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Memory and comprehension for health information among older adults: Distinguishing the effects of domain-general and domain-specific knowledge

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Memory and comprehension for health information among older adults: Distinguishing the effects of domain-general and domain-specific knowledge

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While there is evidence that knowledge influences understanding of health information, less is known about the processing mechanisms underlying this effect and its impact on memory. We used the moving window paradigm to examine how older adults varying in domain-general crystallised ability (verbal ability) and health knowledge allocate attention to understand health and domain-general texts. Participants (n = 107, age: 60–88 years) read and recalled single sentences about hypertension and about non-health topics. Mixed-effects modelling of word-by-word reading times suggested that domain-general crystallised ability increased conceptual integration regardless of text domain, while health knowledge selectively increased resource allocation to conceptual integration at clause boundaries in health texts. These patterns of attentional allocation were related to subsequent recall performance. Although older adults with lower levels of crystallised ability were less likely to engage in integrative processing, when they did, this strategy had a compensatory effect in improving recall. These findings suggest that semantic integration during reading is an important comprehension process that supports the construction of the memory representation and is engendered by knowledge. Implications of the findings for theories of text processing and memory as well as for designing patient education materials are discussed.

Keywords: Knowledge; Reading comprehension; Cognitive ageing; Resource allocation; Health care.

Knowledge is a powerful resource for older adults to maintain high levels of performance. For example, knowledge may support strategies that compensate for cognitive limitations in many tasks,

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such as comprehension and decision-making in health, aviation and other domains (e.g., Meyer, Talbot, & Ranalli, 2007; Morrow, Menard, Stine-Morrow, Teller, & Bryant, 2001). Knowledge helps readers understand information, in part by engendering efficiency in component processes and promoting effective reading strategies (e.g., Stine-Morrow, Miller, Gagne, & Hertzog, 2008). Unlike other cognitive resources such as processing capacity (e.g., working memory), knowledge growth is preserved across the life span (Baltes, 1997; Beier & Ackerman, 2005). Hence, it is important to understand the role of knowledge in maintaining comprehension skill as an aspect of successful ageing. While studies have investigated how knowledge promotes comprehension (e.g., Miller, Gibson, & Applegate, 2010; Miller, Stine-Morrow, Kirkorian, & Conroy, 2004), our focus was on the distinctive effects of crystallised ability (i.e., verbal ability) and domain-specific knowledge on comprehension.

We investigated the effects of domain-general crystallised ability and health-related knowledge on understanding information about health. While adult development generally affords the growth of knowledge, crystallised abilities (e.g., verbal ability and generalised knowledge structures, such as that measured by vocabulary) and domain-specific knowledge are influenced by different sorts of experiences and have the potential to develop independently (Ackerman, 2008). Crystallised ability grows as a function of broad-based literacy experience (Stanovich, West, & Harrison, 1995). Domain-specific knowledge, on the other hand, requires engagement with activities specific to that domain (Ericsson & Charness, 1994). The importance of understanding health information to older adults' daily functioning is reflected in the large research based on health literacy (DeWalt, Berkman, Sheridan, Lohr, & Pignone, 2004). Health literacy is defined as the capacity to obtain, understand and use information to make health decisions (U.S. Department of Health and Human Services, 2010). Because adults with lower health literacy are less likely to comprehend health care information, studies often found that health literacy measures are associated with a wide range of health outcomes (DeWalt et al., 2004). Health literacy is often found to be lower among older adults (e.g., Baker, Gazmararian, Sudano, & Patterson, 2000), but a substantial amount of age-related variance in commonly used measures of health literacy can be attributed to domain-general age-related declines in processing capacity necessary for comprehension (Chin et al., 2011). Hence, there is actually very little understanding of how domain-specific health knowledge factors into comprehension and memory of health information among older adults.

We developed the process-knowledge model of health literacy to help explain the interactive contributions of processing capacity, crystallised ability and health knowledge as determinants of health literacy (Chin et al., 2011). According to this model, there are multiple components contributing to the development of health literacy, including processing capacity (e.g., processing speed and working memory), crystallised ability (as indexed by verbal ability) and health knowledge. We have observed that adequate health-related knowledge and crystallised ability can compensate for declines in processing capacity, allowing older adults to achieve high levels of performance on health literacy measures. In other words, the ability components that contribute to comparable levels of health literacy (as measured by conventional assessments) can vary across individuals. Assuming that a theoretical model of health literacy grounded in cognitive science is necessary to develop interventions, the extent to which a given level of health literacy might arise from varying profiles of processing capacity, crystallised ability, and knowledge matters. In the current study, we investigated the effects of crystallised ability and health knowledge on strategies in reading health texts to examine the extent to which knowledge may compensate for limited processing capacity to promote high levels of recall of health information among older adults. We focused on hypertension as our health domain because it is a relative common chronic illness among older adults over age 65 (American Heart Association Statistics Committee and Stroke Statistics Subcommittee, 2013).

