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On-line contextual influences during reading normal text: The role of nouns, verbs and adjectives

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ABSTRACT

In a series of multiple-regression analyses conducted on the French part of the Dundee corpus, the time spent inspecting a target word in a given sentence was found to depend on its degree of semantic relatedness (as assessed in the LSA framework) to two content words belonging to a prior part of the sentence, and located at varying distances to the left of the target. However, only verb primes were found to elicit a significant influence when located in the more remote position. In addition, the influence elicited by remote primes was modulated as a function of their position in the constituent structure, relative to the position of the target. This pattern of results suggests that relatively abstract semantic relations, probably involved in processing operations developed at the sentence level, can directly influence eye-movement control mechanisms.

1. Introduction

Word recognition processes are known to benefit from the linguistic environment a word is presented in. In lexical decision and cross-modal naming experiments, words that are preceded by a related prime word or a congruous sentence fragment have been shown to be processed faster and more accurately than words presented in isolation or preceded by an unrelated prime (Meyer & Schvaneveldt, 1971; Schuberth & Eimas, 1977; Stanovich & West, 1981; Stanovich & West, 1983). Similar results have been found tracking eye movements in natural reading experiments, with fixation duration varying with the degree of "predictability" (e.g., as assessed by the classical Cloze task, Taylor, 1953), associated with a given target word (see Clifton, Staub, and Rayner (2007) for a review).

Single-word priming effects have generally been interpreted in terms of spreading activation within a semantic network (Collins & Loftus, 1975). Activation from a prime lowers the amount of perceptual information necessary for the target word to be identified. Whether such an account holds for sentence-level contextual influence remains an open question. Since the words composing a congruent sentence can be thought of as semantically related to each other, inter-lexical priming effects can also be expected to occur during normal reading. Alternatively, context effects observed at the lexical level during reading might be mediated by the processing operations developed at the sentence level, as a side-effect of the reader's effort to understand the linguistic material presented. This distinction is important for current models of eye-movement control in reading like *E-Z Reader* (Pollatsek, Reichle, & Rayner, 2006) and SWIFT (Engbert, Nuthmann, Richter, & Kliegl, 2005), in which predictability is assumed to exert its effects at the level of lexical access. In the present study we investigate another possibility: that context effects in reading are partly driven by relatively late post-access processes. Evidence in favour of this notion has been reported by McDonald and Shillcock (2003), and more recently by Pynte, New, and Kennedy (2008), in a series of multiple-regression analyses conducted on the French part of the Dundee corpus (Kennedy, Hill, & Pynte, 2003), using Latent Semantic Analysis, or LSA (Landauer & Dumais, 1997; Landauer, Foltz, & Laham, 1998) as a way of assessing the degree of semantic relatedness between words and sentence fragments.[1]

Pynte et al. (2008) show that both "Word-level" LSA scores (i.e., assessing the degree of semantic relatedness between two adjacent content words) and "sentence-level" LSA scores (between a given content word and the prior sentence fragment, excluding the

[1] "Latent Semantic Analysis (LSA) is a corpus-based statistical method for inducing and representing aspects of the meaning of words and passages reflected in their usage" (Landauer, 2002). A representative sample of the target language (e.g., French) is first collected and divided into short (e.g., 100-word long) passages. This corpus is then converted to a word-by-passage occurrence matrix, with each cell containing the log of the frequency of a given word in a given passage. This matrix is subsequently submitted to singular value decomposition (Berry, 1992), and the number of its dimensions is reduced (e.g., to 300). Once the semantic space has been built up in this way, any word can be represented as a 300-dimensional vector, and it is straightforward to compute the similarity between vectors by means of the cosine function.

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immediately prior word) influence inspection times, suggesting an independent contribution of associative priming and sentence-level processing operations. Whereas word-level LSA scores affected both gaze and single fixation durations, an effect of sentence-level LSA scores only appeared in measures of gaze duration, i.e. for a measure which included refixations. However, the significance of our results at the sentence level can be questioned, because LSA is totally syntax blind. That is, since neither morphology nor word order is taken into account in the computations the nature of any semantic relations LSA might capture at the sentence level becomes rather problematic.

Willits, D'Mello, Duran, and Olney (2007) provide an interesting comment on this issue. For these authors, LSA taps into the level of "thematic role" relations (Carlson & Tanenhaus, 1988; Carnie, 2006; Stowe, 1989). These express the meaning that a Noun Phrase (NP) or Prepositional Phrase (PP) plays with respect to the action described by the verb, and as such, hold at the lexical/sentential interface. Willits et al. compared LSA scores for thematically related and unrelated verb/noun pairs (taken from McRea et al., 2005; McRea, Hare, & Tanenhaus, 2005) and found that thematically related pairs were more "distributionally similar" (i.e. produced higher LSA scores) than thematically unrelated pairs. They also found that pairs that entertained stronger thematic relations were more distributionally similar than pairs that entertained weaker relations.[2]

The results of Willits, D'Mello, Duran, and Olney (2007) provide the basis for a further investigation using LSA scores to assess the nature of sentence-level contextual influences. Instead of considering an entire prior sentence fragment, as in the previous study (Pynte et al., 2008), we focus here on the semantic relationships between a given target word and two specific content words located to its left in the same sentence. The possible contribution of these words to the sentence-level effects observed in our previous study was examined as a function of their lexical category (verb, noun or adjective), their physical position relative to the target word, and their embedding in the constituent structure, relative to the embedding of the target word.

(1) Les discussions ont *débouché* dans la *nuit* sur un accord.
(*The discussions ended up during the night with an agreement.*)

Consider the French word "accord" as the specified target in example (1). The semantic relatedness between this target and the two closest content words in the previous sentence fragment will be analysed. The closest content word ("nuit") will be referred to as the "close prime" and the next content word to its left ("débouché"), as the "remote prime". The noun "accord" is part of a Prepositional Phrase (PP) which is an argument of the verb "débouché" and, as such, fulfils a specific thematic role with respect to the action denoted by the verb. Thus, although further to the left, the remote prime can be expected to exert an influence at the moment when the target word is encountered.

(2) Les discussions ont débouché le jour venu sur un accord.
(*The discussions ended up, come daylight, with an agreement.*)

Such relations may be relatively independent of the specific syntactic construction the verb NP and PP in question are embedded in (the agent and patient roles remain unchanged in the passive voice, for example). Syntax cannot be totally ignored, however. The closest verb to the left of a given noun does not necessarily entertain a thematic relation with this noun. How do we know that "débouché" is thematically related to the target word? In (2), for example, the verb "venu " is part of an adverbial expression inserted between the main verb " débouché " and the complement PP that the target word "accord" is embedded in. Taking into account the depth of embedding of the target relative to the prime word, as suggested above, may partly solve this difficulty. In example (2), "débouché", which is the main verb of the sentence, is located higher up in the constituent structure than "accord", whereas "venu" is not.

