, readers do not typically attempt to allocate time to every possible aspect of the text so as to encode every detail and main point represented by the text. Conceptualizations of what constitutes good enough depend on the individual’s reading goals as well as his or her abilities, for example, knowledge and working memory capacity.

When levels of comprehension fall below the desired levels of comprehension, readers adjust their allocation policy in an attempt to rectify the discrepancy. Readers can adjust their policy to increase or decrease attention to various processes in an attempt to reach their goals. Broadly speaking, these processes can be organized into three levels. At the word or surface level, individuals decode graphic symbols and access the meaning of individual words to form a representation of the surface form of the text. At the text base level, individuals parse the text into various constituents, form ideas units, and organize and integrate these ideas to form a text base representation. At the discourse or situation model level, readers connect this literal text base representation with what they already know about the world and the topic (i.e., apply knowledge) to form a situation model (e.g., Kintsch, 1988). The SRLP model argues that, due to age-related declines in working memory capacity, computational efficiency of language

processing at the text base level is compromised, placing greater reliance on top-down processes such as those supported by knowledge.

The amount of time individuals allocate to specific reading processes is an outcome of their allocation policy (e.g., Stine, 1990; for a review, see Stine-Morrow et al., 2006). Thus, the total amount of time spent reading a text provides a summation of the total effort expended, representing a global index of the allocation policy. By itself, overall reading time is often less sensitive to individual differences in abilities and task demands than are estimates of individual reading processes (e.g., Noh et al., 2007; Stine-Morrow et al., 2004). However, when global estimates are related to “what the reader got out of the text” as captured by, for example, memory for the passage, this time can be used to determine efficiency of the allocation policy (for similar approaches to reading efficiency, see Hartley, Stojack, Mushaney, Annon, & Lee, 1994; Stine & Hindman, 1994; Stine-Morrow, Shake, Miles, & Noh, 2006). In the present study, the efficiency of allocation policies was examined among readers varying in age and domain knowledge.

Language Processing and Knowledge

Literature on age differences in the effects of domain knowledge on language processing can be divided into studies examining age and knowledge effects on global estimates of reading time, individual reading processes, and memory for text. The literature examining the effects of knowledge on memory for text is the most extensive and generally shows that individuals with more knowledge remember more from what they read relative to those with less knowledge (e.g., Chiesi, Spilich, & Voss, 1979; Tobias, 1994). Although it is clear that knowledge supports memory of older adults, the literature is unclear as to whether these benefits increase with age (e.g., Morrow, Leirer, Altieri, & Fitzsimmons, 1994), or remain constant (e.g., Arbuckle Vanderleek, Harsany, & Lapidus, 1990).

Research focusing on the effects of knowledge on processing time (e.g., global estimates of reading time, individual reading processes) can be conceptualized using the SRLP model which argues that knowledge affects language processing by influencing how readers allocate attention to the text (Stine-Morrow et al., 2006). Research examining the effects of age and knowledge on allocation policy has been conducted on specific reading processes. For example, older adults are more likely than younger adults to allocate more time to conceptual processing when reading passages for which they have relevant background knowledge suggesting they apply more effort to integrating concepts in the text with prior knowledge (Miller, Stine-Morrow, Kirkorian, Conroy, 2004; Miller & Gagne, 2008). However, greater attention to a particular process does not necessarily mean that global estimates of reading time increase (e.g., Noh et al., 2007; Stine-Morrow et al., 2008).

Research findings on the effects of knowledge on global indices of reading time are mixed. Some evidence suggests that knowledge reduces passage reading time (Caillies, Denhière, & Kintsch, 2002) and some research shows little or no effects of knowledge (e.g., McNamara, Kintsch, Songer, & Kintsch, 1996) regardless of age (Morrow, Leirer, & Altieri, 1992). Although knowledge increases memory for both younger and older readers, these findings suggest that there is a good deal of variability in the amount of time that high- and low-knowledge individuals spend reading. Reading efficiency measures that consider the variability in time allocation relative to the quality of the text representation may provide insight into how knowledge affects language processing and whether there are age differences in these effects. It could be that allocation policies of high-knowledge individuals are more efficient than those of low-knowledge individuals. To the extent that age-related declines in working memory capacity limit reading efficiency in later life, knowledge may have greater effects on efficiency of older adults.

