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Thematic influences on word-to-text integration across a sentence boundary

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ABSTRACT

We report ERP evidence for local (preceding sentence) and global (thematic centrality) influences on word-to-text integration. Helder et al. (2019) found that the preceding sentence, rather than the central theme, is the primary source of integration, indexed by the N400 on the sentence-initial noun. The present experiments add evidence for thematic centrality effects. In Experiment 1, an N400 reduction occurred on the sentence-initial noun when an antecedent was remotely positioned in the preceding sentence and referred to the central theme, relative to Baseline. Experiment 2 further encouraged thematic processing by having participants select passage titles, producing an N400 reduction for sentence-initial nouns related to the central theme. Sentence-final nouns showed local influence on the N400 and P600, with no effect of centrality. We conclude that thematic centrality can influence integration across a sentence boundary when the antecedent is less accessible and the reader's task encourages attention to global structure.

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In constructing mental representations of text meaning (Van Dijk & Kintsch, 1983), readers integrate the meanings of words, phrases, and clauses as they are read into their understanding of the text. These integration processes are incremental and very rapid, detectable at the word level in self-paced reading (Boland et al., 1995), eye-movements (Rayner et al., 1989), and Event Related Potentials; ERPs (Kutas & Hillyard, 1980) and are part of the foundation of fluid reading comprehension (Perfetti & Stafura, 2014).



These integrative processes involve text influences from local text structures, at minimum the sentence in which the word occurs (e.g. Frazier & Clifton, 1996; MacDonald et al., 1994), and global text structures, such as the topic, thematic and causal structures of the text as a whole (e.g. Graesser & Clark, 1985; Trabasso & van den Broek, 1985). The issue of whether global text factors (e.g. the central theme of a text), beyond local text factors (preceding sentence), can influence the integration of single words into text memory is addressed in two ERP studies by Helder et al. (2019).


A particular feature of the experimental paradigm in these studies is that it separates text influence from sentence influence by measuring ERPs on the first substantive word (the noun of a subject noun phrase) across a

sentence boundary. Thus, any integrative effects indexed by ERPs are attributable to the preceding text and not the sentence in which the word occurs.

In an example passage from Helder et al. (2019) (see Table 1) the final sentence “The rain ruined her beautiful sweater” was preceded by “... it started to storm.”, providing a local binding opportunity for the critical word at the beginning of the sentence (“rain”). The sentence with the local binding opportunity was preceded by two sentences that set up the global context of the passage; in one condition, Local binding + Central theme, the critical word (“rain”) was related to the central theme of the passage (“weather”), in the other condition, Local binding only, the same critical word was presented in a passage in which the critical word was less related to the central theme (“clothes”).

To test whether the local context influenced word-to-text integration at sentence beginnings, ERPs in response to critical words were compared between passages with a local binding opportunity and Baseline passages without a binding opportunity. To test whether the global factor of thematic centrality had an additional influence on word-to-text integration, ERPs were compared between critical words that were related to the central theme of the passage or not. The results were

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Table 1. Example Passage from Helder et al. (2019).

Local Binding + Central theme	Local binding only	Baseline
Cathy likes to check the weather all the time on her iPhone. She is always very excited when stormy weather is predicted. While Cathy was riding her bike in the park, dark clouds began to gather, and it started to storm.	Cathy loves clothes and bought herself a new wardrobe. She is getting ready to go outside and decides to wear her new outfit today. She noticed that a lot of people were looking at her new clothes while it started to storm.	Cathy lives close to a park. She likes to be there as much as she can during the summer. When Cathy saw there were no dark clouds in the sky, she took her bike for a ride in the park.
The rain ruined her beautiful sweater.	The rain ruined her beautiful sweater.	The rain that was predicted never occurred.

(1) an N400 reduction on the critical word (“rain”), relative to baseline, for the two conditions that had a local binding site (“it started to storm”) in the preceding sentence and (2) no additional reduction of the N400 when the local binding site was related to the central theme. Helder et al. (2019) concluded that, for words at the beginning of a sentence, local influences were dominant and the central theme had no additional influence on integrating the word into the text representation.

On the assumption that certain text and reading task factors may be important in the emergence of thematic effects at sentence beginnings, we carried out and report below two experiments designed to enhance the influence of global text structures on word-to-text integration. Before we explain the rationale for these experiments, we review some of the key background issues.

Contextual effects in word processing

It is clear that online word processing is influenced by the context provided by the text beyond the sentence in which the word occurs, as evidenced in both ERP (e.g. Ferretti et al., 2008; Kuperberg et al., 2011; Nieuwland & Van Berkum, 2006; StGeorge et al., 1994; van Berkum et al., 1999) and eye tracking studies (e.g. Filik, 2008; Kambe et al., 2001; Pickering & Traxler, 1998; Warren et al., 2008). Using the ERP word-to-text integration paradigm (Yang et al., 2007), previous studies show that integration across sentences can occur at least at the meaning level and perhaps at the situation-model level (Van Dijk & Kintsch, 1983). That is, although word-to-word lexical-semantic associations produce N400 reductions, the word-to-text integration effects reflect additional text-meaning processes (Stafura et al., 2015; Stafura & Perfetti, 2014). Thus, the word-to-text integration paradigm allows the capture, across sentence boundaries, of both local and global text influences on reading single words.

In ERP studies, contextual effects on word processing are often captured by modulations of the N400

component, a negative going deflection that peaks around 400 ms after the onset of a critical word. Partly because it is pervasive in language processing, the N400 has been subject to various interpretations supported by substantial evidence. On one interpretation, N400 context effects reflect the congruence of the meaning of a word with the meaning of the text, consistent with an integration process (e.g. Hagoort et al., 2004; Stafura & Perfetti, 2014; van Berkum et al., 1999). However, the N400 has become increasingly interpreted as reflecting predictive processes (e.g. Kuperberg & Jaeger, 2016; Kutas & Federmeier, 2011; van Berkum et al., 2005; Van Petten & Luka, 2012) that either produce a specific word that later occurs or activate semantic features that overlap with the meaning of an upcoming word. A third interpretation, also with substantial evidence, is that the N400 does not reflect integrative processing at all, but instead indexes the retrieval of word meaning (Brouwer et al., 2012). Brouwer et al review evidence implicating the P600 as reflecting integration or updating of prior information.

Within the tradition that views the N400 as a marker of integration, there is increasing recognition that a simple “either-or” account (prediction or memory-based integration) fails to capture the multiple components of integrative processes (Kutas & Federmeier, 2011). Indeed, as argued by Calloway and Perfetti (2017), memory-based integration and prediction as semantic activation are two complementary perspectives on a single underlying process. When a word is read, its meaning interacts with a multi-leveled associative memory that includes meaning features from prior text and non-text knowledge sources during the early construction phase of word processing (Kintsch, 1988). From the position of the prior text, such processes prepare for the integration of meaning features that occurs when a later word is read. From the position of the word currently being read, these processes provide information in memory to support integration. Still, even on this more unitary interpretation, it is possible that distinct aspects of ERP shifts in the N400 window (e.g. the rising and falling segments of the N400 wave form) can distinguish the predictive and memory-based aspects of the overall integration process (Nieuwland et al., 2020), at least when texts produce a strong expectation for specific words.

The present study focuses on words at the beginning of a sentence, where word-specific prediction is unlikely and where previous research supports a memory-based integration account over a word-specific prediction account (Calloway & Perfetti, 2017; Stafura et al., 2015). Prior activation of semantic features that overlap with the meaning of the word across the boundary remains a possibility.

Sentence beginnings versus sentence endings.

The word-to-text integration processes depend on the structural role of the word within a particular sentence (e.g. Frazier & Clifton, 1996; MacDonald et al., 1994). A word is integrated into its (multiple) syntactic structures and a word at the end of a clause or sentence closes multiple open structures, including the clause or sentence as a whole. Thus, to integrate a word at the end of a sentence, integrative processes must link the word to the local sentence structures, providing contextual constraints that facilitate predictive and integrative processes. In contrast, at the beginning of a sentence, the reader uses the first word to open a new initial structure, often a noun phrase. Because the processing obligation is to build a new structure, integration with preceding text is not required. However, integration with the preceding text can occur when the word that is being read triggers retrieval of an antecedent word or phrase in text memory whose referential meaning binds with the meaning of the word being read. Thus, building a new structure is the default operation at sentence beginnings, making integration a process that occurs only when the word being read prompts retrieval of a text memory.

The current study

As we noted, the results of Helder et al. (2019) indicated that local context influences word-to-text integration across a sentence boundary and that no further influence is exerted by the global factor of thematic centrality (Experiment 1). Further, adding a title to the texts to strengthen centrality had no effect (Experiment 2). These results suggest that integration across a sentence boundary, when it occurs, is driven by local context. However, it is possible that factors associated with the text or the reader influence whether global effects are observed. For example, one factor may be that longer texts may establish a more prominent central theme than the short passages of Helder et al. (2019). A second factor may be the accessibility of a local binding site. If the potential binding site is recent in the text, as it was in Helder et al. (2019) where it occurred at the end of the preceding sentence, this local binding site will be highly accessible in memory during the reading of the word across the sentence boundary. Its linkage establishes local coherence, leaving little chance for an additional global effect. Making the local binding site less accessible by placing it earlier in the preceding sentence should allow the central theme to enhance the accessibility of the local binding site. A third factor concerns the reader's goal, which was to

answer true-false comprehension questions in Helder et al. (2019). This task may lead readers to attend more narrowly the facts conveyed in sentences, again reducing the opportunity for global influences. We chose to address the last two of these three possibilities in the experiments reported below.

