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The interplay of discourse congruence and lexical association during sentence processing: Evidence from ERPs and eye tracking

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Abstract

Five experiments used ERPs and eye tracking to determine the interplay of word-level and discourse-level information during sentence processing. Subjects read sentences that were locally congruent but whose congruence with discourse context was manipulated. Furthermore, critical words in the local sentence were preceded by a prime word that was associated or not. Violations of discourse congruence had early and lingering effects on ERP and eye-tracking measures. This indicates that discourse representations have a rapid effect on lexical semantic processing even in locally congruous texts. In contrast, effects of association were more malleable: Very early effects of associative priming were only robust when the discourse context was absent or not cohesive. Together these results suggest that the global discourse model quickly influences lexical processing in sentences, and that spreading activation from associative priming does not contribute to natural reading in discourse contexts.

Keywords

Discourse; Lexical; Association; Eye movements; Event-related potentials

Introduction

Language comprehension involves rapidly extracting a coherent message from spoken or written input. In listening or reading, we must retrieve word meanings from memory, but since words seldom appear in isolation, lexical processing alone is not enough. Word meaning is woven into a context to form a cohesive message. This context, in turn, can have effects on lexical processing. It is well established that the retrieval of word meaning can be facilitated by a single-word related context during the processing of word lists. However, it is not clear if and when effects of intralexical priming interact with higher-level, discourse representations in real-time language comprehension. The studies presented here were designed to address three important issues in the field of psycholinguistics: (1) the effects of global discourse congruity on semantic processing in a coherent local sentence context, (2) the extent to which lexical association can enhance comprehension when word pairs are embedded in meaningful passages, and (3) the degree to which these different levels of context interact during real-time

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comprehension. ERPs and eye tracking are ideal tools to address these issues as neither depends on an extraneous task, allowing participants to simply read for comprehension. Moreover, these methods provide excellent temporal resolution with which to track discourse-level and word-level context effects.

Message-level processing

Several behavioral studies have examined the effect of global message coherence on local sentential processing. On the basis of a series of probe-word identification studies, McKoon and Ratcliff (1992) have proposed the minimalist hypothesis, which claims that readers only try to establish global coherence when there is a break at the local level. In contrast, O'Brien and Albrecht (Albrecht & O'Brien, 1993; O'Brien & Albrecht, 1992) have used reading time studies to show that global inconsistencies can affect processing time even when local coherence is maintained. In a later reading time study, Long and Chong (2001) found individual differences in the maintenance of local and global coherence. Their findings suggest that only good comprehenders (as assessed by the Nelson–Denny Reading Comprehension Test) are affected by incongruities at a global level, whereas both poor and good comprehenders show disrupted processing for local inconsistencies.

This distinction between local, sentential context and global, discourse context has also been addressed by a handful of electrophysiological studies. With event-related potentials, or ERPs, effects of semantic context have been primarily observed on one specific component that has been labeled the N400. The N400 is a negative-going wave, maximal around 400 ms and over centro-posterior electrode sites. The amplitude of the N400 is reduced to words that can be easily integrated into the preceding context (Brown & Hagoort, 1993; Swaab, Camblin, & Gordon, 2004) and it is also influenced by the structure of the mental lexicon (Kutas & Federmeier, 2000). While most ERP studies of semantic congruency have focused on processing of local context in single sentences, the few ERP studies that have used longer and/or more complex stimuli have found effects of semantic incongruity that are comparable to those found with sentences. At the sentence and discourse level, a reduced N400 has been found to words that are semantically congruent relative to words that are semantically incongruent (Federmeier & Kutas, 1999; Kutas & Hillyard, 1980; Kutas, Van Petten, & Besson, 1988; Neville, Nicol, Barss, Forster, & Garrett, 1991; Rösler, Putz, Friederici, & Hahne, 1993; van Berkum, Hagoort, & Brown, 1999).

van Berkum et al. (1999) compared integration difficulty for critical words that were incongruous at the sentence or discourse level. In one experiment, the critical words were always congruous in the local sentential context, but were either plausible or implausible in the wider discourse. When these sentences were presented in isolation, the critical words elicited comparable N400 amplitudes. However, when the sentences were presented in the wider discourse, the amplitude of the N400 to the critical words depended on their plausibility within the discourse context: The N400 to the plausible critical words was reduced relative to the N400 to implausible words. Importantly, the onset latency of this N400 effect was the same as the onset of N400 effects that were found to sentential incongruencies in a second experiment. This finding is consistent with behavioral findings of O'Brien and Albrecht (1992, 1993), and supports the idea that discourse level information can immediately influence lexical integration at the local sentence level. Furthermore, in a recent study Nieuwland and van Berkum (2005) observed that animacy violations failed to produce a classic N400 effect in local sentence contexts when these incongruities were embedded in multi-sentence paragraphs. This finding suggests that integration of critical words in local contexts may be *hampered* in cases where anomalies appear in larger texts. The studies by van Berkum and colleagues have identified a strong and immediate role of discourse on the processing of words

in local sentence contexts, but thus far no other studies have been done that have replicated these findings.

Effects of sentential context have also been studied with eye-tracking measures (Braze, Shankweiler, Ni, & Palumbo, 2002; Ni, Fodor, Crain, & Shankweieler, 1998; Rayner, Warren, Juhasz, & Liversedge, 2004; Traxler, Foss, Seely, Kaup, & Morris, 2000). With this method studies have generally looked at first pass reading times such as first fixation (the duration of the first fixation on a word), gaze duration (the time spent on a word before moving off that word to the left or right), and regression-path duration (the total time from the first encounter with a word until the reader moves to subsequent text), which are thought to reflect lexical access and integration processes. Implausible continuations at the *sentence* level have produced increased first-pass reading times in both the target (Braze et al., 2002) and post-target regions (Rayner et al., 2004); and in the case of selection restriction violations effects were found in the pre-target region, presumably as a result of processing during para-foveal preview (Rayner et al., 2004). At the *discourse* level, using paragraphs of text, Grabe, Antes, Thorson, and Kahn (1987) showed that readers made more regressive eye movements when encountering inter-sentence contradictions. However, analyses in this study were only performed on the frequencies of eye-movement patterns produced and not on the typical fixation duration measures, which makes it difficult to compare with the eyetracking studies of sentence incongruities. In addition, incongruous text in this latter study spanned multiple words instead of being localized to a single word. Thus while eye-movement studies have been performed to examine several aspects of discourse comprehension, including the introduction of subtopics into a discourse (Hyönä, 1995), coreferential processing (Gordon, Camblin, & Swaab, 2004) and the effects of discourse context on world knowledge (Cook & Myers, 2004; Duffy & Keir, 2004), the effects of single-word, discourse incongruities have not yet been studied in locally congruent texts. Therefore, it is unclear whether such violations of discourse representations would also produce effects on first-pass reading durations, as has previously been observed for sentential incongruities.

In addition to effects of congruity, the influence of the predictability (cloze probability) of words in context has been studied using both ERP and eye-tracking measures. The results of these studies show that the effects of cloze probability appear to be constrained mostly to highly expected words. For example, a recent study by van Berkum, Zwitserlood, Hagoort, and Brown (2003) showed that the expectancy of words given the discourse context did *not* influence the size or onset latency of the N400 effect when the cloze probabilities of the critical words were relatively low (1% and 30%). This is in contrast to Federmeier and Kutas (1999) who found that for high cloze stories (average cloze 74%) the N400 amplitude was more dependent upon a word's relatedness to the expected word than to the congruency of the word itself. In eye-tracking studies similar patterns of results have been obtained, with the largest expectancy effects for very high cloze words (Ehrlich & Rayner, 1981; Rayner & Well, 1996), and some evidence that predictability does not have an effect on the processing of stimuli of moderate cloze (Hyönä, 1993). These results indicate that effects of congruency may be qualitatively different for high and medium/low cloze stimuli. Thus to obtain a more pure analysis of the effects of congruence, *per se*, it is important to use stimuli of only moderate cloze.

Effects of association

Single words that are preceded by a related prime word are processed faster and more accurately than targets preceded by an unrelated prime word (Meyer & Schaveneveldt, 1971; for a review see Neely, 1991). This has been shown in both behavioral studies (e.g., faster naming and lexical decisions) and ERP studies (Bentin, McCarthy, & Wood, 1985; Holcomb, 1988; Holcomb & Neville, 1990; Kutas & Hillyard, 1989; Swaab, Baynes, & Knight, 2002). ERP studies have found effects of associative priming on the N400 (reduced amplitude) and on the

late positive complex (LPC). The LPC follows the N400, peaking around 600–800 ms after the onset of an eliciting word, and like the N400 it is maximal over central posterior electrodes. Though primarily linked to repetition priming (Paller, Kutas, & McIsaac, 1995; Paller & Gross, 1998; Rugg et al., 1998; Van Petten & Senkfor, 1996; Wilding, Doyle, & Rugg, 1995), modulations of LPC amplitude and/or latency have also been found with semantic priming manipulations (Anderson & Holcomb, 1995; Hill, Strube, Roesch-Ely, & Weisbrod, 2002).

Effects of associative priming have also been observed in meaningful sentences. For example, Van Petten and colleagues (Van Petten, 1993; Van Petten, Weckerly, McIsaac, & Kutas, 1997) found a reduced N400 for associated words embedded in sentences. In addition, an enhanced LPC has been reported for associated words in certain sentential contexts (Hoeks, Stowe, & Doedens, 2004; Van Petten et al., 1999).

With eye tracking, Sereno and Rayner (1992) first demonstrated that automatic semantic priming could be obtained using a fast priming paradigm. In their study, the related or unrelated prime was briefly flashed at the target location as the reader crossed a word boundary. Presentation of a related prime elicited shorter gaze durations on the target. However, without this fast priming technique facilitative effects of association on eye movements appear to be more tenuous. For example, Morris and Folk (1998) found decreases in gaze duration only for schematically related words embedded in congruous sentences when the prime word of the pair was in linguistic focus. Similarly, a study by Carroll and Slowiaczek (1986) indicated that associative priming effects in meaningful sentences were limited to targets that appeared in the same clause as their prime. This suggests that intralexical priming during natural reading may be constrained by structural aspects of the sentence.