There is some evidence that schematic or contextual knowledge increases reading efficiency among older adults (Miller et al., 2006). Miller and colleagues (2006) used a Bransford and Johnson-type passage title manipulation (1972) such that half of the participants received a title that provided the topic of the passage (a script or schema) and half did not. Without the title, the passages were vague and difficult to understand. We found that the benefits of contextual knowledge were exaggerated for older adults, particularly among those with a reduced working memory capacity and when challenged by a difficult reading condition (i.e., reading while responding to a secondary task). However, the pattern of findings for schematic knowledge (as well as other types of highly familiar text with little new content) may not generalize to domain knowledge. Domain knowledge (e.g., baseball, physics, dinosaurs, cooking) is often conceptualized as complex and ill-structured, requiring some degree of transfer or mapping from what is known to the current situation (Britton & Tesser, 1982; Graesser, Haberlandt, & Koizumi, 1987; Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987). In contrast, texts that draw on schematic knowledge more readily map onto what the reader already knows, and therefore, likely require less overall effort to apply while reading (cf., Miller & Gagne, 2008).

The goal of the present study was to examine age differences in the effects of domain knowledge on reading efficiency. The prediction was that complex domain knowledge will enable readers to allocate attention more efficiently (i.e., to extract more from the text with relatively less time invested) even given some mapping that may be required for the knowledge to be applied while reading. High-knowledge readers may use an allocation policy that is able to sift through elements of the text to identify the most essential elements that will yield effective retrieval structures. It may also be the case that they accomplish these goals in time frame that does not differ significantly from low-knowledge readers. If retrieval structures are able to reduce demands on working memory capacity, knowledge would be expected to benefit older adults to a greater extent than younger adults. Finally, the possibility remains that variability in working memory capacity among older adults creates the added potential for support from knowledge. That is, low-span older adults may receive the largest benefits of knowledge, which would be supported by a triple interaction among age, knowledge, and working memory span.

Method

Participants

The sample included 279 adults between the ages of 18 and 85, with 110 younger individuals (ages 18–34), 86 middle-aged individuals (ages 35–59), and 83 older individuals (ages 60 – 85) who were recruited from a wide range of sources including advertisements in local newspapers, cooking schools, and continuing education offices. Individual difference measures of speed of processing and vocabulary were administered to determine whether the sample showed the expected age-related declines in the former ability and stability or increases in the latter ability. Means and standard deviations for these measures are presented in Table 1. Speed of processing was assessed with letter and pattern comparison tasks (Salthouse & Babcock, 1991). For these tasks, individuals compared strings of letters or patterns, as quickly as possible, to determine whether they were the same or different. Scores (number correct in the 1 minute time allotment) were averaged across the two measures to obtain a single estimate of speed of processing. This score was negatively correlated with age, $r = -.69, p < .001$. Vocabulary was assessed using the Extended Kit of Factor-Referenced Tests (KFRT, Ekstrom et al., 1976). This task consisted of 32 multiple-choice synonym items; scores were calculated by summing the correct responses then deducting .25 for each incorrect response (as per standard scoring instructions). There was a positive correlation between vocabulary scores and age, $r = .30, p < .001$.

Vision was also assessed to determine whether individuals had adequate visual skills to read the passages. Visual ability was assessed using the Pelli-Robson test of contrast sensitivity (Pelli, Robson, & Wilkins, 1988). Not surprisingly, contrast sensitivity decreased with age, $r = -.61, p < .001$. However, the pattern of findings did not change when this variable was included in the analyses, therefore results without covarying contrast sensitivity are reported.

Materials

Cooking Knowledge—Knowledge within the domain of cooking was assessed using a 20-item test that was found to have good internal consistency (Cronbach's $\alpha = .88$) in an earlier study (Miller, 2001). In the present study, the reliability was somewhat lower; 5 items were omitted to improve reliability (from .73 to .76). Items drew from many areas of cooking (e.g., understanding of terms such as *zest*, and knowing the difference between baking powder and baking soda) but none specifically overlapped with topics presented in the passages.

Working Memory Span—Working memory span was assessed using a loaded sentence span task (Daneman & Carpenter, 1980; Stine & Hindman, 1994) and computation span task (Salthouse & Babcock, 1991). For these tasks, participants read a statement (sentence or mathematical equation), indicated whether it is True or False, and retained a piece of information from the statement (the last word in the sentence or the second operand of the equation) before receiving another statement. After reading the final statement in a set (set size ranged from 2 to 8 statements), participants were asked to recall the designated pieces of information in the order in which they appeared. The experimenter monitored performance on the True/False task.¹ Scores were the highest number of words or numbers that were recalled in the correct order.

