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Use of Contextual Information and Prediction by Struggling Adult Readers: Evidence From Reading Times and Event-Related Potentials

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ABSTRACT
We employed self-paced reading and event-related potential measures to investigate how adults of varying literacy levels use sentence context information when reading. Community-dwelling participants read strongly and weakly constraining sentences that ended with expected or unexpected target words. Skilled readers showed N400s that were graded by the cloze probability of the targets, with larger N400s for more unexpected words. Moreover, it took these participants longer to read unexpected targets in strongly than weakly constraining sentences, suggesting a processing cost for revising predictions. Among less skilled readers, a reliable N400 difference was found between expected and unexpected targets only for the strongly constraining sentences. They also took longer when targets were unexpected, regardless of the context. These findings suggest that lower literacy readers could only immediately take advantage of strongly constraining context information to facilitate word processing and that they do not make as much use of predictive processing during comprehension.

A well-established phenomenon in the study of language comprehension is that the processing of individual words is shaped by higher level sentence and discourse information. In particular, context facilitates the processing of individual words by decreasing the time needed for word recognition (e.g., Morton, 1969) and integration processes (e.g., Miller & Stine-Morrow, 1998; Perfetti & Stafura, 2014; Perfetti, Yang, & Schmalhofer, 2008; Stine-Morrow, Miller, & Hertzog, 2006). In behavioral studies, words with strong contextual support, compared to words without, are fixated less often and for less time (Ehrlich & Rayner, 1981) and are responded to more quickly in lexical decision tasks (Schwanenflugel & Shoben, 1985). In event-related potential (ERP) studies, context-based facilitation is robustly observed in the form of graded amplitude reductions of the N400 component (Baggio & Hagoort, 2011; Kutas & Hillyard, 1980), a negative-going voltage deflection, largest over central and parietal electrode sites, that peaks around 400 ms after word onset. However, most of these findings were established through university students, that is, adults with high reading ability. The important question, then, is whether adults with limited literacy skills are also able to take advantage of contextual facilitation in reading. The current study employed reading times and ERPs to examine this.

Context can be used in multiple ways, entailing different cognitive processes and skills and allowing for different comprehension outcomes (Federmeier, 2007), mechanisms that have been largely uncovered with electrophysiological methods. In some cases, semantic and syntactic information can be used to narrow down the set of candidate word continuations, allowing prediction-based facilitation for aspects of word processing even before the critical word appears (see reviews by

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Kuperberg & Jaeger, 2016; Pickering & Garrod, 2013). ERP studies have provided strong evidence for predictive processing strategies, revealing reduced N400s for words that are not themselves predicted in a context but that share semantic, phonological, or orthographic characteristics with predicted words (DeLong, Groppe, Urbach, & Kutas, 2012; Federmeier & Kutas, 1999; Laszlo & Federmeier, 2009). Evidence for predictive processing has also been seen in the form of post-N400 responses to words that violate strong predictions. For example, in Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (2007), college students read sentences that were strongly or weakly constraining and ended with critical words that were either expected or unexpected but plausible (e.g., strongly constraining: *He bought a pearl necklace for her birthday/collection*. weakly constraining: *I was impressed by how much he knew/published*.). N400 amplitudes tracked cloze probability: strongly constraining contexts with expected targets produced the smallest N400, followed by weakly constraining contexts with expected targets, and unexpected targets in both contexts elicited identical, large N400s. In a later time window (500–900 ms), however, unexpected words in strongly constraining contexts produced a larger positivity over frontal electrode sites than words in other conditions. This late positivity was argued to reflect the cost of having made a prediction and then having it violated.

Although reaction time, eye-tracking, and ERP studies converge in showing that proficient college-age readers rapidly use contextual constraints to facilitate word processing, in part through the use of predictive processing strategies, these context and prediction-based effects are not ubiquitous. The use of prediction requires rapid computation of meaning and application of language knowledge and past experience to identify word candidates, and thus is not available in all circumstances or for all types of comprehenders (e.g., Huettig & Mani, 2016; Wlotko & Federmeier, 2015; Wlotko, Federmeier, & Kutas, 2012). In other cases, then, context may have its greatest impact later in processing, when a word that has been encountered is integrated with information obtained from previous words. Effective integration demands its own set of skills, as linguistic components are assembled and pragmatic knowledge is used to build message-level representations (Morris, 2006; Perfetti & Stafura, 2014; Stine-Morrow & Payne, 2016; Stine-Morrow, Soederberg Miller, Gagne, & Hertzog, 2008). The availability of different mechanisms, then, will vary as a function of the type of material and task, as well as across people as a function of factors including their age, general cognitive abilities, and language skills. Important questions remain, therefore, about how—and how effectively—comprehenders of different reading skill levels use these strategies and what role they might play in contributing to comprehension difficulty.

As a group, children from second to sixth grade have been shown to benefit from context information (e.g., Briggs, Austin, & Underwood, 1984; Perfetti, Goldman, & Hogaboam, 1979; Schwantes, Boesl, & Ritz, 1980; Stanovich & West, 1981; West & Stanovich, 1978). Within that group, context effects tend to correlate negatively with word reading scores and spelling ability, suggesting that greater use of context is related to poorer lexical skills (Andrews & Bond, 2009; Hersch & Andrews, 2012; Schwantes et al., 1980; West & Stanovich, 1978). Similarly, dyslexic children and adults (who have specific deficits in decoding) show greater contextual facilitation relative to age-matched typical-reader controls (Ben-Dror, Pollatsek, & Scarpati, 1991; Bruck, 1990; Nation & Snowling, 1998). On the other hand, readers who have less well-developed linguistic knowledge but may not have decoding difficulty, such as second-language learners, seem to use context less effectively in some cases. For example, based on ERP findings in Spanish–English bilinguals and native English speakers, Martin et al. (2013) argued that second-language learners are not able to build a message-level representation from the context fast enough to actively predict upcoming words.

