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How struggling adult readers use contextual information when comprehending speech: Evidence from event-related potentials

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ABSTRACT

We investigated how struggling adult readers make use of sentence context to facilitate word processing when comprehending spoken language, conditions under which print decoding is not a barrier to comprehension. Stimuli were strongly and weakly constraining sentences (as measured by cloze probability), which ended with the most expected word based on those constraints or an unexpected but plausible word. Community-dwelling adults with varying literacy skills listened to continuous speech while their EEG was recorded. Participants, regardless of literacy level, showed N400 effects yoked to the cloze probability of the targets, with larger N400 amplitudes for less expected than more expected words. However, literacy-related differences emerged in an earlier time window of 170–300 ms: higher literacy adults produced a reduced negativity for strongly predictable targets over anterior channels, similar to previously reported effects on the Phonological Mapping Negativity (PMN), whereas low-literacy adults did not. Collectively, these findings suggest that in auditory sentence processing literacy may not notably affect the incremental activation of semantic features, but that comprehenders with underdeveloped literacy skills may be less likely to engage predictive processing. Thus, basic mechanisms of comprehension may be recruited differently as a function of literacy development—even in spoken language.

1. Introduction

Language comprehension is multifaceted. Decoding skills are required to rapidly translate acoustic signals into linguistic units during listening or to extract visual word information from print during reading. Regardless of modality, comprehension involves the ongoing construction of a message-level representation of semantics and situations, which, in turn, can be used to resolve ambiguity and make predictions about the language stream as it unfolds. While decoding skill is well understood as a contributor to reading difficulties, less is known about the role of "higher level" comprehension abilities, such as making sense of word sequences. One of the most well-studied higher level comprehension skills is the use of context to facilitate word processing. Less-skilled decoders have been shown to use contextual information to assist word reading in some circumstances (e.g., Stanovich, 1980). However, if poor decoders are also poor language comprehenders (e.g., Landi, 2010), this pathway—bootstrapping from the larger context to enable word recognition on the fly—may be less available. We have recently shown deficits among less-skilled readers in using contextual information during reading (Ng et al., 2017). The present investigation focused on understanding the extent to which similar problems also arise in spoken language comprehension—conditions under which deficits in print decoding are not a barrier to comprehension.

In fact, reading and listening comprehension often show moderate to high correlations in studies of both children and adults, suggesting that the ability to achieve a message-level interpretation from linguistic units may be a common thread across modality (e.g., Palmer et al., 1985). In Smiley et al. (1977), for example, seventh graders read and listened to stories and then recalled their gist. The skilled readers were able to distinguish the importance of different idea units better than the less skilled readers, and this difference did not interact with the modality of story presentation. In a sample of adult literacy learners, Mellard et al. (2010) observed a moderate correlation between reading and listening comprehension, although listening comprehension lagged behind other factors, such as vocabulary knowledge, reading fluency, and word reading ability, in predicting reading comprehension.

Given that domain-general language understanding is ultimately the sum of many processes, online studies that can reveal how processing unfolds moment by moment are especially valuable in identifying the process that may contribute to fluency and success in understanding

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language. For example, in the visual world paradigm, eye movements are monitored while participants prepare to select a target object based on a spoken sentence. Mishra et al. (2012) used this paradigm to investigate the impact of literacy differences on the ability to use context information to predict likely upcoming words. High- and low-literacy adult speakers of Hindi in India listened to sentences with a prenominal adjective that matched in grammatical gender with the name of one of the objects displayed. High-literacy adults moved their eyes to the target object before the noun was heard; low-literacy participants, however, did not fixate on the target object until the noun was presented, suggesting that they were not making use of the gender cues to predict likely upcoming nouns. Similarly, in Huettig and Brouwer (2015), dyslexic adults showed a delayed use of gender information to anticipate target objects, compared to adults with typical reading abilities. Such findings suggest that adults without intact reading skills, regardless of etiology, may not be able to take full advantage of the morphosyntactic features in language—even when spoken—to prepare to process upcoming words.

Measurements of brain electrical activity, in the form of event-related potentials (ERPs), provide an especially sensitive means of tracking language comprehension over time. ERPs are the electrophysiological response of the brain time-locked to the onset of an event, typically a word in language studies. The excellent temporal resolution afforded by ERPs allows a fine-grained examination of multiple neurocognitive processes in language comprehension as they occur. Most importantly, ERPs have been used to study visual and auditory language processing for several decades, thereby producing a set of functionally well-specified indices of language subprocesses that can be used to make specific inferences about the nature and success of the processes unfolding during comprehension.

One of the most well-studied ERP components is the N400, a negative-going voltage deflection that peaks approximately 400 ms after stimulus onset. The N400 indexes the ease of accessing semantic information linked to a stimulus (Kutas and Federmeier, 2011). Thus, less expected words in a context produce larger N400s than more expected words, because the semantic features of an expected word have already become activated in the course of processing the prior context. This contextual congruency effect has been observed in both visual and auditory modalities (e.g., Kutas et al., 1987), indicating that these mechanisms are similarly engaged in reading and listening.