PROCESSES AND REPRESENTATIONS IN COMPREHENSION

Comprehension entails constructing, updating and maintaining mental representations at multiple levels, including the word-level, textbase and situation model (Kintsch, 1998). Word-level representations involve decoding orthographic or acoustic information to access word meanings (concepts); textbase representations involve integrating these meanings into a propositional representation of the ideas conveyed by the text; and the situation model involves a more elaborated representation of

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the situation implied by the text. According to the self-regulated language processing model (Stine-Morrow, Miller, & Hertzog, 2006), readers allocate attention differentially to compute these representations so as to be "good enough" to satisfy comprehension goals (Ferreira, Bailey, & Ferraro, 2002). Attentional resources allocated to constructing multiple levels of representation can be measured by the reading time individuals spend on different text features reflecting word-level, textbase and situation model processing. Random regression models (Lorch & Myers, 1990; Stine-Morrow, Milinder, Pullara, & Herman, 2001; Stine-Morrow et al., 2008) or mixed-effect models (Payne, Gao, Noh, Anderson, & Stine-Morrow, 2012) can be used to decompose the reading time into components specific to different text features to examine how readers allocate attention to construct different levels of representation. For example, word-level processes include lexical access and decoding. Lexical access is operationally measured by the increase in reading time as a function of the unit change of log word frequency; the orthographic decoding process is operationally measured by the increase in reading time as the number of syllables increase. Readers often slow down for longer or less frequent words to reflect more attentional resources needed to generate word-level representations.

Conceptual integration (CI) is central to creating the textbase representation. Readers often spend extra time (i.e., pause) when encountering the ends of syntactic constituents such as clauses and sentences, reflecting the effort that readers devote to integrate the concepts they have read so far so as to create a coherent mental representation of the meaning of the text (Just, Carpenter, & Wooley, 1982; Kintch, 1998). In fact, the relatively longer times at such boundary sites have been shown to increase as a function of the number of concepts introduced up to that point in the text (Haberlandt & Graesser, 1989). Hence, the term "wrap-up" used to describe this phenomenon is apt in implying a consolidation process.

There is evidence that CI is functionally important in reading comprehension. For example, the allocation of effort to CI has been shown to result in better recall of the text, presumably because it enables the creation of more elaborate, coherent and enduring textbase representations (Stine-Morrow et al., 2008). Clause-final CI in particular may be an efficient comprehension strategy because it can facilitate downstream CI processes at the end of the sentence. Stine-Morrow et al. (2010) manipulated the structures of sentences, so as to encourage reader to engage CI relatively early in the sentence. They found that this early CI decreased allocation to later sentence-final CI, leading to more efficient processing. Thus, clause CI may play a crucial role among older readers in engaging efficient, as well as effective, reading processes.

IMPACT OF AGE-RELATED CHANGES IN COGNITION ON COMPREHENSION

Cognitive development has distinctive trajectories across the life span (Baltes, 1997), with processing capacity (e.g., working memory and processing speed) declining but knowledge sustained with ageing. Domain-specific knowledge and crystallised ability may promote effective learning despite declines in processing capacity (Beier & Ackerman, 2005). For example, older adults with hypertension learn about their illness over time (Chin et al., 2009) and such knowledge might facilitate learning new information about the disease despite the decline in processing capacity (cf. Miller & Stine-Morrow, 1998). Therefore, the interplay between processing capacity constraints and knowledge growth may shape comprehension among older adults (e.g., Stine-Morrow et al., 2006) and may be critical for promoting self-care among older adults with limited health literacy (Chin et al., 2011).

Comprehension processes such as CI are more difficult for older adults because of age-related declines in processing capacity. Previous research has consistently documented that older adults need to invest more time in word-level and textbase processing than younger adults (Stine-Morrow et al., 2008). Older adults have been found to allocate more time to CI than younger adults, especially at the ends of clauses, in order to reach levels of performance comparable to the young. This clause-final integration may serve as a compensatory strategy for older adults (e.g., Miller et al., 2004; Stine-Morrow et al., 2008, 2010).

Comprehension is also shaped by crystallised ability. Crystallised abilities, as operationalised by vocabulary or exposure to print, are related to increased allocation to CI processes among adults (Payne et al., 2012; Stine-Morrow et al., 2008). Older readers with higher levels of crystallised ability tend to allocate more attention to CI than those with lower crystallised ability, an advantage that may be conferred by both practice in creating mental representations from print, and the relative

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autonomisation of word-level processing (e.g., Payne et al., 2012; Stine-Morrow et al., 2001, 2008).

Domain-specific knowledge, on the other hand, would be expected to have effects on comprehension that are distinct from crystallised ability, for example, in expanding the lexicon in particularised ways and in affording access to knowledge that stimulates elaborative inferencing (Graesser, Haberlandt, & Koizumi, 1987). In a study directly relevant to the present experiment, Miller et al. (2004) investigated the impact of health knowledge on age differences in text comprehension. Participants were randomly assigned to a training session in which they learned about the heart and circulatory systems, or to a control group. Trained (high knowledge) older adults allocated more resources to CI than trained younger adults did, with the effects localised to clause-level integration.

Thus, the behavioural signatures of crystallised ability and domain-specific knowledge on sentence processing may be comparable in promoting wrap-up, indicating enhanced elaborative processing and conceptual integration, but to our knowledge, there has been no systematic investigation separating out these effects in a single experiment. It is especially important to understand the interplay of general (crystallised ability) and health-related knowledge on comprehension of health information because both types of knowledge are key components of health literacy (Chin et al., 2011), which predicts health behaviours and outcomes (DeWalt et al., 2004).

CURRENT STUDY

We examined the distinctive effects of crystallised ability and health knowledge on processing and recall of general and health texts (sentences) among older adults, testing three hypotheses: (1) crystallised ability would increase conceptual integration across text domains; (2) health knowledge would increase conceptual integration in health but not general texts; (3) Conceptual integration would promote better recall performance.

METHOD

Participants

One hundred and eleven older adults were recruited from the community. Four did not finish the study due to fatigue. The analysis was based on the remaining 107 participants. These 107 participants ranged in age from 60 to 88 (mean age = 70.3, SD = 6.6), they were predominately females (62.6%) and varied widely in education (18.7% did not complete high school, 31.8% had graduated with high school degree and 49.5% had more than high school level of education). Most participants (N = 100) were diagnosed with hypertension, for an average duration of 13 years (SD = 10.25). More than 90% of participants had adequate health literacy (>22 out of 36) as measured by the short test of functional health literacy in adults (STOFHLA; Baker, Williams, Parker, Gazmararian, & Nurss, 1999).