Collectively, such findings are consistent with the Simple View of Reading, which states that reading proficiency depends on both decoding/word recognition skills and the ability to effectively and efficiently build message-level meaning representations from context (Hoover & Gough, 1990; Kendeou, Savage, & van den Broek, 2009). The on-line processing of individual words is thus a combined function of the "bottom-up" activation of word-related information and the "top-down" activation of features that constrain lexical selection and thus leads to efficient reading (McClelland, 1987). The system is interactive, such that when the skills underpinning one source of activation are weak, the other source of activation may predominate (Stanovich, 1980). Among children acquiring reading skills, word recognition/decoding is the typical bottleneck, producing the pattern of exaggerated contextual benefit; however, decoding and other comprehension-critical skills can develop somewhat independently (e.g., Nation & Snowling, 1998), so as to produce the reverse pattern.

Less is known about how the use of these top-down and bottom-up processes varies among adult readers. To the extent that this has been examined, the focus has been on comparisons of healthy younger and older adults. As people age, sensory and fluid abilities (e.g., working memory and speed of processing) decline but crystalized verbal ability (e.g., vocabulary) remains relatively intact (Hartshorne & Germine, 2015). A number of behavioral studies show that, relative to the young, older adults differentially benefit from context information in word recognition, especially when inputs are degraded, in both reading (e.g., Madden, 1988; Stine-Morrow et al., 2008) and speech comprehension (e.g., Cohen & Faulkner, 1983; Stine-Morrow, Soederberg Miller, & Nevin, 1999). Thus, when aging diminishes sensory capabilities, older adults may rely more on context for word recognition. At the same time, work with ERPs has shown that older adults also gain less information from context, compared to their younger counterparts, and may be especially less likely to be able to use weaker contextual constraints and to predict features of upcoming words (Federmeier & Kutas, 2005; Federmeier, McLennan, De Ochoa, & Kutas, 2002; Wlotko & Federmeier, 2012). Taken together, this literature thus suggests that older adults both rely on context more, especially when decoding is relatively difficult, and use it less rapidly and effectively, especially for prediction.

This pattern highlights the fact that multiple mechanisms are at work. Skilled readers may be able to use context more effectively (demonstrated by predictive processing) but also may be better able to process individual words with minimal contextual support. Along the same lines, then, individuals with weaker language skills (e.g., underdeveloped decoding skills, lower fluency, less accurate linguistic knowledge) may be less likely to use context predictively but also may be more dependent on context for word recognition and integration, as demonstrated by greater contextual facilitation in reading times. However, given that people who differ in age and native language may also differ in many other respects (e.g., general knowledge and the availability of various cognitive resources), comparisons between adults with similar backgrounds but different literacy skills are particularly important for discerning the specific role that language experience may play in shaping online comprehension.

According to a report from the National Research Council (2012), 65 million adults in the United States are able to read only simple texts with adequate comprehension. Yet there is very little understanding of online reading comprehension by lower-literate adults. For example, it is unknown whether lower-literate adults rely more on contextual information to compensate for their weaker decoding skills or, instead, have greater difficulty in constructing message-level representations and thus a reduced ability to use context to predict and to facilitate word processing. The limited literature that exists points to the possibility of important shifts in context use as a function of literacy skill. For example, using the visual world paradigm, Mishra, Singh, Pandey, and Huettig (2012) found that higher-literate participants used gender cues in Hindi to start looking at a target object before it was mentioned, whereas lower-literate participants did not, suggesting that literacy skills may have a direct effect on comprehension strategies like prediction.

The current study therefore aimed to investigate how lower-literate adults, relative to adults with high school reading skills, make use of strongly and weakly constraining contexts to facilitate word processing. To assess on-line processing with high temporal accuracy and to obtain sensitive and functionally specific indices of context use and prediction, we measured brain electrical activity along with reading times as participants self-paced to read sentences word by word. We used self-paced reading rather than the conventional rapid serial visual presentation (RSVP) method in this ERP study because self-paced reading would accommodate participants varying widely in reading skills. One previous study similarly used this simultaneous self-paced and ERP technique and obtained results consistent with those of other ERP studies that used the RSVP method (e.g., Ditman, Holcomb, & Kuperberg, 2007). Moreover, the simultaneous collection of ERP and reading-time data affords the ability to look into both the fine-grained time-course of word processing as it unfolds (ERPs), as well as the overall processing costs at the word itself and downstream (reading times), thus providing insight into multiple levels of sentence processing.

The stimuli were strongly and weakly constraining sentence frames that ended with an expected or unexpected target word. Strongly constraining sentence frames tend to lead to consistent expectations, and thus afford predictions, for a particular word as a completion. Weakly constraining contexts, on the other hand, allow a much broader range of completions, so that activation is distributed among features of plausible targets. Expectancy was crossed with constraint, such that sentences in both constraint conditions were completed with an expected target or an (equally) unexpected but plausible target. This design allowed us to test whether lower-literate adults could, on one hand, make use of strongly as well as weakly constraining contexts to facilitate processing and, on the other hand, use predictive processing when possible.

Method

Participants

Participants were native English speakers recruited from the local community through adult basic education programs and advertisements posted in community centers, shopping areas, and buses. Their literacy level was determined by the results of our language measures, as described next. If we used the ninth-grade reading level (= high school level reading abilities) as the cutoff, half (n = 20; 10 females) of our sample had higher literacy skills (HL; M = 11.2, SD = 1.4; range = 9.1–14.3) and the other half (n = 20; 12 female) had lower literacy skills (LL; M = 7.1, SD = 1.3; range = 3.9–8.8), although in statistical analyses participants' literacy level was treated as a continuous variable. The sample was, on average, 46 years of age (HL range = 27–65, LL range = 23–68). HL adults (M = 12.2 years, SD = 1.7, range = 8–15) had slightly more formal education than LL adults (M = 11.7 years, SD = 1.6, range = 8–14). Six HL participants were left-handed or ambidextrous.

Literacy skill was measured as the mean grade-equivalent scores of the three assessments associated with reading ability: the Slosson Oral Reading Task, the Woodcock–Johnson Reading Fluency task, and the Rapid Automatized Naming/Rapid Alternating Stimulus (RAN/RAS). In Slosson Oral Reading Task, participants were required to read out loud isolated words of differing levels of unfamiliarity. In Reading Fluency, participants decided the truthfulness of as many sentences in a list as possible within 3 min. In RAN/RAS, participants named a series of letters, objects, numbers, and colors as quickly as possible. The reading times determined their reading level. The RAN/RAS is not a direct measure of reading itself, but it is a strong predictor of reading ability (Norton & Wolf, 2012). These three measures formed a coherent construct representing reading ability (Cronbach's α = 0.66).[1] Our neuropsychological battery, which included these three measures, took approximately 1.5 hr to complete and was not administered on the same day as the EEG study. All the tests and procedures were approved by the Institutional Review Board of the University of Illinois, and informed consent was obtained from all participants prior to participation.