Crossing contexts

While the studies described above have demonstrated effects of global message-level context and intralexical relationships, of particular relevance to the studies presented here are experiments wherein lexical context and message-level context were orthogonally manipulated. This was done in an ERP study by Van Petten et al. (1999), in which they varied the congruency of the critical word within an otherwise coherent sentence context. Associated and unassociated word pairs (e.g., *life–death* and *life–prison*, respectively) were embedded in sentences wherein the target was either congruous (e.g., “When someone has a heart attack a few minutes can make the difference between *life* and *death*” and “The gory details of what he had done convinced everyone that he deserved *life* in *prison*”) or incongruous (e.g., “When someone has a heart attack a few minutes can make the difference between *life* and *prison*” and “The gory details of what he had done convinced everyone that he deserved *life* in *death*”). These associated word pairs had already shown N400 priming effects in a word list experiment used to pretest the stimuli. Cloze probability was matched for associated-congruent and unassociated-congruent sentences to better isolate the effect of association, and for both of these conditions cloze probability was very high (~71%). Van Petten et al. (1999) found an N400 effect of congruency for both associatively primed and unprimed terminal words. However, they did not find an N400 priming effect of association in either the congruous or incongruous sentences. Association did affect the LPC component such that a larger positive shift was obtained to associated terminal words in incongruous sentences. The authors suggest that this effect reflects the realization of conflict between sentential and associative context.

In a follow-up study, Coulson, Federmeier, Van Petten, and Kutas (2005) examined hemispheric differences in processing association and sentence congruence by presenting the sentence-final words of the four conditions described above laterally in a visual half-field paradigm. Presentation to both hemispheres showed a robust congruity effect, as was found in the central presentation study (Van Petten et al. 1999). Effects of association were relatively

small, and association only produced a canonical N400 effect for incongruent words presented in the left visual field.

Overall, these results indicate that associative context effects can be greatly attenuated or overridden by sentential-level meaning. However, it is unclear whether effects of association would play a larger role if expectancy were reduced. As discussed above, for such highly constraining sentences the effects of predictability may be mediating effects of pure congruency. It is possible that in less constraining passages the effects of association would re-emerge.

Possible evidence for this idea has been found in a study by Hoeks et al. (2004), in which message-level constraint and schematic relatedness were varied. They found comparable N400 amplitudes for schematically associated words that were highly expected (e.g., The javelin was by the athletes *thrown*) and schematically associated words that were anomalous in the context (e.g., The javelin has the athletes *thrown*). The message-level manipulation of constraint only had an effect when the final word did not benefit from schematic relatedness. As in the study by Van Petten et al. (1999) a larger positivity followed the N400 for the incongruent words that were intralexically primed. From these findings Hoeks and colleagues (2004) argue that both message-level constraint and intralexical, schematic relationships affect lexical processing in sentences. They suggest that the message-level representations that influence early stages of lexical processing may be underspecified and rely on schemas evoked by intralexical relationships. This study does suggest that in cases where expectation is not as high, association may have a stronger effect, particularly on the processing of incongruent words.

The interplay of message-level and word-level context has also been examined with eye tracking. Morris (1994) found that reading time measures were reduced for words that were preceded by a weakly related noun and verb. However, these priming effects were not found when the meaning of the sentence was changed even though the lexical context remained the same. For example, the word mustache was facilitated in the sentence – *The gardener talked as the barber trimmed the mustache*, but not the sentence – *The gardener talked to the barber and trimmed the mustache*. Furthermore, facilitation was not found when only one schematically related word was present.

More recently, Traxler et al. (2000) orthogonally varied schematic relatedness and sentence congruence. They, too, failed to find effects of word relatedness for schematically related word pairs (e.g., lumberjack–axe), nor was there an interaction between word relatedness and plausibility for first-pass reading. They also did not obtain effects of priming with synonym pairs (e.g., pastor–minister). In contrast, word plausibility had an effect on total reading time or first fixation measures. Taken together, these eye-tracking studies show higher-level context effects of congruity or plausibility, but no intralexical priming for schematically related or synonym pairs.

The present study

The experiments presented here used ERPs and eye tracking to investigate the extent to which discourse level representations affected intralexical priming, and allowed for a comparison of the time course of discourse and lexical effects during on-line sentence processing. Associated and unassociated words pairs were embedded in congruous, coherent sentences. The target word was made congruent or incongruent at the discourse level by preceding information in the passage, while the manipulation of association occurred locally (within 1–3 words of the target). (For examples: see Table 1)

In Experiments 1 and 2 the processing of sentence-final words in a coherent passage context was examined using ERPs and eye tracking, respectively. These sentence-final words varied in discourse congruence and association, as described above. Experiment 3 used eye tracking to examine these same factors for mid-sentence targets. These sentences were taken out of their passage context in Experiment 4 to examine the effects of association on eye movements using mid-sentence targets in isolated sentential contexts. Finally, in Experiment 5 association and overall passage coherence was varied to further assess the importance of a discourse model on the effects of association.

Possible effects of global discourse congruity

The minimalist hypothesis (McKoon & Ratcliff, 1992) was formulated with regard to global processing that occurs across several paragraphs. But an extension of this theory might predict that discourse incongruities of the type used here will not affect on-line processing of words in the local sentence context either, because local coherence is maintained. While the available ERP evidence indicates that discourse contexts affect lexical processing when words are presented rapidly, one word at a time (RSVP), analogous eye-tracking studies have not been performed to identify whether these effects occur under natural reading conditions with arguably faster processing rates. Therefore, the possibility remains that no immediate effects of discourse congruence on critical words in local sentences will be found under natural reading conditions.

In contrast, discourse congruency effects may interact with association such that effects of congruency are only found for unassociated words. Nieuwland and van Berkum (2005), for example, did not find an immediate effect of incongruency using passage texts when the incongruent word was semantically related to the expected continuation. We will further assess the influence of semantic relatedness on congruity in the present study, where the critical words are actually preceded by a related or unrelated word in the local sentence context. Discourse effects may only be obtained when the local sentence context does not contain any associations. This would indicate that in cases where sentential and local word context support lexical processing, global coherence is not checked.

Finally, the effects of discourse congruence in reading may be present for both associated and unassociated words. Finding effects of discourse congruence for these single-word incongruities with eye tracking would also show that these effects are not limited to the slower processing speed of RSVP. Such effects would indicate that words are rapidly integrated into discourse-level representations during text comprehension.

Possible effects of lexical association

As was discussed before, both ERP and eye-tracking studies have shown that the effects of association may be extinguished for words appearing in rich discourse texts. While effects of association have been found in several ERP studies, it is important to note that most, if not all, of these studies have used single sentences or relatively weak global contexts. When rich and constraining sentences were used in Van Petten et al. (1999), effects of association were absent. In a similar study where lexical relatedness and discourse congruence were varied, Traxler et al. (2000) also failed to find effects of schematic and synonym relatedness on first-pass reading measures.

However, some studies indicate that the effects of association may emerge in meaningful texts under certain conditions: Some studies only find effects of association on congruous words, (Morris, 1994), whereas others have only found effects of association for incongruous words (e.g., Coulson et al., 2005; Hoeks et al., 2004). Furthermore, Morris and Folk (1998) found schematic priming, as evidenced by shorter gaze durations, only when the prime word of the

related pair was in focus in the sentence. Perhaps the relationship between the associated words may draw more focus, and perhaps by extension more facilitation, when that association is not supported by the global text.

Finally, effects of association may have an effect for both globally congruent and incongruent words. As was discussed before, the absence of effects of lexical association in the study by Van Petten and colleagues (1999) may have been due to the use of highly constraining sentences, where expectancy could have exerted an influence beyond that of basic congruence. In the present study, we made sure that the expectancy of the critical words was not as high, and that the manipulation of association was always within a clause, since Carroll and Slowiaczek (1986) have shown that effects of association in meaningful texts can be found when the associates are embedded in the same clause. Finding effects of association in these discourse contexts would be consistent with theories that association priming is an automatic and immutable part of lexical processing, occurring both in semantically impoverished word lists as well as meaningful discourse.

Experiment 1

This ERP study examined the effects of discourse congruence and lexical association on the processing of critical words in the final sentences of three-sentence stories as shown in Table 1. Unlike previous ERP studies that have examined association and message-level effects (Coulson et al., 2005;Hoeks et al., 2004;Van Petten et al. 1999), we kept local, sentential congruence constant and varied global congruence in moderate cloze stories. The use of moderate cloze stories should reduce the role of expectancy, possibly allowing more robust effects of associative priming to be observed if such effects have been partially obscured in previous studies by expectancy (or variation in local context). Conversely, the use of a rich discourse context in this experiment could result in stronger message-level facilitation and eliminate associative priming altogether.

We examined three ERP components, the previously discussed N400 and LPC, but we also looked at an ERP effect in an earlier time window, the P2, since Coulson et al. (2005) have shown that association can have an effect in this earlier time window as well.

Methods

Stimulus construction—Two levels of association and discourse congruity were crossed in a factorial design (see sample stimuli in Table 1). For the association factor, a total of 72 associated prime-target word pairs were selected, 66 from the Edinburgh Associative Thesaurus (Kiss, Armstrong, Milroy, & Piper, 1973) and 6 from an association pretest with 20 participants. The task in this pre-test was to write down the first word that came to mind after reading the prime word. All related pairs had an association strength of at least 20% (average score of 39.8%, range 20–90%). These association scores represent the percentage of respondents who provided the target word when presented with the prime. Unassociated word pairs were created by using control words that were not associated or were only very mildly associated with the prime (average association score of 0.2%, range 0–4%). The associated and unassociated words were matched for overall word length (associated: $M = 5.26$, SD = 1.4; unassociated: $M = 5.19$, SD = 1.4; $t < 1$) and written word frequency according to Francis and Kucera (1982) (associated: $M = 83.71$ per million, SD = 136; unassociated: $M = 83.86$ per million, SD = 182; $t < 1$). The critical words were always at the end of the third (target) sentence, with 1–3 words intervening between prime and target ($M = 1.6$ words).