Measures

Processing speed was measured by pattern comparison (Salthouse, 1991) and identical pictures tasks (Ekstrom, French, Harmon, & Dermen, 1976). Working memory was measured by letter-number sequencing (Wechsler, 1997). Processing capacity was measured by a composite score, the sum of z-scores of these three measures (Cronbach's α = .73). Crystallised ability was measured by the advanced vocabulary task (Ekstrom et al., 1976; α =.79). Health knowledge was measured by the hypertension knowledge questionnaire, which consisted of 33 true/false and 4 multiple-choice questions and was modified from Gazmararian, Williams, Peel, and Baker (2003) (Cronbach α = .90; Chin et al., 2009).

Materials

Experimental stimuli were 48 18-word sentences. Half of the sentences were about hypertension and other topics related to cardiovascular disease. They were modified versions of texts from online articles, pamphlets or drug prescriptions related to hypertension and cardiovascular disease (e.g., *Hypertension is the "silent killer" because it usually has no symptoms until it causes damage to the body*). The other half was about general topics in science, nature and history, and adopted from Stine-Morrow et al. (2001; e.g., *A leopard is strong and agile enough to be able to tackle prey weighing twice its own weight*). The words in the health sentences were slightly higher in log word frequency (Balota et al., 2007) than those in the general sentences ($t(46) = -2.23$, p = .03; general: M = 11.38, SD = .74; health: M = 11.87, SD = .80).

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However, the two types of sentences did not differ in number of syllables per word ($t(46) = -1.29$, $p = .20$; general: $M = 1.57$, SD = .21; health: $M = 1.65$, SD = .23), number of propositions ($t(46) = -.21$, $p = .84$; general: $M = 7.58$, SD = 1.18; health: $M = 7.67$, SD = 1.58) or number of new concepts ($t(46) = 1.26$, $p = .21$; general: $M = 6.21$, SD = 1.61; health: $M = 5.63$, SD = 1.58). All participants read both the health and general sentences, with domain blocked and the order of blocks counterbalanced across participants.

Procedure

Sentences were presented one word at a time on a computer screen (using E-Prime 1.2) following the moving window paradigm (Just et al., 1982), with presentation self-paced. Text was displayed in white non-proportional Courier New 24-point font on a black background. Participants were instructed to read the sentences for understanding, and then to recall as much of the information from each sentence as possible. The recall was audio recorded and later transcribed. Based on the gist criterion (Stine-Morrow et al., 2008), proportion of propositions recalled was scored for each participant.

RESULTS

We used linear mixed-effects models to analyse the effects of individual difference variables, including processing capacity (PC), crystallised ability (Gc) and health knowledge (HK); text domain (health and general); and text features on individual reading times. This enabled us to model resource allocation to text demands for different types of individuals reading different types of texts. Regression analysis was then used to predict recall performance from individual difference variables and indices of reading strategies derived from the mixed-effects models. Mixed-effect models have been applied to many areas of research including education, neuroscience and social science (e.g., Baayen, Davidson, & Bates, 2008). Unlike random regression models (Lorch & Myers, 1990), these models estimate both fixed effects and random effects of participants and items in a single step. We used R software and the function lmer in package lme4 (Bates, 2005; Bates & Sarkar, 2007) and Baayens MCMC function to estimate significance intervals for the parameter estimates (Baayen et al., 2008). The mixed-effects model equations are summarised in the Appendix.

Reading strategies

We first screened each participant's reading times for outliers. We replaced values larger than 3 SD above the mean with the upper limit (i.e., 3 SD from the mean; less than 2% of the data were replaced). Values smaller than 200 ms were eliminated because these durations do not likely reflect reading processes (less than 1% of the data were eliminated). Reading time was then log transformed to approximate a normal distribution.

In order to model the reading times, each word in the sentences was coded for text features that index word-level and sentence-level processes. The word-level variables were number of syllables ($M = 1.61$, SD = .89) and log word frequency ($M = 11.63$, SD = 3.89) (Balota et al., 2007). The textbase level variables were created by assigning dummy codes (0/1) to the presence of intrasentence syntactic (clause) and sentence boundaries weighted by the number of new concepts introduced up to that point (Stine-Morrow et al., 2001). Thus, these indices can be interpreted as the increase in reading time at the boundary (clause or sentence) for each new concept encountered to that point, to operationalise clause ($M = .73$, SD = 1.71) and sentence wrap-up ($M = .31$, SD = 1.32).

The results of our modelling are summarised in Table 1. We first examined the fixed effects of the four text features on reading time in the resource allocation model (Model 1, first column of Table 1). The model suggested that these variables captured distinct components of resource allocation to word-level and textbase processing. As expected, participants spent more time reading lower frequency and longer words. They also spent more time at the end of clauses and sentences as the cumulative number of new concepts increased, suggesting that they allocated resources to conceptual integration at the end of syntactic constituents.

Given that readers allocated resources to word-level and textbase processing in a meaningful pattern, we then conducted analyses to examine whether individual differences in crystallised ability and domain knowledge moderated text features at the word and textbase level to test our hypotheses.