Materials

The stimuli were adapted from Federmeier et al. (2007) and consisted of 140 pairs of sentences. The mean Flesch-Kincaid grade level (based on Microsoft Word) was 2.3 (range = 0–4.6). The target word was always the last word in the first sentence and was always a plausible continuation. Two

[1]Participants in our studies are routinely administered a comprehensive battery of neuropsychological assessments including measures of fluid and crystallized abilities, as well as more specific language and reading-related abilities. In the larger sample of participants (N = 232) from which the current sample was drawn, Cronbach's α = .76. Furthermore, factor analysis on this battery showed that these three measures loaded onto a common factor, one that was separate from fluid and crystallized abilities.

Table 1. Examples of stimulus materials.

Sentence Constraint	Word Expectancy	*M* Cloze	Example
Strongly constraining	Expected	.85	*The prisoners were planning their escape. The time was running out.*
	Unexpected	.01	*The prisoners were planning their party. The time was running out.*
	Q: Did the prisoners have enough time?		
Weakly constraining	Expected	.27	*He slipped and fell on the floor. He had to go to the hospital.*
	Unexpected	.02	*He slipped and fell on the rock. He had to go to the hospital.*
	Q: Was his fall serious?		

factors were manipulated: (sentential) Constraint and (target word) Expectancy, leading to four types of sentences. Table 1 presents examples in which the target word is underlined and the corresponding comprehension questions that followed each sentence.

Constraint refers to how much a given context leads to a consistent expectation for some particular word. It was defined based on the cloze probability of the most expected word for that context ("best completion"), as established through norming (details in Federmeier et al., 2007). Strongly constraining contexts had best completions whose cloze probabilities varied between 1 and .69, whereas weakly constraining contexts had best completions with cloze probabilities of .11 to .41. Expected words were always the best completion for their context; therefore, in absolute terms, expected words in strongly constraining contexts were more probable and, thus, more expected than those in weakly constraining contexts. Unexpected words in both types of context were plausible but had a cloze probability near zero (and were never semantically related to or associated with the expected word). Cloze probabilities of unexpected words were carefully matched across strongly and weakly constraining contexts so that comparisons between them provide an assessment of the influence of constraint uncontaminated by expectancy. Target words were matched across condition for frequency, length, concreteness, familiarity, and imaginability (see Table 2).

Two lists were created such that, across lists, each sentence frame appeared with both target words, but no sentence frame was repeated within a list. Thus, each list contained 35 sentence pairs from each Constraint × Expectancy condition. The stimuli were pseudorandomized so that no more than four pairs from the same condition were presented consecutively.

Procedure

Participants were seated in a quiet room, about 100 cm from a 46 cm CRT monitor. They read the sentences one word at a time with a self-paced presentation controlled by a button on a response pad. Each trial began with a "Ready?" prompt. Participants were instructed to blink only during this time. With a button press, the prompt was immediately replaced by a fixation cross (+), which was replaced by the first word of the sentence with another button press. The cross and each word were presented in the center of the screen and stayed on the screen until a button press or the 5,000 ms time limit was reached. An ISI of 200 ms was imposed before the presentation of each subsequent word. The hand used to advance the sentence was counterbalanced across participants. Participants were instructed to sit still and avoid eye movements when reading the sentences. After each sentence, participants were presented with a Yes/No question in its entirety that assessed gist comprehension and given 20 s to respond. No feedback was provided. Both reading times and EEG were recorded as

Table 2. Analysis of variance results of target word measures for the factors of constraint, expectancy, and their interaction.

	Frequency		Length		Concreteness		Familiarity		Imaginability		Cloze	
	$F(1, 276)$	p	$F(1, 276)$	p	$F(1, 276)$	p	$F(1, 276)$	p	$F(1, 276)$	p	$F(1, 276)$	p
Constraint	0.44	.51	2.09	.15	0.20	.66	0.18	.67	0.77	.38	892.96	< .001
Expectancy	0.75	.39	1.07	.30	0.35	.55	0.05	.82	0.23	.63	4480.25	< .001
Constraint × Expectancy	0.00	.97	0.75	.39	1.07	.30	0.04	.85	0.03	.87	895.93	< .001

participants read. All words appeared in an Arial 48-point font with white text on a black background. The experiment began with practice sentences to familiarize participants with the procedure.

EEG recording and processing

Continuous EEG was recorded using 26 scalp Ag/AgCl active electrodes, arranged according to the 10–20 system (Prefrontal: FP1, FP2; Frontal: Fz, F3, F4, F7, F8; Fronto-central: FC1, FC2, FC5, FC6; Central: Cz, C3, C4; Centro-parietal: CP1, CP2, CP5, CP6; Parietal: Pz, P3, P4, P7, P8; Occipital: Oz, O1, O2). The signal was referenced online to the left mastoid and re-referenced offline to the average of the right and left mastoids. Eye-movements and blinks were monitored using four electrodes placed on the outer canthus and over the infraorbital ridge of each eye. The EEG signal was recorded at a sampling rate of 200 Hz.

Offline, the EEG was filtered between 0.1 and 30 Hz. Trials with artifactual contamination, such as saccades, blinks, and excessive muscle noise, which affected 11.4% of data, were removed from analysis. Artifact rejection thresholds were adjusted for each participant. ERPs were computed from 100 ms before the onset of the critical words to 900 ms after. They were averaged according to condition for each participant, after subtraction of the 100 ms prestimulus baseline.