If LSA is able to capture thematic relations, we predict an influence of LSA scores computed for both remote and close primes. Furthermore, differential effects for close and remote primes can be expected, depending on the mechanisms thought to be at work. Purely associative relations and relations defined at a thematic level are likely to behave differently as a function of the position of the prime relative to the target word. Associative relations are more likely to operate at a relatively local level, e.g., when they immediately precede the target word. In contrast, more abstract thematic relations should be relatively insensitive to physical distance. Verbs, in particular, can be expected to exert an influence even when separated from a thematically related noun by one or more intervening words.

Differential effects can also be expected as a function of whether primes are verbs, nouns, or adjectives. Unlike associative links, thematic relations must be thought of as essentially asymmetrical. That is, lexical representations for verbs are usually thought of as specifying a list of potential arguments (or empty slots) that surface complements will have to fill with thematic roles (Grimshaw, 1990). In which case, thematic role relations will be ineffective until the verb has actually been encountered and context effects should thus show up in the verb → noun direction only. This question has been investigated by McRae and colleagues. In a series of experiments using both single-word and sentence priming tasks, Ferretti et al. (2001) found that thematically related nouns (e.g., good agents) recruited a greater priming effect from a preceding verb than thematically unrelated nouns. As similar priming effects were also found in the opposite direction, from nouns to thematically related verbs (McRea, Hare, Elman et al., 2005; McRea, Hare, & Tanenhaus, 2005), McRae and colleagues concluded that thematic knowledge probably includes a conceptual (non-linguistic) component. This latter point will be further discussed in the general discussion.

2. Method

2.1. Materials

The analyses were conducted on the French part (52,173 tokens and 11,321 types) of the Dundee Corpus (Kennedy et al., 2003) which is based on extended articles taken from the French language newspaper *Le Monde*. Over a number of testing sessions, ten French-speaking participants read the texts presented at a viewing distance of 500 mm from a display screen, five lines at a time. The set of articles presented to participants was selected from those used by Abeillé, Clément, and Toussenel (2003) to construct their French tree-bank, and the embedding indices used in the present study were based on the syntactic descriptions provided by these authors. Each sentence in the tree-bank was double-checked by two French Ph.D. students in Linguistics, and disambiguation was obtained by agreement among them. An example of how syntactic bracketing was done is provided below

[2] It has been argued that LSA, which is based on co-occurrence data, is unable to capture abstract relation at the sentence level, including thematic role relations (Ferretti, McRae, & Hatherell, 2001; McRea, Ferretti, & Amyote, 1997; McRea, Hare, Elman, & Ferretti, 2005; McRea, Hare, & Tanenhaus, 2005). As noted by Willits, D'Mello, Duran and Olney (2007), this criticism fails to take into account an important aspect of LSA, namely the fact that the co-occurrence data are submitted to singular value decomposition, a data reduction method similar to principal component analysis. This means that LSA actually captures higher order relations: high LSA scores can be obtained between two words even though these words do not co-occur in any document, provided they appear in documents that share many other words.

(adapted from Abeillé et al's original annotations. VN = Verbal Nucleus; Srel = Relative clause; Ssub = Subordinate clause; PP = Prepositional Phrase; NP = Noun Phrase; AP = Adjectival Phrase; VP = non-finite clause; COORD = Coordinate phrase):

[NP **Les troubles** [Srel [NP **qui**] [VN **ont éclaté**]
[PP **à** [NP **la frontière** [PP **entre** [NP **l'Azerbaidjan** [AP **soviétique**]]
[COORD **et** [NP **l'Iran**]]]]]]
[PP **au** [NP **début** [PP **de** [NP **janvier**]]]]]]
[VN **ont autant surpris**] [NP **Téhéran**]]] [Ssub **que** [NP **le reste** [PP **du** [NP **monde**]]]]
(*The troubles which broke out at the border between Iran and Soviet Azerbaidjan at the beginning of January surprised Teheran as much as the rest of the world*)

2.2. Selection criteria

For selection in the present analyses, a word (''word *n*" or ''target word" hereafter) was a noun, a verb or an adjective, and must have been reached by a right-going saccade launched from a word located to its left. Function words were not used as target or prime words: LSA scores are of little interest in the case of high-frequency function words such as determiners, prepositions, pronouns, etc., simply because such words can be found in any context.

2.3. The prime words

Each selected target word was associated with two primes. Both were content words (verb, noun or adjective) and were located in the same, current, sentence fragment (i.e., not farther back than the punctuation mark functioning as terminator for the prior sentence). Commas were ignored (see Pynte and Kennedy (2007) for details about the influence of punctuation on eye movements in reading). The ''close prime" (41149 cases, 64% nouns, 26% verbs, 10% adjectives) was either immediately to the left of the target word or was separated from it by one or more function words but no intermediate content word. The ''remote prime" (38373 cases, 26% nouns, 49% verbs, 24% adjectives) was also located to the left of target word, but was separated from it by at least one other content word (and by zero, one, or several function words). For selection, the remote and close primes must have belonged to different lexical categories, i.e., if the close prime was a noun, the remote prime was either a verb or an adjective (the first verb or adjective encountered to the left of the target word). If the close prime was a verb, the remote prime was the first encountered noun or adjective to the left of the target word. If the close prime was an adjective, the remote prime was the first encountered noun or verb to the left of the target word.

2.4. Semantic relatedness

Each selected target word was associated with a measure of its semantic relatedness to these two prime words. Semantic relatedness was assessed in the Latent Semantic Analysis framework (Landauer & Dumais, 1997; Landauer et al., 1998).[3] A large corpus of novels (14.7 millions words) and film dialogues (16.6 million words) was first used to build up a 300-dimension LSA space in which the semantic content of words of the Dundee Corpus could be represented as vectors. The cosine of the angle between the vector associated with a given target word in the eye-movement corpus and the vector associated with each associated prime words was then computed (the higher the value, the more similar the meanings). All words, at all steps of the procedure, were submitted to lemma transformation. The obtained values were log transformed. They will be referred to below as LSA scores.