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TABLE 1
Estimated parameters (with standard error of estimates) of mixed-effects modelling

	Model 1		*Model 2*		*Model 3*		*Model 4*		*Model 5*	
Fixed effect	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*	*B*	*t*
Intercept	7.01 (.05)	145.02*	7.08 (.31)	22.82	7.06 (.31)	22.73*	7.08 (.31)	22.83*	7.06 (.31)	22.73*
Item predictors										
Domain					−.14 (.07)	−2.18*			−.14 (.07)	−2.18*
LogWF	−.03 (.002)	−16.11*	−.03 (.002)	−16.10*	−.03 (.002)	−14.86*	−.03 (.002)	−16.11*	−.03 (.002)	−14.87*
Syll	.07 (.01)	8.88*	.07 (.007)	8.90*	.08 (.008)	9.35*	.07 (.008)	8.88*	.07 (.008)	9.33*
CCI	.02 (.005)	4.12*	.02 (.005)	4.10*	.02 (.005)	3.97*	.02 (.005)	4.12*	.02 (.005)	3.99*
SCI	.08 (.006)	13.14*	.08 (.006)	13.06*	.08 (.006)	13.14*	.08 (.006)	13.14*	.08 (.006)	13.23*
Subject predictors										
Age			−.001 (.004)	−.22	−.001 (.004)	−.22	−.001 (.004)	−.22	−.001 (.004)	−.22
PC			−.05 (.01)	−3.61*	−.05 (.01)	−3.61*	−.05 (.01)	−3.62*	−.05 (.01)	−3.61*
Gc			−.18 (.04)	−4.88*	−.18 (.04)	−4.86*	−.14 (.04)	−4.05*	−.14 (.04)	−4.05*
HK			−.03 (.03)	−1.08	−.03 (.03)	−1.08	−.04 (.03)	−1.42	−.04 (.03)	−1.51
Cross-level interactions										
Gc × logWF			.003 (.0004)	7.67*	.003 (.0004)	7.42*				
Gc × Syll			−.01 (.002)	−5.43*	−.01 (.002)	−5.37*				
Gc × CCI			.01 (.001)	10.29*	.01 (.001)	10.00*				
Gc × SCI			.006 (.001)	4.33*	.007 (.001)	4.49*				
Domain × logWF					.006 (.004)	1.51			.006 (.004)	1.51
Domain × Syll					.02 (.02)	1.08			.02 (.02)	1.08
Domain × CCI					.009 (.01)	.91			.009 (.01)	.91
Domain × SCI					−.005 (.01)	−.40			−.005 (.01)	−.42
Domain × Gc					.004 (.02)	.23				
Domain × HK									−.01 (.02)	−.79
Gc × logWF × Domain					−.001 (.001)	−1.50				
Gc × Syll × Domain					.002 (.004)	.55				
Gc × CCI × Domain					.00007 (.002)	.03				
Gc × SCI × Domain					−.002 (.003)	−.65				
HK × logWF							.001 (.0004)	2.56*	.001 (.0005)	2.83*
HK × Syll							−.002 (.002)	−1.01	−.001 (.002)	−.64
HK × CCI							.002 (.001)	1.61	.002 (.001)	1.87
HK × SCI							−.001 (.001)	−.69	−.001 (.001)	−.88
HK × logWF × Domain									.0005 (.0009)	.60
HK × Syll × Domain									.0007 (.004)	.18
HK × CCI × Domain									.006 (.002)	2.42*
HK × SCI × Domain									−.009 (.003)	−3.16*
−2 Log likelihood	92,134		91,606		91,568		92,058		92,028	
Chi-squared			528.32*		37.28*		75.50*		29.93*	

LogWF = word frequency; Syll = number of syllables; CCI = clause conceptual integration; SCI = sentence conceptual integration; HK = studentised residuals of health knowledge on crystallised ability; PC = processing capacity; Gc = crystallised ability. The Chi-squared is the improvement in model fit relative to the prior model.

*$p < .05$.

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Hypothesis 1. Crystallised ability increases conceptual integration across domains.

In Model 2 (second column of Table 1), we tested the effects of Gc and its differential impact on component text processes. Models were adjusted for age, PC and HK. Because HK was moderately correlated with Gc (r = .57), we computed the studentised residuals of HK on Gc to reduce the overlap of explained variance. The HK residual provides an index of the level of health knowledge at the average level of Gc. Because the variance in HK accounted for by vocabulary was partialed out, the effects of domain knowledge that we report likely represent conservative estimates.

First, we found that the Gc × word frequency and the Gc × number of syllables interactions were significant, showing that crystallised ability facilitated word-level processing. Participants with more crystallised ability spent relatively less time than those with less crystallised ability, reading the lower frequency and longer words. More importantly, the Gc × clause CI and Gc × sentence CI interactions were significant. Older adults with more crystallised ability allocated more time to wrap-up for conceptual integration processes both at the end of clauses and sentences.

To evaluate whether the effect of crystallised ability on word-level and CI processes generalised across the two domains, we added text domain and its interaction term with crystallised ability and text features to the model (Model 3, third column of Table 1). None of the three-way interactions was significant, suggesting that crystallised ability facilitated word-level processing and increased resource allocation to conceptual integration to the same extent in the general and health sentences (Figure 1). Therefore, the results supported Hypothesis 1 that crystallised ability promotes conceptual integration across domains.

Hypothesis 2. Health knowledge increases conceptual integration in health-related texts, but not general texts.

We next analysed the effects of health knowledge on resource allocation. With the effect of crystallised ability controlled, we entered the text features and their interaction terms with health knowledge (HK) to the model (Model 4, Table 1). The HK × word frequency interaction was significant. Readers with more health knowledge spent less time processing lower frequency words. However, collapsing across text domains, HK × clause CI and HK × sentence CI interactions were not significant.