Data analysis

Both ERPs and behavioral data were submitted to linear mixed-effects modeling, using the lme4 package for R (Bates, Maechler, Bolker, & Walker, 2015). For the EEG data, mean amplitudes were computed separately for each subject and condition. We started with the most complex model that included Literacy Level, Constraint (strong, weak), Expectancy (expected, unexpected), and their interaction as fixed factors. Literacy Level was treated as a continuous variable so that we did not arbitrarily bin subjects into discrete groups (see Payne, Lee, & Federmeier, 2015).[2] If no three-way interaction was found, we would model the data with all the two-way interaction and main effect terms, and then with only main effect terms if no interactions were found. A maximal random-effects structure for the within-subjects variables was fit across subjects (Barr, 2013 ; Barr, Levy, Scheepers, & Tily, 2013), but only a random intercept was fit for electrode location, because some models would not converge if a random slope was added for electrodes. Significant interactions with categorical variables (e.g., Constraint × Expectancy interaction) would be followed by post hoc comparisons using the package *lsmeans* in *R*, with Tukey adjustment for multiple comparisons. Wald *t* values exceeding 2 were considered statistically significant and would be formally tested via a log-likelihood ratio test (LLRT; i.e., comparing the change in the log-likelihood between the model and a nested model excluding the significant term). The *p* values from the test are reported, together with the corresponding chi-square values.

Self-paced reading times below 70 ms or above 3,000 ms were removed from analysis. This affected 2% of data at the target word, and 1.5% and 2% of data for the two words following the target. Reading-time data at the targets and the two subsequent words were fitted with linear mixed-effects models with the same fixed effect structure as the EEG data and following the same modeling procedures. The random structure included random intercepts for participants and sentence items. Because the comprehension questions probed understanding of different parts of a sentence, a comprehension error might not indicate misunderstanding of the critical portion of the sentence. Thus, trials with comprehension errors were included in the ERP and reading time analysis.

[2]Theoretically, cloze could also be treated as a continuous variable. However, by design, the cloze of our materials tended to cluster at three levels of probability (high, mid-to-low, and very low), making it more like a categorical rather than a continuous variable.

For the comprehension questions, accuracy rates and reaction times were computed per condition for each participant. Mixed-effects models were fitted to the data with the same fixed effect structure as the EEG data and Participant as a random intercept.

Because participants' ages varied considerably and previous studies have found age effects on context use, we initially included age as a fixed factor to examine its contribution to the models. We found no significant interaction with other predictors for the ERP data (ts < 1.5). Moreover, age and literacy level were not correlated (r = .13). Thus, we excluded age as a fixed factor in further modeling. That said, it should be noted that age could potentially interact with literacy level to shape context effects on reading (Steen et al., under review); however, the limited number of our participants might reduce the statistical power to examine this complex interaction.

Results

Comprehension questions

Performance on the comprehension questions was good, with accuracy rates of 91% and 85%, for higher and lower literacy samples, respectively, showing that we succeeded in developing materials that were generally comprehensible to readers with this range of ability. Mixed-effects models did not reveal any significant interactions. Both accuracy and response time were reliably different as a function literacy level. There was a significant advantage in accuracy for the participants with higher literacy (t = 2.53), LLRT $\chi^2(1)$ = 6.21, p = .013, who also answered the comprehension questions more quickly than participants with lower literacy (t = 5.60), LLRT $\chi^2(1)$ = 24.04, p < .001; HL = 4,373 ms, LL = 3,094 ms. This suggested that the somewhat poorer performance in the LL group was not attributable to a speed–accuracy trade-off. For response times, there were also main effects of Constraint (t = 2.89), LLRT $\chi^2(1)$ = 8.21, p = .004, and Expectancy (t = 2.50), LLRT $\chi^2(1)$ = 6.19, p = .013, such that participants took longer to answer questions for weakly constraining sentences and sentences with an unexpected target word.

ERPs

Figures 1 and 2 show the grand average ERPs of the higher- and lower-literate participants, respectively, to expected and unexpected endings in strongly and weakly constraining sentence frames. Sentence-final target words in all conditions elicited components that are characteristic of ERPs to visual stimuli, including a negativity (N1) peaking around 100 to 150 ms and a positivity (P2) around 200 ms. The most distinctive later component was a centro-parietal negativity (N400), seen between about 300 and 600 ms, for which, as we discuss next, the HL and LL groups showed differential ERP patterns across the sentence conditions. Over frontal sites, the HL group showed a relatively late (after 500 ms) frontal negativity to the expected targets in strongly constraining sentences, which was not present in other three conditions, a pattern that was not visually apparent in the LL group; we also comment on this effect below.

N400. Analyses of N400 effects were conducted across eight a priori chosen centro-parietal electrode sites (Cz, C3, C4, CP1, CP2, Pz, P3, P4), where N400 effects are typically largest; see Figure 3A for the waveforms of the four conditions at Pz. Mean amplitudes were measured between 300 and 600 ms. There was no reliable Constraint × Expectancy × Literacy Level interaction (t = 0.56), but there were significant Constraint × Expectancy (t = 4.58), LLRT $\chi^2(1)$ = 17.2, p < .001 (see Figure 4A) and Expectancy × Literacy Level (t = 2.05), LLRT $\chi^2(1)$ = 4.15, p = .042 (see Figure 3B) interactions. Post hoc tests for the Constraint × Expectancy interaction showed that strongly constrained expected endings differed from all other ending types and that weakly constrained expected endings differed from strongly (but not weakly) constrained unexpected endings (ts > 4.00, ps < .001). Unexpected endings did not differ as a function of constraint. This replicated past patterns using these stimuli showing that effects of Expectancy were different in the strongly