Passages—In order to obtain a broad range of topics, a pool of 26 short expository and procedural (i.e., recipes) passages were selected from cooking texts and websites (Barham, 2001; Child, 1989, 2000; Child, Bertholle, & Beck, 2001; StarChefs.com; The Exploratorium, www.exploratorium.edu). Passages were selected to represent a wide range of topics (baking, sauces, soups, dishes) within the domain of cooking.²

Passages were reviewed by 5 cooking experts (who were between the ages of 29 and 70, and had between 8 and 33 years of professional chef experience) to obtain ratings of usefulness and familiarity and to ensure that texts were clearly written and did not contain misleading or inaccurate information. The final pool of passages contained 12 recipes (between 62 and 141 words; Flesch-Kincaid grade level: $M = 7.8, SD = 1.5$) and 12 expository texts (between 71 and 133 words; Flesch-Kincaid grade level: $M = 9.9, SD = 1.4$), which were then divided into two sets of 6 recipes and 6 expository texts. Participants read one of the two sets of 12 passages. Item analyses based on expert ratings of perceived usefulness and familiarity showed that the two genres and two lists were comparable, $t < 1$, for all contrasts. Passages were arranged in quasi-random fashion with the restriction that one genre could not appear more than 2 times consecutively.

Procedure

Participants read texts at their own pace on a computer monitor segment-by-segment (2 to 7 words per segment). Participants pressed the space bar to advance each segment, while millisecond reading times for each segment were recorded.³ At the end of each passage,

¹Participants rarely made errors on the T/F portion of the working memory span tasks; when errors were made, participants were reminded to read carefully.

²The knowledge test was intended to assess knowledge of the field rather than to assess understanding of the contents of the specific passages presented in the study. Therefore, passages were selected so as to avoid overlap with items on the knowledge test.

participants were asked to recall as much as they could out loud into a tape recorder for later transcription and scoring. Half way through the reading task, participants were given a break and then completed the vocabulary test before finishing the remainder of the reading task. They then completed the cooking knowledge test, working memory span task, and speed of processing task.

Results

Preliminary analyses were conducted to examine age differences in domain knowledge, working memory span, reading time, and recall as well as bivariate correlations among these variables. Hierarchical regressions were then used to obtain residuals of reading efficiency after partially out reading time and recall. The residuals then were predicted by age, knowledge and working memory span and their interactions. Finally, structural equation models were used to examine further the relations among age, knowledge, working memory span, and reading efficiency when reading time and recall were included in the model.

Preliminary Analyses

Domain knowledge was assessed by the total number of items answered correctly on the cooking knowledge test. Results showed that knowledge increased with age, $r = .28, p < .001$, such that younger adults ($M = 6.7, SD = 3.3$) answered fewer questions correctly than did middle-aged ($M = 8.7, SD = 3.7$), and older adults ($M = 8.6, SD = 3.0$). A composite measure of working memory span was calculated by averaging across the sentence and computation span tasks (Cronbach alpha for the two measures was .71). Means for young ($M = 5.8, SD = 1.1$), middle-aged ($M = 5.0, SD = 1.3$), and older adults ($M = 4.5, SD = 1.3$) showed age-related declines, which were confirmed by significant bivariate correlation, $r = -.37, p < .001$. Figure 1 depicts both measures (in standardized units) and shows the expected cross-over pattern that is consistent with past work showing age-related declines in fluid abilities and age-related increases in crystallized abilities.

Global estimates of allocation to passages were estimated by the median segment reading time for the passage. Median reading times were preferred over total passage reading time because the latter is more likely to include non-reading activities (e.g., adjusting the chair, eye glasses) that would add noise to an estimate of reading time. Reading times showed excellent internal consistency across passages, $\alpha = .98$. Composites of reading time for each genre were calculated by taking the average of the medians for each passage. Reading times increased with age for expository passages, $r = .33, p < .01$, and recipes, $r = .26, p < .01$. Means in milliseconds for expository texts were: $M_y = 1280, SD_y = 519; M_m = 1558, SD_m = 651; M_o = 1788, SD_o = 683, M_y = 1492$ and means for recipes were: $SD_y = 645; M_m = 1756, SD_m = 763; M_o = 1973, SD_o = 856$.