2.5. Relative embedding

Additional secondary predictors will be considered, in relation to specific questions. One of these secondary factors is relative embedding, examined in the preliminary analysis. Each target word was associated with measures of its depth of embedding (EMB index) in the constituent structure, relative to the prime words. The depth of embedding of each word was obtained by counting the total number of syntactic brackets open at that point in the sentence where the word was encountered, minus the number of closing brackets (ending a constituent) encountered since the beginning of the sentence. Two measures of relative depth were subsequently associated with each target word, namely (1) the difference between its own depth of embedding and the depth of embedding of the first encountered content word to its left (close prime) and (2) the difference between its own depth of embedding and the depth of embedding of the second closest content word to its left (remote prime). Relative Depth differences were translated into binary factors, with the 1 value associated with cases where the prime was located higher up in the constituent structure and the 0 value associated with cases where the prime was lower down or at the same level.

2.6. Distance

As context effects are also likely to vary as a function of the distance of the remote prime word, relative to the target, this factor (rPos: number of intervening words between the remote prime and the target) was considered in the main analysis. In the case of close prime, the relevant factor is the class of the word immediately to the left of the target word (Class $n-1$). As the close prime was defined as the closest content word encountered to the left of the target, it follows that the close prime was located either immediately to the left of the target (if the prior word is a content word) or separated by at least one function word (if the prior word was a function word).

2.7. Procedure

The influence of the close and remote primes on the time spent inspecting the target was assessed via a series of regression analyses. Context variables were successively added to a baseline model comprising a set of predictors known to influence inspection time. Their contribution to the goodness of fit of the model was evaluated relative to this baseline model. The analyses were conducted in the linear-mixed effects model (*lme*) framework, using the *lme4* package (Bates & Sarkar, 2007) in the *R* system for statistical computing (R Development Core Team, 2007). Both readers and words were treated as random factors. Priming and position effects were estimated as varying across readers.

2.8. Baseline model

In addition to the length and frequency of the target word and the length and frequency of its prior word, the baseline model comprised three predictors whose purpose was to account for variation in inspection time arising as a function of landing position and preview benefit. These were: the size of the saccade entering the target word, its relative landing position (landing position

[3] ''Semantic relatedness" will be used hereafter as a descriptive term, without any connotation of mechanisms. In other words, ''semantic relatedness" precisely refers here to the type of relations that LSA deals with, whatever these relations might be. The aim of the present study is to disentangle potential components of semantic relatedness (e.g., associative vs. thematic relations).

divided by word length), and the square of this latter measure (this quadratic trend captures the fact that first fixations are usually longer at word centre, see O'Regan, Pynte, & Coëffé, 1986; Vitu, McConkie, Kerr, & O'Regan, 2001). To maintain compatibility with previous analyses (Pynte & Kennedy, 2006, 2007), measures of lexical frequency were based on the texts used in the Dundee Corpus and were submitted to log transformation. All independent variables were centred and standardised.

2.9. Correlation between predictors

The correlation matrix is provided as an Appendix A. Correlation coefficients were computed for the full data set (bottom left corner) and for a subset restricted to cases where the remote prime was located higher up in the constituent structure, relative to the target word (top right corner). The obtained values were nearly identical. High correlations were obtained between relative landing position (Landing) and Landing,^{2} between the length and the frequency of word $n-1$, and between these latter two variables and the class of word $n-1$. This is due to the well-known fact that function words are shorter and higher frequency than content words.

Table 1
Regression coefficients with associated standard errors from the preliminary analysis, with gaze duration as the dependent variable.

		Close prime Variance		Remote prime Variance
Random effects				
Item (intercept)		634.01		598.39
Reader (intercept)		886.25		916.41
Reader LSA		4.82		1.70
Residual		12692.63		12762.50
	Estimate	Std. error	Estimate	Std. error
Fixed effects				
(intercept)	313.29	9.63	312.75	9.86
Saccade	1.52	0.11*	1.49	0.12*
Landing	−143.12	6.91*	−137.47	7.92*
Landing^2	119.42	6.20*	114.02	7.11*
Freq. $n-1$	−2.10	0.81*	−1.52	0.93
Length $n-1$	−6.58	0.82*	−6.27	0.94*
Frequency	−9.83	0.51*	−10.66	0.59*
Length	27.39	0.54*	27.23	0.61*
LSA	−2.23	0.85*	−2.16	0.69*
EMB	−2.78	0.98*	−3.78	1.13*
Interaction				
LSA:EMB	−1.15	0.97	−2.44	1.12*

Note: asterisks correspond to significant effects (abs(t) > 2).

3. Results

3.1. Preliminary analysis: position in the constituent structure

As indicated in Section 1, the semantic relations we are interested in, namely thematic relations, partly depend on the relative position of the prime and target words in the constituent structure. The aim of this preliminary analysis was to examine whether semantic priming effects, as assessed by LSA scores, are indeed sensitive to this factor. The question was separately examined for the close and remote primes. As syntax-sensitive effects are likely to affect later, post-access processes, in line with the results of our prior study, the dependent variable was gaze duration. In interpreting these results it should be borne in mind that relative embedding (EMB) was a binary factor, based on the difference between the depth of embedding of the target word and the depth of embedding of the prime word (1 = the prime is located higher up in the constituent structure; 0 = lower down or at the same level).

The results are summarised in Table 1. All the predictors constituting the baseline model (target word length and frequency, length and frequency of the preceding word, size of the entering saccade, relative landing position, square of this latter measure) yielded significant effects. The only exception was the frequency of the prior word in the analysis concerning the remote prime which failed to achieve significance, $t = 1.6$, (right part of Table 1). This discrepancy between two analyses conducted on the same set of data is explained by a difference in the number of cases included in the analyses (there were fewer cases in the remote-prime analysis). Indeed, some target words were preceded by only one content word. The influence of semantic relatedness (see the LSA variable in the Table) was estimated relative to this baseline model. The goodness of fit was improved when LSA scores were included in the regression equation, $X^2 = 35.09$, $p < 0.003$ and $X^2 = 8.13$, $p < 0.005$ for the close- and remote-prime analyses, respectively.

Importantly, the LSA × EMB interaction was significant in the analysis conducted for remote primes, $t = -2.17$ and the corresponding interaction term contributed to the goodness of fit of the model, $X^2 = 4.74$, $p < 0.03$ (there was no significant interaction in the close prime analysis, $X^2 = 1.42$, $p > 0.23$; $t = -1.19$). We interpret the interaction as showing that semantic facilitation, associated with higher LSA scores, was only present when the remote prime was higher up in the constituent structure than the target. When no such dominance relation was present, semantic relatedness was apparently irrelevant (or possibly inhibitory, see Fig. 1). In the following analyses, only a subset of the data will be considered, with the constraint that the remote prime dominated the target in the constituent structure.

3.2. The specific contribution of remote primes

Both primes were found to modulate the time spent inspecting the target. However, these effects were obtained in separate analyses, the possible influence of the other prime being ignored in each case. In this section, we examine whether the effect associated with the remote prime remains unchanged in an analysis where both sources of influence are taken into account. In other words, will the remote prime improve the goodness of fit of a model already comprising a closer source of facilitation?