To evaluate whether health knowledge affects resource allocation differently across the two text domains, we added text domain and its interaction terms with HK and text features to the model (Model 5, Table 1). As predicted, the HK × text domain × clause CI and HK × text domain × sentence CI interactions were both significant, suggesting that health knowledge influenced conceptual integration differently across the two text domains. To decompose the three-way interactions, we tested the HK × CI interactions separately for each domain (with covariates of age, PC and Gc). Results showed that there were significant HK × clause CI (t = 3.05, p < .05) and HK × sentence CI (t = −2.75, p < .05) interactions in the health texts, but not in the general texts (t = −.43 and t = 1.40, respectively). Therefore, health knowledge only affected conceptual integration

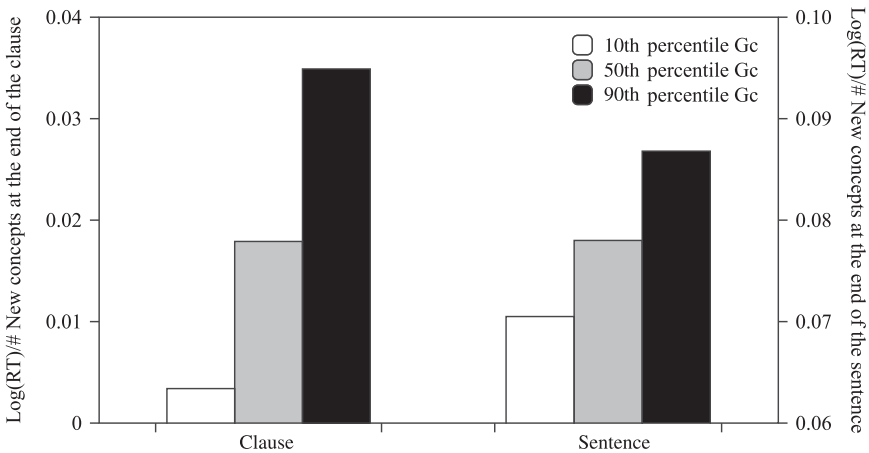

Figure 1. Domain-general effects of crystallised ability (Gc) in promoting conceptual integration at the end of the clause and the sentence.

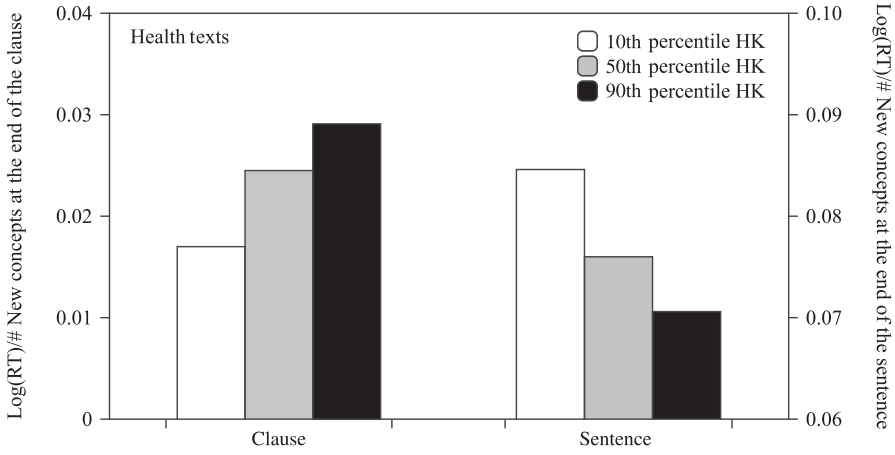

Figure 2. Health knowledge (HK) promoted clause conceptual integration and facilitated sentence conceptual integration in the health texts.

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in the health-related texts, but did not generalise to the other texts.

The significant effects of HK on conceptual integration at clause and sentence boundaries within health-related texts are plotted in Figure 2. Readers with higher levels of health knowledge allocated more resources to clause CI in the health texts. In absolute terms, the magnitude of effect is small. For example, in health texts, for individuals at the 10th percentile of health knowledge, there was an increase of 21 ms per new concepts at clause boundaries, whereas for individuals in the 90th percentile of health knowledge, there was an increase of 33 ms per new concepts at clause boundaries. Nevertheless, these were reliable effects, and this variation in time allocation had an impact on recall performance. This finding supported Hypothesis 2 that health knowledge would promote CI selectively in domain-relevant text. However, health knowledge had the reverse effect at sentence boundaries, producing facilitated conceptual integration. Collectively, our findings on the effects of health knowledge on CI were only partially consistent with our expectations, a topic to which we will return in the Discussion.

Recall performance

The mean propositional recall for health texts was 43.97% (SE = .03) and mean recall for domain-general texts was 50.53% (SE = .02). Thus, recall was somewhat higher for the domain-general texts ($t(106) = 3.19$, $p < .002$). Our goal in the next analysis was to determine the extent to which resource allocation to CI contributed to recall performance. The clause and sentence CI parameters were the best linear unbiased predictors (BLUPs) derived from the mixed-effects model (model 6). In spite of the fact that Gc and HK showed distinctive effects on CI, we collapsed across domains because of the high correlation between recall ($r = .92$), clause CI ($r = .72$) and sentence CI ($r = .72$) across domains.

Hypothesis 3. Conceptual integration promotes better recall performance.