Recall was scored by matching idea units correctly recalled to the ideas presented in the text, using a gist criterion. Inter-rater reliability, $r = .92$, of this scoring method was good, and internal consistency across the passages was also good, Cronbach alpha = .93. Partial recall data for 8 participants were lost due to equipment failure or experimenter error. The proportion of idea units recalled from each passage was used to assess memory performance. A composite variable was constructed by taking the mean across the 6 passages within each genre. There were age-related declines on the recall scores from the expository passages, $r = -.28, p < .01$, $M_y = .40, SD_y = .16; M_m = .32, SD_m = .16; M_o = .30, SD_o = .15$, as well as the recipes, $r = -.30, p < .01, M_y = .35, SD_y = .16; M_m = .30, SD_m = .15; M_o = .24, SD_o = .12$.

³Half of the passages were preceded by titles and half were not in an attempt to manipulate difficulty. Preliminary analyses showed that, as expected, when titles were absent, reading efficiency decreased. However, this effect did not depend on knowledge or age, and therefore for simplicity, this variable was dropped from subsequent analyses.

Reading efficiency was operationalized as the median segment reading time divided by the proportion recalled for a passage. This time-per-unit-recall value reflects time allocated to a passage relative to how much was recalled. Measures of passage reading efficiency were log transformed because inspection of the data indicated heteroscedasticity reflecting greater variability among older individuals and among more knowledgeable individuals. The transformed measures showed good internal consistency across the 6 passages, $\alpha = .93$.

Bivariate correlations were conducted to explore the relationships among the key variables. Table 2 contains the correlations among age, knowledge, working memory span, as well as reading time, recall, and time per unit of recall for each for each genre. Age was positively correlated to knowledge and reading time but negatively correlated to recall performance. Age effects were magnified for efficiency relative to recall but knowledge effects were similar for recall and efficiency. This is likely because, across all passages, knowledge scores were unrelated to reading time but were significantly related to memory performance. Working memory span also was correlated with memory performance but not reading time. Thus, knowledge and working memory span appear to lead to a wide range of reading times, likely reflecting a variety of allocation policies.

Reading Efficiency Residuals

To examine reading efficiency data that were independent of time spent reading and levels of recall, reading efficiency for each passage was regressed onto reading time and recall measures for that passage to obtain residuals.⁴ These residuals were then averaged across passages within each genre. Figure 2 shows time per unit of recall for expository texts (left) and recipes (right) in relation to knowledge after controlling for time and recall. Best fitting lines for each age group are shown. In general, the data indicate that older adults increased efficiency (allocated less time per unit of recall) with increasing knowledge, whereas middle-aged and younger adults did not. For recipes, older adults showed efficiency gains of .42 in standardized units for each additional point on the cooking knowledge test (i.e., for every addition point, they decreased time per unit of recall by a little less than one half a standard deviation). In contrast, younger adults showed a loss of .21 standardized units of efficiency with each additional point and middle-aged adults showed no change. Expository texts showed smaller effects relative to recipes, yet the overall pattern was similar. On average, older adults displayed a gain of .13, younger adults displayed a loss of .18, and middle-aged adults showed no change as a function of knowledge.

Figure 3 shows standardized efficiency residuals with fit lines for high and low working memory span (dichotomized by a median split across the sample). These data show a tendency for low span individuals to increase efficiency and high span individuals to decrease efficiency with increasing knowledge (expository texts: .13 gain for low-span, .11 loss for high span; recipes: .21 gain for low-span, .10 loss for high span).

Hierarchical linear regressions predicting efficiency residuals were used 1) to more specifically examine the possibility that older adults gain even more from knowledge when they have a smaller working memory capacity (i.e., test for a 3-way interaction among age, working memory span and knowledge); and 2) to obtain independent assessments for expository texts and recipes of variance accounted for by the two cross-product terms of interest: Age x Knowledge and WM Span x Knowledge. Three sets of regressions were conducted for each genre. The first two were conducted to obtain an estimate of variance accounted for by the interaction of interest and the last regression was conducted to examine possible 3-way

⁴The use of residual scores was preferred over the use of hierarchical regressions to partial out effects of reading time and recall because the former controls for these individual components at the level of the passage whereas the latter requires averaging reading time and recall across passages within a genre.

interactions. In the first set of regressions, the main effects of age and knowledge were entered in the first step and the cross-product term of Age x Knowledge was entered in the second step (interactions were created using mean-centered variables, Cohen & Cohen, 1983). The Age x Knowledge term accounted for 3.1% of the variance, $p < .01$, in expository efficiency residuals, 10.7% of the variance, $p < .001$, in recipe residuals.

In the second set of regressions, the main effects of WM span and knowledge were entered in the first step and the cross-product term of WM span x Knowledge was entered in the second step. The WM Span x Knowledge term accounted for 1.2%, $p = .075$, regression predicting expository residuals and 4.7%, $p < .001$, in recipe residuals.