As remote primes are less likely to exert their influence via associative priming mechanisms, and since only those cases where the remote prime was likely to entertain a thematic relation with

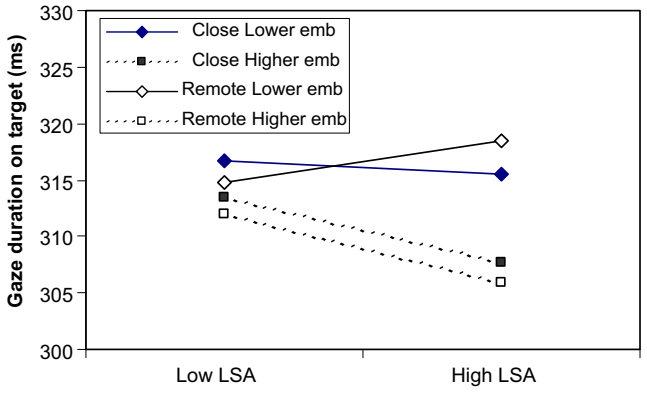

Fig. 1. Semantic relatedness effects elicited by close and remote primes as a function of their position in the constituent structure, relative to the position of the target word (higher vs. lower embedding).

the target were included in the analysis, the remote vs. close distinction can be thought of as distinguishing these two potential types of contextual influences. Accordingly, and following the argument set out in the Introduction, two measures of inspection time were contrasted, namely gaze duration and single fixation duration.[4] In line with our prior study, remote/thematic effects were expected to show up only in measures of gaze duration (i.e. capturing later effects), whereas close/associative effects were expected to show up in both measures.

Both LSA scores were successively included in the regression equation. They will be referred to as cLSA (assessing the degree of semantic relatedness between the close prime and the target word) and rLSA (assessing the degree of semantic relatedness between the remote prime and the target word), respectively. As indicated in Section 3.1 cases for which the remote prime did not dominate the target word were excluded from the data set. Furthermore, as both cLSA and rLSA scores were used in the analysis, the data set was inevitably restricted to cases for which both a cLSA and rLSA score was available.

Again, the contribution of semantic relatedness was estimated relative to a baseline model comprising the same predictors as in the previous analyses. In order to account for the possible influence of physical distance, the following two predictors were added to the baseline model:

- rPos: distance between rPrime and Target (number of intermediate words).
- Class $n-1$: class of the word immediately to the left of the target word (referred to as the prior word or word $n-1$ hereafter). A binary factor, word $n-1$ being either a content or a function word. As indicated in Section 2.6, Class $n-1$ can be redefined in terms of the position of the close prime relative to the target: either immediately adjacent or separated by at least one function word.

The results are summarised in Table 2 (gaze duration on the left, single fixation duration on the right). Again, all the predictors included in the baseline model (apart from word $n-1$ frequency) yielded significant effects. This was true for both gaze and single fixation durations. The class of the word to the left of the target word did not exert a significant influence on the gaze duration recorded on the target word, $t = 1.69$.

Neither cLSA nor rLSA significantly contributed to the goodness of fit of the model accounting for single fixation durations ($X^2 = 4.91$, $p > 0.08$, $t = -2.21$, $p < 0.05$, and $X^2 = 0.90$, $p > 0.63$, $t = -0.95$, n.s., for cLSA and rLSA, respectively). The significant t value obtained for cLSA scores was reduced to a marginally significant $t = -1.91$, when rLSA scores were added to the regression equation. Crucially, adding both cLSA and rLSA significantly improved the fit in the analysis of gaze durations ($X^2 = 14.55$, $p < 0.0007$, $t = -3.15$ and $X^2 = 11.31$, $p < 0.004$, $t = -2.47$, respectively). That is, adding rLSA to a model that already included cLSA further increased the goodness of fit of the model.

In the case of cLSA, a significant interaction with the class of word $n-1$ was observed, $X^2 = 21.06$, $p < 0.0006$, $t = 4.59$. The influence of the close prime was only present when it was the immediately prior word (i.e. no intermediate function word was present, see Fig. 2). In contrast, no significant effect was entailed by the rLSA:rPOS interaction term. Apparently, the effect of the remote prime did not depend on its physical distance to the target.

[4] The term "inspection time" will be used hereafter in order to refer to both measures when appropriate.

Table 2
Regression coefficients with associated standard errors from the combined analysis of close and remote priming effects, with gaze and single fixation durations as dependent variables.

	Gaze duration Variance		Single fix. duration Variance	
Random effects				
Item (intercept)	578.75		283.77	
Reader (intercept)	943.40		191.79	
Reader rLSA	3.28		0.00	
Reader cLSA	2.15		0.00	
Reader rPOS	0.00		0.82	
Residual	12911.00		4639.80	
	Estimate	Std. error	Estimate	Std. error
Fixed effects				
(intercept)	305.67	10.28	217.85	5.04
Saccade	1.44	0.16*	1.46	0.11*
Landing	−140.75	10.10*	43.22	7.41*
Landing^2	120.30	9.15*	−27.74	6.59*
Freq, $n-1$	−1.08	1.44	2.26	1.01
Length $n-1$	−2.94	1.25*	2.38	0.89*
Frequency	−10.93	0.77*	−4.54	0.55*
Length	26.16	0.77*	4.38	0.53*
Class $n-1$	5.05	2.68	−3.45	1.88*
rPOS	−0.94	0.69	−0.20	0.57
cLSA	−2.10	0.85*	−0.97	0.51
rLSA	−2.26	0.92*	−0.48	0.51
Interactions				
cLSA:Class $n-1$	6.90	1.50*	1.27	1.07
rLSA:rPOS	−0.56	0.69	−0.71	0.48
rLSA:cLSA	0.68	0.57	0.35	0.40
cvLSA	0.12	1.42	0.35	0.93
cnLSA	−3.41	1.06*	−1.80	0.68*
caLSA	−1.49	1.72	−0.93	1.19
rvLSA	−2.82	1.10*	−0.66	0.67
rnLSA	−0.50	1.58	0.59	1.04
raLSA	−2.52	1.58	−0.82	1.03
rLSA:cvLSA	−0.50	1.10	−0.63	0.74
rLSA:cnLSA	1.74	0.71*	0.89	0.50
rLSA:caLSA	0.79	1.19	1.30	0.84
rvLSA:cLSA	1.87	0.77*	1.08	0.54*
rnLSA:cLSA	−0.39	0.92	−0.23	0.63
raLSA:cLSA	1.47	1.22	0.89	0.86

Note: asterisks correspond to significant effects (abs(t) > 2).