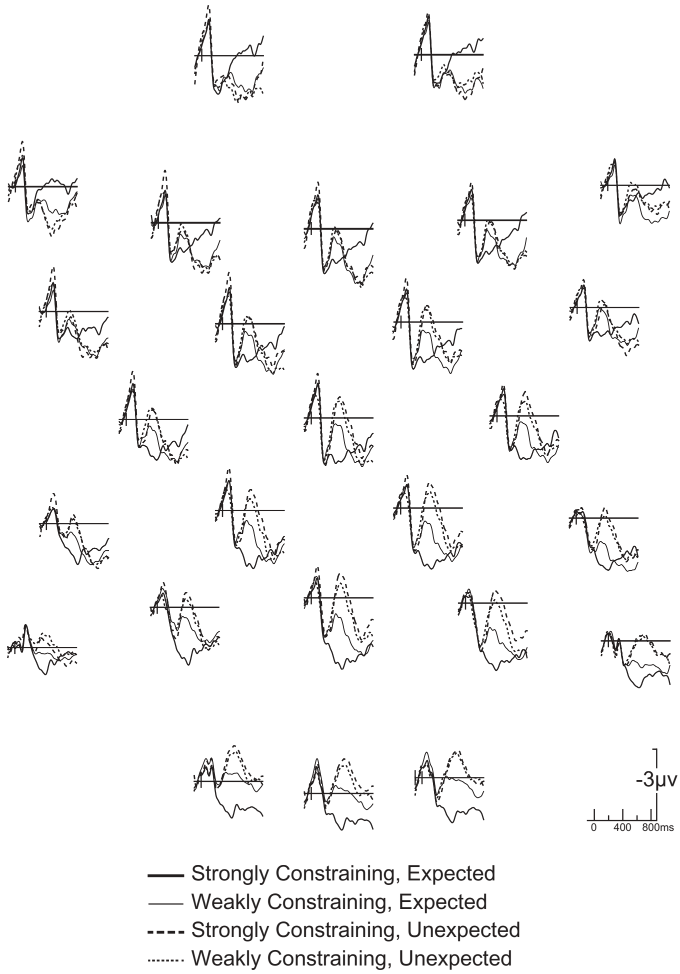

Figure 1. Grand average event-related potentials for all expectancy by constraint conditions are plotted at all channels (front of head at the top of the figure) for *high-literacy adults* (here grouped for visualization purposes). *Note*. Negative is plotted up in this and all subsequent event-related potential figures.

constraining sentences (where the cloze probability difference between expected and unexpected endings is higher) compared to the weakly constraining sentences. Literacy level also interacted with expectancy; higher-literate participants showed larger N400 effects of expectancy than did lower-literate participants.

Because effects of expectancy differ across constraint (as shown here and in past work with these items), and given prior findings using these stimuli showing that individual differences (e.g., due to age) tend to be most pronounced for weakly constraining contexts (Wlotko & Federmeier, 2012), we fit models testing the Expectancy × Literacy Level interaction separately in strongly and weakly constraining sentences. In strongly constraining sentences, the Expectancy × Literacy Level interaction was not statistically significant (t = 1.10), but in weakly constraining sentences, this interaction reached statistical significance (t = 1.98), LLRT $\chi^2(1)$ = 3.92, p = .048, as higher-literate participants showed a larger expectancy effect than did those with lower literacy levels.

Post-N400 frontal effects. To investigate possible effects of constraint and expectancy on post-N400 anterior activity, analyses were conducted across the seven frontal channels (FP1, FP2, Fz, F3,

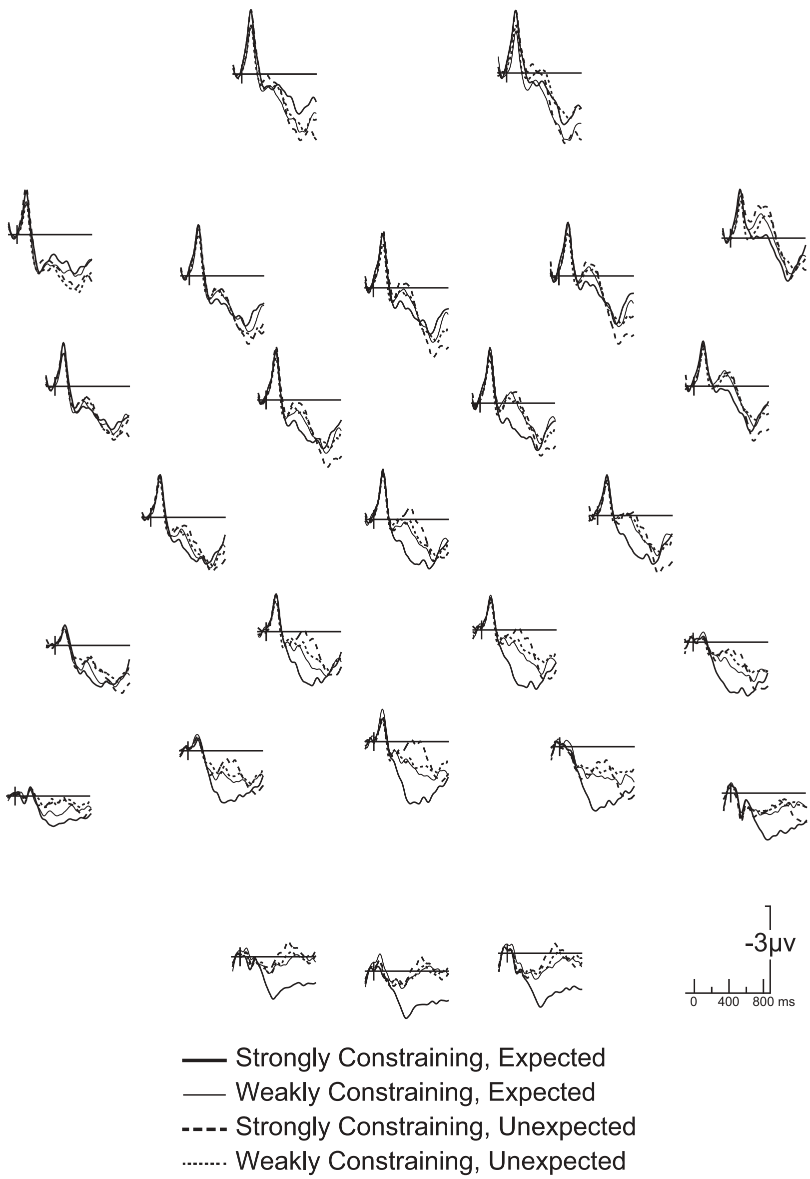

Figure 2. Grand average event-related potentials for all expectancy by constraint conditions are plotted at all channels (front of head at the top of the figure) for *low-literacy adults* (here grouped for visualization purposes).

F4, F7, F8) in the time window following the N400 (600–900 ms). The results showed no interaction with literacy level, but there was a reliable Constraint × Expectancy interaction (t = 2.49), LLRT χ^2 (1) = 5.89, p = .015 (see Figure 4B). Post hoc comparisons showed that only the expected and unexpected items in strongly constraining sentences were significantly different (t = 3.353, p = .009).