Data from the third set of regressions are presented in Table 3. For this set of regressions, all main effects (age, knowledge, WM span) were entered in the first step, all 2-way interactions were entered in the second step (Age x Knowledge, WM Span x Knowledge, Age x WM Span) and the 3-way cross-product term (Age x WM Span x Knowledge) was entered in the last step. As can be seen in Table 3, the 3-way interaction was ns, $t < 1$, for both genres, suggesting that the trend for an Age x Knowledge interaction for expository texts and the significant Age x Knowledge interaction for recipes did not depend on working memory span.

Structural Equation Models

Relations among age, knowledge, working memory span, and reading efficiency were examined in greater detail using a series of structural equation models (SEMs) that included reading time and recall. More specifically, the purpose of the models was 1) to provide additional support for the notion that older adults show greater reductions in time per unit of recall (increases in reading efficiency) with increasing knowledge and 2) to consider whether a similar pattern is evident when considering individuals who vary in working memory capacity. Reading time and recall were included in the models to partial out their effects (i.e., so that the effects of age, knowledge, and working memory span on efficiency could be assessed independently of amount of time spent reading and levels of recall) while at the same time provide a general assessment of their relative contributions.⁵

Model parameters were estimated in AMOS 16 using maximum likelihood. Reading efficiency data were parceled into three groups within each genre by averaging across efficiency scores for an arbitrary selection of two passages (for a discussion of this procedure, see Kishton & Widaman, 1994). Two indicators of fit were used to evaluate each model: Comparative Fit Index (CFI; Bentler, 1990) and Root Mean Square Error of Approximation (RMSEA; Browne & Cudeck, 1993). CFI represents the degree of fit between an independent model and the observed data (values greater than .90 indicate a relatively good fit). RMSEA is an index of fit that incorporates the error of approximation in the population (values less than .05 reflect a good fit; values greater than .10 reflect a poor fit).

The central model included the main effects of age, knowledge, and working memory span in addition to an Age x Knowledge interaction term as shown in Figure 4. The central model yielded an adequate fit to the data, $\chi^2(N = 81) = 218$, CFI = .961, RMSEA = .078. Signs for the standardized path coefficients in Figure 4 have been reversed so that higher efficiency scores reflect greater efficiency (i.e., *less* time per unit of recall). Dashed lines represent nonsignificant standardized path coefficients and solid lines represent significant coefficients, $p < .05$. The data indicate that the individual components of reading efficiency had a large impact on reading efficiency, with time detracting from efficiency, and recall contributing to efficiency. Although zero-order correlations in Table 2 show that age was significantly related to the efficiency

⁵Ideally, reading time and recall would be partialled out of efficiency estimates at the level of the passage rather than across each genre. However, general indices for each genre were used in the structural equation models to avoid creating overly complex models.

variables, the nonsignificant path coefficients between age and efficiency suggest that the other variables accounted for the age-related variance. The paths between the Age x Knowledge term and efficiency were significant for both genres. This pattern is consistent with the data shown in Figure 2 suggesting that knowledge is more supportive to older adults than to younger adults. Nevertheless, the magnitude of these effects was relatively small.

Two additional models were examined to determine whether a WM Span x Knowledge cross product term or an Age x WM Span term fit the data as well as the Age x Knowledge term in the central model. Results for the model including the WM Span x Knowledge term showed that the fit was comparable, $\chi^2(N = 81) = 217$, CFI = .962, RMSEA = .078. The path coefficients between the interaction term and efficiency variables were also similar, .04 for expository efficiency, .05 for recipe efficiency, $p < .05$ for both. The fit of the model containing the Age x WM Span term was still adequate, but was somewhat reduced, relative to the other two models, $\chi^2(N = 81) = 229$, CFI = .958, RMSEA = .081. However, paths connecting the interaction term to the efficiency variables were nonsignificant, .00 for expository texts, .02 for recipes, $p > .10$, for both.

In general, the data are consistent with the notion that knowledge offers greater support to older relative to younger adults and to those with a smaller relative to larger working memory capacity. However, the hypothesis that there is an added benefit of knowledge for older, low-working memory span adults was not supported. It is important to note that the use of cross-product terms in SEM to explore group differences is relatively rare compared to multiple-group analyses, and thus these data should be considered exploratory. At the same time, the results of the hierarchical linear regressions and the SEMs were largely consistent, suggesting that this approach may be useful for exploring age differences using SEM with relatively small sample sizes.