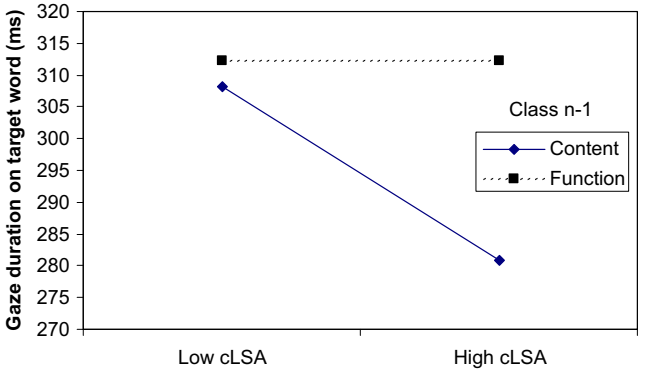

Fig. 2. Semantic relatedness effects elicited by close primes as a function of the class of the word located to the left of the target word (content vs. function word).

3.3. The contribution of verbs, nouns and adjectives

As suggested in Section 1, verbs, nouns and adjectives can be expected to exert different effects. Verbs entertain thematic role relations with NP and PP complements and are thus more likely to exert long distance influences. In contrast, nouns and adjectives can be expected to operate at a more local level. cLSA and rLSA effects were partitioned out, as a function of the syntactic category of each prime. cLSA scores associated with verbs, nouns and adjec-

tives are referred to as cvLSA, cnLSA and caLSA, respectively in Table 2. Similarly, rLSA scores for the three categories are referred to as rvLSA, rnLSA and raLSA. As can be seen in Table 2, a significant close prime effect was obtained when the close prime was a noun (cnLSA), $t = -3.21$ and $t = -2.66$ for gaze and single fixation durations, respectively. In contrast, a significant remote-prime effect was only obtained for rvLSA, that is, when the remote prime was a verb, and then only in the analysis of gaze duration, $t = -2.56$.

A new analysis of gaze duration (Table 3) was conducted on a subset of the data, with the remote prime being set to the Verb value, thus excluding all cases where the remote prime was a noun or an adjective. As a consequence of the selection criteria the close prime was, therefore, either a noun or an adjective (see Section 2.3). Again, both cLSA and rLSA were significant, $t = -2.48$ and $t = -2.10$, respectively. The goodness of fit of the model was improved when cLSA was included, $X^2 = 16.02$, $p < 0.0004$, and further improved when rLSA was subsequently included, $X^2 = 7.64$, $p < 0.03$. In contrast, neither cLSA nor rLSA significantly improved the goodness of fit of the model in two complementary sub-analyses with the remote prime set to either "Noun" or "Adjective" (and the consequential changes to the close prime category).

This pattern of results suggests that nouns and verbs elicit specific contextual effects during reading, with nouns and adjectives exerting their influence at a local level, and verbs at a more remote one, probably via quite different mechanisms (given the differential effects on measures of single fixation duration and gaze). Note however, that these effects were not independent from each other, as witnessed by the presence of two significant interactions (see the rLSA:cnLSA and rvLSA:cLSA interaction terms in Table 2). The influence of a close noun was smaller when the remote prime (either verb or adjective) was also related to the target, $t = 2.45$. Moreover, the influence of the close prime (either noun or adjective) was smaller when a remote verb was also related to the target, $t = 2.42$. This is illustrated in Fig. 3.

Table 3
Regression coefficients with associated standard errors from the analysis restricted to cases where the remote prime was a verb and the close prime a noun or an adjective.

	Gaze duration Variance		Single fix. duration Variance	
Random effects				
Item (intercept)	535.68		259.78	
Reader (intercept)	1003.99		195.36	
Reader rLSA	5.55		0.00	
Reader cLSA	7.05		0.00	
Reader rPOS	4.42		2.38	
Residual	12885.05		4654.20	
	Estimate	Std. error	Estimate	Std. error
Fixed effects				
(intercept)	303.85	11.14	215.60	5.69*
Saccade	1.47	0.22*	1.41	0.15*
Landing	−143.78	14.42*	48.73	10.57*
Landing^2	123.41	13.12*	−34.23	9.44*
Freq, $n-1$	−0.80	2.05	0.72	1.43
Length $n-1$	−2.44	1.74*	2.20	1.22*
Frequency	−11.00	1.09*	−4.52	0.78*
Length	26.41	1.09*	4.34	0.76*
Class $n-1$	8.25	4.02*	0.34	2.81
rPOS	−0.04	1.18*	0.05	0.85*
cLSA	−3.26	1.32*	−1.48	0.72*
rLSA	−2.63	1.25*	−0v52	0.71
Interactions				
cLSA:Class $n-1$	6.28	2.07*	−0.58	0.74
rLSA:rPOS	−0.27	1.05	1.36	1.47
rLSA:cLSA	1.23	0.80	0.76	0.57

Note: asterisks correspond to significant effects (abs(t) > 2).

4. General discussion

The present study was conducted as a follow-up to a prior study (Pynte et al., 2008), in which Latent Semantic Analysis (LSA) was used to assess the degree of contextual influence words and sentence fragments exerted on a given target word during the reading of normal text. Both word-level and sentence-level contextual influences were found in that study, an outcome suggesting that in addition to inter-lexical priming effects, word recognition during continuous reading may be subject to more abstract, sentence-level, sources of influence. However, as indicated in the Introduction, the nature of the semantic properties that LSA can capture is itself contentious: the most that can be claimed is that *some* of the relations that sentence-level processing relies on were indeed captured in this prior study.

In the present study we sought to avoid this criticism by focussing on the possible influence (on a given target word) of two content words located at varying distances in the prior sentence fragment. The degree of semantic relatedness between these words and the target was independently assessed, and their position in the constituent structure, relative to the target, was controlled. As in the prior study the possible contribution of the prime words was evaluated by successively adding their corresponding LSA scores to a baseline regression model that included well-established predictors of processing time (frequency, length, landing position, etc.).