Self-paced reading times

Figure 5 shows the mean reading times of the target and subsequent two words in the four sentence conditions for the two groups of participants. Table 3 lists the mean reading times of the three critical words and summarizes the findings. At the target word, there were significant Expectancy ×

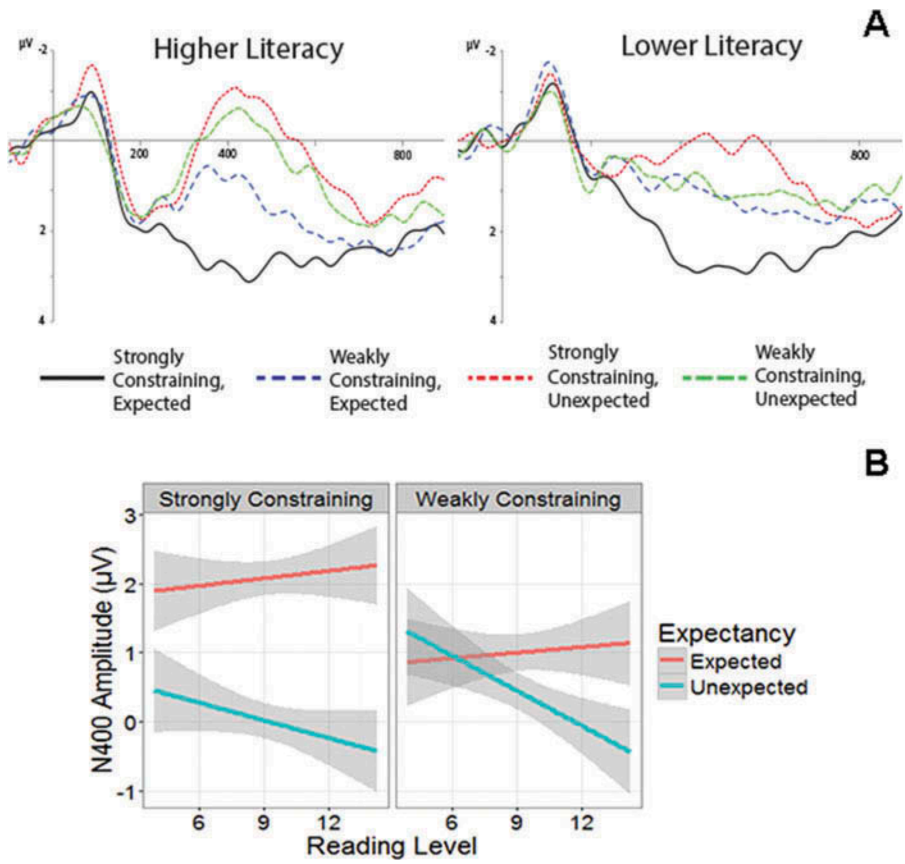

Figure 3. Panel A shows the event-related potential waveform at the Pz site to illustrate group differences in effects of constraint and expectancy on N400 amplitude. *Note*. Panel B shows the N400 amplitude plotted as a function of literacy level for unexpected and unexpected endings in strongly constraining and weakly constraining contexts.

Literacy Level (t = 3.74), LLRT $\chi^2(1)$ = 14.00, p < .001, and Constraint × Literacy Level (t = 3.14), LLRT $\chi^2(1)$ = 9.88, p = .008, interactions. The reading times suggested that, at the targets, adults with lower-literacy levels showed a reading time cost for unexpected compared to expected words. This cost diminished as literacy level increased. In addition, with lower levels of literacy, there was an overall reading time slowdown for words in weakly as compared with strongly constraining contexts (see Figure 6A). Taking these effects together, higher-literacy readers appeared to show a selective slowdown for unexpected words in strongly constraining contexts, a pattern that has also been observed in college samples (Payne & Federmeier, 2017). Lower-literacy participants, on the other hand, showed both costs for targets in weakly, compared to strongly, constraining sentences and costs for unexpected relative to expected words.

At the first word that followed the target, there was significant Constraint × Expectancy × Literacy Level interaction (t = 2.04), LLRT $\chi^2(1)$ = 4.17, p = .041. Among lower-literacy readers, reading times were fastest to expected words in strongly constraining contexts compared to the other three conditions, whereas all reading time differences were reduced with increasingly literacy (see Figure 6B). These reading time differences seen in readers with lower literacy diminished by the second word following the target, such that none of the interactions were significant (ts < 1.7) at that word position (see Figure 6C).

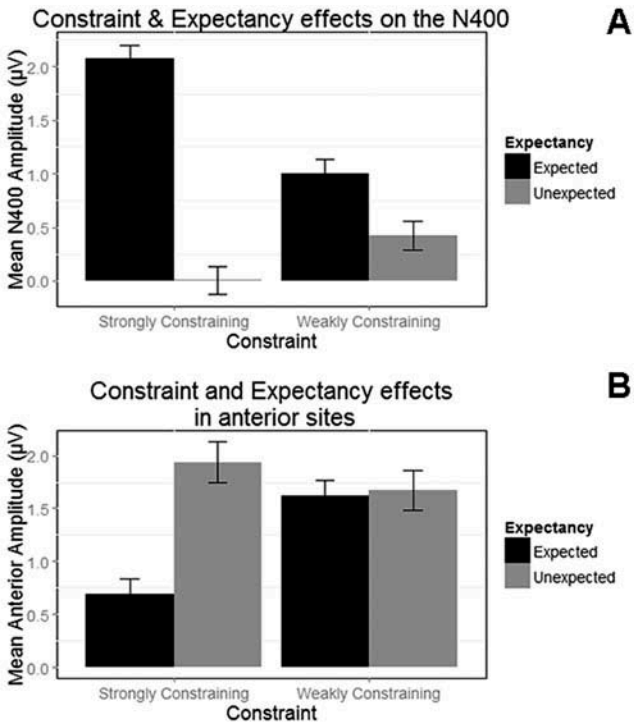

Figure 4. Amplitude of N400s (Panel A) and frontal potentials (Panel B) are plotted for unexpected and unexpected endings in strongly and weakly constraining contexts. *Note*. The N400 amplitudes illustrate the larger difference between the expected and unexpected targets in the strongly constraining contexts. The frontal potentials illustrate the negativity to the expected items in strongly constraining contexts. The error bars represent the between-subject standard error of the mean.