Studies using ERPs, primarily with samples of college-aged readers with well-developed literacy skills, have shown that at least some of this context-based facilitation can arise through predictive processing mechanisms (e.g., Kutas and Federmeier, 2011). This prediction-based N400 effect is most clearly observed in response to unexpected target words that share semantic, phonological, or orthographic features with a predicted word. Words with similar features as the predicted words elicit a smaller N400 than those with dissimilar features, even in cases wherein both types of words are semantically incongruent with the context. This suggests that prediction afforded by context activates relevant semantic and linguistic features of upcoming words, thereby facilitating the processing of words that share those features (Federmeier and Kutas, 1999; Laszlo and Federmeier, 2009). Among literate college-aged adults, this context-based pre-activation of semantic features on the N400 has been observed in both reading and listening and, thus, is modality-independent (Federmeier and Kutas, 1999; Federmeier et al., 2002). Prediction has also been linked to other ERP effects observed when predictable or unpredictable words are encountered, such as modulations of sensory components to predictable words and a post-N400 frontal positivity to unpredictable words (e.g., Federmeier et al., 2007), as well as effects observed in advance of a predictable target, based on gender match/mismatch at articles or adjectives preceding an expected target noun (Van Berkum et al., 2005; Wicha et al., 2003).

An ERP component that has provided evidence for predictive processing in listening is the Phonological Mismatch Negativity, also called the Phonological Mapping Negativity (PMN; Connolly and Phillips, 1994; Connolly et al., 1992). Linguistic or not, sounds whose features mismatch versus match the immediately preceding auditory context have been associated with a relatively early, frontally distributed effect known as the Mismatch Negativity (see review by Naatanen, 1995; Naatanen et al., 2007). Specifically in the context of speech, when auditory language context engenders an expectation for a particular word, a target whose initial sounds do not match those of the expected word elicit more negative-going ERPs than inputs that match with this expectation in their initial phonemes (McCallum et al., 1984). This PMN tends to occur between 150 and 300 ms post-stimulus onset with a broad, fronto-central scalp distribution, and has been argued to reflect prediction of the (sub)phonemic features of an incoming word (Archibald and Joanisse, 2011; Newman and Connolly, 2009; Newman et al., 2003). It is often taken to reflect phonological processing, although overlap in timing and distribution with the N400 component can make the separation and identification of these two components difficult, so, historically, some have argued that this could be an earlier onset of the N400, or the reflection of an early lexical selection process. However, results from more recent research lend support to the notion that the PMN and N400 represent different aspects of language processing, the former of which is specific to phonological processing. Importantly, regardless of the precise underlying process(es) that engender this effect, it clearly reflects expectations for likely upcoming words (Connolly and Phillips, 1994; Connolly et al., 1992; D'Arcy et al., 2004; Hagoort and Brown, 2000; van den Brink et al., 2001; van den Brink and Hagoort, 2004; Van Petten et al., 1999).

The focus of the current investigation was to use these ERP indices of context use and prediction to assess variability in semantic access and predictive processing as a function of literacy skill. Adapting the stimuli from Federmeier et al. (2007), we recently examined this issue in the print modality (Ng et al., 2017). Community-dwelling adults read sentences that provided strong or weak constraint for a target word (based on cloze probability norms). Contextual constraint was crossed with expectancy of the sentence-final target, such that the context sentence was completed with either the most expected word or a plausible but unexpected word. Readers self-paced the presentation of the text word-by-word (cf. Payne and Federmeier, 2017), so as to accommodate the range of reading rates in this sample. Importantly, stimuli were selected so as to only include items within the reading level of the sample. As shown in the upper panel of Fig. 1, participants with well-developed literacy skills showed an ERP pattern very similar to that of the college-aged adults in Federmeier et al. (2007), with N400 amplitudes graded by cloze probability (strongly constrained-expected < weakly constrained-expected < unexpected in both constraint conditions). This pattern indicates that proficient readers use contextual information in a graded manner to facilitate processing of incoming words. However, the pattern was different for low-literacy participants. Although this group showed an N400 effect of target word expectancy in the strongly constraining condition that was comparable to the high-literacy group, they showed no N400 expectancy effect at all in the weakly constraining condition. Moreover, among the more literate readers, the cost of prediction disconfirmation manifested in longer reading times for the unexpected word in strongly, compared to weakly, constraining contexts, but such a cost was not observed for the lower literacy adults. Collectively, these data suggest two sources of difficulty for low-literacy adults in reading: they do not take advantage of the full range of sentence constraint to facilitate semantic access, and they do not appear to engage in predictive processing.

These results raise the question of whether this reduced sensitivity to context and the failure to use prediction among lower literacy adults is restricted to the visual domain, in which demands on print decoding may draw resources away from semantic processing (Gao et al., 2012; Gao et al., 2011), or whether these adults have a domain-general deficit in integrative and predictive processing that spans across modality of input. Thus, in the present study, we examined the impact of constraint