In Experiment 1, we tested whether a thematic centrality effect would emerge at sentence-initial nouns when the local binding opportunity in the preceding sentence is located in the first part of the preceding sentence, farther away from the critical word. Making the local binding opportunity more remote should make it less accessible in memory, thus allowing the central theme to enhance its accessibility. Retrieval of the meaning of the relevant text segment (the local binding opportunity) produces integration with the meaning of the critical sentence-initial noun. If so, a reduced N400 on the critical sentence-initial noun will reflect this integration process, compared with a baseline that provides no obvious local binding opportunity. Moreover, by making the local binding opportunity less accessible, the central theme may now show its influence on word-to-text integration. If so, we expect a greater N400 reduction for nouns that are related to the central theme of the passage than for nouns that are not. Integration effects are sometimes observed in the late positivity or P600 component (Brouwer et al., 2012), including semantic processes that update the reader's mental model of the text (Burkhardt, 2007; Schumacher, 2014; Schumacher & Hung, 2012), although semantic effects also may arise from meaning relations extracted from syntactic structures (Bornkessel-Schlesewsky & Schlewsky, 2008). Because of its interpretation as reflecting higher level integration, we tested the P600 as well.

In Experiment 2, we further encouraged global integration by changing the task instruction. Instead of answering true/false comprehension questions after each passage, Experiment 2 required participants to choose which of two titles best fits the passage they just read. This title selection task should encourage readers to attend to global meaning features and may allow the emergence of a thematic centrality effect on the N400 or the P600.

For critical sentence-final nouns in both experiments our expectations are less clear. The two experiments of Helder et al. (2019) showed N400 and P600 reductions for sentence-final nouns that were related to the central theme relative to nouns that were not related to the central theme, possibly reflective of integrative (N400) and updating (P600) processes. However, the sentence-final nouns in those experiments contrasted only on whether they were related to the central theme;

unlike for the first word across a sentence boundary, there was no local binding opportunity for the text-final word. Thus, those experiments show a thematic centrality effect on the sentence-final nouns in the absence of any local binding opportunity. In the present experiments, the sentence-final nouns have a local binding opportunity in the preceding sentence, making possible a direct comparison between sentence-final nouns with and without local binding opportunity as well as with or without a relation to the central theme. If the global text factor of thematic centrality has an influence on the integration of sentence-final nouns, a reduced N400 or P600 is more likely to be observed for sentence-final nouns that are related to the central theme than for sentence-final nouns that are not related to the central theme.

Experiment 1

Method

Participants. Thirty-eight participants (ages 18–36) were recruited through their responses to flyers posted on the campus of the University of Pittsburgh. All were native English speakers with normal or corrected-to-normal vision and were right handed with no history of head injuries, neurological disorders or learning disabilities. The data of two participants were discarded because of technical problems during data collection. After preprocessing the EEG data, the data of three additional participants were discarded because of artefacts arising from excessive blinking, eye movements, and faulty electrodes. Thus, data from 33 participants (19 female, M_{age}

= 21.55; $SD = 3.75$) were available for ERP analyses. All procedures were approved by the University of Pittsburgh's Institutional Review Board. All participants received \$10 per hour for their participation.

Materials. Each participant read 90 four-sentence passages that were preceded by a title using the same procedures as in Helder et al. (2019): ERPs were measured on two words of the final sentence: the noun at the sentence-initial position and the noun at the sentence-final position. The central theme was established in the first three sentences of the passage by explicitly referring to the central theme twice and by including three words within the first three sentences that were semantically related to the central theme. The title contains another explicit mention of the central theme. In contrast to Helder et al. (2019), the local binding opportunity for nouns at the beginning of the fourth sentence now appeared at the first part of the preceding sentence, rather than near the end, making it less accessible at the point where the critical noun of the next sentence occurs.¹ The number of words between the critical noun and the binding opportunity ranges from 4–16 words with an average of 9 ($SD = 3$). Finally, nouns in the sentence-final position had a binding opportunity at the end of the preceding sentence, something that was not controlled for in the materials of Helder et al. (2019). See Table 2 for two examples.

The sentence-initial noun of the final sentence was the same across the three conditions for a given passage. These conditions varied according to the opportunity the third sentence presented for integration of this sentence-initial noun, defined as in Helder et al. (2019): (1) Local Binding + Central (LB + C). The critical sentence-

Table 2. Example Passages.

	<i>For sentence-initial nouns:</i> Local Binding + Central (LB + C) <i>For sentence-final nouns:</i> Local Binding + Non Central (LB + NC)	<i>For sentence-initial nouns:</i> Local Binding + Non Central (LB + NC) <i>For sentence-final nouns:</i> Local Binding + Central (LB + C)	Baseline
Example 1	Vivian the Photographer Vivian has been an amateur photographer for a few years now. She enjoys experimenting with a variety of camera settings, lighting, and lenses. The photos she posts on her blog are usually of food. The pictures show that she is especially interested in desserts .	Vivian the Food Critic Vivian is a highly regarded food critic in the restaurant world. She writes reviews of a restaurant's most popular dishes and publishes her critiques on her blog. The photos she posts on her blog are usually of food. The pictures show that she is especially interested in desserts .	Vivian's Website / Vivian's Twitter Account (only in Exp 2) Vivian might be addicted to social media. She is constantly posting on Facebook, and she is always tweeting about things that annoy her. She even has her own website where she blogs about her lifestyle. The pictures show that she is especially interested in desserts .
Example 2	Lisa Likes Hiking Lisa enjoys being outside and experiencing nature. She frequently goes to the park nearby and treks through the woods. For her weekly hike, she packed snack bags filled with fruit. The trail she went on had many patches of blueberries .	Lisa Likes Fruit Lisa really likes fruit. Watermelons and peaches are her favourite because they are both juicy and very sweet. For her weekly hike, she packed snack bags filled with fruit. The trail she went on had many patches of blueberries .	Lisa Explores/Lisa Got Lost (only in Exp 2) Lisa and her friends were lost. They were exploring an empty road and forgot their way. However, they still had fun because they got to see a new part of their town. The trail she went on had many patches of blueberries .

initial noun has a binding opportunity in the preceding sentence that is related to the central theme of the passage; e.g. the sentence-initial noun “pictures” could trigger the retrieval of the binding opportunity in the preceding sentence (“photos”) and, additionally, is related to the central theme “photographer”. (2) Local Binding + Non Central (LB + NC). The critical sentence-initial noun has the same binding opportunity in the preceding sentence, but is unrelated to the central theme of the passage; e.g. the sentence-initial noun “pictures” could trigger the retrieval of the binding opportunity in the preceding sentence (“photos”), but occurs in a passage with “food critic” as the central theme. (3) Baseline condition. The critical sentence-initial noun “pictures” has no direct binding opportunity and occurs in a passage that is equal in length to the LB + C and LB + NC conditions.

The same logic applies to the critical sentence-final nouns. Depending on condition, the critical sentence-final noun (“desserts”) has (1) a binding opportunity in the preceding sentence (“food”) and is related to the central theme “food critic” (LB + C), (2) this same binding opportunity in the preceding sentence but occurs in passage with “photographer” as the central theme, (LB + NC) or (3) has no obvious binding opportunity in the preceding sentence (Baseline) and is equal in length to the LB + C and LB + NC conditions.

To assess our local and global text manipulations, we measured the lexical-semantic relationship between the critical nouns and the local (preceding sentence) and global (all words before the critical noun) context. Table 3 shows Latent Semantic Analyses (LSA) values for both sentence-initial and sentence-final nouns, confirming our local and global text manipulations.

Three separate lists of 30 passages per condition were created so that each subject saw only one condition of each of the 90 passages. Participants were randomly assigned to one of the three lists.

Sentence-initial noun. The first critical word (“pictures”) appeared at the beginning of the final sentence where ERP’s were measured and compared across three conditions: (1) LB + C (local binding opportunity: “photos”, central theme: “photographer”), (2) LB + NC (local binding opportunity: “photos”, central theme: “food critic”) and (3) Baseline.

First, to test whether the critical word cues the retrieval of the local binding opportunity presented at the beginning of the preceding sentence, mean amplitudes on sentence-initial nouns were compared between LB + NC and Baseline. Second, to test whether the global context of the central theme influences word-to-text integration, mean amplitudes on sentence-initial nouns were compared between LB + C and LB + NC.

Table 3. Means (and SD) of LSA Cosine Values¹ for Local and Global Context Manipulations for Critical Sentence-initial and Sentence-final Nouns.

Sentence-initial nouns		
Local context ^(a1)	Local Binding + Central	M (SD) .14(.16)
	Local Binding + Non central	.14(.16)
	Baseline	.04(.08)
Global context ^(b)	Local Binding + Central	.27(.18)
	Local Binding + Non central	.14(.13)
	Baseline	.07(.11)
Sentence-final nouns		
Local context ^(a2)	Local Binding + Central	M (SD) .11(.10)
	Local Binding + Non central	.11(.10)
	Baseline	.04(.07)
Global context ^(b)	Local Binding + Central	.22(.16)
	Local Binding + Non central	.11(.09)
	Baseline	.05(.07)

^(a1)Local context (critical word vs S3^(a1) or S3 and S4^(a2)): Baseline < LB + NC = LB + C, $p < .001$.