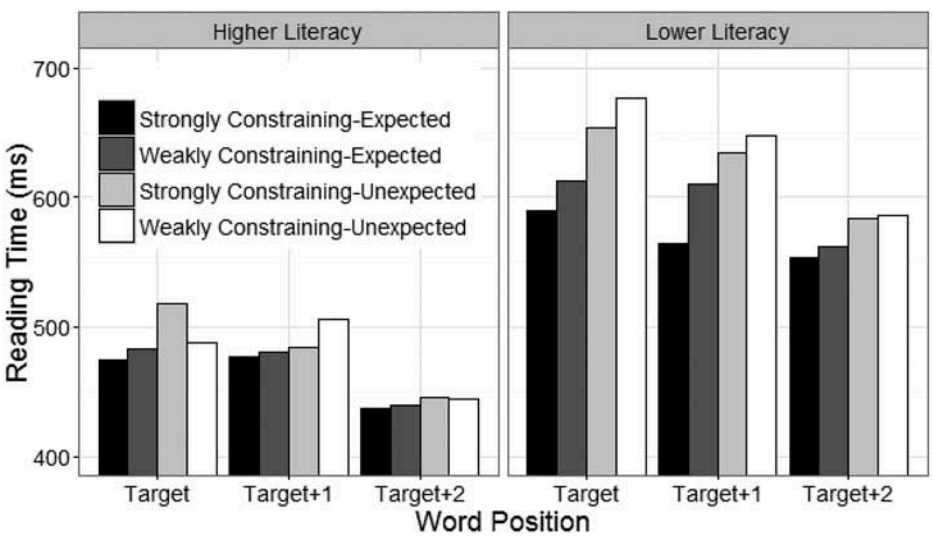

Figure 5. Reading times as a function of constraint and expectancy at the target and two subsequent words, for high-literacy and low-literacy readers, grouped for visualization purposes.

Table 3. Mean self-paced reading times (ms) and results of statistical analyses of the targets and the following two words for the HL and LL groups.

	Mean Reading Times					
	Target		Target+1		Target+2	
	HL	LL	HL	LL	HL	LL
Strongly constraining, expected	474	590	477	564	437	553
Strongly constraining, unexpected	518	654	485	634	445	583
Weakly constraining, expected	483	613	481	610	439	561
Weakly constraining, unexpected	488	676	506	648	444	586
Summary of findings						
	t		t		t	
Constraint × Expectancy × Reading Level	0.52		2.04*		0.64	
Constraint × Expectancy	1.22		—		0.29	
Constraint × Reading Level	3.14**		—		0.58	
Expectancy × Reading Level	3.74***		—		1.69	

Note. HL = higher literacy; LL = lower literacy.
**p* < 05. ***p* < .01. ****p* < .001.

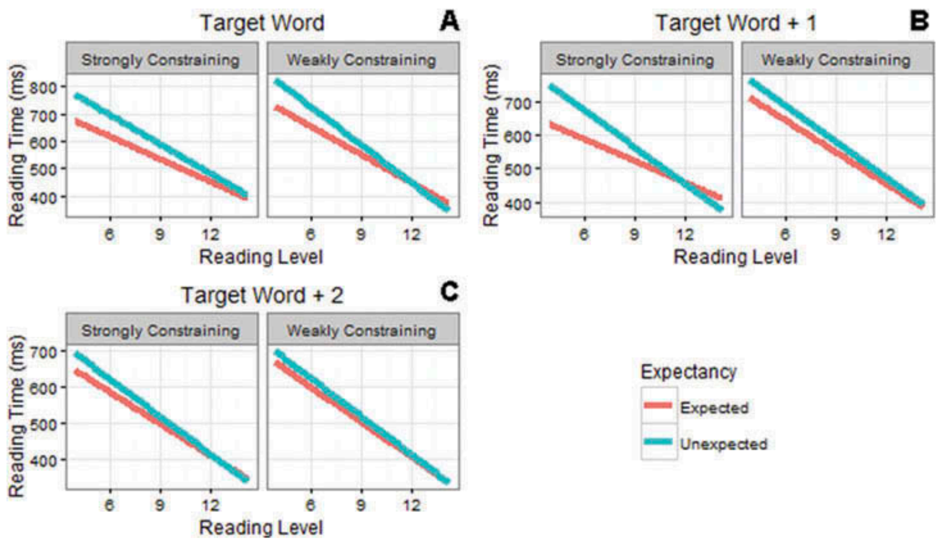

Figure 6. Reading times plotted as a function on literacy level for unexpected and unexpected endings in strongly constraining and weakly constraining contexts at the target and two subsequent words.

Discussion

The current study examined how message-level semantics is assembled during reading and interacts with bottom-up lexical input among adult readers with a range of literacy skill, using both ERPs and reading time as dependent measures. We measured the N400 component of the ERP as an index of readers' ability to make rapid use of context information to affect the initial access of semantic information associated with an incoming word. Reading times were used to then examine summed benefits and costs across multiple stages of processing, including the integration of the word with context and general knowledge. We found that, as indexed both by ERPs and reading-time measures, lower literacy adults showed more difficulty in accessing and integrating the meaning of a word, especially when context did not provide strong constraint specifically for that word—which is arguably the most typical situation in natural reading.

The control population against which the processing of low-literate adults was gauged was a group of community-dwelling adults with higher literacy skills. Given that most work in psycholinguistics has relied on college students to establish effects, one question is the extent to which higher-literate adults in this community sample showed the typical effect pattern. The N400 pattern at the target word for these participants was comparable to that in Federmeier et al. (2007), showing amplitudes graded with cloze probability. This suggests that, like college students, literate community-dwelling adults (who are not selected for high levels of literacy attainment) are sensitive to fine-grained differences in word expectancy. In addition, in the post-N400 time window we replicated the distinctive negative-going ERPs over the frontal sites for the strongly constraining sentences with an expected target, especially relative to the same type of sentences with an unexpected target, but we found no evidence that this frontal shift was modulated by literacy skills. This negativity for moderately-high cloze target words has been associated with the need to update context as new information is received[3] and has been found in the ERPs of college students and older adults in sentence reading (Wlotko & Federmeier, 2012; Wlotko et al., 2012), although the cognitive process that produces the effect is still not well understood.