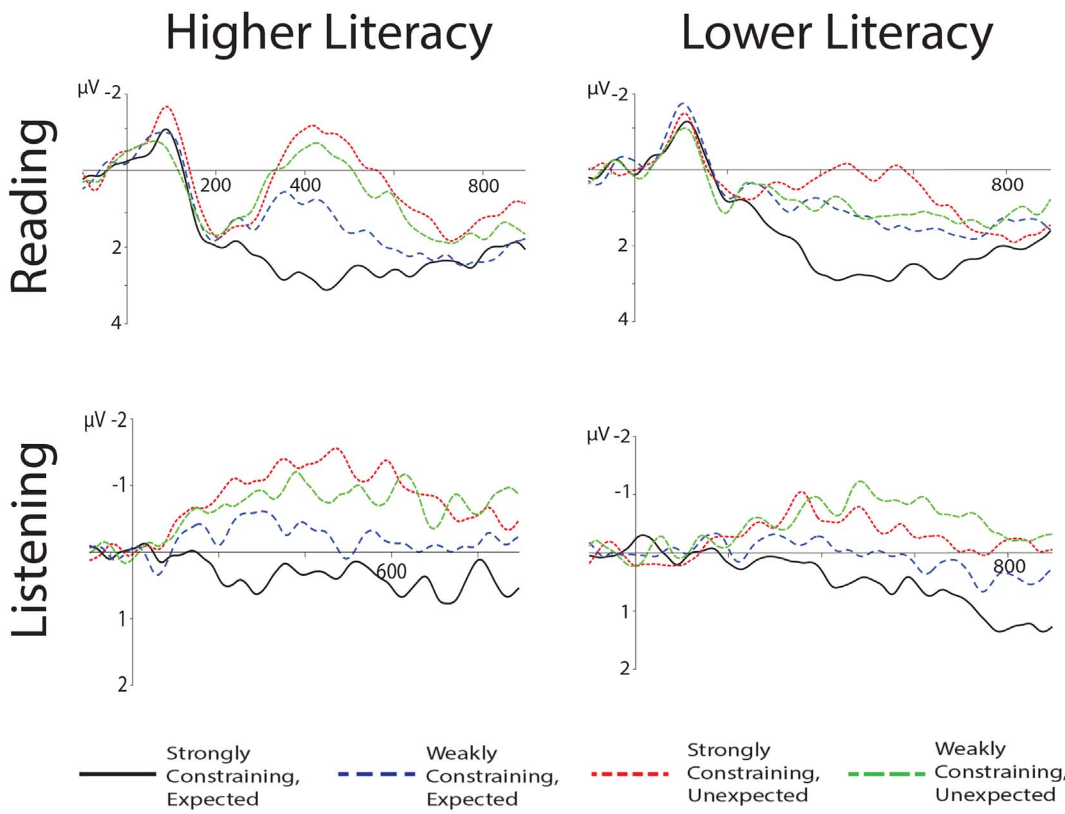

Fig. 1. ERP waveforms at the Pz site, illustrating group differences in effects of constraint and expectancy on N400 amplitude in reading (top panel) and listening (bottom). The figure in the top panel has been adapted from Fig. 3 in Ng et al. (2017). Negative is plotted up in this and all subsequent ERP figures. Reading grade level of 9 is used for dividing participants into literacy groups. Grouping is for visualization purposes only; in statistical analyses, Literacy Level was treated as a continuous variable.

Table 1
Participant demographics (the values in parentheses show the range of minimum-maximum values).

	Higher literacy (N = 20)	Lower literacy (N = 20)
Mean age	45 (20–64)	44 (23–72)
Number of female	9	10
Mean years of education	13.0 (11–15.5)	11.5 (7–16)
Mean reading grade level	11.8 (9.9–14.3)	7.5 (4.5–8.8)

and expectancy on listening comprehension in a community sample similar to that in Ng et al. (2017). We expected the higher literacy participants to show similar patterns of N400 responses to those that we observed in reading (Friederici et al., 1993; Hagoort and Brown, 2000; Kutas and Hillyard, 1984; McCallum et al., 1984). Our particular question was whether the lower literacy participants would show N400 effects similar to those of their higher literacy counterparts when print decoding was not a factor, or instead, whether they would still manifest deficits in context use that transcend basic orthography-to-phonology/semantics mapping skills. We were also interested in literacy-related effects in predictive processing, as reflected in the PMN.

2. Method

2.1. Participants

Participants (N = 40; 19 women) were recruited from the local community. They were 20–70 (M = 45, SD = 13.4) years of age and had received 7–16 years of formal education (M = 12.3, SD = 1.9). Five were left-handed. Mean reading grade level, operationalized as a composite of the Slosson Oral Reading Task (SORT) (Slosson and Nicholson, 1990), Woodcock Johnson (WJ) Reading Fluency task (Schrank et al., 2014), and RAN/RAS (Rapid Automatized Naming/Rapid Alternating Stimulus) (Wolf and Denckla, 2005), was 9.7 (SD = 2.6; Range: 4.5–14.3). SORT required participants to read aloud a word list with progressive levels of difficulty. The WJ Reading Fluency task required participants to determine the truthfulness of a list of simple sentences within 3 min. In RAN/RAS, participants named a series of objects, numbers, and colors as quickly as possible; such naming times have been shown to predict reading ability (Norton and Wolf, 2012). Literacy level was analyzed as a continuous variable, although for purposes of characterizing the participants, we distinguished a lower literacy group (N = 20) who read below a 9th grade level, and a higher literacy group (N = 20) who read at or above a 9th grade level. Group information is shown in Table 1. There was no correlation between literacy level and age, $r(38) = 0.16$, and the wide age range allowed us to examine the effects of literacy skill on spoken language processing across the adult lifespan into early old age.

2.2. Stimulus materials

There were 140 experimental sentences. Half were strongly constraining and the other half were weakly constraining for a sentence-final word, which was either the most expected word for the context, as established by norming (see more detail in Federmeier et al., 2007), or an unexpected but plausible continuation. Each experimental sentence was followed by a continuation sentence to create a short passage. See examples and cloze probabilities of the experimental sentences in Table 2. The strongly constraining sentence frame, by definition, licensed a highly predictable word in the target word position, and was completed with the most expected word (=SCE) or an unexpected word (=SCU). The weakly constraining sentence frame afforded a greater range of completions and, correspondingly, the most expected word (=WCE) was less predictable, although it was always the most probable

Table 2
An example of the experimental sentences in four conditions and the mean cloze probabilities of the target words (underlined) in each condition (the values in parentheses show the range of minimum-maximum values).