^(b)Global context (critical words vs passage context): Baseline < LB + NC < LB + C, $p < .001$.

¹Retrieved from <http://lsa.colorado.edu/>

Sentence-final noun. The second critical word (“desserts”) appeared at the end of the final sentence where ERP’s were measured and compared across three conditions: (1) LB + C (local binding opportunity: “food”, central theme: “food critic”), (2) LB + NC (local binding opportunity: “food”, central theme: “photographer”) and (3) Baseline.

As for the sentence-initial nouns, local binding effects were tested by comparing mean amplitudes on sentence-final nouns in LB + NC to those in Baseline. To test for an effect of the central theme, mean amplitudes on sentence-final nouns were compared between LB + C and LB + NC.

Norming study sentence-initial nouns. Two separate norming studies were conducted to obtain a measure of integrability and cloze-based predictability (as defined in Calloway & Perfetti, 2017) of the sentence-initial critical nouns of our materials. For both norming studies, three lists were created in a Qualtrics survey with 30 items in the baseline condition and 30 items in the local binding condition so that every participant saw 60 items, consisting of the beginning of the final sentence and the preceding sentence of each of the experimental passages. Note that the sentence preceding the critical sentence-initial word is the same for LB + C and LB + NC conditions. Native English-speaking participants living in the United States were recruited through Amazon’s Mechanical Turk.

Integrability scores. Each participant ($N = 87$) saw each sentence-initial noun and the preceding sentence (e.g. Chuck grabbed a double espresso before entering the classroom because he knew his students would be

Table 4. Integrability and Predictability Scores for Sentence-initial Nouns.

	Integrability Likert scale (1 = very easy; 7 = very difficult)		Predictability Cloze probability	
	<i>M</i>	(<i>SD</i>)	<i>M</i>	(<i>SD</i>)
Local binding	2.14	(.65)	.040	(.07)
Baseline	3.79	(1.30)	.009	(.02)

causing trouble. The *caffeine.*) and answered the question “How easy is it to connect the meaning of the word with the preceding sentence?” on a 7-point Likert scale ranging from Very Easy (1) through Very Difficult (7). Average integrability scores displayed in Table 4 show that nouns with a local binding opportunity are easier to integrate than the same words in the baseline condition.

Predictability scores. Each participant ($N = 89$) saw the sentence and the article preceding each sentence-initial noun, and was instructed to “please try to predict the next word in the sentence”. The predictability scores (averaged across participants and items; see Table 4) show that predictability of sentence-initial nouns is low overall, although higher in the local binding condition (4%) than the baseline (1%).

Procedure. The procedure was the same as in Helder et al. (2019). Participants were fitted with an EEG net and seated inside a soundproof, electrically insulated booth on an adjustable chair 60 cm from the center of a 15-in. (38.1 cm) CRT display. They were instructed to read text passages for comprehension and to make true/false judgements to statements that followed each passage. All materials were presented in white letters on a black background, font Arial size 16, using E-prime (Version 2.0; Psychology Software Tools, Inc. Pittsburgh, PA, USA). Each trial began with a fixation cross displayed for 350 ms. The title and the first two sentences were then displayed as full sentences; after reading the first sentence, the participant pressed the spacebar to replace it with the second sentence. The third and fourth sentences were presented one word at the time with an inter-stimulus interval (ISI) of 300 ms and a stimulus onset asynchrony (SOA) of 600 ms. True/false statements were designed to be easy to answer when the reader attended to the content of the passage. Immediate feedback was presented on the screen after each trial, either by “good job” for correct responses or “wrong” for incorrect responses.

The passages were presented in three blocks of 30 randomly ordered passages with short breaks between blocks. To ensure participants understood the task instructions, three practice trials preceded the

experimental trials. The experiment took around 60 minutes to complete.

ERP recordings and preprocessing. All preprocessing steps were the same for critical sentence-initial and sentence-final nouns and follow the procedure described in Helder et al. (2019). ERP recordings were made from a 128 electrode Geodesic sensor net (Tucker, 1993) with Ag/AgCl electrodes (Electrical Geodesics, Inc., Eugene, OR) with impedances kept below 40 k Ω (Ferree et al., 2001) and a vertex reference during the recording. The EEG signals were digitally sampled at a rate of 1000 Hz, and hardware filtered during recording between 0.1 and 200 Hz.

A 30 Hz low-pass finite impulse response filter was applied to the recorded EEGs, which were segmented into 1000 ms ERP epochs from 200 ms before the onset of the critical noun to 800 ms after. Automatic artefact detection removed segments on the basis of blink detection on superior and inferior eye channels that showed voltage fluctuations of $> 140 \mu\text{V}$; horizontal eye movements (e.g. saccades) were detected at the left outer canthi electrode and removed for voltage fluctuations of $> 55 \mu\text{V}$. For sentence-initial nouns, this procedure lead to the exclusion of 6.97% ($SD = 6.84\%$) of trials in the LB + C condition, 6.67% ($SD = 6.12\%$) in the LB + NC condition, and 6.87% ($SD = 6.61\%$) in the Baseline condition. For sentence-final nouns, 5.96% ($SD = 5.64\%$) of trials were excluded in the LB + C condition, 5.56% ($SD = 6.38\%$) in the LB + NC condition, and 6.16% ($SD = 5.96\%$) in the Baseline condition. Finally, datasets were visually inspected for any remaining bad channels.

Channels removed because of artefacts were replaced by data from neighbouring channels using spherical spline interpolation (Ferree, 2006). The data were then re-referenced to the average of all channels, as is common with dense-array electrode nets² (Dien, 1998; Luck, 2014) and then averaged for each participant for each condition. A baseline correction was applied to the averaged waveforms by subtracting the mean amplitude of the baseline period (200 ms before critical words) from each sample in the segment. The data were then exported to EPToolkit v2.63 (Dien, 2010) and SPSS 24.0 for statistical analyses.

Results

Behavioural data. Accuracy on the true/false statements that followed each passage was high, with an average of 95.72% ($SD = 2.75\%$) across conditions.

ERP data. For measurements on the critical sentence-initial noun and sentence-final noun, mean amplitudes between 300 and 500 ms (N400) and between 500 and 700 ms (P600) following word onset were averaged

across participants. These time windows were based on previous ERP text research (e.g. Burkhardt, 2007; Helder et al., 2019) and confirmed by inspection of peak latencies. Mean amplitudes for all participants were compared in two repeated measures ANOVAs: the first was a 3 (Condition; LB + C, LB + NC, Baseline) \times 3 (Cluster; Fz, Cz, Pz), referred to as midline analysis. The second was a 3 (Condition; LB + C, LB + NC, Baseline) \times 2 (Cluster laterality; F3/C3/P3, F4/C4/P4) \times 3 (Cluster posteriority; F3/F4, C3/C4, P3/P4), referred to as laterality analysis. Figure 1 shows the electrodes used for each cluster.

We report significant main effects and/or interactions of condition with electrode cluster. When a main effect of condition was significant, we conducted two planned comparisons: (1) to test for local binding effects on sentence-initial nouns, mean amplitudes were compared between LB + NC and Baseline; (2) to test for global text influences (i.e. thematic centrality) on word-to-text integration, mean amplitudes were compared between LB + C and LB + NC. When there was no significant difference between LB + C and LB + NC, we did a post-hoc comparison of LB + C vs Baseline to test whether a condition that had both local binding and thematic centrality produced an effect compared with a condition that had neither. These same comparisons were applied to the mean amplitudes on sentence-final nouns. Greenhouse-Geisser corrected p -values are reported when sphericity could not be assumed.

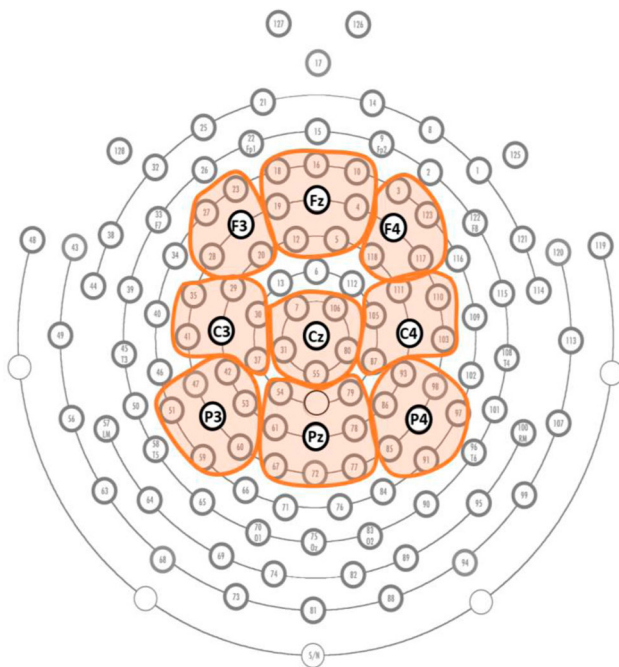


Figure 1. Electrode clusters used in the Midline analyses (Fz, Cz, Pz) and Laterality analyses (F3, F4, C3, C4, P3, P4) for the 128 electrode Hydro-Cel Geodesic Sensor Net 1.0.