Discussion

The multifaceted nature of cognitive aging has lead researchers to question whether stability or growth in one type of ability can help mitigate declines in another. Because knowledge has been shown to be a powerful element of cognition (Fiegenbaum, 1989) that remains strong in later life, researchers have focused on knowledge and experience as potential mitigating factors (e.g., Charness, 2000; Salthouse, 2003). Research has consistently shown that knowledge supports memory for text among younger and older adults (e.g., Arbuckle et al., 1990; Chiesi et al., 1979), yet the literature does not provide a uniform picture of how knowledge affects overall reading times for any age group. The current study was undertaken to explore whether the processing time as it relates to memory performance can provide insight into how knowledge affects language processing in later life.

Knowledge and Allocation Policy

The time individuals spend reading represents an allocation policy that reflects a trade off between time invested in various processes and the quality of the representation that is being formed (Stine-Morrow et al., 2006). By linking time spent reading to an index of the quality of the representation that was produced with that time (e.g., memory for text), the measure of reading efficiency used in the present study represents an attempt to assess the trade off as it occurs for each passage.

The key finding was that knowledge had a greater effect on reading efficiency among older relative to younger adults. Although the magnitude of the interaction effects was relatively small, efficiency measures were more sensitive to age-by-knowledge effects than either reading time or recall alone. The finding that knowledge was more helpful to older adults than younger adults is consistent with the SRLP model's assertion that age-related losses in computational

efficiency of language can be mitigated through top-down processes such as those provided by knowledge (Stine-Morrow et al., 2006). When readers have relevant prior knowledge to draw upon, they can produce a larger number of connections between the text and prior knowledge. This leads to a richer representation of the text which in turn supports higher levels of recall. The present data suggest that older knowledgeable readers are less likely to allocate additional time to form a richer representation. Instead, they may use their knowledge to guide attention to aspects of the text that are most salient to forming an effective retrieval structure. Although this approach may not lead to levels of recall that match those of younger high-knowledge individuals, it does enable them to be efficient.

The finding that older knowledgeable adults spend less time reading per unit of recall relative to younger knowledgeable adults may reflect age-related changes in an allocation policy that places greater emphasis on conserving cognitive resources. That is, due to age-related decreases in working memory capacity, older adults may place a greater premium on efficiency in an attempt to conserve cognitive resources (e.g., Hess, 1990; Park, Morrell, & Shifren, 1999). Low-knowledge older adults would presumably also prefer to place a premium on allocating less time per unit of recall. However, without knowledge to draw upon, they may be unable to create retrieval structures that support higher efficiency. Past research has shown that younger adults do not always strive for greater efficiency when reading. Stine-Morrow and colleagues (Stine-Morrow et al., 2006) found that younger adults showed evidence of over-allocation (i.e., labor-in-vain) when they were encouraged to achieve high accuracy relative to when they were encouraged to read for efficiency. For younger adults, it could be that possessing knowledge about a domain encourages an accuracy approach to the text. That is, they adopt an allocation policy that strives to achieve an elaborate representation with less regard to the “cost” in terms of time.

Associations between Working Memory and Knowledge

Individuals with a smaller working memory capacity showed differential benefits of knowledge relative to those with a larger working memory capacity. The finding that knowledge was particularly helpful among low-span individuals is consistent with long-term working memory theory (Ericsson & Kintsch, 1995). Specifically, retrieval structures supported by knowledge provide a system of cues that link the contents of short-term and long-term memory (referred to as long-term working memory). In this way, retrieval structures offer rapid access to memory stores, placing fewer demands on short-term storage. The data are also consistent with past research showing that the advantages of knowledge are greater among those with a relatively smaller working memory capacity (Miller et al., 2006; Sohn & Doane, 2003). However, some research has shown that knowledge effects are slightly greater among those with a relatively high working memory capacity (Hambrick & Engle, 2002) or that knowledge and working memory operate independently (Hambrick & Oswald, 2005). Although it is not clear why findings across these studies differ, one possibility is that memory performance is less sensitive to knowledge-by-working memory capacity interactions than are measures that also include self-regulation of time. The finding from the present study that low-span readers gained more from knowledge than did high-span readers suggests that low-span individuals adopt an allocation policy geared towards conservation of resources, an approach that is more likely to succeed when knowledge is available to support efficient processing.