Constraint condition	Example	Cloze	
		Expected	Unexpected
Strong	The prisoners were planning their escape/party. The time was running out. Q: Did the prisoners have enough time?	0.85 (0.69–1.00)	0.01 (0.00–0.06)
Weak	He slipped and fell on the floor/rock. He had to go to the hospital. Q: Was his fall serious?	0.27 (0.11–0.41)	0.02 (0.00–0.09)

response generated in the norming study. Unexpected words in weakly constraining contexts (=WCU) were matched in cloze probability with the SCU items. The maximum Flesch-Kincaid reading grade level across all the passages was 4.6 ($M = 2.3$; $SD = 1.1$). Among the strongly constraining sentence frames, 93% of the expected and unexpected words differed in the initial phoneme. Thus, if predictions were being made, early appreciation of the difference between the predicted and obtained word should be possible. Among the weakly constraining sentence frames, 88% of the expected and unexpected words also differed in the initial phoneme, although these sentences were not shown to afford predictive processing in prior work.[1] A comprehension question followed each test passage.

The short passages and their corresponding comprehension questions were spoken by a female American English speaker at an average speech rate of 213 words per minute and were digitally recorded and normalized in amplitude. An artificial 700 ms break was inserted at the end of the first sentence in each trial, to allow EEG to be recorded to the target word before the passage continued. Sentences were pseudo-randomized for each participant, such that no more than four sentences of the same condition were presented consecutively.

2.3. Procedure

A neuropsychological battery was administered in a 90-minute session on a separate day from the experimental session, which lasted 60–90 min. Participants were seated in a quiet room, approximately 100 cm from the monitor. The volume of the speakers was adjusted to a comfortable level for each participant. They listened to each sentence and answered the comprehension question. The questions aimed to ensure continuous attention of the participants and assess whether they had achieved a basic understanding of the sentences. While the sentence was presented, a dot was displayed at the center of the screen. Participants were instructed to look at the dot so as to limit eye movements. The dot disappeared at the end of the sentence, followed by a 1000 ms ISI before a question mark appeared, during which the comprehension question was auditorily presented. Participants were required to answer, within 20 s, yes or no to the question by pressing the designated buttons on a response box. No feedback was provided. Two rest breaks were inserted throughout the study.

[1] We did not uniformly ensure a mismatch in the phonemic onset of the expected and unexpected words because we wanted to use exactly the same stimuli in this experiment as had been used previously for our reading study (Ng et al., 2017), so as to facilitate cross-study comparisons. However, it should be noted that the small number of matching stimuli works against us because it could potentially dampen PMN effects. Thus, any PMN effects (and literacy modulations thereof) we do find would be expected to be even stronger with a more targeted stimulus set.

2.4. EEG recording

Continuous EEG was recorded by a Brain Vision ActiCHamp system 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.

The EEG was filtered between 0.1 and 30 Hz offline. Artifacts including blinks, saccades, and excessive muscle noise were rejected using thresholds adjusted for each participant. On average, 15% of trials were removed from further analysis. ERPs were computed from 100 ms before the onset of the critical words to 900 ms after and were averaged per condition for each participant after the 100 ms pre-stimulus baseline correction.

2.5. Data analysis

Data (https://data.mendeley.com/datasets/4v8nvv938b/3) from both behavioral and EEG responses were analyzed with linear mixed-effects models using the lme4 package for R version 3.4.0 (Bates et al., 2015). Literacy level was always treated as a continuous variable. Our critical question was whether literacy level would modulate the behavioral and EEG responses to contextual features. *p*-Values for each predictor variable were obtained using the lmerTest package for R, based on Satterthwaite approximation for degrees of freedom.

For the EEG data, the key decisions were to choose the analysis time windows for the PMN and N400 effects. Fig. 2A shows the grand average ERPs for all participants, and participants with higher and lower literacy skills, respectively, at four midline channels across the head. Visual inspection of the waveforms suggests that the ERPs of the sentence conditions diverged early, in the 100-200 ms time window, with a peak around 400 ms (N400). As our previous reading study used 300–600 ms for the N400 analysis (see Fig. 1) (Ng et al., 2017), we kept this same analysis window for the N400 in the present study to facilitate comparisons between the two.

We were also interested in examining any earlier effects, such as the PMN, to see whether literacy effects on predictive processing would emerge on this component (cf. Ng et al., 2017). The time window for the PMN, as well as the scalp distribution of this effect, has been somewhat variable in the literature. Therefore, to empirically select a time window for examining a potential PMN effect, we adopted a data-driven approach (cf. Brooks et al., 2016), collapsing across individual differences in literacy level. We performed a mass univariate regression analysis, in which we assessed the basic effect of expectancy (unexpected vs. expected target words), independent of subjects' literacy-level and constraint, every 5 ms across the whole epoch (0–895 ms) in every channel. By focusing on the basic effect of expectancy blind to constraint or literacy, we could determine when the brain first began to differentiate between the conditions in a manner that does not bias our critical analyses that test for the interaction of target cloze with literacy level. We determined a priori that a continuous series of significant expectancy effects (Wald t-values smaller than -2, showing the anticipated larger negativity for unexpected compared to expected words (Bates et al., 2015)) for 5 or more time points at any channel would be used as the start time of the PMN analysis, and that we would then use from that starting point to the start point of the a priori N400 window as the time window of analysis for the PMN. Although we expected that the PMN effect, if any, would emerge around 200 ms, we avoided imposing an arbitrary (and thus possibly premature) cutoff time for the analysis. Fig. 3 summarizes the results. Persistent Expectancy effects emerged at 170 ms in the occipital channels and slightly later in other