Grand average waveforms for all electrode clusters are displayed in Figure 2 for sentence-initial nouns and in Figure 3 for sentence-final nouns. The full ANOVA table with results for sentence-initial and sentence-final nouns can be found in the supplementary materials available online.

Sentence-initial nouns

N400 analyses. Neither the local binding opportunity nor thematic centrality produced a reliable N400 effect: LB + NC elicited reduced negativity relative to Baseline and LB + C elicited reduced negativity relative to LB + NC, but these comparisons did not reach significance. Sentence-initial nouns that had a local binding opportunity and were related to the central theme (LB + C) did produce a reduced N400, but only relative to Baseline and not compared with local binding only (LB + NC). These conclusions are based on the following analyses.

Midline analyses (Fz, Cz, Pz). A significant interaction of condition with electrode cluster, $F(4, 128) = 3.71, p = .029, \eta_p^2 = .10$ indicated significant condition differences at parietal electrodes, Pz, $F(2, 64) = 4.49, p = .018, \eta_p^2 = .12$, but not at Cz, $F(2, 64) = 1.81, p = .172$ and Fz, $F(2, 64) = 2.64, p = .103$. At Pz there was no local binding effect; the N400 was reduced for LB + NC [$M = -1.27\mu V$; 95% CI (-1.77, -.76)] relative to Baseline [$M = -1.53\mu V$; 95% (-2.08, -.97)], but not reliably ($p = .196$). There was also no effect of the central theme. However, an N400 reduction for LB + C [$M = -.82\mu V$; 95% CI (-1.28, -.36)] relative to LB + NC is visible in Pz, but did not reach standard reliability ($p = .087$).

A post-hoc comparison of LB + C vs Baseline indicated N400 reductions for nouns that had a local binding opportunity and were related to the central theme (LB + C), relative to Baseline, $p = .011$.

Laterality analyses (F3, C3, P3, F4, C4, P4). As in the midline analyses, a significant interaction of condition with cluster posteriority, $F(4, 128) = 3.77, p = .027, \eta_p^2 = .11$ indicated significant condition differences at parietal electrodes, P3/P4, $F(2, 64) = 5.25, p = .008, \eta_p^2 = .14$, but not at C3/C4, $F(2, 64) = 1.18, p = .314$ and F3/F4, $F(2, 64) = 1.94, p = .152$. At P3/P4 there was no local binding effect; the N400 was reduced for LB + NC [$M = -.72\mu V$; 95% CI (-1.03, -.41)] relative to Baseline [$M = -.95\mu V$; 95% CI (-1.34, -.56)], but not reliably ($p = .110$). There was also no effect of the central theme. The expected N400 reduction for LB + C [$M = -.40\mu V$; 95% CI (-.72, -.08)] relative to LB + NC is visible in parietal electrodes, but did not reach standard reliability ($p = .084$).

A post-hoc comparison of LB + C and Baseline indicated an N400 reduction for LB + C relative to Baseline, $p = .006$.

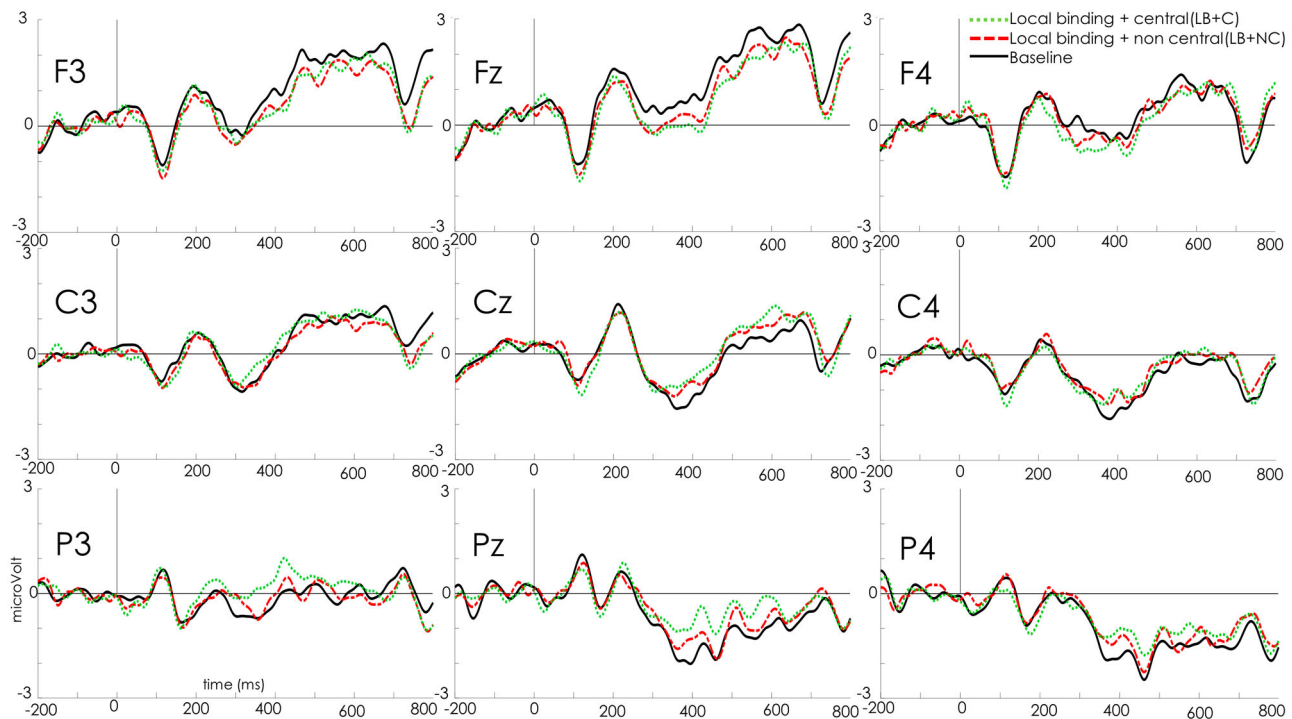


Figure 2. Grand average wave forms for critical sentence-initial nouns in local binding + central (LB + C), local binding only (LB + NC), and baseline conditions in Experiment 1. The data is re-referenced to the average of all channels. Negativity is plotted downwards. Pairwise comparisons show significant condition differences in the N400 time window in parietal electrodes (Pz/P3/P4): No local binding effect (LB + NC vs Baseline); no thematic centrality effect (LB + C vs LB + NC); N400 reduction for LB + C relative to Baseline.

P600 analyses. There were no significant main effects of condition or interactions of condition with electrode cluster in neither the midline nor laterality analyses, all p 's > .149.

Sentence-final nouns

N400 analyses. The local binding opportunity in the preceding sentence produced an N400 effect: LB + NC elicited a reduced N400 relative to Baseline. The thematic centrality (LB + C vs LB + NC) did not have an effect. These conclusions are based on the following analyses.

Midline analyses (Fz, Cz, Pz). A significant interaction of condition with electrode cluster, $F(4, 128) = 3.74, p = .025, \eta_p^2 = .11$ indicated significant condition differences at central electrodes, Cz, $F(2, 64) = 4.01, p = .023, \eta_p^2 = .11$ and parietal electrodes, Pz, $F(2, 64) = 4.18, p = .020, \eta_p^2 = .12$, but not at frontal electrodes, Fz, $F(2, 64) = 1.78, p = .176$. There was a local binding effect at Cz: LB + NC [$M = .92\mu\text{V}$; 95% CI (.39, 1.45)] showed N400 reductions relative to Baseline [$M = .30\mu\text{V}$; 95% CI (-.10, .89)], $p = .023$, as well as at Pz: LB + NC [$M = 1.38\mu\text{V}$; 95% CI (.92, .23)] > Baseline [$M = .57\mu\text{V}$; 95% CI (-.03, 1.16)], $p = .030$. There was no effect of the central theme: LB + C and LB + NC showed no significant differences at either Cz (LB + C, [$M = .99\mu\text{V}$; 95% CI (.44, 1.53)], LB + NC [M

$= .92\mu\text{V}$; 95% CI (.39, 1.45)], $p = .794$) or Pz (LB + C, [$M = 1.19\mu\text{V}$; 95% CI (.57, 1.80)], LB + NC [$M = 1.38\mu\text{V}$; 95% CI (.92, .23)], $p = .559$).

A post-hoc comparison of LB + C and Baseline at Cz indicated N400 reduction for LB + C relative to Baseline, $p = .006$. This was also the case at Pz, LB + C showed N400 reductions relative to Baseline, $p = .007$.