As shown in Table 1, discourse congruity was manipulated by varying the first two sentences of a three-sentence passage in such a way that the critical word (associated target or matched control) was either congruent or incongruent with the discourse meaning created up to that

point. Note that the third sentence (which contained the critical word and the preceding prime) was always locally coherent. The mean number of words in the congruous and incongruous stories was matched (congruent = 24.6, incongruent = 24.6) and the average length of the critical sentence was 10.3 words. Although they were never presented, congruous completions were also written for the incongruous stories to ensure that such a completion was possible.

Stimulus evaluation

Congruency: Thirty-two participants took part in a congruency rating pretest. These participants were paid $10 per hour or given course credit as compensation. None of these subjects participated in any other part of the experiment. The stimuli were divided into four lists so that each participant saw only one story from any given set. Stimuli were rated on a scale of 1–5, with 1 indicating that the word fit perfectly with the story context and 5 indicating that the word made no sense in the context of the story. The 71 story sets that passed both congruency and cloze probability tests all had average scores above 3 for each incongruent condition and average scores below 3 for each of the congruent conditions. Congruency ratings by condition are shown in Table 2. These ratings showed that: (1) congruence was successfully manipulated for both associated and unassociated endings (Associated: $F_1(1, 31) = 1158.02$, $p < .001$; $F_2(1, 70) = 1327.00$, $p < .001$; min $F'(1, 81) = 618.37$, $p < .001$; Unassociated: $F_1(1, 31) = 962.17$, $p < .001$; $F_2(1, 70) = 1500.86$, $p < .001$; min $F'(1, 71) = 586.30$, $p < .001$) and (2) association did not influence congruence for either the congruent or incongruent stories (Congruent: $F_1(1, 31) = 1.81$, $p = .189$; $F_2 < 1$; min $F' < 1$; Incongruent: Fs < 1).

Cloze probability: Forty participants took part in a cloze test. These participants were compensated with course credit and did not take part in any of the other studies presented. Two lists were created such that none of the participants saw both the congruent and the incongruent version of the same stimulus set and they saw an equal number of stimuli from the two conditions. All story stimuli were truncated just before the critical word, which was replaced with a blank line. Participants were asked to write down the first word that came to mind to complete the passage. The cloze test was performed after the experimental data were collected and the results prompted us to drop one of the stimulus sets from the analyses because the unassociated ending was produced multiple times in the incongruent condition. Table 3 shows the results from the cloze test.

The results show that for congruent stories the associated words were of significantly higher cloze than the unassociated words ($t(70) = 6.91$, $p < .001$). Surprisingly, the associated words were sometimes provided in the incongruent condition, even though these words were rated as incongruent in the congruency pretest. So, when subjects were given the associated word they judged it as incongruous, but when asked to supply an end to the passage other participants sometimes provided this incongruous word. This effect was driven by a small subset of the subjects tested.[1] It is possible that the increased effort required in the cloze task (relative to the congruency ratings) made some participants more likely to skip or skim the first two sentences of the passage and focus solely on the final sentence for which they needed to provide a response. For participants who engaged in this strategy the task and instructions for the cloze test were very similar to those in the association pre-tests, which may explain the presence of these incongruent, associated words in the cloze test results. This could also be the result of the only moderately constraining quality of the passages used. While avoiding highly constraining passages allowed for the examination of congruence without pre-activating lexical items, it may have caused participants to rely more heavily on association when explicitly forced to supply a passage-final word. Thus, when the context did not cause strong expectations

[1]Fifteen percent of the subjects provided 67% of the associated responses in the incongruent condition, and 28% were responsible for 86% of these responses.

for a particular word, the participants may be more affected by local, lexical relationships, at least under conditions where prediction was mandatory.

Because of the differences in predictability of congruent and incongruent words, additional post-hoc analyses were performed on cloze-matched stimuli when significant effects of discourse congruence were found for sentence-final words. These analyses ensure that variations in expectancy were not the source of congruity effects in this study.

Participants—Twenty-four right-handed, native English speakers participated in two ERP sessions. The ERP sessions were separated by a minimum of three weeks (average lag 8.1 weeks, range 3–18 weeks). Participants were paid for their participation at a rate of $10 per hour. None reported any neurological or psychiatric disease, and all had normal or corrected to normal vision. An additional five participants were not asked to return for the second session because of experimenter/equipment error (2) or excessive EEG artifacts (3) during the first session. Two other participants chose not to return for the second session, and could therefore not be included. Only the data from those participants who took part in both ERP sessions were used in the analysis.

Materials—Seventy-two story sets were divided into four lists with each story set only presented once within each list. Each list contained 18 stories per condition. The lists also contained 40 filler stories. Twenty of these stories were congruous and 20 ended with a word that was anomalous at both the discourse and sentence level. Lists 1 and 2 and lists 3 and 4 were matched such that a story that appeared in an incongruent form on one list (e.g., list 1) would appear in a congruent form on the matched list (e.g., list 2), and stories that appeared with an associated ending in one list would appear with an unassociated ending on the matched list. Participants either saw lists 1 and 2 across the two sessions or lists 3 and 4, with presentation order counter-balanced. In addition, proper names in the experimental stimuli were changed across sessions. These steps were taken so that story similarity was minimized across sessions. Filler sentences were also not repeated across sessions to reduce feelings of familiarity. The story set that produced unexpected responses in the cloze test was not included in the analysis.

Procedure—During the experiment, participants were seated in a sound-attenuating, electrically shielded recording booth. Stimuli were presented on a computer screen approximately 100 cm in front of the participant, with words appearing in white Tahoma 16-point font on a black background. The first two sentences of the passage appeared on the screen in their entirety. Participants were instructed to press a button on a hand-held button box after they had completed reading these two sentences. Upon pressing the button, a fixation cross appeared for 1 s. Following the fixation cross, the critical sentence was presented one word at a time, with a presentation duration of 250 ms per word and a 150 ms interstimulus interval. All words were presented at the center of the screen. Both the fixation cross and the words in the target sentence were presented between two horizontal bars, to help subjects remain fixated. The final word of the passage was presented with a period.

After the critical sentence appeared, the two horizontal bars remained on the screen for one second. Participants were asked to keep their eyes still and refrain from blinking during the presentation of the sentence and the brief period following the sentence. The blank screen was then replaced with one of two phrases: (1) “press for next” instructing the participant to press the button for the next trial, or (2) “please summarize” in which case the subject was asked to paraphrase the story in a pamphlet before pressing the button to start the next trial. This task was used to ensure that the subjects had read the stories for comprehension.

ERP recording and data analysis—During stimulus presentation the electroencephalogram (EEG) was recorded via an Electro-Cap with 29 embedded electrodes.

Electrodes were also placed on the outer canthi and below the left eye to monitor horizontal eye movements and blinks. The EEG was referenced to the right mastoid, and off-line the EEG was re-referenced to the algebraic average of both mastoids. Electrode impedances were kept below 5 kΩ. The EEG was amplified by NeuroScan amplifiers, sampled at 250 Hz, and filtered with a bandpass of 0.01–30 Hz.

ERPs were averaged for each individual participant over a 1200 ms epoch for the critical words in all conditions. This epoch began 200 ms before the onset of the critical word. Trials were screened for eye movements and electrode drift, and contaminated trials were not included in statistical analysis (average 12% per subject, range across subjects 3–22%, with no asymmetry across conditions). Repeated measures analyses of variance (ANOVAs) were performed on the mean amplitude of the ERPs during three latency ranges of 150–250 ms, 300–500 ms, and 500–900 ms, to capture the P2, N400, and LPC, respectively. One ANOVA was conducted for midlines sites only (midline analysis) and one was done comparing electrode sites over left and right hemispheres at different levels of anteriority (scalp topography analysis).

The midline analysis included the factors of association, congruence, and electrode site (AFz, Fz, Cz, Pz, and POz). The scalp topography analysis also included the factors of hemisphere (left or right) and anteriority (three levels: anterior, central, and posterior, going from the front to the back of the head), which created six regions: left-frontal (F3, FC1, FC5), right-frontal (F4, FC2, FC6), left-central (C3, CP1, CP5) right-central (C4, CP2, CP6) left-posterior (P3, T5, O1) and right-posterior (P4, T6, O2). Follow-up ANOVAs were performed when interactions were found, specifically on a predetermined region over central and posterior electrodes, where the N400 is maximal (Cz, CP1, CP2, Pz, P3, and P4). The Greenhouse/Geisser correction was applied to *F* tests with more than one degree of freedom in the numerator. Due to the large number of trials needed for averaging in ERPs, statistics are only reported for a by subjects analysis, and an analysis by items is not included.

Results

Difference wave ERPs over selected frontal, central and posterior electrode sites are shown in Figs. 1 and 2. Results from ANOVAs that included factors of both association and discourse congruence are presented in Table 4.

P2 (150–250 ms)

Main effects of discourse congruence: No significant effects were found in the midline analysis. In the scalp topography analysis a significant interaction between congruence and hemisphere was found. This interaction resulted from a greater positivity for congruent words over the leads on the right side of the head. Follow-up analyses were performed on frontal electrodes (FP1, FP2, AFz, F3, F4, and Fz) where the P2 is largest. In this region there was no effect of congruence ($F < 1$), nor was there an interaction between congruence and electrode ($F(5, 115) = 2.23$, $p = .117$). In contrast, the effect of congruence in the P2 time-window was significant over the centro-posterior region where the N400 is maximal ($F(1, 23) = 5.17$, $p = .033$). This suggests that the discourse congruence effect found in this time epoch is not a P2 effect but an early onset of the N400 effect.

Post-hoc cloze-matched analyses of discourse congruence: To identify if the ERP effects of congruence in this time window were not driven by the higher cloze probability in the associative congruent condition, an ANOVA was performed on a subset of the stimuli in the unassociated conditions. For these stimuli, the cloze probability of the critical words was zero in both the congruent and incongruent conditions (39 of the 71 stories). This did not yield significant effects ($F < 1$). This may have been due to the very small effect size and the reduced number of items that went into this ANOVA. However, an indication that the effect of

congruence was not driven by cloze probability was that the size of the discourse congruence effect found with the whole data set (0.49 μV) was similar to that found when only unassociated, cloze-matched items were analyzed (0.45 μV).

