# EYE TRACKING THE INFLUENCE OF LEXICAL EMBEDDINGS IN WRITTEN WORD RECOGNITION: A FIRST INVESTIGATION

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*Running head:* Lexical embeddings in written words

**Authors note**

*Acknowledgements:* The eye-tracking equipment used in this research was funded by a grant from the Swiss National Foundation 10011-107768/1 to Dirk Kerzel.

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## ABSTRACT

A word containing an embedded word is supposed to be more difficult to recognize than a word without a lexical embedding because of an increased lexical confusability. However, previous studies indicated that such a lexical configuration finally benefits word recognition. The current study first aimed at replicating these findings in the visual modality by investigating the recognition of French monomorphemic nouns containing an embedded word. Second, it aimed at exploring the processing of these words with eye-tracking. Our findings confirmed that lexical embeddings were processed and that they influenced word recognition favorably. Lexical embeddings facilitated the recognition of their carrier word and refixations were away from lexical embeddings. Facilitation was likely due to processes occurring at the lexical level.



**Key words**

Word recognition, Embedded word, Eye-tracking, Lexical access, Facilitation, TRACE.

## INTRODUCTION

The perceptual process of word recognition, whether for written words or for spoken words, implies an activation of lexical representations stored in long-term memory. During the last 30 years, numerous psycholinguistic studies have demonstrated that a selection process must go together with this activation process in order to recognize the correct word among the alternative neighbors that are also activated. Actually, one stimulus word generally activates more than one candidate representation in the mental lexicon, and a disambiguation process is therefore necessary.

Selection mechanisms have been considered, from the progressive targeting of the correct candidate through cohort reduction of the activated mental representations (Marslen-Wilson & Welsh, 1978), to lateral inhibition between the alternative activated representations (Grossberg, 1968; McClelland & Rumelhart, 1981). Such mechanisms refer to the general theoretical concept of lexical competition. Lexical competition can be summarized in the following way: If a stimulus word activates more than one lexical representation at the same time in the mental lexicon, a competitive process between the activated lexical representations is triggered. Usually, the selection process is supposed to occur between the lexemes (mental representations of the formal aspects of the word), but, at least theoretically, it could be possible too at the lemma level (mental representations of the conceptual aspects of words).

TRACE (McClelland & Elman, 1986; McClelland & Rumelhart, 1981) is among the most influential models dealing with word recognition in psycholinguistics. Its connectionist implementation describes simple and well-defined mechanisms, which successfully explains and predicts many behavioral observations. Therefore, TRACE offers an interesting theoretical framework, and we chose this model to frame the present research. Because of the lateral inhibition which achieves selection in TRACE, a word is more difficult to recognize if it has competitors (the stimulus word activates more than one lexical representation in the mental lexicon and these representations are in conflict), than a word with no competitors (the stimulus word activates only one lexical representation in the mental lexicon and there is no conflict).

**Predictions of TRACE for lexical embeddings**

One particular lexical configuration of words in which more than one lexical representation is activated in the mental lexicon is lexical embeddedness, or word superimposition. A word is superimposed to another, or embedded into it, when the sequence of letters or phonemes composing the embedded word is a subpart of the sequence of letters or phonemes composing the carrier word. For instance, the word CARRIER carries the embedded word CAR. CAR and CARRIER are therefore superimposed.

This lexical configuration is extremely frequent in any given language. For instance, in English, more than 98% of the words contain at least one embedded word (Cutler, McQueen, Jansonius, & Bayerl, 2002). Furthermore, this lexical configuration is universal. It is found in all natural human languages based on an alphabet-like code. The use of a limited number of sublexical units (alphabet, set of phonemes) for the production of a theoretically infinite number of lexical units causes this redundancy in the lexicon.

The consequence for word recognition, according to TRACE, is that most of the words will be difficult to recognize. The two main reasons for this increased difficulty are (1) the increased confusability between words due to lexical superimpositions, and (2) the supplementary computations needed to resolve this ambiguity through selection processes.

Living systems tend to spare energy as a valuable resource. Consequently, they should tend to adopt structures that fulfill a function at the minimum cost in terms of resources. Concerning the issue of processing lexical embeddings, a system like TRACE appears to be more like a metaphor than like a model: It may recognize a word, but it does not do it parsimoniously. Indeed, it seems curious that a natural system of word recognition would be in trouble for recognizing most of the words because the lexicon’s architecture makes lexical embeddedness the rule, not the exception. Why and how would such lexicons have been developed? Starting from these inconsistencies, an interesting trail to follow was to reverse the theoretical proposition of TRACE, by stating that human lexicons have a superimposing structure because this structure is an advantage for the process of word recognition.