Laterality analyses (F3, C3, P3, F4, C4, P4). A main effect of condition, $F(2,64) = 3.83, p = .027, \eta_p^2 = .11$ was qualified by an interaction of condition with cluster posteriority, $F(4, 128) = 4.74, p = .009, \eta_p^2 = .13$. This interaction indicated significant condition differences at central electrodes, C3/C4, $F(2, 64) = 4.95, p = .010, \eta_p^2 = .134$ and parietal electrodes, P3/P4, $F(2, 64) = 8.03, p = .001, \eta_p^2 = .201$, but not at frontal electrodes, F3/F4, $F(2, 64) = 1.25, p = .292$. There was a local binding effect at C3/C4: LB + NC [$M = .58\mu\text{V}$; 95% CI (.26, .89)] showed N400 reductions relative to Baseline [$M = .16\mu\text{V}$; 95% CI (-.12, .43)], $p = .041$, as well as at P3/P4: LB + NC [$M = 1.00\mu\text{V}$; 95% CI (.75, 1.25)] > Baseline [$M = .39\mu\text{V}$; 95% CI (.04, .74)], $p = .001$. There was no effect of the central theme: LB + C and LB + NC showed no significant differences at either C3/C4 (LB + C [$M = .47\mu\text{V}$; 95% CI (.19, .76)], LB + NC [$M = .58\mu\text{V}$; 95% CI (.26, .89)], $p = .472$) or P3/P4 (LB + C [$M = .92\mu\text{V}$; 95% CI (.58, 1.25)], LB + NC [$M = 1.00\mu\text{V}$; 95% CI (.75, 1.25)], $p = .654$).

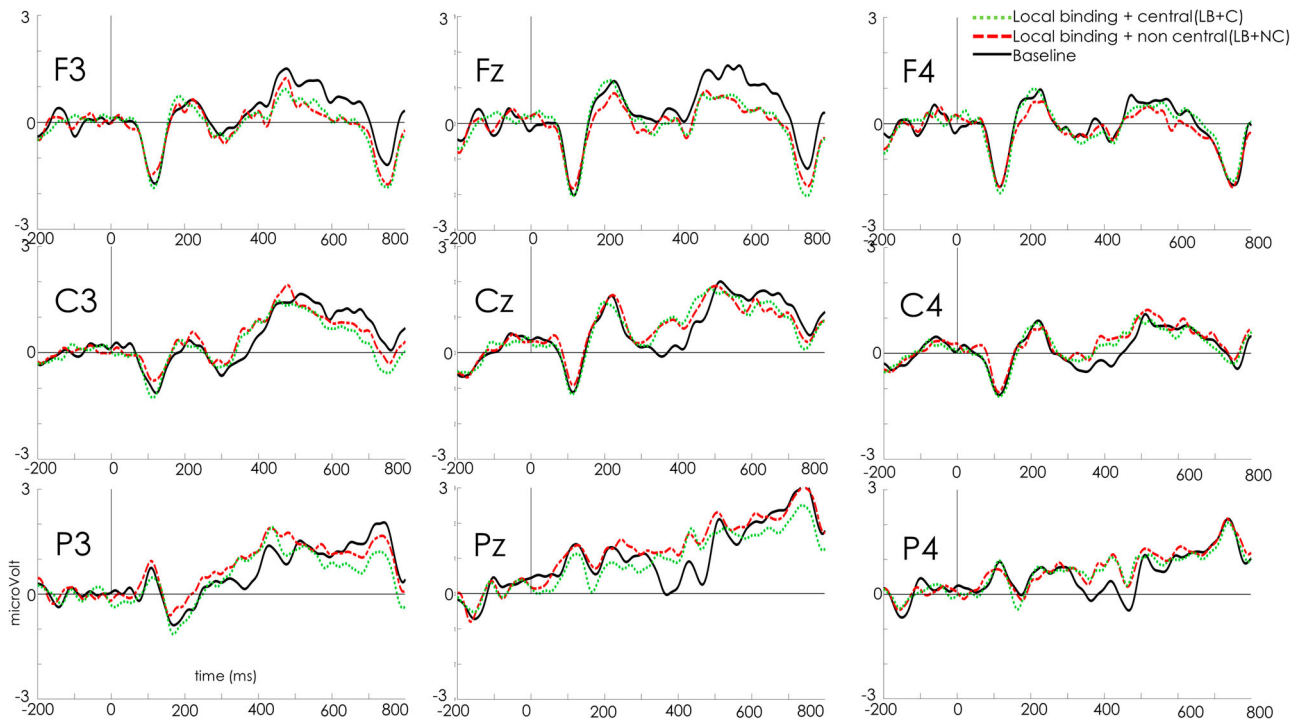


Figure 3. Grand average wave forms for critical sentence-final nouns in local binding + central (LB + C), local binding only (LB + NC), and baseline conditions in Experiment 1. The data is re-referenced to the average of all channels. Negativity is plotted downwards. Pairwise comparisons show significant condition differences in the N400 time window at central and parietal clusters (Cz/C3/C4, Pz/P3/P4): N400 effect for the local binding comparison (LB + NC > Baseline); no thematic centrality effect (LB + C vs LB + NC); N400 reduction for LB + C relative to Baseline. Pairwise comparisons show significant condition differences in the P600 time window across all clusters, visible in left central and frontal electrodes: P600 effect for the local binding comparison (Baseline > LB + NC (midline clusters only)); no thematic centrality effect (LB + C vs LB + NC); larger P600 for Baseline relative to LB + C.

A post-hoc comparison of LB + C and Baseline at C3/C4 indicated N400 reduction for LB + C relative to Baseline, $p = .004$. This was also the case at P3/P4, LB + C showed N400 reductions relative to Baseline, $p = .001$.

P600 analyses. Sentence-final nouns in the baseline condition produced more positivity in the P600 time window than the same nouns with a local binding opportunity (LB + NC), mostly visible in left central and frontal electrodes. The central theme (LB + C vs LB + NC) did not have an effect. These conclusions are based on the following analyses.

Midline analyses (Fz, Cz, Pz). A main effect of condition, $F(2, 64) = 3.83$, $p = .027$, $\eta_p^2 = .107$ indicated a local binding effect: the P600 was more positive for Baseline [$M = 1.58\mu\text{V}$; 95% CI (1.21, 1.95)] than for LB + NC [$M = 1.25\mu\text{V}$; 95% CI (.77, 1.73)], $p = .040$, mostly visible at Fz. There was no effect of the central theme: LB + C [$M = 1.17\mu\text{V}$; 95% CI (.79, 1.55)] and LB + NC showed no significant differences, $p = .636$.

A post-hoc comparison of LB + C and Baseline at all midline clusters indicated that the P600 was more positive for Baseline relative to LB + C, $p = .009$.

Laterality analyses (F3, C3, P3, F4, C4, P4). A main effect of condition, $F(2, 64) = 3.31$, $p = .043$, $\eta_p^2 = .09$ indicated a

local binding effect: the P600 is visible in left central and frontal electrodes and was more positive for Baseline [$M = .90\mu\text{V}$; 95% CI (.67, 1.12)] than for LB + NC [$M = .73\mu\text{V}$; 95% CI (.44, 1.01)], but did not reach standard reliability, $p = .084$. There was no effect of the central theme: LB + C [$M = .64\mu\text{V}$; 95% CI (.43, .85)] and LB + NC showed no significant differences, $p = .419$.

A post-hoc comparison of LB + C and Baseline at all laterality clusters indicated that the P600 was more positive for Baseline than for LB + C, $p = .021$.

Discussion

The results of Experiment 1 suggest that the N400 local binding effect at the sentence-initial nouns was weak in the absence of centrality; the differences between LB + NC and Baseline were in the expected direction, but did not reach standard significance for parietal clusters. The effect of centrality was also weak, significantly different from the baseline, but not from local binding only (LB-NC).

In Helder et al. (2019), the local binding antecedent was positioned at the end of the preceding sentence. In the present experiment, the accessibility of the local

binding antecedent may have been weakened by its more remote positioning near the beginning of the preceding sentence. When this antecedent was related to the central theme, its accessibility could have been enhanced, allowing an N400 reduction relative to baseline. Thus, the effects of thematic centrality and local binding were sufficient in combination for an integration effect on the N400.

Sentence-final nouns with a local binding opportunity in the preceding sentence showed reduced negativity in the N400 time window relative to sentence-final nouns that had no such binding opportunity, reflecting the retrieval and binding of text information upon reading the critical noun. Additionally, a more positive left central and frontal P600 for sentence-final nouns in the baseline condition, compared with both LB + C and LB + NC, suggests that final integrative processes (closure and updating) were facilitated by the binding opportunity of the preceding sentence. As was the case for sentence-initial nouns, thematic centrality (LB + C) was not significantly different from local binding only (LB + NC).

Experiment 2

The goal of the second experiment was to stimulate the use of global context (the central theme) in word-to-text integration by influencing participants' reading goals. To do so, we used the same materials and procedure as Experiment 1, but with a different task: Instead of asking true/false comprehension questions after each passage, participants were asked to pick which of two titles better fits with each passage. With these instructions, we aimed to influence the reader's focus on the central theme of the passage.

Method

Participants. Thirty-nine participants (ages 18–30) were drawn from the same population and meeting the same criteria as the first experiment: English speakers, right-handed, with normal or corrected-to-normal vision and without a history of head injuries, neurological disorders or learning disabilities. Two participants did not finish the experiment. After preprocessing the EEG data, the data of seven participants were discarded because of excessive blinking, eye movements, or faulty electrodes. Thus, data from 30 participants (20 female, $M_{age} = 20.88$; $SD = 2.51$) were available for ERP analyses. All procedures were approved by the University of Pittsburgh's Institutional Review Board. All participants received \$10 per hour for their participation.