Main effects of association: There was no main effect of association or interaction between association and any other factors in the midline analysis or in the scalp topography analysis.

Interactions between association and discourse congruence: There were no significant interactions between association and congruence for the midline and scalp topography analyses.

N400 (300–500 ms)

Main effects of discourse congruence: The overall effect of discourse congruence was significant in both the mid-line- and scalp-topography analyses. There were also significant interactions with electrode in the midline analysis and significant two-way interactions with hemisphere and anteriority in the scalp topography analysis. The interactions with hemisphere and anteriority indicated a larger effect over central-posterior electrodes with a slightly right biased distribution. An analysis of the predetermined N400 region showed a significant reduction in N400 amplitude for congruous words ($F(1, 23) = 39.67$, $p < .001$). There was no interaction with electrode in this region ($F(5, 115) = 1.56$, $p = .209$).

Post-hoc cloze-matched analyses of discourse congruence: In an analysis restricted to the N400 region these cloze-matched, unassociated words also produced an effect of congruence ($F(1, 23) = 6.98$, $p = .015$), indicating that indeed congruence and not cloze probability alone resulted in the N400 effect obtained here.

Main effects of association: There was a main effect of association in both the midline and scalp topography analyses, indicating a reduced negativity for associated words. There was a significant interaction with electrode in the midline analysis. In the scalp topography analysis there was a significant interaction between association and anteriority, but no other interaction reached significance. These interactions indicated that the effects of association were larger over central electrodes. The analysis of the predetermined N400 region showed a significant priming effect of association ($F(1, 23) = 22.76$, $p < .001$) and an interaction between association and electrode ($F(5, 115) = 3.49$, $p = .021$), again indicating the central distribution of the effect.

Interactions between association and discourse congruence: As in the P2 time window, no interactions were found for the effects of association and discourse congruence in either the midline or scalp topography analyses.

LPC (500–900 ms)

Main effects of discourse congruence: Congruence did not have an overall effect in either the midline or scalp topography analyses. But, there was a significant interaction with electrode in the midline analysis and significant interactions between congruence and hemisphere and congruence, hemisphere, and anteriority in the scalp topography analysis. This distribution pattern results from lingering N400 effects over central/posterior electrodes in the right hemisphere, coupled with a greater negativity for congruous words over left frontal sites.

Main effects of association: The LPC time-window did not show an overall effect of association in the midline and scalp topography analyses. However, there was an interaction between association and electrode in the midline analysis and an interaction between association and anteriority in the scalp topography analysis. This was the result of a greater negativity for associated words over posterior electrodes.

Interactions between association and discourse congruence: In the midline analyses there were no significant interactions between association and congruence or association, congruence and electrode. In the scalp topography analysis a significant interaction was found between association, congruence, hemisphere, and anteriority. This interaction was followed up with pair-wise analyses using the scalp topography analysis (presented in Table 5).

In pair-wise analyses congruence effects were found for both associated and unassociated words. For the scalp topography analysis of associated words, there was a significant interaction between congruence and hemisphere and a three-way interaction between congruence, hemisphere, and anteriority. Similarly, unassociated words also produced a congruence by hemisphere interaction in the scalp topography analysis.

A comparison of associated and unassociated incongruent words did not elicit an overall effect in the scalp topography analysis, but there were significant interactions between association and scalp factors in the scalp topography analysis. This resulted from an increased negativity for associated words over posterior electrodes and an increased positivity for associated words over prefrontal and frontal regions. For congruent words, association had no effect during this time window.

Discussion

One of the important findings of this study was that the discourse congruence manipulation had an effect as early as 150–250 ms after onset of the critical word. The posterior distribution of this effect suggests that it reflects an early onset of the N400. This finding could be due in part to cloze probability. However, analyses over a subset of the stimuli that were cloze-matched showed the same pattern. It is also important to note that even if cloze probability influenced the onset of the effect of discourse congruence, the effects of cloze probability in our study necessarily arise from a global discourse model, because the critical words in congruent and incongruent conditions were identical and appeared in identical sentences. N400 amplitude was also affected by discourse congruence, and a restricted analysis showed that discourse congruence affected N400 amplitude elicited by unassociated words that were matched for cloze probability. This reinforces the findings of van Berkum and colleagues (van Berkum et al., 1999; van Berkum et al., 2003), indicating that even in only moderately constraining texts, without breaks in local coherence, discourse congruence can affect lexical processing. In addition, the data here also provide evidence that discourse representations can have an earlier effect on processing than local manipulations of association. Effects of discourse congruence also lingered, persisting into the 500–900 ms LPC window.

Association, on the other hand, did not produce an effect until the 300–500 ms N400 time window. Therefore, effects of association emerged later than those of discourse congruence. In addition, during the 500–900 ms LPC epoch, association only had an effect for incongruent words. In sum, association had a transient effect in the N400 time window with effects lasting into the LPC epoch only when there was a conflict between local and global context.

While these data suggest a rapid use of discourse congruence and comparatively delayed effect of association in the processing of words in text, it is possible that earlier effects of association may be found with eye tracking. Similar to the studies presented here, Ledoux, Gordon, Camblin, and Swaab (in press) used ERPs and eye tracking to examine the effect of a discourse-level manipulation on word-word priming. In their ERP study repetition priming was eliminated in one of the discourse conditions. However, when the same manipulation was tested using eye tracking, early and robust effects of repetition priming reemerged, suggesting that eye tracking may be better able to capture early priming effects.

Experiment 2

Experiment 2 used eye-tracking during reading to determine if the observed ERP effects of association and discourse congruence in the previous study occur under natural reading conditions. Previous eye-tracking studies have shown that discourse information can be brought to bear on the processing of incoming words (Cook & Myers, 2004; Duffy & Keir, 2004; Grabe et al., 1987; Hyönä, 1995). However, the time course of processing semantic incongruities remains unclear. Using isolated sentences Braze et al. (2002) found processing difficulty at the target region, whereas Rayner et al. (2004) only found effects in the post-target region for this type of incongruity. It is possible that with manipulations of discourse congruence that do not violate the local sentence context effects may be even further delayed.

While the circumstances of natural reading may delay effects of discourse congruence, they may also uncover an earlier effect of association. It is particularly important to determine if association has a facilitative effect in these passages, as only a handful of eye-tracking studies have looked at the effects of intralexical relationships, with the majority examining schematically related words. These studies have either failed to find facilitative effects for word pairs (Morris, 1994; Traxler et al., 2000) or only found intralexical priming when the prime word of the pair was in focus (Morris & Folk, 1998). We are aware of only one previous eye-tracking study that used associated word pairs like those used in these studies (Carroll & Slowiaczek, 1986). While Carroll and Slowiaczek, 1986, did find effects of association for words embedded in the same clause (like the word pairs used here), they were only using single sentences so it is unclear whether facilitation would be found for associated pairs embedded in richer texts.

Methods

Participants—Thirty-six new participants took part in a single-session eye-tracking experiment. Subjects received course credit for their participation. All had normal or corrected to normal vision.

Materials—Thirty-five experimental stimuli that were selected from the ERP materials were presented to each subject. To each of these selected passages a fourth sentence was added. This was necessary because the analysis of eye-tracking data requires that participants be able to read past the critical word. The fourth sentence was the same across any given stimulus set and was constructed so that it was congruent with both incongruent and congruent discourse conditions. For example, in the sample stimulus presented in Table 1 the fourth sentence was: “Unfortunately scratching only hurts irritated skin.” For this subset of stimuli, associated and unassociated words were matched for word length (associated: $M = 5.17$, SD = 1.4; unassociated: $M = 5.17$, SD = 1.4; $t < 1$) and written word frequency according to Francis and Kucera (1982) (associated: $M = 94.20$ per million, SD = 165; unassociated: $M = 89.11$ per million, SD = 167; $t < 1$). These stimuli were mixed with 36 passages from another experiment and 12 additional filler stories. Each participant only saw one condition from each stimulus set and 8–9 passages of each type.

Procedure—Testing was done in a small experimental chamber, with the participants seated approximately 60 cm from the computer screen. Eye position was tracked using a head mounted eye-tracker (SMI Eyelink), with a 250 Hz sampling rate. Each trial began with a calibration check and recalibration was performed if necessary. Following this, a fixation point appeared on the left side of the screen. Once the participant fixated on this point, it disappeared and the whole passage was presented with the first word appearing in the same location as the fixation point. The text was presented as black print on a white background in Times New Roman font. After reading a passage participants were instructed to press the space bar on a computer

keyboard. The passage was replaced with a fixation point and then a true or false question appeared. Participants responded to this question by pressing one of two appropriately marked keys. This task ensured that subjects read the stories for comprehension.

Eye-tracking recording and data analysis: Prior to data analysis eye tracks were checked individually using TeView (Feng, 2003), a visual display program that allows for the correction of vertical drift. Fixations with a duration shorter than 80 ms that were on the same word as a temporally adjacent fixation were added to that fixation; fixations shorter than 80 ms that did not meet this criterion were omitted from data analysis (Pickering, Traxler, & Crocker, 2000). Fixations that lasted longer than 800 ms were trimmed to 800 ms because it is not clear whether the extended duration of these fixations is a part of normal reading (Folk & Morris, 2003).

Analyses were done on first fixation (the duration of the first fixation in the region), gaze duration (the time spent in the region before exiting to the left or right), regression-path duration (the total time from the first fixation in the region until the reader moves to subsequent text), and rereading time (total reading time minus gaze duration) for the target word and post-target regions. Skipping rates were also calculated for the target word and post-target regions. The target region consisted of the target word and included five characters to the left of the target. A contingent expansion technique was used for skipping rates, first fixation and gaze duration such that fixations to the left of the target word itself were only used if the target was not fixated (Rayner & Duffy, 1986). The post-target region consisted of the first three words of the final sentence. All duration measures were conditionalized. That is, cases wherein the region of analysis was skipped during first pass reading were not included in the analysis of first fixation, gaze duration, regression-path duration and rereading measures. Statistical analyses were performed by subjects (F_1) as well as by items (F_2).