Pearson correlations among recall, reading process (clause and sentence CI parameters) and individual difference variables are reported in Table 2. We used multivariate regression to examine the effects of age, PC, Gc, HK and CI at clause and sentence boundaries on recall. We included Gc × clause CI and Gc × sentence CI interactions as predictors to examine whether Gc moderated the effects of conceptual integration on text recall. Variables were centred before creating the interaction terms. Without the interaction terms in the equation, both Gc ($B = .65$) and clause CI ($B = .16$) were each significant predictors of recall performance (adjusted $R^2 = .47$, $F(6, 101) = 16.72$). When the interaction terms were entered, the effects of Gc and clause CI remained significant ($B = .63$ and .23, respectively; adjusted $R^2 = .50$, $F(8, 99) = 14.07$). In addition, the, Gc × clause CI interaction was significant ($B = -.21$). Age, PC, HK, sentence CI and Gc × sentence CI did not explain additional variance on recall performance ($B = -.11$, $-.02$, $-.03$, $-.11$ and $-.08$, respectively).

The simple slope technique (Preacher, Curran, & Bauer, 2006) was used to visualise the Gc × clause CI interaction (Figure 3). Clause CI was positively associated with recall for participants

TABLE 2
Correlations among age, processing capacity, crystallised ability, health knowledge, conceptual integration (CI) at the end of clause and sentence, recall performance across two texts

	Mean (SD)	*Age*	*Processing capacity*	*Gc*	*HK*	*CCI*	*SCI*
Age	70.27 (6.59)						
Processing capacity	.05 (2.43)	−.04					
Pattern comparison	13.33 (4.04)						
Identical picture	18.88 (5.25)						
Letter-number sequencing	8.30 (2.95)						
Crystallised ability (Gc)	.03 (.98)	.18	.58*				
Health knowledge (HK)	28.45 (2.39)	.15	.46*	.57*			
Clause CI (CCI)	.02 (.03)	−.02	.32*	.34*	.24*		
Sentence CI (SCI)	.09 (.07)	−.07	.08	.08	.04	−.20*	
Recall	.49 (.21)	.02	.42*	.68*	.38*	.40*	−.05

Processing capacity was a composite score of standardised scores from three processing capacity measures (pattern comparison, identical picture and letter-number sequencing). Crystallised ability was a standardised score of verbal ability. Clause CI and sentence CI were BLUPs estimated from the multilevel models of reading time on the text characteristics.

*$p < .05$.

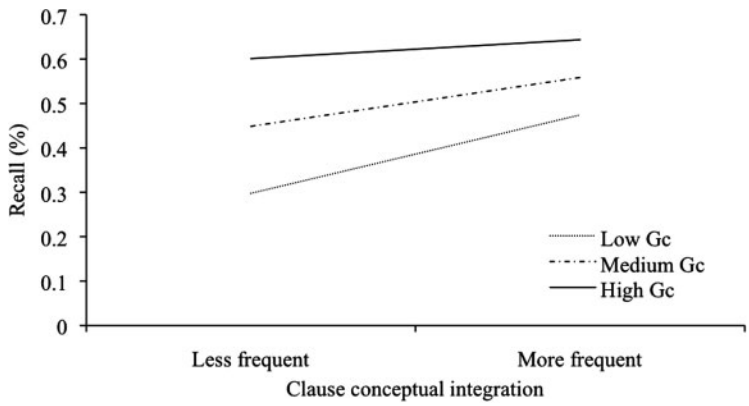

Figure 3. Crystallised ability (Gc) moderates the effect of clause conceptual integration on text recall.

with low crystallised ability (i.e., 1 SD below the mean) ($t(103) = 3.89$, $B = .09$, $p < .001$) and those with medium crystallised ability (i.e., mean) ($t(103) = 3.23$, $B = .06$. $p < .01$), but not for those with high crystallised ability (i.e., 1 SD above the mean) ($t(103) = .91$, $B = .02$, $p = .37$). This pattern suggests that readers with lower crystallised ability benefitted from frequent clause CI on recall performance to a greater extent than readers with higher crystallised ability. Although older readers with lower crystallised ability allocated fewer attentional resources to clause CI, they differentially benefitted when they adopted this strategy. Hence, clause CI tended to compensate for the lower crystallised ability. Our findings supported Hypothesis 3 that conceptual integration would promote better recall, but the beneficial effects were restricted to the case when it was conducted more frequently within sentences. Further, these data suggested that the effects of clause CI on recall performance depended on the reader's level of crystallised ability.

DISCUSSION

Our study used the moving window paradigm to investigate the effects of domain-general (crystallised ability) and domain-specific (health) knowledge, and processing capacity on comprehending general and health texts among older adults with hypertension. Consistent with our hypotheses, after controlling the effects of processing capacity and health knowledge, crystallised ability had domain-general effects in promoting conceptual integration, regardless of text domain. In addition, after controlling the effects of processing capacity and crystallised ability, health knowledge showed selective, domain-specific, effects in promoting

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conceptual integration. The results are consistent with previous research showing that high-verbal older adults allocate more cognitive resources to conceptual integration (Stine-Morrow et al., 2008); and that older adults with domain knowledge allocate more resources to conceptual integration in domain-related texts (Miller et al., 2004). The current research extends this literature by (1) distinguishing the effects of domain knowledge from those of general verbal (crystallised) ability on comprehension and (2) localising the effect of knowledge to domain-relevant texts. These data are important in showing that these two sorts of knowledge, while typically correlated, have independent effects in promoting attentional engagement in reading (Stine-Morrow, 2007), which support the creation of more elaborated and enduring mental representations of the ideas contained in the text.

It is important to note that while crystallised ability increased conceptual integration more broadly, at both clause and sentence boundaries, domain knowledge selectively boosted conceptual integration at clause boundaries—but then facilitated these processes at sentence boundaries. We do not have a ready explanation for these divergent effects of crystallised and domain knowledge. It should be noted that Miller et al. (2004), who experimentally examined the effects of domain knowledge with training, also found enhanced conceptual integration selectively at clause boundaries, as in our data. However, findings have been somewhat mixed; for example, Miller (2001, 2003) has shown effects of cooking knowledge in increasing wrap-up at sentence boundaries for more extended texts. One possibility is that the self-regulation of how knowledge-based integration is conducted depends on the overall length of the text, with clausal integration more likely in relatively short texts that are unsupported by discourse structure, and therefore, more taxing on working memory resources (Stine & Wingfield, 1990; Stine-Morrow et al., 2008).