Materials and procedure. The materials consisted of the same 90 four-sentence passages as used in Experiment

1. However, in Experiment 2 we implicitly orient participants toward the central theme of the passage by asking, after each passage, which of two titles fits better for that passage. For the LB + C and LB + NC conditions we used the titles that were presented in Experiment 1; one of the two titles consisted of the name of the protagonist and the central theme of the LB + C condition. The other title consisted of the name of the protagonist and the central theme of the LB + NC condition. For each baseline passage, we created two titles that could both fit. Titles in the Baseline condition consisted of the name of the protagonist and a word or phrase about something that is mentioned in the passage, with the constraint that the content of the title is not related to the critical sentence-initial and sentence-final nouns.

After participants chose the title that they thought fits best, feedback was provided by a screen that reported the title choices of other people, expressed as percentages. See Figure 4 for an example. To provide participants with authentic feedback percentages, i.e. based on real title judgments, as well as to reinforce the cover story that the experiment was about choosing titles, we provided percentages from a norming study carried out through a Qualtrics survey on Amazon's Mechanical Turk. Participants in the norming study ($N = 71$) were given 90 passages with two titles, 30 in each condition, and were asked to choose the title that better fits each passage. For passages with a central theme (LB + C and LB + NC conditions), 86.82% ($SD = 8.03\%$) of the participant responses chose the title that we defined as reflecting the central theme. As expected, for passages in the baseline condition, participants responses were more variable; 59.61% ($SD = 13.30\%$) of the responses chose title option 1 and the remaining 40.39% chose title option 2.

Results

Behavioural data. There was no right or wrong answer to the title judgment question. However, by comparing their own judgment with the majority judgment displayed on the screen participants remain engaged with the task of title selection. In their selection of the better title, participants in the ERP experiment showed high agreement ($M = 88.07\%$, $SD = 3.87\%$) with the title that was chosen as better by the majority of the participants in the online norming study, which was always the central theme title. Choosing a title for the Baseline passage was more variable, consistent with the variability in the norming responses, with ERP participants showing an average agreement of 59.06% ($SD = 7.78\%$) with title option 1.

93% chose "Vivian the Photographer"
 7% chose "Vivian the Food Critic"
 Press {SPACEBAR} to continue.

Figure 4. Example of a feedback screen after choosing which of two titles best fits with the passage (Experiment 2).

ERP data. Data preprocessing and analyses were the same as in Experiment 1. For sentence-initial nouns, automated artefact detection led to the exclusion of 7.44% ($SD = 7.51\%$) of trials in the LB + C condition, 7.56% ($SD = 9.05\%$) of trials in the LB + NC condition, and 8.11% ($SD = 8.96\%$) of trials in the Baseline condition. For sentence-final nouns, 7.33% ($SD = 8.64\%$) of trials in the LB + C condition were excluded, 7.33% ($SD = 8.18\%$) in the LB + NC condition, and 8.78% ($SD = 8.05\%$) of trials in the Baseline condition. Grand average waveforms for representative electrode clusters are displayed in Figure 5 for sentence-initial nouns and in Figure 6 for sentence-final nouns. The full ANOVA table with results for sentence-initial and sentence-final nouns can be found in the online supplementary materials.

Sentence-initial nouns

N400 analyses. The local binding opportunity did not produce an N400 reduction: LB + NC and Baseline did not differ reliably. In contrast to Experiment 1, thematic centrality had a reliable effect on the N400: Sentence-initial nouns that were related to the central theme (LB + C) elicited reduced negativity relative to the same nouns that were not related to the central theme (LB + NC) in midline clusters. These conclusions are based on the following analyses.

Midline analyses (Fz, Cz, Pz). A main effect of condition, $F(2, 58) = 6.09, p = .004, \eta_p^2 = .17$ indicated that there was no local binding effect: there were no significant N400 differences between LB + NC [$M = -.67\mu V; 95\% CI (-1.02, -.32)$] and Baseline [$M = -.68\mu V; 95\% CI (-1.05, -.31)$], $p = .956$. There was an effect of the central theme: The N400 for LB + C [$M = -.25\mu V; 95\% CI (-.59, .10)$] was reduced relative to LB + NC, $p = .001$, most visible at Cz and Pz.

Laterality analyses (F3, C3, P3, F4, C4, P4). The main effect of condition was only marginally significant, $F(2, 58) = 3.25, p = .062, \eta_p^2 = .08$. Additional tests found no significant N400 differences between LB + NC [$M = -.32\mu V; 95\% CI (-.56, -.07)$] and Baseline [$M = -.24\mu V; 95\% CI (-.45, -.03)$], $p = .554$. However, the N400 was reduced for the central theme (LB + C [$M = -.07\mu V; 95\% CI (-.26, .13)$] relative to local binding only (LB + NC), $p = .007$.

P600 analyses. The main effect of condition was only marginally significant in the midline analyses, $F(2, 58) = 3.30, p = .053, \eta_p^2 = .10$. Additional tests found no significant P600 differences between Baseline [$M = .37\mu V; 95\% CI (.07, .67)$] and LB + NC [$M = .48\mu V; 95\% CI (.15, .81)$], $p = .561$. Although the effect of the central theme showed reliable P600 differences between LB + C [$M = .78\mu V; 95\% CI (.53, 1.04)$] and LB + NC, $p = .022$, this difference appears to sustain the voltage shift initiated in the N400 time window, rather than reflect an independent ERP component.

Sentence-final nouns

N400 analyses. Neither the local binding opportunity nor the central theme produced a reliable N400 effect: LB + NC elicited a reduced N400 relative to Baseline but this difference did not reach significance, nor did the difference between LB + C and LB + NC. These conclusions are based on the following analyses.

Midline analyses (Fz, Cz, Pz). A significant interaction of condition with cluster, $F(4, 116) = 3.39, p = .048, \eta_p^2 = .11$ indicated condition differences at parietal electrodes, Pz, $F(2, 58) = 3.15, p = .036, \eta_p^2 = .11$, but not at central electrodes, Cz, $F(2, 58) = 1.68, p = .195$ and frontal electrodes, Fz, $F(2, 58) = 3.08, p = .067$. At Pz there was no local binding effect; the N400 was reduced for LB + NC [$M = 1.43\mu V; 95\% CI (.80, 2.06)$] relative to Baseline [$M = .78\mu V; 95\% CI (.23, 1.33)$], but not reliably ($p = .087$). There was also no effect of the central theme: LB + C [$M = 1.61\mu V; 95\% CI (1.06, 2.16)$] and LB + NC showed no significant differences ($p = .564$).

A post-hoc comparison of LB + C vs Baseline at Pz indicated N400 reductions for nouns that had a local binding opportunity and were related to the central theme (LB + C), relative to Baseline, $p = .012$.

Laterality analyses (F3, C3, P3, F4, C4, P4). There were no significant main effects of condition or interactions of condition with cluster, all p 's > .096.

P600 analyses. Sentence-final nouns in the baseline condition produced more positivity in the P600 time window than the same nouns with a local binding opportunity (LB + NC), most visible in left central and parietal electrodes. The central theme (LB + C vs LB + NC) did not have an effect. These conclusions are based on the following analyses.

Midline analyses (Fz, Cz, Pz). There were no significant main effects of condition or interactions of condition with cluster, all p 's > .281.

Laterality analyses (F3, C3, P3, F4, C4, P4). A main effect of condition $F(2, 58) = 5.50, p = .009, \eta_p^2 = .15$ was qualified by an interaction of condition, cluster laterality, and cluster posteriority, $F(4, 116) = 2.95, p = .035, \eta_p^2 = .15$.