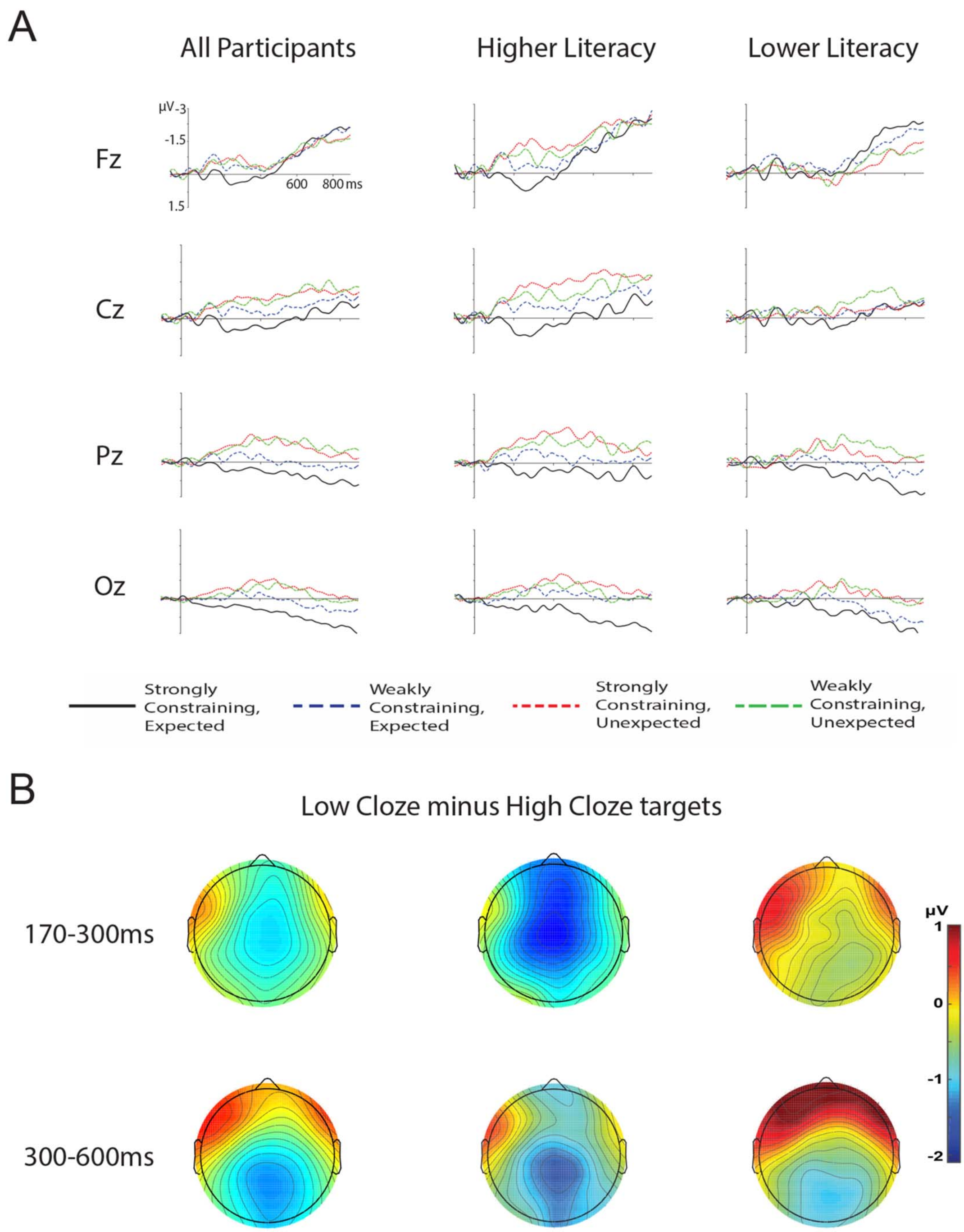

Fig. 2. Panel A: Grand average ERP waveforms as a function of constraint and expectancy at the four midline sites across the head for all participants, higher literacy participants, and lower literacy participants, respectively. Panel B: Scalp maps that show the topographical distribution of the voltage difference between the High Cloze and Low Cloze targets in the 170–300 ms and 300–600 ms time windows for the three groups of participants. High Cloze targets come from the strongly constrained-expected condition. Low Cloze targets are derived from averaging the two unexpected conditions.

channels.[2] Thus, we set the analysis time window encompassing 170–300 ms as the PMN. Although previous research using written stimuli and a similar paradigm has found post-N400 effects over frontal channels (Federmeier et al., 2007; Ng et al., 2017), we only observed effects after 600 ms that seemed to be a continuation of the N400 effect. Thus, we do not report any further analyses after 600 ms.

[2] The PMN is not commonly found in the occipital channels. However, we did not want to introduce bias against this possibility, or the possibility of some other effect. Thus, we did not use distributional factors in our initial selection of time-window, but did characterize the distribution of the effects we observed across each selected time window, and these took the expected form for the components of interest.

Given that, for this stimulus set and others, past work has found minimal effects of constraint on processing of the two types of unexpected words through the N400 time window (Federmeier, 2007; Ng et al., 2017), we expected to be able to simplify the model by collapsing these two conditions and using Cloze as the predictor variable to represent context features. Cloze would, then, have three levels: Low Cloze (SCU + WCU i.e., no contextual support), Moderate Cloze (WCE), and High Cloze (SCE). To ascertain that constraint, indeed, did not affect responses to the unexpected items in this study, we performed a mixed-effects linear regression analysis with all channels, checking the main effect of Constraint and its interaction with Literacy Level on ERP amplitudes in both the PMN (170–300 ms) and N400 (300–600 ms)