**Facilitation due to embedded words contradicts TRACE**

Luce and Lyons (1999), and Lachaud (2005), reported a behavioral pattern differing from that predicted by TRACE for the recognition of monomorphemic spoken nouns beginning with a lexical embedding: Embedded words proved to facilitate the recognition of their carrier compared to a control situation (word without lexical embedding). This behavioral pattern is in agreement with the evolutionary logics behind a general superimposing structure of the lexicon, and what the effect of this structure should be on recognition: An advantage. Luce and Lyons (1999) obtained this effect with a lexical decision task. English disyllabic monomorphemic nouns starting with a first lexical syllable (“cherish” starts by “chair”) were recognized 52 ms faster than control nouns (“flourish”). Disyllabic nouns with a final lexical syllable did not show any advantage (“chloride” ending with “ride”, vs. “chlorine”).

In a series of experiments using a ‘go, no-go’ lexical decision task, Lachaud (2005) replicated the observations of Luce and Lyons for French words. He obtained facilitation for disyllabic monomorphemic spoken nouns starting by a lexical embedding (24 ms to 62 ms facilitation depending on the experiment -- nouns such as /tɛʁmɔs/ “thermos”/thermos flask beginning by /tɛʁ/ “terre”/earth, compared to controls without initial lexical embeddings such as /kʁavat/ “cravate”/tie), but not for nouns ending by a lexical embedding (such as /fʁomaʒ/

“fromage”/cheese ending by /maʒ/ “mage”/witch). He obtained this facilitation effect for monosyllabic monomorphemic spoken nouns too (19 ms facilitation -- pairs of nouns matched phonologically, such as /dʁag/ “drague”/chatting-up, beginning by /dʁa/ “drap”/sheet, and /dʁɔg/ “drogue”/drug, having no initial embedded word).

The effect was also replicated with other tasks, by Luce and Lyons (shadowing) and by Lachaud (non-linguistics target detection).[1] With this last task, Lachaud found that targets detection was 30 ms faster at the end of nouns starting with a lexical embedding (“thermos”) than at the end of control nouns (“cravate”). This effect implies that the computational load was decreasing more rapidly for words with an initial lexical embedding than for control words. Therefore, lexical ambiguity occurring at the beginning of the stimulus word was rapidly resolved, which supports the notion that the recognition process is tuned to the structure and requirements of the lexicon. Nouns ending with a lexical embedding (“fromage”) did not show this advantage.

Agreement between the observations of Luce and Lyons (1999) and Lachaud (2005) underline the robustness and consistency of the effect. The facilitation caused by the initial lexical embedding would be language independent as well as task independent. From this, it seems reasonable to conclude that, contrary to the claims of the TRACE model, the lexical configuration of initial embeddedness is probably easier to process than other lexical configurations like words with a final lexical embedding and words without lexical embeddings.

**The massive superimposing structure of the lexicon: New data for French**

In an attempt to understand how the French lexicon was organized, Lachaud (2005) analyzed a subpart of the lexical database BRULEX (Content, Mousty, & Radeau, 1990). This subpart was composed of all monomorphemic nouns and morphologically derived nouns, compound words being taken out as well as words from grammatical categories other than the "noun" category. This analysis revealed that 2.3 times more words start with a first syllable being a word itself, compared to words with a first syllable being not a word. Furthermore, people use words containing a word as first syllable 9.4 times more often than words not containing a word as first syllable. The difference was not so large for word endings, with a ratio only 1.2 in favor of final lexical embeddings for the lexical count, and 4.9 for the lexical frequency, compared to words without a final lexical embedding.

It is important to note that these ratios should be lowered if the morphological dimension was removed from the analysis. Davis (2000) took this precaution for the same type of analysis as Lachaud which he ran on the English lexicon provided by the CELEX database (Baayen, Pipenbrook, & Guilikers, 1995). He found that 50% of the words start with a syllable being a word when the morphological dimension was not neutralized, 39% if the derivational superimpositions were taken out, and 27% if all types of morphological superimpositions were taken out. Therefore, neutralizing the morphological dimension only reduced the ratio of words with lexical embeddings by a factor of two, from 50%.

It is also important to note that the count done by Lachaud and by Davis was underestimated by the syllabic restriction. The number of words starting by a lexical embedding is larger if the sequence of phonemes or letters is considered instead of the sequence of syllables (see also the lexical statistics obtained by Cutler, McQueen, Jansonius and Bayerl (2002)). Because of the congruency between behavioral and lexical statistics, a logical conclusion to draw is that initial superimpositions may play an influential role by facilitating the recognition of words.

**Alternative explanation: Stimulus-induced experimental bias**

One point was still unclear from the above-mentioned behavioral studies. Due to the dynamical nature of the sound wave, a spoken word stimulus is delivered gradually over time to the listener. Consequently, the lexical and the perceptual processes overlap in time, and the processes occurring at the beginning of acoustical input could be masked by the delay of measurement, or by additional processing occurring during this gap. This could explain why no lexical competition was observed, despite the prediction of TRACE that lexical competition should occur between the lexeme of the embedded word and the lexeme of the carrier word.