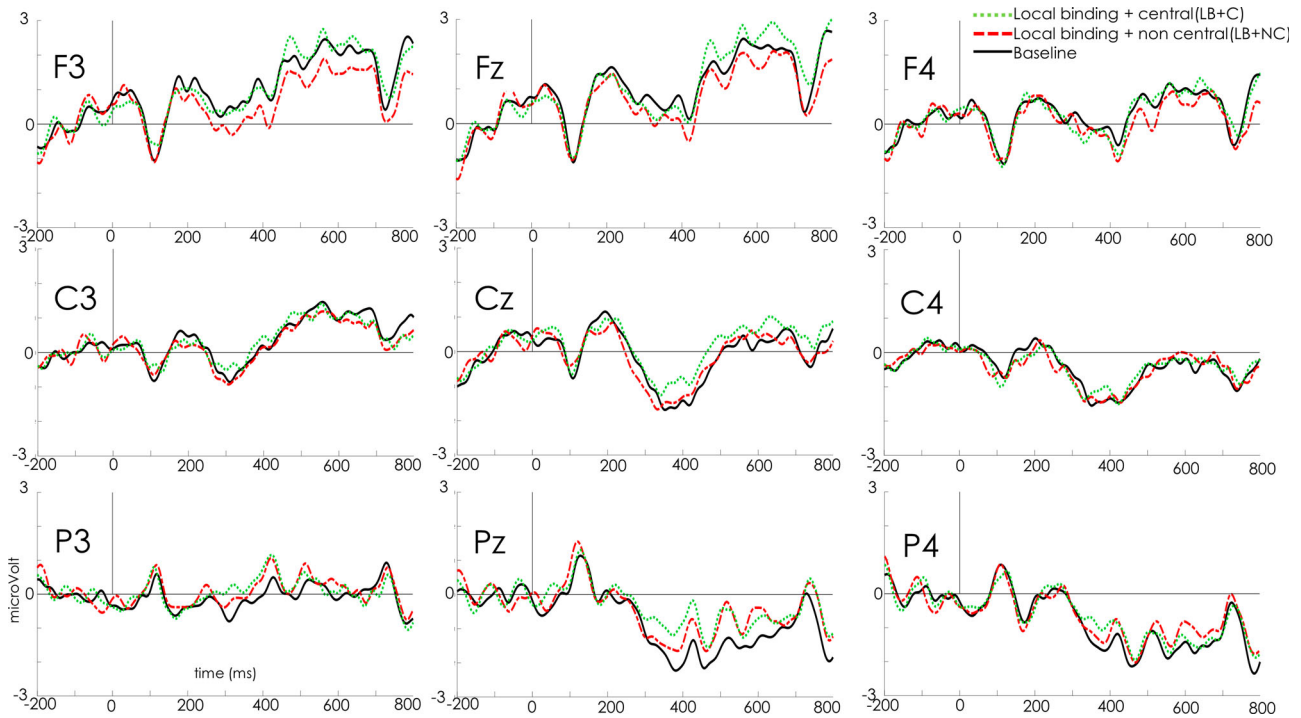


Figure 5. Grand average wave forms for critical sentence-initial nouns in local binding + central (LB + C), local binding only (LB + NC), and baseline conditions in Experiment 2. The data was re-referenced to the average of all channels. Negativity is plotted downwards. Pairwise comparisons show significant condition differences in the N400 time window at midline clusters (Fz/Cz/Pz): No local binding effect (LB + NC vs Baseline); N400 effect for the thematic centrality comparison (LB + C > LB + NC).



Figure 6. Grand average wave forms for critical sentence-final nouns in local binding + central (LB + C), local binding only (LB + NC), and baseline conditions in Experiment 2. The data is re-referenced to the average of all channels. Negativity is plotted downwards. Pairwise comparisons show significant condition differences in the N400 time window at parietal electrodes (Pz): No local binding effect (LB + NC vs Baseline); no thematic centrality effect (LB + C vs LB + NC); N400 reduction for LB + C relative to Baseline. Pairwise comparisons show significant condition differences in the P600 window at C3: P600 effect for local binding comparison (Baseline > LB + NC); no thematic centrality effect (LB + C vs LB + NC); larger P600 for Baseline relative to LB + C.

= .09. All clusters showed more positivity for Baseline than for LB + NC most visible in left central and parietal electrode clusters, but this difference reached significance only at C3 (Baseline [$M = .92\mu\text{V}$; 95% CI (.50, 1.34)] > LB + NC [$M = .45\mu\text{V}$; 95% CI (.15, .74)], $p = .022$). There was no effect of the central theme at C3: LB + C [$M = .57\mu\text{V}$; 95% CI (.16, .97)] and LB + NC showed no significant differences ($p = .547$).

A post-hoc comparison of LB + C vs Baseline at C3 indicated a more positive P600 for Baseline relative to LB + C, $p = .037$.

Discussion

As in Experiment 1, evidence for local integration was weak when the local antecedent did not refer to the central theme. The differences between LB + NC and Baseline were in the expected direction, but did not reach standard significance. In contrast to Experiment 1, antecedent nouns that were related to the central theme (LB + C) produced a reduced N400 relative to antecedents that were not (LB + NC). This centrality effect suggests that the instruction to choose which of two titles fits better with each passage encouraged participants to attend to thematic elements.

The pattern of results for sentence-final nouns was similar to that of Experiment 1. However, the local binding effect at the N400, although in the same direction as Experiment 1, was not statistically reliable ($p = .087$). Similar to Experiment 1, we found a more positive P600 for sentence-final nouns in the baseline condition than the local binding condition. Finally, sentence-final nouns with a local binding opportunity and thematic centrality (LB + C) showed the same N400 and P600 patterns as in Experiment 1: not significantly different from the local-binding-only condition (LB + NC), but significantly different from baseline.

General discussion

Helder et al. (2019) found that, at the beginning of a sentence, word-to-text integration effects reflected in the N400 were restricted to the local sentence context (the preceding sentence) with no further influence of global context as instantiated by thematic centrality. Although the conclusion that local context dominates integrative processes is consistent with theories of text processing that emphasise word-initiated bottom-up processes (e.g. Kintsch & Van Dijk, 1978), we reasoned that specific text and reader factors may influence the relative contributions of local and global influences on the processing of a single word. The two experiments reported here created conditions designed to enable the

emergence of global context effects (thematic centrality) in word-to-text integration. First, we positioned the text segment that provides a local binding opportunity across a sentence boundary farther from the critical word on which ERPs were measured. Thus, the antecedent for the sentence-initial noun was near the beginning of the preceding sentence, rather than at the end, in contrast with Helder et al. (2019). We reasoned that this should make the text segment less accessible in memory, thus allowing its reduced accessibility to be boosted by thematic centrality. The results of Experiment 1 were somewhat mixed concerning this possibility. When an antecedent text referred to the central theme and was remotely positioned near the beginning of the preceding sentence (still defined as “local”), the sentence-initial noun showed a reduced N400 relative to a baseline. However, a direct comparison of the two conditions that provided local binding – one with centrality (C) and one without (NC) – showed only a nonsignificant advantage of centrality. Thus, in Experiment 1, the thematic centrality effect is weak, observable compared to a baseline condition that had no local binding opportunity and no central theme, but not compared to a condition that had only a local binding opportunity.

In Experiment 2, reasoning that thematic centrality effects would be encouraged by a task that required more global integration, we asked readers to judge the suitability of titles for the passages, rather than make true-false judgments. Indeed, the central theme now had a clear effect on ERP measures, showing a significantly reduced N400 for the central condition relative to the noncentral condition, as well as relative to the baseline. The noncentral condition, local binding without centrality, did not differ significantly from baseline, although, as in Experiment 1, it was in the predicted direction.

Thus, across the two experiments, integrative processes were in evidence at the first noun across a sentence boundary: The N400 was reduced when the local binding opportunity was remotely positioned in the preceding sentence and was related to the central theme. The centrality effect occurred weakly (relative to noncentral) in Experiment 1 and more robustly in Experiment 2, where instructions encouraged global processing. The occurrence of a reduced N400 when the antecedent information was relatively remote further supports the interpretation that the N400 across a sentence boundary can reflect integration of the word with a text memory rather than local word-to-word associations, consistent with conclusions from previous studies of effects across a sentence boundary (Calloway & Perfetti, 2017; Stafura et al., 2015; Stafura & Perfetti, 2014). The results also provide some support for each of the possibilities hypothesised for the conditions for a global effect to emerge: (1)

a more remote binding site that reduced the recency of the antecedent text, allowing its accessibility to be boosted by centrality and (2) instructions that encouraged more global processing. The experiments cannot inform us whether both conditions are necessary for the effect. These key conclusions are intertwined with related results that we discuss below before returning to the implications of the results for integrative text processes.

Word-to-text integration at sentence beginnings and sentence endings

Sentence beginnings. The mechanisms that underlie the integration of words into text memory depend on a word's position in the sentence. Ends of sentences require the closing of structures that produces integration at multiple levels. Beginnings of sentences allow (rather than require) integration only when the word being read serves as a retrieval trigger for text memory. The first words of a new sentence prompt the building of new structures, a default obligatory operation that excludes the routine integrative processes that occur subsequently in a sentence. In Experiment 1, the presence of a binding site in the preceding sentence that was related to the central theme produced a reduction in the N400 on the critical word, the first noun across the sentence boundary, compared with a baseline condition that lacked a binding site and a central theme. In Experiment 2, when the task encouraged readers to build a representation based on the text as a whole, thematic centrality produced a reduction of the N400. Thus, sentence-initial effects of thematic centrality were observable in short texts when conditions encourage global processing.

Sentence endings. At the final word of a sentence, the reader has multiple open structures to close – the current sentence, the current clause, one or more constituent phrases, and, in the current experiments, the end of a passage. A word that meaningfully and grammatically closes these structures, as in our baseline condition, provides an integrative fit with the passage as a whole. A local binding site at the end of the preceding sentence produced an N400 reduction on the final word of the passage-ending sentence in Experiment 1. In Experiment 2, however, where participants were encouraged to attend to the central theme of the passage, the N400 was reduced only for nouns that had a local binding opportunity and were related to the central theme, relative to Baseline. These results are slightly different from those of Helder et al. (2019, Experiment 2), which showed a trend toward an N400 centrality effect at the end of sentences when centrality was reinforced by a title. However, the texts of those experiments differed from the texts of the current experiments

in not having a local binding site for the final word and also in not having a baseline reference point. If a local binding site is the dominant locus of integration, the absence of a local binding site in Helder et al. (2019) may have allowed emergence of a global influence. Thus, we suggest that, in general, end-of-sentence effects indicated in the N400 are especially sensitive to local sentence operations that include closing open structures and integrating the meaning of the final word with local text meaning, rather than global effects.