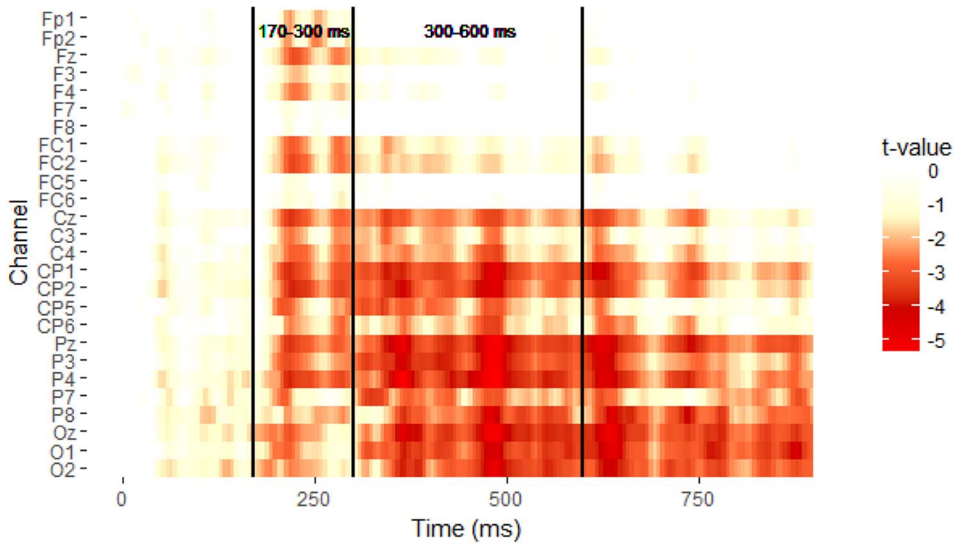

Fig. 3. Heat map showing the t-values from mass univariate regression analyses with Expectancy as the predictor for instantaneous EEG amplitudes 0–895 ms (5 ms intervals) at all channels. T-values larger than 0 were set at 0 to emphasize the negative t-values, showing effects in the direction of interest. Two analysis time windows are delineated on the map.

time windows for the unexpected targets only. No effects approached significance (*ts* < 0.7). Thus, we simplified the model by combining the SCU and WCU conditions.

After we determined the two time windows for ERP analysis, we fit a mixed-effects model to the data based on the cloze probability of the target word, with Low Cloze as the reference in comparison to the other two conditions. Since our critical question was the effects of participants' literacy levels on the processing of contextual features, the predictor variables for the initial model were Cloze, Literacy Level, and their interaction. A maximal random-effects structure for the within-subjects variables was fit across subjects (Barr, 2013; Barr et al., 2013) but only a random intercept was fit for electrodes because some models would not converge if a random slope was also fit for electrodes. This random-effects structure was also consistent with that used in Ng et al. (2017). Once again, literacy was treated as a continuous variable.

For both time windows, we first performed an omnibus analysis on the grand average ERPs that tested the Cloze × Literacy Level × Region interaction. Region was a binary variable with the two levels of Anterior and Posterior. The anterior region encompassed all frontal, fronto-central, and central channels, 14 in total, whereas the posterior region included all centro-parietal, parietal and occipital channels, 12 in total. If the interaction was reliable, we then decomposed the effects by performing separate analyses over the front and back of the head, to capture the possibility of distributional differences suggestive of multiple components—as the PMN tends to be more fronto-centrally distributed, whereas the auditory N400 tends to be more prominent over centro-parietal regions.

For the behavioral data, percent accuracy rates and reaction times to answer the comprehension questions were averaged within condition for each participant. Mixed-effects models were fit to the data with the fixed effects of Cloze, Literacy level, and their interaction, and the random intercept of Participant.

3. Results

3.1. Comprehension questions

Participants achieved a mean accuracy rate of 88.7% (range = 78–98%; *SD* = 5.3%) on the questions. No reliable interactions of Cloze and Literacy Level were found for both High vs. Low Cloze and Moderate vs. Low Cloze contrasts (*ts* < 0.6).

Reaction times were measured from the question onset. The mean reaction time across conditions was 3045 ms (range = 2068–4462 ms; *SD* = 483 ms). Once again, no significant interactions of Cloze and Literacy Level were observed (*ts* < 1.5). Note, however, that questions were not always identical across Cloze Conditions; hence, the absence of interaction effects of these variables should be interpreted with caution.

3.2. Electrophysiological responses

Early negativity (170–300 ms). Results from the omnibus analysis indicated that the Cloze × Literacy Level × Region interaction was reliable for both High vs. Low Cloze and Moderate vs. Low Cloze contrasts (*ts* > 4, *ps* < 0.001). In the distributional analyses (shown in Fig. 4A), the High/Low Cloze × Literacy Level interaction was found only in anterior (β = 0.277, *SE* = 0.092, *t*(38) = 3.00, *p* = 0.005) but not posterior (β = 0.112, *SE* = 0.075, *t*(38) = 1.60, *p* = 0.119) regions. These findings can also be visualized in Fig. 2. In Fig. 2A, the strongly constrained-expected condition diverged from the other three conditions early, but only for the higher but not lower literacy participants. Fig. 2B plots the scalp maps of the difference waves between Low and High Cloze, which shows the widespread early fronto-central negativity limited to the higher literacy participants.

Thus, at the anterior sites, the High/Low cloze contrast was robust for high-literacy adults, but negligible for the low-literacy adults. By contrast, in posterior regions, both the High vs. Low Cloze contrast (β = 0.659, *SE* = 0.205, *t*(39) = 3.210, *p* = 0.003) and the Moderate vs. Low Cloze contrast (β = 0.282, *SE* = 0.129, *t*(39) = 2.184, *p* = 0.035) were significant collapsed across literacy level, and these contrasts were not significantly moderated by literacy level (*ts* < 1.5). Thus, the effect specific to the High vs. Low cloze contrast was only present in anterior regions among the participants with higher literacy attainments, whereas the ERP differences in response to the three cloze conditions were observed in posterior regions across participants—and likely reflect the onset of the N400 effect, described next.