Another possibility is that a wide range of knowledge and working memory capacity is required to observe interactions between the two abilities. Hambrick and Oswald (2005), for example, examined only younger adults which may have limited the variability of working memory span relative to samples that include older adults. In the present study, the effects of knowledge on efficiency of younger adults would likely be similar across all levels of working memory. Hambrick and Engle (2002) included a wide range of age and working memory span scores;

however, they found no evidence that older adults gained more from knowledge. Knowledge was uncorrelated with age in that study. Thus, it may be that in order for knowledge to support those with a smaller working memory capacity, relatively more knowledge is required. This combination is more likely to exist in samples that include older adults who have migrated into higher knowledge groups (Salthouse, 2003).

As noted earlier, the age-by-knowledge effects in the present study were modest. More research is needed to determine whether differential advantages of knowledge among older adults are more likely to occur for efficiency measures that provide variability in terms of self-regulatory processes, or for older adults who have migrated into higher knowledge groups. An additional factor could be domain relevance which is considered next.

Domain Relevance

In the present study, the connections between knowledge and reading efficiency were stronger for recipes than for expository cooking texts. Individuals with high levels of cooking knowledge are likely to accumulate their knowledge through experience with cooking and recipes are commonly used when cooking. In addition, age-by-knowledge effects on reading efficiency were larger for recipes than for expository cooking texts. This finding is consistent with the notion that more domain-relevant tasks offer greater support to older adults (Morrow et al., 1994).

The constraint attunement hypothesis (Vicente & Wang, 1998) can also provide some explanation as to why greater mitigation was found for recipes than for expository cooking texts. This hypothesis states that the magnitude of expertise effects on memory will depend on the task and, in particular, the degree to which the task provides opportunities for experts to structure the information provided in the task. These opportunities are referred to as goal-relevant constraints and reflect “relationships pertinent to the domain” (p. 36). Thus, when more goal-relevant information is available, greater expertise advantages are apparent. Recipes may contain more of this type of information because they are a tool that is designed to guide preparation of foods. For example, recipes convey both the quantity and types of ingredients to be used as well as how the ingredients are to be assembled. In this way, knowledge may enable individuals to attend to, and organize, key elements of information with less effort. Although the expository passages also drew on cooking knowledge, they may have provided fewer goal-relevant constraints which limited the efficiency with which the information could be processed. Expository texts, for example, provided explanations regarding why a technique or step should be performed a certain way. These explanations, although informative, may be less goal-relevant than the steps themselves.

Different Types of Knowing

Past research on the effects of schematic knowledge on language processing suggests there is a reduction in overall reading time (e.g., Sharkey & Sharkey, 1987), particularly among older adults (Miller & Stine-Morrow, 1998) when schemas are available. In contrast, domain knowledge sometimes takes additional time to utilize (Britton & Tesser, 1982; see Ericsson et al., 2000; Vicente & Wang, 1998 for discussion outside the area of reading). Extra time is particularly evident when considering specific reading processes such as inference generation and conceptual integration (Graesser et al., 1987; Miller, 2003; Miller & Gagne, 2008; Miller et al., 2004). Although some processes may take additional time when knowledgeable individuals read texts in their domain of expertise, these processes do not appear to affect overall time appreciably. Because memory performance increases when individuals possess knowledge, the net effect is greater efficiency. When time and memory are statistically removed from efficiency measures, the findings show that older adults gain more from domain knowledge.

In past work examining age and working memory capacity differences in the effects of schematic knowledge on reading efficiency, we found that older adults with a relatively smaller working memory capacity benefitted more from having a schema to draw upon than did their larger span counterparts (Miller et al., 2006). This interaction may have been due to a very difficult low-knowledge condition that challenged older readers to keep trying to obtain a “good enough” representation of the text when the passage title was absent. In the present study, low-knowledge older adults may have been less challenged to comprehend the passages, thereby reducing the opportunity for working memory span to moderate the age by knowledge interaction.

In general, older adults appear to benefit from knowledge to a greater extent when the criterion is reading efficiency. This appears to be true regardless of whether older adults have schematic knowledge that is easily mapped on to contents of long-term memory or complex domain knowledge that may require some transfer to apply to the text. This pattern is less likely to occur, however, when the criterion is reading time or memory performance alone. The findings from the present study suggest that knowledge may play a greater role in the self-regulation of processing efficiency in later life, perhaps due to its ability to mitigate reliance on working memory capacity.

Acknowledgments

Support for the preparation of this article was provided by the NIH, grant R01AG19196. The author is indebted to Tanja Gibson, Jeannette de Dios, and Savita Kumar for recall scoring, and to the Cambridge School of Culinary Arts and the American Institute of Wine and Food for assistance with participant recruitment. The author also wishes to thank Elizabeth Stine-Morrow and Harold and Selena Soederberg for their helpful comments on earlier drafts of this article.