In the current study, the more frequent consolidation among high-knowledge readers reduced the downstream processing load in the sentence. Such trade-offs between early and late wrap-up in managing the load of assembling the semantic representation for sentence processing have been demonstrated experimentally (by inducing early wrap-up with small structural changes in the sentence that preserve semantic complexity) and dubbed the "pay-now-or-pay-later" (PNPL) effect (Stine-Morrow et al., 2010). Why domain-specific knowledge would engender this sort of frequent chunking in sentence processing, while verbal ability would engender higher levels of conceptual integration across the board is an interesting question. This may have to do with the distinctive sorts of integration processes that are engendered by different sorts of knowledge. Verbal ability reflects knowledge built on literacy experience (Stanovich et al., 1995) so that increased wrap-up reflects the procedural skill of reading, which requires the regular consolidation of meaning within and between sentences. Domain-related knowledge, on the other hand, reflects declarative knowledge about the topic so that wrap-up would be expected to reflect an inferencing process in which domain-related ideas are activated and effort is allocated to integrate these ideas with the text content (Graesser et al., 1987). It may be that the inferencing function engendered by domain-related knowledge is relatively sensitive to the PNPL effect, such that early consolidation of ideas reduces the cognitive load of ideas that must be integrated. On the other hand, the procedural skill of opportunistic conceptual integration at syntactic boundaries that is engendered by literacy experience may be a more automatised engagement of resources (a "habit of mind"; Stine-Morrow et al., 2006) that is triggered regardless of cognitive load. This procedural-declarative account of wrap-up would imply that clause wrap-up should be more sensitive to idea consolidation than sentence wrap-up. In fact, we found that it was clause CI that predicted recall and not sentence CI. This explanation is, of course, speculative but does provide an account of the divergent effects of knowledge on reading strategies, as well as the way in which reading strategies predicted recall. Further research is needed to explore semantic consolidation processes in text as both a core reading skill and as an outcome of particularised domain knowledge.

Although research suggests that older adults can be proficient with sentence CI (e.g., Stine-Morrow et al., 2001, 2008), there is also evidence that sentence CI is more of a drain on attentional resources for older readers (Payne & Stine-Morrow, 2012) and that older readers often shift wrap-up to earlier points in sentence processing (e.g., Miller & Stine-Morrow, 1998; Stine-Morrow et al., 2010). Hence, clause CI may be a more robust reading strategy for older adults that compensates for their processing capacity limits. Future study should examine the effects of domain-general and domain-specific knowledge

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on conceptual integration across a wider age range, as well as a wider range of texts, to better understand the complex relationships among knowledge, processing capacity limits and reading strategy across the life span.

Our findings have implications for developing more effective patient education materials. First, the health knowledge × word feature interactions suggest that older adults with lower health knowledge will benefit from simpler (more common) words, which is consistent with the suggestion that adults with inadequate health literacy will better understand health texts with lower readability scores (simpler language; e.g., Wolf et al., 2007). Second, we found that health knowledge promotes clause CI, which is also associated with better recall of health texts. Given this knowledge-driven advantage, older adults' comprehension of health information may be improved by training to engage reading strategies with more frequent integration, or redesigning health texts to encourage more frequent consolidation, for example by signalling important syntactic constituents with punctuation, line breaks or font variation (e.g., Stine-Morrow et al., 2010). In this way, patients with less health knowledge may be encouraged to use the same strategy of earlier conceptual integration as more knowledgeable adults. This strategy in turn may help patients develop more elaborate knowledge about their illness, which could eventually leverage to more easily learn the information they need for effective self-care.

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APPENDIX

This appendix contains the generalised linear mixed-effects models used in the current paper.

Model 0: Empty model (unconditional means model)

$$\ln(Y_{ijk}) = \gamma_{000} + U_{0j0} + V_{00k} + e_{ijk}$$

This model contains the intercept γ_{000}, random effect of each participant U_{0j0}, the random effect of each word item V_{00k} and the residual component e_{ijk} in explaining the log-transformed reading time Y_{ijk}.

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Model 1: Resource allocation model

$$\ln(Y_{ijk}) = \gamma_{000} + \gamma_{001}(\text{logWF})_k + \gamma_{002}(\text{Syll})_k + \gamma_{003}(\text{CCI})_k + \gamma_{004}(\text{SCI})_k + U_{0j0} + V_{00k} + e_{ijk},$$

where logWF is the natural log of word frequency; Syll is the number of syllables; CCI is the cumulative number of new concepts introduced at the end of a clause; SCI is the cumulative number of new concepts introduced at the end of a sentence.