The degree of semantic relatedness between both prime words and the target was shown to significantly improve the goodness of fit of the baseline model. In particular, evidence of contextual influence was found for both the "remote" and the "close" prime words, and this was true for both the separate (Table 1) and combined analyses (see Table 2 in which the cLSA and rLSA variables corre-

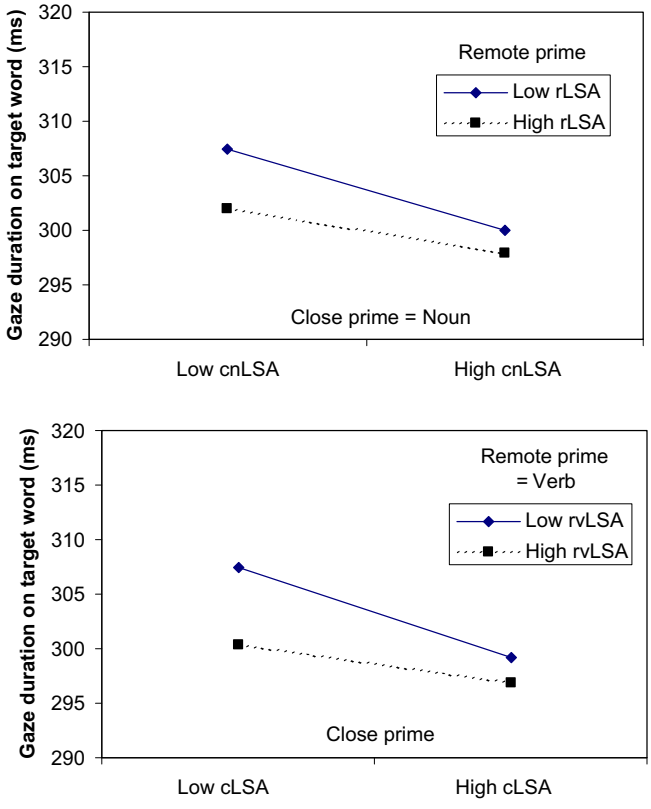

Fig. 3. Interaction between the close and remote primes in two sub-analyses, with the constraint that the close prime was a noun (top panel) or that the remote prime was a verb (bottom panel).

spond to the degree of semantic relatedness associated with the close and remote prime words, respectively). That is, the degree of contextual influence the target word received from a remote prime word was a significant predictor of gaze duration independent of any competing influence of a close prime word.

Interestingly, the contribution of a remote prime to target processing time did not depend on its physical separation from the target (i.e. there was no statistical interaction between rLSA and rPOS), whereas a close prime only exerted an influence when located immediately to the left of the target. As suggested in the Introduction, physical distance is less relevant to more abstract relations, such as thematic relations, whereas associative links probably operate at a local level, between adjacent words. In fact, the way these effects are manifested in the eye-movement record suggests that LSA scores from remote and close primes may implicate two quite different types of mechanism. Gaze duration was apparently sensitive to both close and remote sources of influence; in contrast, only close prime effects were evident in measures of single fixation duration. Although it is difficult to separate from more general questions regarding the kind of semantic relations that LSA can plausibly capture, such a pattern is, at least, consistent with the operation of two processing levels because the measure of gaze duration (typically involving refixation), is likely to reflect post-lexical integration processes. This conclusion is important for current models of eye-movement control in reading, which have generally failed to distinguish between these two distinct sources of contextual influence. Reichle, Warren, and McConnel (2009) recently proposed an extension to the E-Z Reader model (Pollatsek et al., 2006) aimed at accounting for high-level influences (e.g., syntactic and sentence-level semantic processes). However, their basic assumption is still that these high-level processes either run "invisibly" (e.g., after attention has moved to the next word) or manifest themselves by introducing occasional disruptions (e.g., wrap-up effects and regressions) in the normal course of visual inspection. In contrast to this view, the present results suggest that the processing operations developed at the sentence level may influence gaze durations more directly.

We will turn now to consider the possible role played by thematic role relations in these results. The first and most obvious pointer in this direction stems from the fact that the influence exerted by a remote prime was modulated by its position in the constituent structure, relative to the position of the target word. Semantic relatedness, as indexed by LSA scores, is apparently ineffective when the position of the remote prime in the constituent structure excludes the possibility of a thematic role relation. Second, remote influences were restricted to verbs. This is consistent with the notion that the argument structure associated with a verb must be available before thematic relations can become effective (Grimshaw, 1990).[5] The fact that no remote effect (on a verb target) was found for noun prime words contrasts with the claim made by McRea et al., 2005; McRea et al., 2005 that thematic relations can operate in both directions. However, as suggested by these authors, symmetrical effects of this type may involve the existence of semantic representations enriched by conceptual knowledge, something that LSA probably fails to capture. The fact that verb primes did not exert any influence when located close to the target (only nouns did) is surprising. Assuming that the principal effects of close primes are mediated by inter-lexical priming, an explanation might be found in the type of associative link likely to produce such effects (at a purely associative level, verbs may be less good primes than nouns). Equally, the lack of apparent thematic priming in the close prime condition possibly means that additional time is needed before argument structures become available, allowing thematic roles to be filled.

Our results contrast with several studies that have failed to find any distant effect of word relatedness in sentence reading experiments (see for example, Traxler, Foss, Seely, Kaup, & Morris, 2000). The discrepancy is only apparent, however, since most of these studies manipulated schematic (lumberjack-axe) or synonymy (pastor-minister) rather than thematic relations. The fact that remote verb primes were found to exert an influence in the present study suggests that something different from associative priming was involved, since associative priming was apparently unable to elicit such effects in these other studies.

Given this set of converging evidence, we are tempted to conclude that remote contextual influences were driven by thematic role relations. Does this conclusion tell us anything more about the way these mechanisms impact on eye-movement control during reading? Thematic role have been shown to play an important role in sentence comprehension (Altmann & Kamide, 1999; Ferreira & McClure, 1997; Frederici & Frisch, 2000; Frish, Hahne, & Frederici, 2004; Huettig & Altmann, 2005; Juliano & Tanenhaus, 1994; Kuperberg, Caplan, Sitnikova, Eddy, & Holcomb, 2006; Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007; McElree & Griffith, 1995; Yee & Sedivy, 2006), giving some credence to the general hypothesis, formulated in the Introduction, that some of the contextual influences observed in natural reading are a by-product of processing operations developed at the sentence level. Unfortunately, little is known as to how and when thematic roles enter into play during sentence comprehension. They have been thought to operate either immediately, together with all other available sources of information (McClelland, St. John, & Taraban, 1989; McDonald, 1994) or at a later processing stage, subsequent to syntactic analysis (Ferreira & Clifton, 1986; Frazier, 1977; Frazier & Rayner, 1982; McElree & Griffith, 1995; Mitchell, 1994; Rayner, Carlson, & Frazier, 1983). For example, Ferreira and Clifton (1986) have provided evidence in favour of the notion that an initial syntactic structuring of the sentence may occur before the thematic restrictions that the verb imposes on its arguments (e.g., animacy) have a chance to come into play (Clifton et al., 2003, for further evidence, but see also Staub (2007) and Trueswell, Tanenhaus, and Garnsey (1994) for contrasting results). Furthermore, Mitchell (1987) argued that the sub-categorisation information associated with verbs (e.g., intransitivity) is initially ignored during sentence comprehension (see also van Gompel & Pickering, 2001). As the present study suggests that thematic influences are contingent on accessing a verb's argument structure (see the verb/noun asymmetry discussed above), this would mean that the locus of thematic influence must be looked for after an initial syntactic analysis has been performed. In contrast to this view, Staub (2007) recently presented evidence in favour of the notion that thematic influences may manifest themselves before any syntactic structuring of the sentence. As indicated by Staub (2007), this does not mean that a prior syntactic structuring does *not* occur, provided this initial structuring is informed by the verb's argument structure (see also Ferreira & McClure, 1997, for a discussion). In fact, current debate regarding the possible locus of thematic influence in sentence comprehension parallels that in the reading literature concerning the locus of contextual influences. More research will be necessary in both domains to clarify the issue.