Like college students, the higher-literate community participants also showed evidence for predictive processing, as seen in a selective cost in reading time for unexpected words in strongly constraining contexts compared to the cloze-probability-matched unexpected words in weakly constraining contexts. Using the stimuli from Federmeier et al. (2007) in a college sample but with a self-paced design, Payne and Federmeier (2017) found that the frontal positivity emerged only when reading rates were relatively fast. When self-pacing was slower than RSVP presentation, the cost of violating a prediction instead emerged in the form of a slowdown selective to unexpected words in the strongly constraining contexts—as also observed in the higher-literate adults in the present study. Overall, then, the results indicate that adults with higher literacy skills can quickly use contextual information to facilitate word processing, as well as actively predict upcoming words based on context.

Relative to this control population, the lower-literate readers showed divergent patterns on both ERP and reading-time measures. Although they produced N400 expectancy effects in strongly constraining sentences comparable to higher-literate readers, they showed reduced N400 effects of expectancy when the sentence conditions were less constraining. Thus, although readers with lower literacy skills are able to make some use of context information to facilitate on-line access to word representations, this rapid use of context is diminished and may not be sufficient to distinguish words that are only weakly expected from wholly unexpected words. Differences between the expected and unexpected words in the weakly constraining sentences emerged only later—in reading times on the target words—and then persisted into the next word. A similar, persistent reading time cost for unexpected compared to expected words in strongly constraining sentences was also seen in this group, whereas the higher-literate adults showed a selective reading time cost for disconfirmed predictions, which was evident only on the target word itself. Overall, then, the lower-literate adults were less able to make use of the full range of contextual information, showed more sustained processing difficulty for unexpected words in both contexts, and did not manifest evidence of using context information predictively.

What causes the poorer use of context in reading by the lower-literate adults? We consider three possibilities, which are not mutually exclusive. One possibility is that struggling readers have poor quality of lexical representations (Perfetti, 2007). Individuals vary in how stable and well connected their orthographical, phonological, grammatical, and semantic representations of words are and how efficiently and consistently they retrieve this information. Whereas good

[3]The frontal negativity shows up for moderately expected words and in particular under circumstances when people seem to be using the incoming information to "fill in" or "update" aspects of the mental model that were not clear, for example, where there are multiple possible interpretations: "They used the fertilizer to enrich the ..." *soil* is most expected but *grass* is a secondary competitor, and they entail somewhat different mental models (farming vs. lawn care).

readers have precise and flexible lexical representations, poor readers may have inaccurate or incomplete lexical representations, which could result in activation of inappropriate semantic and syntactic features and therefore create an incomplete and even fragmentary context message. This problem could be particularly acute when the sentence is only weakly constraining because there is likely less redundancy in linguistic features among words in getting the message across. Lexical knowledge—often assessed empirically through vocabulary measures—has been shown to affect reading comprehension across the lifespan. For example, in a sample of struggling adult readers, Hall, Greenberg, Laures-Gore, and Pae (2014) found that expressive vocabulary explained 16.4% of the unique variance in reading comprehension, even after taking into account decoding and word reading skills (see also Braze, Tabor, Shankweiler, & Mencl, 2007; Richter, Isberner, Naumann, & Neeb, 2013).

Alternatively, more diffuse activation of semantic features in weakly constraining contexts may place special demands on conceptual integration and meaning consolidation. Research on the correlates of variation in print exposure among competent adult readers has shown that, among adults from a wide age range, time allocated to sentence wrap-up, which is thought to reflect meaning consolidation (and is related to subsequent memory performance), is reduced among adults with lower levels of vocabulary (Stine-Morrow et al., 2008) or with lower levels of print exposure (Payne, Gao, Noh, Anderson, & Stine-Morrow, 2012). Not surprisingly, such readers also show less efficient lexical processing, which may indirectly compromise conceptual integration by consuming attentional resources for decoding (Gao, Stine-Morrow, Noh, & Eskew, 2011).

Another possibility for the inadequate use of weakly constraining context by struggling readers is that their reduced practice with written language results in their inability to form the kind of strong, efficacious top-down connections that afford predictive processing. Past literature supports the idea that fluency is related to prediction. For example, highly proficient English learners of Spanish were found to use gender features of the article to predict upcoming nouns, whereas less proficient learners did not predict (Dussias, Valdés Kroff, Guzzardo Tamargo, & Gerfen, 2013). Even within a native language, vocabulary skill is correlated with the use of prediction. Borovsky, Elman, and Fernald (2012) found that children and adults with higher vocabulary scores were more likely to make anticipatory looks to a relevant grammatical object when listening to a verb (e.g., *The pirate hides the treasure*.). Such predictive processing strategies may be particularly important for helping comprehenders make best use of weakly constraining information. ERP studies have shown that older adults as a group are less likely to predict during comprehension (although individual differences in verbal fluency again are associated with the tendency to use predictive processing in this age group; Federmeier, Kutas, & Schul, 2010; Federmeier et al., 2002; Wlotko & Federmeier, 2012), and intriguingly, older adults—similar to our lower-literate adults—also manifest a reduced N400 expectancy effect within weakly constraining contexts (Wlotko & Federmeier, 2012; Wlotko et al., 2012). Together, these findings suggest that the ability to make best use of available context information may be yoked to the ability to use context predictively. An important question for future research, then, is whether this pattern in lower-literate adults is specific to reading or extends to language comprehension in general.

In conclusion, the present study was the first that employed both reading times and ERPs to investigate the higher-order reading processes of adults as a function of their literacy skills. The two measures yielded high temporal resolution and offered multidimensional data that allowed us to look into brain and behavioral responses of struggling adult readers to reading sentences with varying levels of constraints. The findings not only give insight into how less skilled readers use contextual facilitation but also have broad implications for adult education and training, suggesting that, in addition to the typical focus on decoding skills, it may be important for adult literacy instruction to emphasize the use of top-down processing strategies in larger language structures such as sentences and passages, where prediction, semantic integration, the relation of linguistic components, message conveyed, and general knowledge are taught and practiced. With focus on reading at both word and passage levels, struggling readers may choose the reading strategy that builds on their strengths and compensates for their weaknesses in certain areas.

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