Results

Table 6 shows descriptive statistics (mean skipping rate, first fixation duration, gaze duration, regression-path duration, and rereading times) for the critical regions, and Table 7 shows corresponding inferential statistics. All of the confidence intervals (CIs) reported in the text are halfwidths of the 95% confidence intervals for the differences between means.

Target region

Main effects of discourse congruence: Skipping rates were not affected by discourse congruence. There were also no main effects of congruence on first fixation or gaze duration. Congruent words did elicit 157 ms shorter regression-path reading times (95% CI of 79 ms) and 116 ms shorter rereading times (95% CI of 34 ms).

Post-hoc cloze-matched analyses of discourse congruence: This comparison was performed to test whether effects on first pass reading in the target region were the result of differences in expectancy, rather than congruency, *per se.* Analysis was restricted to unassociated words that produced cloze probabilities of zero in both the congruent and incongruent conditions, resulting in the analysis of 20 of the 35 passages. Effects on regression-path duration were still significant in this analysis (Regression Path: $F_1(1, 35) = 9.83$, $p = .003$; $F_2(1, 19) = 13.04$, $p = .002$; min $F'(1, 53) = 5.60$, $p = .022$).

Main effects of association: Association did not influence skipping rates or first fixation duration. Gaze duration was 16 ms shorter for associated words, with a 95% CI of 15 ms. This effect was significant by subjects but only marginal by items. Associated words also produced shorter regression-path reading times (effect size of 66 ms with a 95% CI of 64 ms). As with

the gaze duration effect, this was only significant by subjects. Association had a more robust effect on rereading with an effect size of 57 ms and a 95% CI of 41 ms.

Interactions between association and discourse congruence: Finally, there were no interactions between association and discourse congruence for any of the duration measures or the skipping rates.

Post-target region

Main effects of discourse congruence: Congruence did not affect skipping rates, first fixation, or gaze durations in this post-target region. Incongruent words did elicit longer regression-path durations and rereading times than their congruent counterparts. Regression-path durations were 115 ms shorter (95% CI of 79 ms) and rereading times were 49 ms shorter (95% CI of 36 ms) for congruent words.

Main effects of association: Association did not affect skipping rates, first fixation, gaze duration, or rereading. Associated words elicited 67 ms shorter regression-path durations than unassociated words, with a 95% CI of 66 ms. The effect was significant by subjects but marginal by items.

Interactions between association and discourse congruence: As with the target region, there were no interactions between association and congruence in the post-target region.

Discussion

Similar to the ERP study, there were significant effects of both discourse congruence and association. Discourse congruence exerted its influence on regression-path reading for the target region, indicating that participants were able to appreciate the manipulation before moving past the anomalous word. Regression-path duration was also longer for incongruent words in the post-target region and effects on rereading for both regions show a lingering influence of congruence.

In the target region association had effects on gaze duration and regression-path duration, however these effects were not significant in the items analysis. In the post-target region effects of regression-path duration were also only significant by subjects. Therefore, association did not show statistically robust effects for any of the first-pass reading analyses. Association did produce differences in rereading for the target region, but the size of this effect was much smaller than that found for discourse congruence on the same measure and was localized to the critical word.

These effects show a powerful influence of discourse congruence and a weaker effect of association. However, marginal effects of association on gaze duration suggest that this manipulation may have had an earlier effect than congruence on lexical processing. It is important to note that all conditions elicited relatively high regression percentages from the critical word, presumably as a result of sentential wrap-up (regression percentage ranged from 23% to 36% across conditions). While the mechanisms underlying sentence wrap-up are not well understood, the high percentage of regressions off of the critical word could be systematically affecting our reading measures. Therefore, it is possible that these early effects of association may have been more robust if readers were not engaged in sentential wrap-up processing. To eliminate this possible confound, mid-sentence targets were used in Experiment 3.

Experiment 3

In the following experiment the critical word no longer appeared in sentence-final position. This was done in order to examine the effects of association and discourse congruence without the increased number of regressive eye movements that is a hallmark of sentence-final words. In addition to a high percentage of regressions, previous research has also shown that the processing time on sentence-final words is longer, as compared to words occurring in the middle of a sentence (Rayner, Sereno, Morris, Schmauder, & Clifton, 1989). It is possible that either of these factors may be making it difficult to detect effects of association.

Discourse congruence effects may also be altered for mid-sentence targets. The only first-pass measure to show effects of congruence in the target region was regression-path duration. This measure could, arguably, be the one that is most affected by the high percentage of regressions for sentence-final words. With mid-sentence targets, where the number of regressive eye movements should be decreased, the effects of discourse congruence may not occur until the post-target region. Such a delay would also be consistent with some previous studies of discourse effects. For example, Liversedge, Pickering, Clayes, and Branigan (2003) did not find effects of thematic role congruency until the spillover, post-target region and Ledoux et al. (in press) found similarly delayed effects of coreferential processing with repeated names.

Methods

Participants—Thirty-six new participants took part in a single-session eye-tracking experiment. They received course credit for their participation. All participants had normal or corrected to normal vision.

Materials—Thirty-five experimental stimuli were presented to each subject. Each participant only saw one condition from each stimulus set and 8–9 passages of each type. These stimuli differed from those presented in Experiment 2 in that text was added to the third sentence after the critical word. Care was taken to assure that the words following the critical word did not start a new clause so that both sentential wrap-up and clausal wrap-up effects could be eliminated from analysis of the target region. When necessary, minimal changes were made to the beginning of the third sentence to increase readability. These stimuli were mixed with 36 passages from another experiment and 12 additional filler stories.

Procedure, eye-tracking recording and data analysis—The parameters were the same as those used in Experiment 2. The only change was the way in which the post-target region was defined. Instead of a fixed number of words as in Experiment 2, the post-target region was defined as the text following the target that ended sentence three (average: 2.6 words; range 1–4 words).

Results

Table 8 shows descriptive statistics (skipping rate, first fixation duration, gaze duration, regression-path duration, and rereading times) for the critical regions, and Table 9 shows corresponding inferential statistics.

Target region

Main effects of discourse congruence: There were no effects of congruence on skipping rates or first pass reading measures. However, congruence did affect rereading. Congruent words elicited rereading times 68 ms shorter than the rereading times for incongruent words, with a 95% CI of 25 ms.

Main effects of association: Association did not have an effect on skipping rates, first fixation, or gaze duration. Association had an effect on regression-path duration that was marginal by subjects and significant by items, producing 37 ms shorter regression-path durations (with 95% CI of 39 ms). Also, unassociated words produced rereading times that were 50 ms longer than their associated counterparts, with a 95% CI of 42 ms.

Interactions between association and discourse congruence: There were no interactions between discourse congruence and association for skipping rate, first fixation or gaze duration. However, there were marginal interactions for both the regression-path duration and rereading measures, which prompted pair-wise analyses for these measures (see Table 10). Pair-wise analyses of regression-path duration yielded a significant effect of association for incongruent words. The size of this effect was 70 ms, with a 95% CI of 65 ms. Regression-path duration was not affected by association for congruent words. Discourse congruence did not have an effect on regression-path duration for unassociated or associated words. In contrast, discourse congruence did have an effect on rereading times for both word types. For rereading, association had an effect on incongruent, but not congruent targets. In the incongruent conditions, associated words had rereading times that were 73 ms shorter with a 95% CI of 56 ms.

Post-target region

Main effects of discourse congruence: There was no effect of discourse congruence on skipping rates or first fixation duration. Gaze duration was 47 ms shorter for congruent words, with a 95% CI of 25 ms. In addition, congruent words elicited 192 ms shorter regression-path durations and 60 ms shorter rereading times, with 95% CIs of 57 ms and 26 ms, respectively.

Main effects of association: Association affected regression-path duration and rereading times, although these effects were smaller than those found for discourse congruence. Regression-path duration for associated words was 81 ms shorter and rereading times were 36 ms shorter than those found for unassociated words, with 95% CIs of 65 ms and 28 ms, respectively. No other main effects of association were found during this post-target time window.

Interactions between association and discourse congruence: Association and congruence did not significantly interact on any of the measures tested in this region.

Discussion

Moving the critical word to a mid-sentence position did delay effects of discourse congruence. In this study, discourse congruence only affected first-pass reading for the post-target region producing longer gaze durations and regression-path times for incongruent words. This is similar to the findings reported by Rayner et al. (2004), where implausible words diverged in processing patterns in the text following the critical manipulation. There was still a lingering effect of congruence on rereading measures for both the target and post-target regions. Taken together with Experiment 2, the results here indicate that discourse congruence can have strong effects on first-pass reading and that these effects can be expedited for sentence terminal words. The influence of discourse congruence on rereading also extends past the incongruity, affecting both the target and post-target regions.

Association only had an effect on regression-path and rereading durations in the target region in the case of incongruent words. In the post-target region effects of association were again found for regression-path and rereading times. Like the results from Experiment 2, these effects were smaller than those observed for discourse congruence on the same measures. Therefore, instead of allowing early effects of association to emerge, presenting the targets in mid-sentence

positions eliminated effects on gaze duration that were observed in Experiment 2 and produced effects on regression-path duration and rereading only in the case of incongruent words. The lack of gaze duration effects in the target region also suggests that the effects found were not the result of an automatic, bottom-up process such as spreading activation (Sereno & Rayner, 1992). In sum, effects of association were only found in the target region for incongruous words. Effects of discourse congruence preceded effects of association in the post-target region and were dominant in measures where both manipulations had effects.

Experiment 4

The previous two eye-tracking studies did not present a conclusive picture with respect to the effects of association in discourse contexts. While marginal effects were found in the target region for Experiment 2, effects in this region were only found for incongruent words in Experiment 3. In addition, the marginal effects in Experiment 2 were found as early as gaze duration, whereas the target effects found in Experiment 3 did not emerge until regression-path duration. The present experiment therefore focuses on the effects of association, by presenting target words that are related or unrelated to previous context words in single sentences rather than in multi-sentence discourses.