[5] In a study using event-related brain potentials, Bornkessel, Schlesewsky, and Friederici (2003) have presented evidence for the existence of an autonomous thematic processing stage. They showed that sentential arguments in German can be organised into a thematic hierarchy with respect to one another before the verb is encountered. However, this result was dependent on the presence of unambiguous morphological case marking, suggesting that such autonomous thematic processing "could tentatively be considered a "shortcut" to sentence-level interpretation".

Appendix A

See Table A1.

Table A1
Correlation between predictors.

	Sac	Cla $n-1$	Land	Land^2	Freq	Lgth	Freq $n-1$	Lgth $n-1$	cLSA	rLSA	rPOS
Saccade		0.00	0.02	0.03	−0.05	0.14	0.01	0.05	0.04	0.02	0.00
Class $n-1$	0.01		0.02	0.01	0.12	−0.13	0.82	−0.73	−0.02	−0.03	0.08
Landing	0.02	0.03		0.98	0.03	−0.16	0.03	−0.01	−0.01	−0.02	0.03
Landing^2	0.02	0.02	0.98		0.03	−0.17	0.03	−0.01	−0.02	−0.03	0.02
Frequency	−0.04	0.09	0.04	0.04		−0.26	0.16	−0.14	−0.07	−0.07	0.02
Length	0.14	−0.07	−0.15	−0.16	−0.29		−0.12	0.17	0.12	0.12	−0.06
Frequency $n-1$	0.01	0.78	0.04	0.04	0.11	−0.08		−0.82	−0.04	−0.04	0.06
Length $n-1$	0.05	−0.66	−0.02	−0.02	−0.11	0.13	−0.81		0.06	0.05	−0.07
cLSA	0.03	0.04	−0.02	−0.02	−0.04	0.13	0.00	0.02		0.28	−0.01
rLSA	0.03	−0.01	0.00	−0.01	−0.08	0.14	−0.01	0.03	0.22		−0.03
rPOS	0.01	0.13	0.01	0.01	0.05	−0.03	0.07	−0.08	0.01	−0.01	

References

Abeillé, A., Clément, L., & Toussenel, F. (2003). Building a French treebank. In A. Abeillé (Ed.), *Treebanks: Building and using parsed corpora* (pp. 165–188). Dordrecht: Kluwer.

Altmann, G. T. M., & Kamide, Y. (1999). Incremental interpretation at verbs: Restricting the domain of subsequent reference. *Cognition, 73*, 247–264.

Bates, D., & Sarkar, D. (2007). lme4: Linear mixed-effectsmodels using S4 classes. R package version 0.9975-13.

Berry, M. W. (1992). Marge scale singular value computations. *International Journal of Supercomputer Applications, 6*, 13–49.

Bornkessel, I., Schlesewsky, M., & Friederici, A. D. (2003). Eliciting thematic reanalysis effects: The role of syntax-independent information during parsing. *Language and Cognitive Processes, 18*, 269–298.

Carlson, G. N., & Tanenhaus, M. K. (1988). Thematic roles and language comprehension. In W. Wilkens (Ed.). *Syntax and semantics: Thematic relations* (Vol. 21, pp. 263–300). San Diego, CA: Academic Press.

Carnie, A. (2006). *Syntax: A generative introduction* (2nd ed.). Blackwell Publishers.

Clifton, C., Staub, A., & Rayner, K. (2007). Eye movement in reading words and sentences. In R. V. Gompel, M. Fisher, W. Murray, & R. L. Hill (Eds.), *Eye movements: A window in mind and brain* (pp. 341–372). Elsevier.

Clifton, C., Traxler, M. J., Mohamed, M. T., Williams, R. S., Morris, R. K., & Rayner, K. (2003). The use of thematic information in parsing: Syntactic processing autonomy revisited. *Journal of Memory and Language, 49*, 317–334.

Collins, A. M., & Loftus, E. F. (1975). A spreading activation theory of semantic priming. *Psychological Review, 82*, 407–428.

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005). SWIFT: A dynamical model of saccade generation during reading. *Psychological Review, 112*, 777–813.

Ferreira, F., & Clifton, C. (1986). The independence of syntactic processing. *Journal of Memory and Language, 25*, 348–368.

Ferreira, F., & McClure, K. (1997). Parsing of garden-path sentences with reciprocal verbs. *Language and Cognitive Processes, 12*, 273–306.

Ferretti, T. R., McRae, K., & Hatherell, A. (2001). Integrating verbs, situation schemas, and thematic role concepts. *Journal of Memory and Language, 44*, 516–547.

Frazier, L. (1977). On comprehending sentences: Syntactic parsing strategies. Unpublished doctoral dissertation. University of Connecticut.

Frazier, L., & Rayner, K. (1982). Making and correcting errors during sentence comprehension: Eye movements in the study of structurally ambiguous sentences. *Cognitive Psychology, 14*, 178–210.

Frederici, A. D., & Frisch, S. (2000). Verb argument structure processing: The role of verb-specific and argument-specific information. *Journal of Memory and Language, 43*, 476–507.

Frish, S., Hahne, A., & Frederici, A. D. (2004). Word category and verb-argument structure information in the dynamics of parsing. *Cognition, 91*, 191–219.

Grimshaw, J. (1990). *Argument structure*. Cambridge, MA: MIT Press.

Huettig, F., & Altmann, G. T. M. (2005). Word meaning and the control of eye fixation: Semantic competitor effects and the visual word paradigm. *Cognition, 96*, 23–32.

Juliano, C., & Tanenhaus, M. K. (1994). A constraint-based lexicalist account of the subject/object attachment preference. *Journal of Psycholinguistic Research, 23*, 459–471.

Kennedy, A., Hill, R., & Pynte, J. (2003). The dundee corpus, Poster presented at ECEM12. In *12th European conference on eye movements*. Dundee, August 2003.