ERP studies of text processing sometimes report a late positivity or P600 component associated with the fit of a word with its contexts. This parietal P600 has been interpreted specifically as an indicator of discourse memory updating, with the N400 effect relegated to a more local, early phase of semantic associative integration (Brouwer et al., 2012; Burkhardt, 2007). In Helder et al. (2019) we found a P600 centrality effect in both experiments: Sentence-final nouns in the noncentral condition produced a larger positivity than the same words in the central condition in parietal clusters, consistent with the interpretation that greater cost to updating occurs when the word is unrelated to the central theme. However, in the present experiments, we found no such effect of centrality on the P600. This difference in results, as in the N400, may have resulted from the presence (present experiments) or absence (Helder et al., 2019) of more accessible local binding sites.

In Experiment 1, we did find a late positivity around 600ms that distinguished the local binding condition (less positive) from the baseline condition (more positive), an effect most visible in frontal and left central clusters. Because the frontal location does not correspond to the meaning congruence P600, this late positivity might reflect the frontal post-N400 positivity (fPNP) identified by Van Petten and Luka (2012). Their fPNP was observed for critical words that were congruent with preceding context but low in predictability (and that produce an N400 relative to a high-predictable word). Van Petten and Luka (2012) interpreted the effect as reflecting a cost to failed prediction at the specific word level, an interpretation supported by recent behavioural (Ness & Meltzer-Asscher, 2018) and ERP (Kuperberg et al., 2020; Ness & Meltzer-Asscher, 2018) evidence. This interpretation also might apply to our sentence-final results in the baseline condition, where the baseline sentence-final word produced a central-parietal N400 effect relative to local binding and was congruent with the context, two features of the fPNP. However, unlike the experiments cited above, in the present experiments both the sentence for the final-word comparison and the critical word itself were identical across baseline and local binding conditions; thus, in the present

studies, the effects on the sentence-final word can be localised in the preceding sentence. This would seem a challenge to an exclusively prediction-based account that targets a specific word at the end of the following sentence, and may be more consistent with memory-based integrability. We note the fact that we observe this frontal positivity also in the LH (left central electrodes) and this may distinguish it from the frontal PNP.

In Experiment 2, the sentence-final noun also produced more positivity in the P600 time window for the baseline than for local binding conditions, in left central and parietal electrode clusters but not frontal clusters. This result is consistent with the interpretation that a binding site in the preceding sentence provides updating with less cost than a sentence with no binding site. This end-of-sentence P600 effect is consistent with the results of Helder et al. (2019), who also using high-density recordings with average referencing; however, it is difficult to make comparisons of ERP components (including the N400, the P600, and the fPNP) with the many studies (e.g. most of those cited in Van Petten & Luka, 2012) that used the average of the left and right mastoid electrodes to re-reference the data.

Influence of readers' goals on processing of texts

The results of Experiment 2 suggest that a reader's goal can influence the integrative processes that link a single word to the meaning of the text. This interpretation does not derive from a single experimental design that tests the effects of the instructions readers receive. Rather, it rests on comparisons with the weak effects of centrality in Experiment 1 and in two experiments reported in Helder et al., 2019. In contrast to these weak or null effects, a centrality effect emerged clearly in the present Experiment 2, in which readers made judgments on the appropriateness of titles.

How the integration process could be affected by selecting titles is not entirely clear; however, at a coarse level of description, the effect may reflect the gradual emergence of a higher-level text structure from the successive processing of meaning-related text segments (e.g. Van Dijk & Kintsch, 1983). In these processes, implicit or explicit reading goals determine the allocation of attentional and memory resources and, hence, the eventual mental representation of the text as a whole (van den Broek & Helder, 2017; van den Broek et al., 1999). Underlying this general description is the assumption that the reader builds a foundation for understanding in the first sentence (Gernsbacher, 1991, 1997). Because, in our experiments, the central theme is introduced in the first sentence, the theme begins and remains central to the mental model that the reader builds over the short

passage. Further, a protagonist – one of the organising dimensions of situation models (Zwaan et al., 1995) – is introduced in the first sentence, providing a narrative anchor for the events described by the text. The critical word and its antecedents are associated with the protagonist, together constituting the central theme. Because each of the two title choices always involves the name of the protagonist (e.g. *Vivian the Photographer* vs. *Vivian the Food Critic*), this could allocate attention to the protagonist and lead to the enhancement of the central theme.

Integration or meaning retrieval?

We have interpreted our N400 results as reflecting an initial phase of an integrative process that links the meaning of a word to the contents of recent text memory. The difference between our integration account and a meaning retrieval account (Brouwer et al., 2012; Delogu et al., 2019) lies in the nature of the relevant memory content. Our assumption is that the linkage occurs between a word meaning and a text meaning that includes words and elementary meaning propositions. On the word-meaning retrieval account, the relevant memory content is a set of recently activated unstructured meaning features that serve as primes to facilitate the retrieval of word meaning. Delogu et al. (2019) provide a demonstration of this idea: The N400 on a critical word was unaffected when the sentence in which it occurred was inconsistent with the previous sentence, thus making integration in the usual sense impossible. For example, the N400 on “menu” in the sentence “Before long he opened the menu” was the same whether the preceding sentence conveyed someone entering a restaurant or leaving it; and the N400 was more positive than when the word “restaurant” was absent in the preceding sentence. The implication is that word meaning priming (restaurant-menu), not sentence meaning, produces N400 effects.

We cannot entirely rule out a word-meaning retrieval account for our results, but there is no reason to prefer such an account here. First, unlike in Delogu et al. (2019), where the associated word was at the end of the preceding sentence, the experiments reported here had an average of 9 words and a sentence boundary between an antecedent binding site and the critical word. Further, our previous results have demonstrated that the association strength between a word in the preceding sentence and the key word across a sentence boundary did not affect the magnitude of the N400 (Stafura & Perfetti, 2014) and that when the backward association (from critical word back to preceding sentence word) was stronger than the forward association, N400s were also observed (with a different time course

and topography), implicating a memory process. We also note that the present experiments do not exploit violations, but present consistently meaningful texts. Thus, they allow an incremental perspective that attributes effects to manipulated features within the range of coherent texts, avoiding the risk of overlapping meaning-enhancing and meaning-contradicting influences on ERP data. Finally, our experiments have an atypical focus on the first content word across a sentence boundary, in contrast to the more typical within-sentence and end of sentence locations. As we have argued, sentence beginnings present low word predictability and obligations for structure building. Brouwer et al. (2012) showed that the word-meaning retrieval account provides a parsimonious account of a large number of N400 results. Whether it can account for results in the paradigms used here can be addressed in research specifically designed to do so.

Conclusion: global effects on the processing of a single word

Every word, as it is read, provides an opportunity for structure building and integration. Although structure building is obligatory at the beginning of a sentence, integration can also occur when reading the word prompts retrieval of an associated text meaning. This integration is dependent on the accessibility of sources (binding sites) in text memory. Within-sentence sites are highly accessible through the syntactic and corresponding semantic structures that are being built. Thus, integration is routine across multiple levels of text representation. For words at the beginning of a sentence, the absence of already-opened syntactic structures means that accessibility to binding sites is restricted to memory retrieval cues provided by the word itself. The present experiments suggest that these retrieval cues are strengthened when the word being read is related to an antecedent in the preceding sentences that is also related to the central theme. Thematic contributions to integration may be strengthened when instructions encourage the reader's goal to be directed to the global structure of the text.

To place these observations in the context of research not focused on sentence beginnings, considerable evidence demonstrates global text level effects during reading of a single word. One way to produce global text level effects is to create a fictitious scenario for the reader. For example, when Nieuwland and Van Berkum (2006) presented readers with texts that gave human qualities to inanimate objects (peanuts falling in love), readers showed an N400, indicative of meaning incongruence, upon reading a sentence that conveyed

meaningful real-world attributes (e.g. peanuts are salted). Another way to expose the use of global context is to bias readers away from the dominant meaning of an ambiguous word. An eye-tracking study by Kambe et al. (2001) provides some parallels to the present experiments. Their study presented readers with short paragraphs and manipulated the availability of global and local context to establish a bias toward the meaning of an ambiguous word. Kambe et al. (2001) observed that both local and global context (alone or in combination) were effective in biasing readers towards the subordinate meaning of the ambiguous target word (e.g. "band" presented in the subordinate meaning context of an engraved wedding ring and in the dominant meaning context of a rock concert). Moreover, Kambe et al. (2001) found no additional effect of global context when local context was available and consistent with the global context. Thus, despite the differences between methods (eye-tracking vs. ERP) and critical word properties (ambiguous words vs unambiguous words), we see converging conclusions on the dominant role of local context, when it is available, on processing the meaning of a single word. Our experiments add to the conclusion that there are conditions, including explicit influence on reading goals, that can cause the emergence of global effects beyond those attributable to local context.

Notes

1. The text segment that provided the binding opportunity for critical nouns was more variable than in Helder et al. (2019): for about half of the passages, the binding opportunity was word-specific co-reference, as in Example 1 of Table 2; for the other passages, the binding opportunity was a semantically related word or phrase, as in Example 2 of Table 2.
2. Average channel re-reference method allows comparisons of the present results to previous studies using the cross-boundary word-to-text integration paradigm, including the study of centrality effects (Helder et al., 2019). This average re-referencing procedure is common with the high density arrays used in the present study, but less common overall than using the mastoid electrodes.

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