Surprisingly, few eye-tracking studies have examined effects of association on word pairs embedded in text. While at least one study has found evidence of intralexical priming with word pairs in normally presented text (Carroll & Slowiaczek, 1986), some studies have not (Morris, 1994; Traxler et al., 2000). It is possible that the difference between these studies is a result of the types of intralexical relationships being tested. While Carroll and Slowiaczek (1986) found evidence of priming with associated pairs, it was not found for schematically related pairs (Morris, 1994; Traxler et al., 2000) or synonyms (Traxler et al., 2000).

For this fourth experiment, the effects of association were tested for single-sentence stimuli that were taken from the target sentence in Experiment 3, and thus had the critical word appearing mid-sentence. An absence of associative facilitation in this single-sentence context would indicate that the effects of word relatedness on eye-movements are precarious in all contexts. However, a finding of significant facilitative effects of association in these sentences would support the conclusion that readers rely more heavily on local, lexical relationships when reading stimuli with impoverished global context (be they words in lists or isolated sentences) than when reading multi-sentence passages that provide a comparatively rich context. Furthermore, this would suggest that lexical association has a stronger effect on lexical processing than schematic and synonym relatedness, which were found to have weak or negligible impact by Morris (1994) and Traxler et al. (2000).

Methods

Participants—Twenty-eight participants were run in a single-session eye-tracking experiment. They received course credit for their participation. All participants had normal or corrected to normal vision and none participated in any of the previous experiments.

Materials—Twenty-four experimental sentences were presented to each subject. All sentences were congruent and each contained a target word that was either associated or not to a preceding word in the sentence. Each participant only saw one condition from each stimulus set and 12 sentences of each type. These stimuli were taken from the target sentence in the passages used in Experiment 3. Only a subset of the stimulus sets from the previous eye-tracking studies were used. These sentences were chosen because they required the least amount of modification to be acceptable as stand-alone sentences. This subset did not differ in average associative strength from the previous experiments. The stimuli were mixed with 40 sentences from another experiment and 16 additional filler sentences.

Procedure, eye-tracking recording and data analysis—The parameters were the same as those used in the previous eye-tracking studies. The post-target region was defined in the same way as in Experiment 3, encompassing all of the text following the target until the end of the sentence (range 1–5 words, average 3.1 words). Since there was no text following this post-target region, the only analyses reported for this region will be first fixation, gaze duration, and rereading time.

Results

Table 11 shows descriptive statistics (mean skipping rate, first fixation duration, gaze duration, regression-path duration, and rereading times) for the critical regions, and Table 12 shows corresponding inferential statistics.

Target region—Unlike the previous studies skipping rates were significantly affected by the experimental manipulation. Associated words were skipped 10% of the time while unassociated words were skipped only 5% of the time. As with the analyses of Experiments 2 and 3, all duration measures are conditionalized so that differences in skipping rates were not conflated with duration measures.

In addition, associated words elicited 16 ms shorter first-fixation times, with a 95% CI of 13 ms. This effect was significant by subjects and marginal by items. There was also an effect of association on gaze duration (effect size of 21 ms with a 95% CI of 19 ms) and regression-path duration (effects size of 84 ms with a 95% CI of 60 ms). There was no difference in rereading for the target region.

Post-target region—Associated words elicited shorter first-fixation durations than unassociated words, but this effect was only marginal by subjects and was not significant by items. No effects were found on skipping rates, gaze duration and rereading.

Discussion

Unlike Experiments 2 and 3, significant effects of association were found in very early measures of processing. Associated words were skipped more often than their unassociated counterparts. When these words were fixated during first-pass reading they elicited shorter first-fixation durations, gaze durations and regression-path reading times. These results indicate very early effects of association for word pairs embedded in single-sentence contexts. This suggests that association effects were absent from the target region for congruent words in Experiment 3 because the richer discourse model was able to override facilitation from this lower-level context. Only when the discourse model was disrupted by an incongruent word were effects of association elicited in the target region.

Experiment 5

In Experiment 2 statistically weak effects of association were found for both the sentence-final target and the post-target region. However, when mid-sentence targets were analyzed in Experiment 3 effects of association were only found for incongruent words in the target region, and main effects of association that were not mediated by congruence did not appear until the post-target region. This is in stark contrast to the very early effects of association found with congruent, single sentences where effects localized to the target were found for all first-pass reading measures.

To further probe the importance of a discourse model we performed another eye-tracking study manipulating not just the congruence of the critical word, but the cohesion of the entire passage. If it is the richness of the discourse that is suppressing early effects of association, then

associated pairs embedded in disjointed text should also produce early priming effects. However, if it is simply the length of the passage, and not necessarily the cohesive discourse model emerging from it that is important, then equivalent priming should be seen in coherent and scrambled passages.

Methods

Participants—Thirty-six new participants took part in a single-session eye-tracking experiment. They received course credit for their participation. All participants had normal or corrected to normal vision.

Materials—Thirty-five experimental stimuli were presented to each subject. These stimuli were four-sentence passages that contained the association manipulation as used in the previous experiments, but instead of varying the congruence of the target word the cohesiveness of the entire passage was manipulated. Coherent passages were identical to those used in the congruent condition for Experiment 3, and scrambled passages were produced by mixing up the sentences used in different passages. In these scrambled passages, most pronouns were also changed to names in order to increase the sense of disjointedness. Target sentences were always presented as the third sentence and no sentence was repeated within an experimental list. These sentences were always congruent as stand-alone sentences. Participants saw 8–9 passages per condition. These stimuli were mixed with 30 filler stimuli; 15 coherent and 15 scrambled.

Procedure, eye-tracking recording and data analysis—The parameters were the same as those used in Experiment 3.

Results

Table 13 shows descriptive statistics (mean skipping rate, first fixation duration, gaze duration, regression-path duration, and rereading times) for the critical regions, and Table 14 shows corresponding inferential statistics.

Target region

Main effects of passage coherence: Not surprisingly, coherent passages produced significantly shorter first fixations, gaze durations, regression-path times and rereading times.

Main effects of association: Association had a significant effect on first fixation (effect size of 11 ms with a 95% CI of 8 ms) and gaze duration (effect size of 14 ms with a 95% CI of 10 ms). In addition, there was an effect on rereading that was marginal by subjects and significant by items.

Interactions between association and passage coherence: For skipping rates the interaction between association and coherence was marginal by subjects and not significant by items. Significant interactions were present for both first fixation and gaze duration. These interactions were driven by the difference between the unassociated/scrambled condition and the other three conditions, yielding significant effects in the analysis of association for scrambled endings and for passage coherence with unassociated endings (see Table 15). In scrambled passages, associated words elicited 22 ms shorter first-fixation times (95% CI of 16 ms) and 29 ms shorter gaze durations (95% CI of 22 ms). No other significant effects were found in the pair-wise analyses.

Post-target region

Main effects of passage coherence: There was no effect of passage coherence on skipping rates or first fixation. Passage coherence had an effect on gaze duration that was marginal by

subjects and significant by items. Coherent passages also produced significantly shorter regression-path times and rereading times in the post-target region.

Main effects of association: There were no effects of association in this region.

Interactions between association and passage coherence: Association and congruence did not significantly interact on any of the measures tested in this region.

Discussion

Association interacted with passage coherence on early measures of target processing. This interaction was a result of associative priming for words appearing in scrambled texts but not coherent passages. The lack of priming for words in coherent text replicated the findings in Experiment 3, while the early effects for scrambled texts extends our understanding of the importance of a discourse model for moderating association effects.

General discussion

We conducted one ERP study and four eye-tracking studies to examine how and when discourse and intra-lexical relationships influence lexical processing in a locally coherent sentence context. In all the experiments, critical words that were congruent with the meaning of the local sentence context were preceded by a word that was either associated or not with the critical word. In Experiment 4, these sentences were presented in isolation, but in the first three experiments, sentences containing the critical words were embedded in a short story, which rendered the critical word congruent or not with the multi-sentence discourse. The position of the critical word was manipulated such that it appeared at the end of the sentence, or in a mid-sentence position. Finally, in Experiment 5 the coherence of the entire passage was varied as opposed to the congruence of one word. The results show that (a) effects of discourse congruence are robust and rapid for both ERP and eye-tracking measures and (b) early associative priming effects are robust only when there are difficulties with the discourse model due to incongruities, incoherence, or limited context.

Effects of discourse congruence

One of the objectives of this study was to examine the effect of discourse congruence on the processing of locally coherent words, as the majority of research on congruence processing has confounded local, sentential and discourse congruence. Significant effects of discourse congruence were found for each of the experiments where this factor was manipulated (an effect summary is presented in Table 16). In the ERP study, this began with changes in the 150–250 ms epoch. This effect was maximal over posterior electrode sites, which indicates that it is an early onset of the N400. This effect of congruence was also obtained in the 300–500 ms N400 time window and the 500–900 ms LPC epoch. Therefore, robust effects of congruence were found that started early and persisted throughout the averaged ERP epoch.

In the eye-tracking studies, manipulations of discourse congruence affected first-pass reading. For sentence-final words, effects first emerged on regression path reading of the target, while mid-sentence targets did not show discourse congruence effects until gaze duration in the post-target region. While it is possible to infer from these results that discourse congruence is not checked until the sentence ends, we do not believe that this is the case. Numerous studies have shown effects emerging in the spillover region, and the presence of post-target effects for both the sentence-initial region in Experiment 2 and sentence-final region in Experiment 3 indicates that effects of discourse congruence are not confined to sentence-final regions. Instead, we believe that the regression path measure may be particularly sensitive to manipulations of congruity, and that the higher percentage of regressive eye movements off sentence-final words

allowed this effect to emerge earlier in Experiment 2. In addition to these effects on first-pass reading, incongruent words also elicited longer rereading times in both experiments. Differences in rereading were not localized, but showed a more general disruption to reading affecting both the target and post-target regions in Experiments 2 and 3.

Taken together, Experiments 1–3 show robust effects of discourse congruence. For sentence-final words this was illustrated by ERP effects starting in the 150–250 ms latency window, and with eye-tracking this was evidenced by longer regression-path durations on the critical word. In addition, eye-tracking measures also showed a lingering effect of rereading that was not localized to the critical word. For mid-sentence critical words effects of discourse congruity were found for the early measure of gaze duration in the post-target region. These data are at odds with strict construals of the minimalist hypothesis and suggest that words are rapidly integrated into discourse-level representations.