N400 (300–500 ms). Results from the omnibus analysis showed that the 3-way interaction was reliable for both High vs. Low Cloze and Moderate vs. Low Cloze contrasts (*ts* > 5, *ps* < 0.001). Distributional analyses (shown in Fig. 4B) indicated that once again, Literacy Level modulated the ERPs to High vs. Low Cloze in the anterior region (β = 0.256, *SE* = 0.089, *t*(38) = 2.867, *p* = 0.007) but not in the posterior region (β = 0.042, *SE* = 0.081, *t*(38) = 0.52, *p* = 0.609). However, the High vs. Low Cloze (β = 0.947, *SE* = 0.210, *t*(39) = 4.516, *p* < 0.001) and Moderate vs. Low Cloze (β = 0.602, *SE* = 0.190, *t*(39) = 3.163, *p* = 0.003) contrasts were significant in posterior regions, and, again, did not interact with literacy level. Thus, literacy modulations on high/low cloze persisted into the N400 time window in

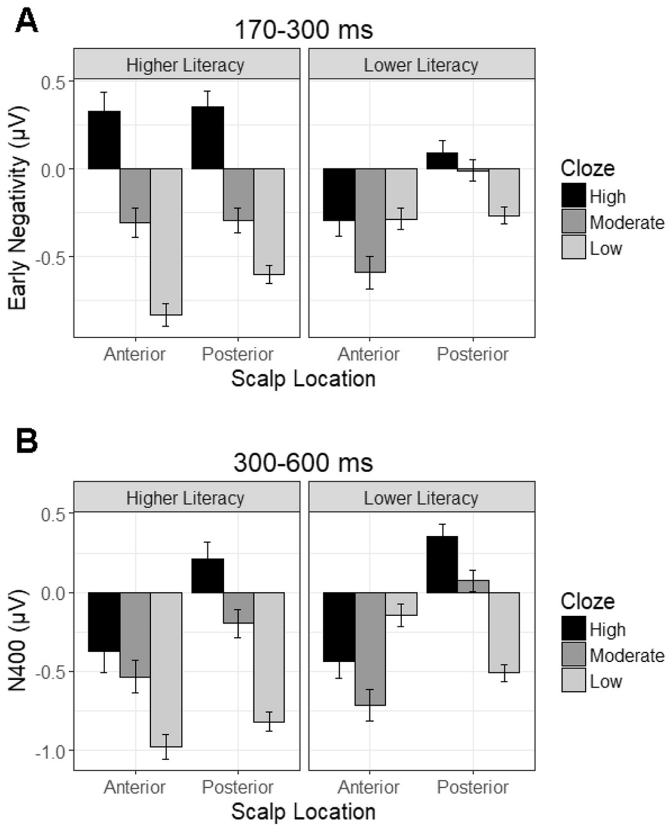

Fig. 4. Panel A shows early effects (170–300 ms) over anterior and posterior scalp regions, plotted as a function of literacy groups for High, Moderate and Low Cloze endings. Panel B shows N400 (300–600 ms) amplitude over anterior and posterior scalp regions plotted as a function of literacy groups for High, Moderate and Low Cloze endings. The error bars represent the between-subject standard error of the mean.

the anterior regions but, over posterior sites, cloze generally modulated N400 amplitude, regardless of participants' literacy skills, with lower cloze producing a larger negativity. Fig. 1 (bottom) shows the N400 effects for each literacy group, for comparison with the reading data previously collected from a comparable sample.

3.3. Effects of age

Previous studies have shown that older adults are less likely to use predictive strategies when comprehending language (Federmeier et al., 2010; Federmeier et al., 2002). Our sample comprised adults across a wide range of ages; thus, age might contribute to some of the variation we observed in the use of prediction. To test this, we a fit a mixed-effects model with High/Low cloze, Age, and their interaction as fixed effects, and another with High/Low cloze, Age, Literacy Level, and all of their interactions as fixed effects, to examine whether age could be one of the factors that explained the differences in the PMN, which has been specifically associated with predictive processing. The results showed that none of the interaction effects was significant ($ts < 0.6$), suggesting that age did not seem to be the driving force for the early PMN effects we observed. The same analyses performed for the anterior effects in the N400 time window also revealed no reliable Age effects ($ts < 1.2$).

4. Discussion

Our study probed the effects of literacy on sentence processing during listening, when visual decoding difficulties are not a barrier to comprehension. In a prior reading study (Ng et al., 2017), we showed that less-skilled adult readers are less able to make use of weak context information and are less able overall to use sentence context information to make predictions about likely upcoming words. Here, we asked whether either or both of these deficits would be mitigated when adults with lower levels of literacy instead listen to these same materials. More specifically, we sought to determine whether literacy impacts context-based facilitation on semantic retrieval, as indexed by the N400, and/or the ability to use context information predictively, as indexed by the early PMN effects in the waveform.