Kuperberg, G., Caplan, D., Sitnikova, T., Eddy, M., & Holcomb, P. J. (2006). Neural correlates of processing syntactic, semantic and thematic relationships in sentences. *Language and Cognitive Processes, 21*, 489–530.

Kuperberg, G., Kreher, D. A., Sitnikova, T., Caplan, D., & Holcomb, P. J. (2007). The role of animacy and thematic relationships in processing active English sentences: evidence from event related potentials. *Brain and Language, 100*, 223–237.

Landauer, T. K. (2002). On the computational basis of learning and cognition: Arguments from LSA. *Psychological Learning and Motivation, 41*, 43–84.

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review, 104*, 211–240.

Landauer, T. K., Foltz, P. W., & Laham, D. (1998). An introduction to Latent Semantic Analysis. *Discourse Processes, 25*, 259–284.

McClelland, J. L., St. John, M., & Taraban, R. (1989). Sentence comprehension: A parallel distributed approach. *Language and Cognitive Processes, 4*, 287–336.

McDonald, M. C. (1994). Probabilistic constraints and syntactic ambiguity resolution. *Language and Cognitive Processes, 9*, 157–201.

McDonald, S. A., & Shillcock, R. C. (2003). Low-level predictive inference in reading: The influence of transitional probabilities on eye movements. *Vision Research, 43*, 1735–1751.

McElree, B., & Griffith, T. (1995). Syntactic and thematic processing in sentence comprehension: Evidence for a temporal dissociation. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21*, 134–157.

McRea, K., Ferretti, T. R., & Amyote, L. (1997). Thematic roles as verb-specific concepts. *Language and Cognitive Processes, 12*, 137–176.

McRea, K., Hare, M., Elman, J., & Ferretti, T. (2005). A basis for generating expectancies for verbs from nouns. *Memory & Cognition, 33*, 1174–1184.

McRea, K., Hare, M., & Tanenhaus, M. (2005). Meaning through syntax is insufficient to explain comprehension of sentences with reduced relative clauses: Comments on McKoon and Ratcliff (2003). *Psychological Review, 112*, 1022–1031.

Meyer, D. E., & Schvaneveldt, R. W. (1971). Facilitation in recognizing pairs of words: Evidence of a dependence between retrieval operations. *Journal of Experimental Psychology, 90*, 227–234.

Mitchell, D. C. (1987). Lexical guidance in human parsing: Locus and processing characteristics. In M. Coltheart (Ed.), *Attention & performance XII: The psychology of reading* (pp. 601–618). Hillsdale, NJ: Erlbaum.

Mitchell, D. C. (1994). Sentence parsing. In M. A. Gernsbacher (Ed.), *Handbook of psycholinguistics*. New York: Academic Press.

O'Regan, K., Pynte, J., & Coëffé, C. (1986). Comment le regard explore un mot isolé. *Bulletin de Psychologie, 39*, 7–10.

Pollatsek, A., Reichle, E. D., & Rayner, K. (2006). Tests of the E-Z reader model: Exploring the interface between cognition and eye-movement control. *Cognitive Psychology, 52*, 1–56.

Pynte, J., & Kennedy, A. (2006). An influence over eye movements in reading exerted from beyond the level of the word: Evidence from reading English and French. *Vision Research, 46*, 3786–3801.

Pynte, J., & Kennedy, A. (2007). The influence of punctuation and word class on distributed processing in normal reading. *Vision Research, 47*, 1215–1227.

Pynte, J., New, B., & Kennedy, A. (2008). On-line contextual influences during reading normal text: A multiple-regression analysis. *Vision Research, 48*, 2172–2183.

R Development Core Team (2007). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL <http://www.R-project.org>.

Rayner, K., Carlson, M., & Frazier, L. (1983). The interaction of syntax and semantics during sentence processing: Eye movements in the analysis of semantically biased sentences. *Journal of Verbal Learning and Verbal Behavior, 22*, 358–374.

Reichle, E. D., Warren, T., & McConnel, K. (2009). Using E-Z Reader to model the effects of higher-level language processing on eye movements during reading. *Psychonomic Bulletin & Review, 16*, 1–21.

Schuberth, R. E., & Eimas, P. D. (1977). Effect of context on the classification of words and non-words. *Journal of Experimental Psychology: Human Perception and Performance, 3*, 27–36.

Stanovich, K. E., & West, R. F. (1981). The effect of sentence context on ongoing word recognition: Tests of a two-process theory. *Journal of Experimental Psychology: Human Perception and Performance, 7*, 658–672.

Stanovich, K. E., & West, R. F. (1983). On priming by a sentence context: Implications for models of reading and lexical processing. *Journal of Experimental Psychology: General, 112*, 1–36.

Staub, A. (2007). The parser doesn't ignore intransitivity, after all. *Journal of Experimental Psychology: Learning, Memory and Cognition, 33*, 550–569.

Stowe, L. (1989). Thematic structures and sentence comprehension. In G. N. Carlson & M. K. Tanenhaus (Eds.), *Linguistic structures in language processing* (pp. 318–357). Dordrecht: Kluwer Academic.

Taylor, W. L. (1953). Cloze procedure: A new tool for measuring readability. *Journalism Quarterly, 30*, 415–433.

Traxler, M. J., Foss, D. J., Seely, R. E., Kaup, B., & Morris, R. K. (2000). Priming in sentence processing: Intralexical spreading activation, schemas, and situation models. *Journal of Psycholinguistic Research, 29*, 581–595.

Trueswell, J. C., Tanenhaus, M. K., & Garnsey, S. M. (1994). Semantic influences on parsing: Use of thematic role information in syntactic disambiguation. *Journal of Memory and Language, 33*, 285–318.

Van Gompel, R. P. G., & Pickering, M. J. (2001). Lexical guidance in sentence processing: A note on Adams, Clifton, and Mitchell (1998). *Psychonomic Bulletin & Review, 8*, 851–857.

Vitu, F., McConkie, G. W., Kerr, P., & O'Regan, J. K. (2001). Fixation location effects on fixation durations during reading: An inverted optimal viewing position effect. *Vision Research, 41*, 3513–3533.

Willits, J. A., D'Mello, S. K., Duran, N. D., & Olney, A. (2007) Distributional statistics and thematic role relationships. In *Proceedings of the 29th annual conference of the Cognitive Science Society* Nashville, Tennessee, August 1–4 (pp. 707–712).

Yee, E., & Sedivy, J. (2006). Eye movements to pictures reveal transcient semantic activation during spoken word recognition. *Journal of Experimental Psychology: Leanring, Memory & Cognition, 32*, 1–14.