Effects of association and the influence of the Discourse Model

Another study objective was to establish if lexical association can facilitate comprehension when related word pairs are embedded in a discourse context. With ERPs, standard association priming was found in the N400 time window, but not in the earlier P2 epoch. This effect did not interact with the congruence manipulation. This N400 reduction is similar to that found with targets in a mid-sentence position (Van Petten, 1993; Van Petten et al., 1997). However, these results can be contrasted with the Van Petten et al. (1999) study where effects of association were eliminated for sentence-final targets. The key distinction between this study (as well as those studies using mid-sentence targets) and that presented by Van Petten and colleagues (1999) appears to be the expectancy produced by the context. Therefore, it seems to be contextual strength, rather than sentential position, that determines if an effect of association is observed, such that with moderately constraining text, association will ease lexical integration at some level regardless of congruity.

The ERPs also revealed an interaction between association and discourse congruence such that association only had a lingering effect in the LPC epoch for incongruous words. This may reflect a realization of the conflict between message-level congruence and lexical association, although the direction of the effect is different than that previously reported (Hoeks et al., 2004; Van Petten, et al., 1999). This may be similar to the effect of association on regression-path duration and rereading in the target region that was only found for incongruous words in Experiment 3.

When critical words were presented in cohesive, congruous passages and under natural reading conditions, effects of association on first-pass reading were not robust in the target region (Experiments 2, 3 and 5). However, when the same sentences were presented in isolation (Experiment 4) or in scrambled texts (Experiment 5), very early effects of association emerged. When these mid-sentence critical words were incongruent with a cohesive discourse text, effects did not emerge until regression-path duration in the target region. The absence of associative priming on first fixation or gaze duration for these incongruous words indicates that the effects that were present were not the result of automatic, bottom-up priming. This suggests that readers may be more biased toward intralexical priming under conditions where the message-level information is sparse. That is, if readers have little context at their disposal to aid in lexical processing they may rely more heavily on simple word-to-word relationships. As more information becomes available for the discourse model, the effects of association become increasingly delayed. Thus, when a cohesive and more detailed discourse model can be constructed this global model may override bottom-up associative facilitation.

A comparison of ERP and eye-tracking results (Experiments 1–3)

As can be seen in Table 16, there is no direct mapping between the ERP and eye-tracking measures as far as where effects were found. However, the two measures do present very similar effect profiles. In each of these studies, an early effect of discourse congruence was found (P2 effects, regression path duration for sentence-terminal targets, and gaze duration in the post-target region for mid-sentence critical words), indicating the rapid use of message-level representations. These effects were followed by effects on measures of later processing that showed non-interacting effects of both association and discourse congruence (N400 effects, rereading of sentence-terminal targets, and rereading of the post-target region for mid-sentence critical words), illustrating that associative relationships can affect comprehension in moderately constraining texts. Also, discourse congruence showed a sustained effect on ERPs, and similarly had a lingering effect on eye-movements, affecting all rereading measures. Finally, when association and congruity did interact, effects were only observed for incongruent words, suggesting that the violation of the discourse model made the associative relationship more salient. This interaction was found for measures of relatively late processing for both ERPs and eye tracking (LPC amplitude and target rereading, respectively). In contrast, in Experiment 3 this interaction was also found for the first-pass reading measure of regression path duration on the target. Perhaps for mid-sentence words (where regressive eye movements are less common) readers perform a very rapid and simple integration process at the word when they need to program the upcoming saccade. If the context supports the incoming word at any level, be it intralexical or more global, the default progressive eye movement takes place. However, if there is no contextual support for the word a regressive eye movement may be triggered.

Conclusions

In multi-sentence passages, effects of discourse congruence had robust effects on both eye movements and ERPs. Disrupted processing occurred for discourse incongruent words even though they were perfectly congruous at the sentence level. In contrast, association had a more malleable effect in eye-tracking studies using these same passages. While effects of association were found with ERPs, these effects emerged after effects of discourse congruence and were more focused in time. Early effects of association on eye-tracking measures reemerged when word pairs were embedded in isolated sentences or sentences in scrambled, incoherent text, suggesting that the effects of association are highly sensitive to the discourse model. In addition, effects of association were reduced as the text in which the word pairs were embedded became increasingly more detailed and congruent. This suggests that automatic spread of activation, as a function of associative relations between words, does not contribute to processing of words in sentences that are part of a larger discourse.

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Fig. 1.
Difference wave ERPs for nine of the 29 electrode sites. The traces are time-locked to the presentation of the target. The effect of discourse congruence (Incongruent–Congruent) for associated words and unassociated words are shown separately. In this and the following figure, the first row contains frontal electrodes, the second consists of central electrodes, and the final row shows posterior electrodes. Midline electrodes are shown in the center column with electrodes over the left of the scalp in the left column and electrodes over the right of the scalp in the right column. Negative is plotted up.

Fig. 2.
Difference wave ERPs for nine of the 29 electrode sites. The traces are time-locked to the presentation of the target. The effect of association (Unassociated–Associated) for congruent words and incongruent words are shown separately.

Table 1

Sample Stimuli

Condition	Story	Target sentence
Associated Congruent	Lynn had gotten a sunburn at the beach. Nothing she tried would help her dry and irritated skin.	Lynn couldn't stop scratching her *arms* and LEGS.
Unassociated Congruent	Lynn had gotten a sunburn at the beach. Nothing she tried would help her dry and irritated skin.	Lynn couldn't stop scratching her *arms* and NOSE.
Associated Incongruent	Lynn's wool sweater was uncomfortable and itchy. She fidgeted as the rough material irritated her skin.	Lynn couldn't stop scratching her *arms* and LEGS.
Unassociated Incongruent	Lynn's wool sweater was uncomfortable and itchy. She fidgeted as the rough material irritated her skin.	Lynn couldn't stop scratching her *arms* and NOSE.

Note. Primes are shown in italics and target words are presented in capital letters. This is only for illustrative purposes—during the experiment all words were presented in standard font with the target in appropriate case.

Table 2

Congruency ratings by condition

Condition	Mean rating	SD
Associated/Congruent	1.44	0.81
Unassociated/Congruent	1.50	0.89
Associated/Incongruent	4.31	1.09
Unassociated/Incongruent	4.32	1.06

Table 3

Results from the cloze testing

Condition	Average cloze		Frequency as highest cloze response		
	Associated	Unassociated	Associated	Unassociated	Other
Congruent	35.92%	8.45%	33	10	28
Incongruent	4.01%	0%	0	0	71

Note. These are the average cloze for associated and unassociated words when subjects were given the congruent or incongruent contexts. Also presented is the number of times a word of a particular type (e.g., the associated word) was given as the highest cloze response for a given context.

Table 4

Statistics for the P2, N400, and LPC time windows time locked to the critical word in Experiment 1

	df	Congruence		Association		Interaction C × A	
		F	*p*	*F*	*p*	*F*	*p*
150–250 ms							
Midline analysis							
Main effect	1,23	2.61	.12	<1		<1	
X electrode	4,92	<1		<1		<1	
Scalp topography							
Main effect	1,23	2.57	.12	<1		<1	
X Hemisphere	1,23	6.38	.02	1.80	.19	<1	
X Anteriority	2,46	<1		<1		<1	
X Hemi × Ant	2,46	1.34	.26	<1		<1	
300–500 ms							
Midline analysis							
Main effect	1,23	21.37	.001	15.49	.001	2.50	.13
X electrode	4,92	21.21	.001	6.60	.003	<1	
Scalp topography							
Main effect	1,23	27.24	.001	19.69	.001	2.04	.17
X Hemisphere	1,23	14.69	.001	<1		<1	
X Anteriority	2,46	5.05	.03	5.31	.05	<1	
X Hemi × Ant	2,46	1.26	.30	1.56	.22	<1	
500–900 ms							
Midline analysis							
Main effect	1,23	<1		<1		<1	
X electrode	4,92	8.64	0.001	8.31	.001	2.67	0.08
Scalp topography							
Main effect	1,23	<1		<1		1.80	0.19
X Hemisphere	1,23	18.86	.001	<1		<1	
X Anteriority	2,46	<1		5.56	.008	2.59	.09
X Hemi × Ant	2,46	5.10	.01	1.78	.19	4.06	.03

Table 5

Pair-wise analyses for the scalp topography analysis in the LPC window(500-900 ms) for Experiment 1

	df	Effect of congruence				Effect of association			
		Associated		Unassociated		Congruent		Incongruent	
		F	*p*	*F*	*p*	*F*	*p*	*F*	*p*
Main effect	1,23	<1		<1		<1		<1	
X Hemisphere	1,23	7.38	.01	6.52	.02	<1		<1	
X Anteriority	2,46	<1		<1		<1		8.97	.001
X Hemi × Ant	2,46	6.12	.005	<1		<1		4.54	.02

Table 6

Skipping rates and various reading time measures (in ms) for the target and post-target region in Experiment 2

	Congruent		Incongruent		95% CI
	Associated	Unassociated	Associated	Unassociated	
Target					
Skipping rate	11%	10%	11%	9%	
First fixation	219	225	225	228	±18
Gaze duration	252	262	256	277	±24
Regression path	505	572	663	728	±114
Rereading	128	175	229	304	±66
Post-target					
Skipping rate	7%	7%	6%	8%	
First fixation	211	207	213	219	±17
Gaze duration	460	445	445	455	±39
Regression path	573	613	662	755	±88
Rereading	115	156	195	173	±55

Note. Confidence intervals shown here and in subsequent tables are for pairwise differences between individual condition means. These were calculated according to the procedures recommended by Loftus and Masson (1994).