Model 2: Effects of crystallised ability (Gc) on resource allocation model with the covariates of age, processing capacity (PC) and health knowledge (HK)

$$\begin{aligned}\ln(Y_{ijk}) = {} & \gamma_{000} + \gamma_{001}(\text{logWF})_k + \gamma_{002}(\text{Syll})_k + \gamma_{003}(\text{CCI})_k + \gamma_{004}(\text{SCI})_k \\ & + \gamma_{010}(\text{Age})_j + \gamma_{020}(\text{PC})_j + \gamma_{030}(\text{HK})_j + \gamma_{040}(\text{Gc})_j \\ & + \gamma_{041}(\text{Gc})_j(\text{logWF})_k + \gamma_{042}(\text{Gc})_j(\text{Syll})_k + \gamma_{043}(\text{Gc})_j(\text{CCI})_k + \gamma_{044}(\text{Gc})_j(\text{SCI})_k \\ & + U_{0j0} + V_{00k} + e_{ijk}\end{aligned}$$

Model 3: Text domain moderates the effects of crystallised ability (Gc) on resource allocation model with the covariates of age, processing capacity (PC) and health knowledge (HK)

$$\begin{aligned}\ln(Y_{ijk}) = {} & \gamma_{000} + \gamma_{001}(\text{logWF})_k + \gamma_{002}(\text{Syll})_k + \gamma_{003}(\text{CCI})_k + \gamma_{004}(\text{SCI})_k \\ & + \gamma_{010}(\text{Age})_j + \gamma_{020}(\text{PC})_j + \gamma_{030}(\text{HK})_j + \gamma_{040}(\text{Gc})_j \\ & + \gamma_{041}(\text{Gc})_j(\text{logWF})_k + \gamma_{042}(\text{Gc})_j(\text{Syll})_k + \gamma_{043}(\text{Gc})_j(\text{CCI})_k + \gamma_{044}(\text{Gc})_j(\text{SCI})_k \\ & + \gamma_{005}(\text{Domain})_k + \gamma_{006}(\text{logWF})_k(\text{Domain})_k + \gamma_{007}(\text{Syll})_k(\text{Domain})_k \\ & + \gamma_{008}(\text{CCI})_k(\text{Domain})_k + \gamma_{009}(\text{SCI})_k(\text{Domain})_k + \gamma_{045}(\text{Gc})_j(\text{Domain})_k \\ & + \gamma_{046}(\text{Gc})_j(\text{logWF})_k(\text{Domain})_k + \gamma_{047}(\text{Gc})_j(\text{Syll})_k(\text{Domain})_k \\ & + \gamma_{048}(\text{Gc})_j(\text{CCI})_k(\text{Domain})_k + \gamma_{049}(\text{Gc})_j(\text{SCI})_k(\text{Domain})_k \\ & + U_{0j0} + V_{00k} + e_{ijk},\end{aligned}$$

where domain is a categorical variable with effects coding.

Model 4: Effects of health knowledge (HK) on resource allocation model with the covariates of age, processing capacity (PC) and crystallised ability (Gc)

$$\begin{aligned}\ln(Y_{ijk}) = {} & \gamma_{000} + \gamma_{001}(\text{logWF})_k + \gamma_{002}(\text{Syll})_k + \gamma_{003}(\text{CCI})_k + \gamma_{004}(\text{SCI})_k \\ & + \gamma_{010}(\text{Age})_j + \gamma_{020}(\text{PC})_j + \gamma_{030}(\text{HK})_j + \gamma_{040}(\text{Gc})_j \\ & + \gamma_{031}(\text{HK})_j(\text{logWF})_k + \gamma_{032}(\text{HK})_j(\text{Syll})_k + \gamma_{033}(\text{HK})_j(\text{CCI})_k \\ & + \gamma_{034}(\text{HK})_j(\text{SCI})_k + U_{0j0} + V_{00k} + e_{ijk}\end{aligned}$$

Model 5: Text domain moderates the effects of health knowledge (HK) on resource allocation model with the covariates of age, processing capacity (PC) and crystallized ability (Gc)

$$\begin{aligned}\ln(Y_{ijk}) = {} & \gamma_{000} + \gamma_{001}(\text{logWF})_k + \gamma_{002}(\text{Syll})_k + \gamma_{003}(\text{CCI})_k + \gamma_{004}(\text{SCI})_k \\ & + \gamma_{010}(\text{Age})_j + \gamma_{020}(\text{PC})_j + \gamma_{030}(\text{HK})_j + \gamma_{040}(\text{Gc})_j \\ & + \gamma_{031}(\text{HK})_j(\text{logWF})_k + \gamma_{032}(\text{HK})_j(\text{Syll})_k + \gamma_{033}(\text{HK})_j(\text{CCI})_k \\ & + \gamma_{034}(\text{HK})_j(\text{SCI})_k + \gamma_{005}(\text{Domain})_k + \gamma_{006}(\text{logWF})_k(\text{Domain})_k \\ & + \gamma_{007}(\text{Syll})_k(\text{Domain})_k + \gamma_{008}(\text{CCI})_k(\text{Domain})_k + \gamma_{009}(\text{SCI})_k(\text{Domain})_k \\ & + \gamma_{035}(\text{HK})_j(\text{Domain})_k + \gamma_{036}(\text{HK})_j(\text{logWF})_k(\text{Domain})_k + \gamma_{037}(\text{HK})_j(\text{Syll})_k(\text{Domain})_k \\ & + \gamma_{038}(\text{HK})_j(\text{CCI})_k(\text{Domain})_k + \gamma_{039}(\text{HK})_j(\text{SCI})_k(\text{Domain})_k \\ & + U_{0j0} + V_{00k} + e_{ijk}\end{aligned}$$

Model 6: Getting BLUPs of recourse allocation parameters

$$\begin{aligned}\ln(Y_{ijk}) = {} & \gamma_{000} + \gamma_{001}(\text{logWF})_k + \gamma_{002}(\text{Syll})_k + \gamma_{003}(\text{CCI})_k + \gamma_{004}(\text{SCI})_k \\ & + V_{00k} + V_{001}(\text{logWF})_k + V_{002}(\text{Syll})_k + V_{003}(\text{CCI})_k \\ & + V_{004}(\text{SCI})_k + e_{ijk}\end{aligned}$$