Appendix

Sample Expository Text: Onions Without Tears (Child, 1989, p. 358)

“It’s the chemical propanethial S-oxide that’s the tear-producing villain here, and this vegetable is full of it. When that combines with the moisture of your eyes it produces sulfuric acid, and it’s no wonder we cry. But S-oxide’s power is soluble in water. Therefore, it could help to peel onions under a running cold-water faucet. It also helps to refrigerate them before slicing because the chemical processes are slowed way down by cold temperatures.”

Sample Recipe Text: Leek and Potato Soup (Child, 2000, p. 3)

“For this recipe, you will need 3 cups of sliced leeks, 3 cups of peeled and roughly chopped baking potatoes, 6 cups of water, 1½ tsp of salt, and ½ cup of sour cream or crème fraîche. Bring these ingredients to the boiling point in a 3-quart sauce pan. Cover partially and simmer 20 to 30 minutes, until vegetables are tender. Serve as is or purée. If desired, top each portion with a dollop of cream.”

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Figure 1.
Standardized knowledge and working memory span scores in relation to age.

Figure 2.
Time per unit of recall (standardized residuals) in relation to knowledge with regression lines for each age group plotted separately. Expository texts on the left side, recipes on the right.

Figure 3.

Time per unit of recall (standardized residuals) in relation to knowledge with regression lines plotted separately for working memory span (dichotomized). Expository texts on the left side, recipes on the right.

Figure 4.

Structural equation model predicting reading efficiency from age, knowledge, and working memory span.

Note. Standardized path coefficients are shown; all paths to efficiency have been reversed so that higher efficiency scores reflect greater efficiency (i.e., *less* time per unit of recall). Solid lines represent significant coefficients, $p < .05$; dashed lines represent nonsignificant coefficients. WM = Working Memory; Expos = Expository; AgexKnowl = Age x Knowledge cross-product term; Sent = Sentence; Comp = Computation; RT = Reading Time; CFI = .961, RMSEA = .078.

Table 1Sample characteristics (means, standard deviations, and age R^2)

	Young (18–34)	Middle (35–59)	Older (60–85)	Age R^2
Speed of Processing	34.3 (5.3)	27.7 (4.8)	24.5 (3.9)	.48**
Vocabulary	18.7 (7.1)	20.4 (8.5)	23.9 (8.0)	.09**
Vision	1.90 (.08)	1.83 (.14)	1.68 (.14)	.37**

**
 $p < .01$.

Table 2
Correlations among key variables with reliability estimates along diagonal (Cronbach alphas)

	1	2	3	4	5	6	7	8	9
1 Age	(-)								
2 Knowledge	.280**	(.76)							
3 WM Span	-.367**	.062	(.71)						
4 Recall - exp	-.304**	.298**	.468**	(.90)					
5 Recall - rcv	-.311**	.320**	.372**	.792**	(.87)				
6 Reading Time - exp	.313**	-.045	-.042	.105	.231**	(.96)			
7 Reading Time - rcv	.247**	-.021	.016	.150*	.296**	.920**	(.96)		
8 Time/Unit Recall - exp	.451**	-.257**	-.401**	-.680**	-.404**	.586**	.500**	(.82)	
9 Time/Unit Recall - rcv	.475**	-.315**	-.363**	-.649**	-.691**	.393**	.386**	.749**	(.89)

Note. WM = working memory; exp = expository texts; rcv = recipes.

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Unstandardized (B) and standardized (β) coefficients and *t*-statistics from regression analyses predicting reading efficiency

Table 3

	Expository			Recipes		
	B	β	<i>t</i>	B	β	<i>t</i>
Step 1						
Age	-.003	-.133	-1.89 [†]	.000	-.018	-0.26
K	.010	.078	1.18	-.008	-.059	-0.90
WMS	-.010	-.031	-0.45	-.034	-.100	-1.43
Step 2						
AgexK	.000	-.119	-1.82 [†]	-.002	-.257	-4.12 [*]
AgexWMS	-.003	-.197	-3.16 [*]	-.003	-.160	-2.68 [*]
WMSxK	.001	.114	1.74	.017	.157	2.51 [*]
Step 3						
AgexWMSxK	.000	-.109	-0.30	.000	.038	0.62

Note. K = knowledge; WMS = working memory span.

* $p < .05$.

[†] $p < .10$.