Table 7

ANOVAs for Experiment 2

	By participants			By items			By min *F′*		
	df	F_1	***p***	**df**	F_2	***p***	**df**	**min *F′***	***p***
Target									
Congruence									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	1.33	.26	1,34	<1				
Regression path	1,35	15.66	.001	1,34	17.50	.001	1,67	8.26	.005
Rereading	1,35	44.18	.001	1,34	19.14	.001	1,59	13.35	.001
Association									
Skipping rate	1,35	2.04	.16	1,34	1.13	.30	1,63	<1	
First fixation	1,35	1.10	.30	1,34	<1				
Gaze duration	1,35	4.59	.04	1,34	3.08	.09	1,66	1.84	.18
Regression path	1,35	4.48	.04	1,34	2.77	.11	1,65	1.71	.20
Rereading	1,35	8.93	.005	1,34	7.81	.008	1,69	4.17	.05
Post-target									
Congruence									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	2.07	.16	1,34	1.37	.25	1,66	<1	
Gaze duration	1,35	<1		1,34	<1				
Regression path	1,35	8.63	.006	1,34	8.53	.006	1,69	4.29	.04
Rereading	1,35	7.80	.008	1,34	8.47	.006	1,69	4.06	.05
Association									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	<1		1,34	<1				
Regression path	1,35	4.19	.05	1,34	3.34	.08	1,68	1.86	.18
Rereading	1,35	<1		1,34	<1				

Note. None of the interactions approached significance and are not included here.

Table 8

Skipping rates and various reading time measures (in ms) for the target and post-target region in Experiment 3

	Congruent		Incongruent		95% CI
	Associated	Unassociated	Associated	Unassociated	
Target					
Skipping rate	20%	20%	17%	17%	
First fixation	210	215	211	214	±11
Gaze duration	237	245	240	251	±18
Regression path	357	360	343	413	±52
Rereading	144	170	189	262	±42
Post-target					
Skipping rate	13%	14%	15%	14%	
First fixation	218	207	212	219	±14
Gaze duration	356	359	404	406	±42
Regression path	516	593	704	788	±111
Rereading	77	100	123	173	±41

Table 9

ANOVAs for Experiment 3

	By participants			By items			By min *F′*		
	df	F_1	***p***	**df**	F_2	***p***	**df**	**min *F′***	***p***
Target									
Congruence									
Skipping rate	1,35	2.24	.14	1,34	2.84	.10	1,68	1.25	.27
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	<1		1,34	<1				
Regression path	1,35	<1		1,34	<1				
Rereading	1,35	29.93	.001	1,34	10.35	.003	1,55	7.69	.008
Association									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	2.64	.11	1,34	1.77	.19	1,66	1.06	.31
Regression path	1,35	3.78	.06	1,34	6.57	.02	1,65	2.40	.13
Rereading	1,35	6.22	.02	1,34	8.43	.006	1,68	3.58	.06
Interaction C × A									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	<1		1,34	<1				
Regression path	1,35	3.76	.06	1,34	3.47	.07	1,69	1.80	.18
Rereading	1,35	3.31	.08	1,34	3.74	.06	1,69	1.76	.19
Post-target									
Congruence									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	15.45	.001	1,34	11.92	.002	1,68	6.73	.01
Regression path	1,35	46.80	.001	1,34	25.67	0.001	1,63	16.57	.001
Rereading	1,35	20.73	.001	1,34	16.57	.001	1,68	9.21	.004
Association									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	<1		1,34	<1				
Regression path	1,35	6.51	.02	1,34	4.43	.04	1,66	2.64	.11
Rereading	1,35	6.26	.02	1,34	7.62	.009	1,69	3.44	.07

Note. None of the interactions in the post-target region approached significance and are not included here.

Table 10

Pair-wise analyses for the regression path and rereading of the target region in Experiment 3

	By participants			By items			By min *F′*		
	df	F_1	***p***	**df**	F_2	***p***	**df**	**min *F′***	***p***
Regression path									
Effect of congruence									
Associated	1,35	<1		1,34	<1				
Unassociated	1,35	3.02	.09	1,34	2.51	.12	1,68	1.37	.25
Effect of association									
Congruent	1,35	<1		1,34	<1				
Incongruent	1,35	4.56	.04	1,34	8.77	.006	1,63	3.00	.09
Rereading									
Effect of congruence									
Associated	1,35	5.35	.03	1,34	5.58	.02	1,69	2.73	.10
Unassociated	1,35	21.64	.001	1,34	10.94	.002	1,62	7.27	.009
Effect of association									
Congruent	1,35	1.19	.28	1,34	2.47	.13	1,62	<1	
Incongruent	1,35	7.13	.01	1,34	8.90	.005	1,69	4.01	.05

Table 11

Skipping rates and various reading time measures (in ms) for the target and post-target region in Experiment 4

	Associated	Unassociated	95% CI
Target			
Skipping rate	10%	5%	
First fixation	215	231	±13
Gaze duration	248	269	±19
Regression path	368	452	±60
Rereading	242	263	±31
Post-target			
Skipping rate	8%	10%	
First fixation	224	239	±15
Gaze duration	525	536	±44
Regression path	1476	1459	±120

Table 12

ANOVAs for Experiment 4

	By participants			By items			By min *F′*		
	df	F_1	***p***	**df**	F_2	***p***	**df**	**min *F′***	***p***
Target									
Skipping rate	1,27	12.87	.001	1,23	5.09	.034	1,40	3.65	.06
First fixation	1,27	5.08	.03	1,23	4.13	.05	1,48	2.28	.14
Gaze duration	1,27	5.23	.03	1,23	6.14	.02	1,50	2.82	.10
Regression path	1,27	8.70	.006	1,23	7.75	.01	1,49	4.10	.05
Rereading	1,27	1.86	.18	1,23	<1				
Post-target									
Skipping rate	1,27	1.11	.30	1,23	<1				
First fixation	1,27	4.13	.05	1,23	2.69	.11	1,46	1.63	.21
Gaze duration	1,27	<1		1,23	<1				
Regression path	1,27	<1		1,23	<1				

Table 13

Skipping rates and various reading time measures (in ms) for the target and post-target region in Experiment 5

	Cohesive		Scrambled		95% CI
	Associated	Unassociated	Associated	Unassociated	
Target					
Skipping rate	16%	17%	18%	11%	
First fixation	210	215	212	234	±11
Gaze duration	231	232	238	267	±18
Regression path	343	369	419	435	±62
Rereading	147	164	198	231	±41
Post-target					
Skipping rate	9%	12%	13%	10%	
First fixation	219	213	213	228	±14
Gaze duration	395	390	447	421	±33
Regression path	562	547	659	678	±75
Rereading	103	92	120	161	±39

Table 14

ANOVAs for Experiment 5

	By participants			By items			By min *F′*		
	df	F_1	***p***	**df**	F_2	***p***	**df**	**min *F′***	***p***
Target									
Coherence									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	5.31	.03	1,34	4.02	.05	1,67	2.29	.14
Gaze duration	1,35	8.07	.007	1,34	7.15	.011	1,69	3.79	.06
Regression path	1,35	20.08	.001	1,34	9.45	.004	1,61	6.43	.01
Rereading	1,35	15.95	.001	1,34	9.76	.004	1,65	6.05	.02
Association									
Skipping rate	1,35	2.53	.12	1,34	1.60	.214	1,65	<1	
First fixation	1,35	5.35	.03	1,34	8.46	.006	1,66	3.28	.08
Gaze duration	1,35	5.08	.03	1,34	4.61	.04	1,69	2.42	.13
Regression path	1,35	<1		1,34	<1				
Rereading	1,35	3.19	.08	1,34	4.83	.04	1,67	1.92	.17
Interaction C × A									
Skipping rate	1,35	3.45	.07	1,34	2.62	.12	1,67	1.49	.23
First fixation	1,35	5.22	.03	1,34	4.46	.04	1,68	2.41	.13
Gaze duration	1,35	5.80	.02	1,34	7.38	.01	1,68	3.25	.08
Regression path	1,35	<1		1,34	<1				
Rereading	1,35	<1		1,34	<1				
Post-target									
Coherence									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	3.85	.06	1,34	6.84	.01	1,64	2.46	.12
Regression path	1,35	14.03	.001	1,34	16.45	.001	1,69	7.57	.008
Rereading	1,35	8.04	.008	1,34	6.23	.02	1,68	3.51	.07
Association									
Skipping rate	1,35	<1		1,34	<1				
First fixation	1,35	<1		1,34	<1				
Gaze duration	1,35	<1		1,34	1.32	.26			
Regression path	1,35	<1		1,34	<1				
Rereading	1,35	<1		1,34	1.14	.29			

Note. None of the interactions in the post-target region approached significance and are not included here.

Table 15

Pair-wise analyses for first fixation and gaze duration on the target region in Experiment 5

	By participants			By items			By min F'		
	df	**F_1**	***p***	**df**	**F_2**	***p***	**df**	**min F'**	***p***
First fixation									
Effect of coherence									
Associated	1,35	<1		1,34	<1				
Unassociated	1,35	8.87	.005	1,34	6.12	.02	1,66	3.62	.06
Effect of association									
Coherent	1,35	<1		1,34	<1				
Scrambled	1,35	8.57	.006	1,34	9.09	.005	1,69	4.41	.04
Gaze duration									
Effect of coherence									
Associated	1,35	<1		1,34	<1				
Unassociated	1,35	13.32	.001	1,34	10.77	.002	1,68	5.96	.02
Effect of association									
Coherent	1,35	<1		1,34	<1				
Scrambled	1,35	8.92	.005	1,34	8.97	.005	1,69	4.47	.04

Table 16

Summary of significant findings

	Discourse congruence (Experiments 1–3)	Association			
		Non-interacting main effects in passages (Experiments 1–3)	Incongruent passages (Experiments 1–3)	Scrambled passages (Experiment 5)	Isolated sentences (Experiment 4)
ERP	P2, N400, LPC	N400	LPC	n/a	n/a
Eye-tracking					
Target					
Skipping rate					5%
First fixation				22 ms	
Gaze duration				29 ms	21 ms
Regression path	157 ms (2)		70 ms (3)		84 ms
Rereading	116 ms (2) 68 ms (3)	57 ms (2)	73 ms (3)		
Post-Target					
Skipping rate					
First fixation					
Gaze duration	47 ms (3)				
Regression path	115 ms (2) 192 ms (3)	81 ms (3)			
Rereading	49 ms (2) 60 ms (3)	36 ms (3)			

Note. For the eye tracking studies effects are only reported if they were significant for both the subjects and items analyses. Experiment number is in parentheses for eye tracking measures in the first three columns.