First, we found that N400 patterns conditioned by cloze probability were similar in participants regardless of literacy level. Responses to both strongly expected (high cloze) and weakly expected (moderate cloze) targets elicited smaller N400s than responses to unexpected words (which did not differ across sentence type). This effect of cloze probability was seen on the N400 (measured from 300 to 600 ms), and before 300 ms over posterior electrode sites. These findings are largely consistent with previous work in college-aged adults reading similar material (Federmeier et al., 2007), as well as results obtained for reading among higher literacy—but not lower literacy—adults from this same population (Ng et al., 2017). The results thus suggest that even adults with lower levels of literacy skill can rapidly build message-level representations through incremental processing (cf. Payne et al., 2015) and make use of the full range of available context information to facilitate lexical retrieval when visual decoding demands are removed. The contrast with the findings from our previous reading study using a similar community population supports the hypothesis that difficulties with print decoding play a role in how effectively contextual information can be used. In reading—but, critically, not while listening—less skilled readers have difficulty using weaker contextual constraints to rapidly and effectively build context-message to assist word processing. Collectively, these findings suggest that the effort allocated to decoding among struggling adult readers may impair comprehension processes (Gao et al., 2011, 2012), in much the same way that impaired hearing ability among older adults can impact comprehension (Tun et al., 2010; Wingfield et al., 2005).

However, despite the intact ability of lower literacy adults to make use of the full range of context information during listening, we find that literacy nonetheless affects auditory comprehension, in particular by altering the mechanisms by which context information is used. We found an early effect of literacy level over anterior electrode sites, reflecting facilitated processing of highly constrained words among proficient readers. This effect thus differentiated the case in which context information was strong enough to allow predictions for a specific upcoming word—and, presumably, its phonology—from cases in which no such strong predictions could be formed or when strong predictions were violated. This facilitation for the highly constrained word, when that word was obtained, increased with increasing literacy. The functional sensitivity, early onset, and distribution of this effect are consistent with the PMN previously described in the literature. The PMN effect for the high-literacy participants may have persisted into the later N400 time window over the anterior sites (marginal effect across the whole N400 window), perhaps reflecting continued phonological processing of the target words (Connolly et al., 2001). Although in the literature, the scalp distribution of the effect varies from anterior to more central or widespread, brain mapping and MEG has source localized it to left anterior auditory cortex (Connolly et al., 2001; Kujala et al., 2004).

The facilitated processing of highly constrained words observed in our current study deserves additional discussion. Most previous studies of the PMN compared words whose initial phoneme was congruent or incongruent with that of the word expected in the context, but did not test phonemic congruency as a function of varying levels of contextual constraint, such that a match and mismatch condition could be compared with a neutral condition (Connolly and Phillips, 1994; Connolly et al., 1992; D'Arcy et al., 2004; Hagoort and Brown, 2000; van den Brink et al., 2001; van den Brink and Hagoort, 2004). Thus, it was not clear whether the effect arose because words with features that match an expectation have facilitated processing or because mismatches caused processing difficulty. Our current study found that among the higher literacy adults, the strongly constrained-expected condition evoked a smaller negativity than the other two conditions between 170 and 300 ms. This pattern thus suggests that it is the phonological match that facilitates processing. It also counters the argument that the PMN is a response to violations.

Our finding that PMN effects are affected by literacy accords with prior work showing associations between the PMN and reading achievement in adults and children (e.g., Bone et al., 2002; MacDonald and Cornwall, 1995). Poor phonological skills may lead to poor word recognition and spelling abilities, affecting lexical retrieval during reading and resulting in effortful text comprehension. Our results show that poor phonological skills may also manifest in the PMN, an indicator of the use of prediction in auditory language comprehension, which is modulated by literacy achievement. Skilled readers use context information to predict the phonology of upcoming words, impacting their early analysis of the incoming signal. In contrast, less skilled readers do not show this differentiation, which may result from ineffective use of context information and/or reduced sensitivity to phonological information.

Coupled with the findings from our previous reading study with community-dwelling adults, it can be concluded that proficient readers use predictive mechanisms during auditory comprehension, just as they do in reading (although some of the specific manifestations of predictive processing are different in the two modalities). Importantly, however, we find that what characterizes language comprehension among lower literacy adults, regardless of the input modality, is their failure to take advantage of predictive processing to facilitate word processing. Here, we show that this is not due simply to print decoding difficulties, since the failure to show effects linked to prediction is also seen during listening (Huettig, 2015). These results are consistent with prior work using the visual world paradigm in listening comprehension (Mani and Huettig, 2014; Mishra et al., 2012), which suggested that low literacy may reduce the ability to use morphosyntactic features or semantic context to predict.

Why do adults with lower literacy skills not predict? Put another way, how does literacy contribute to predictive processing in language comprehension? In order to provide tentative answers to these questions, we need to understand what skills predictive processing requires and why low literacy may hinder their acquisition. Previous studies have shown that prediction necessitates sufficient time (Wlotko and Federmeier, 2015), high verbal fluency (Federmeier et al., 2010; Federmeier et al., 2002), and high general language skill (Martin et al., 2013). Prediction is also associated with the volitional control of reading (Payne and Federmeier, 2017) and controlled lexical access (Rommers et al., 2016). Collectively, we hypothesize that because both reading and prediction are controlled processes, and frequent reading trains readers to exert control over the input, reading may also train the use of predictive mechanisms. People with less experience controlling the reading process may thus be more likely to adopt a passive—“wait and see”—strategy, natively learned for auditory comprehension. Future research may investigate whether prediction is related to some aspect of executive function and how reading might be related to its acquisition and maintenance.

In conclusion, the present study confirms that lower literacy adults are more sensitive to sentence constraints and word expectancy in listening than in reading. However, in neither input modality was there evidence that predictive processing is used among low-literacy adults. Underdeveloped literacy skill, therefore, has an impact on language comprehension independent of modality. From an applied perspective, our findings suggest that a potential target of intervention is the improvement of context-based prediction. Thus, this research fits nicely into “Pasteur's quadrant” of use-inspired basic science (Stokes, 1997), in which an exploration of cognitive mechanisms can inform application. As such, empirical testing of instructional approaches that promote predictive processing is warranted.

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