A solution for testing this hypothesis is to use written word stimuli, delivered statically to the subject, i.e. entirely at the same moment. Of course, one may argue that written and spoken words are not processed similarly. However, the initial version of TRACE was for written words (McClelland & Rumelhart, 1981), and supports the idea of a simultaneous activation of multiple lexical representations as well as a subsequent selection phase based on lexical competition. Similarly, because word representations are supposedly stored in the same lexicon for spoken and written words (even though the mental lexicon might be accessed differently according to the sensory modality) and because competition occurs within the lexicon, it makes sense to use written words to check that the absence of lexical competition with spoken words starting by a lexical embedding is not due to the dynamics of the stimulation.

Taft and Forster (1976) showed facilitation effects of lexical embeddings for written words in experiments using a lexical decision task. Although these authors did not focus exactly on the same research question, but on a related one (lexical storage and lexical retrieval of polymorphemic and polysyllabic words), their findings are consistent with those obtained in the auditory modality for monomorphemic words (Lachaud, 2005; Luce and Lyons, 1999) and ask for further exploration in the visual modality.

**Rationale and overview of the present experiments**

Considering the general framework of research described above, it was important to investigate the visual recognition of monomorphemic French nouns containing an initial lexical embedding in order to control, explore and document this facilitation phenomenon. The first aim of our study was to control, with French written words, if findings obtained in the auditory modality for French words and for English words could be replicated. If yes, it would allow ruling out competition masking due to delayed measurement with spoken words as an alternative hypothesis. We designed Experiment 1 to measure with a lexical decision task the recognition speed of French monomorphemic written nouns starting with a lexical embedding.

The second aim of the study was to explore and document the processing of non-morphological lexical superimpositions with an eye-tracking technique (Experiments 2 and 3). Eye movements being an automatic behavior during reading, the eye-tracking technique had the advantage to allow task-independent measures. Eye-tracking has been used in a wide variety of experiments studying processes occurring during reading, like syntactic processing (Pynte & Frenck-Mestre, 1997) or sensori-motor control (Baccino, 1999; Lachaud, 1997). Eye-tracking has also been used for studying word recognition, as a direct measure (Kennedy, 2000), or as an indirect measure (Allopenna, Magnuson, & Tanenhaus, 1998; Dahan, Magnuson, & Tanenhaus, 2001). Studies exploring the parafoveal pre-processing of a letter sequence (Beauvillain & Doré, 1998; Beauvillain, Doré, & Baudouin, 1996) or the parafoveal pre-processing of morphological words (Beauvillain, 1996) are more relevant for our study. They showed that the structure of letter strings composing a stimulus word influence the eyes' landing position in a word. Other researchers showed that eye movements are a direct measurement of lexical processes, which define the landing position in a word (McDonald &

Shillcock, 2005; Shillcock, Ellison, & Monaghan, 2000). Consequently, eye-tracking appeared highly relevant for measuring perceptual space curvatures that lexical superimpositions, we supposed, should create. We suggested that facilitation obtained with chronometric measurements were possibly resulting from this curvature of perceptual space, a curvature that is also expected to shift the foveal landing position towards the embedded word.

The third and last aim of our study was to control different findings from the first three Experiments, to ensure the reliability of observations. First, we designed Experiment 4 to check that facilitation depended on the amount of activation of the embedded word, i.e. depended on where the eyes were looking. Second, we reanalyzed eye movement data from Experiments 2 and 3 in the light of the split-fovea model (Shillcock et al., 2000) to ensure that landing position drifts were related to the experimental factors, and not, as suggested by this model, due to the lexical neighborhood. Taken together, the different parts of this study provide a clearer view of the relation existing between word recognition and the configuration of lexical embeddedness.

## EXPERIMENT 1

Experiment 1 follows up on a set of experiments investigating the recognition of isolated French monomorphemic spoken nouns in the auditory modality, using a 'go, no-go' lexical decision task (Lachaud, 2005). These experiments were specifically testing the effect of an embedded noun, semantically unrelated to its carrier noun, on the processing of its carrier word. Results recurrently showed easier recognition of the stimulus carrier words instead of the inhibition predicted by TRACE.

Though the theoretical framework of lexical competition could not explain facilitation, it was suggested that lexical competition predicted by TRACE may have occurred at the very beginning of the stimulus presentation, but was not measurable in the auditory modality because of the stimulus dynamics. If lexical competition existed between the carrier word's representation and the representation of the embedded word, and if the stimulus dynamics were masking it in the auditory modality, using written stimuli instead of spoken words should allow revealing lexical competition.

Experiment 1 was conceived to test this hypothesis by manipulating the presence of a lexical embedding at the beginning of a carrier word. The experimental hypothesis was that reaction times to recognize words containing an initial lexical embedding would be longer than for words without a lexical embedding because of lexical competition.

**Method**

*Participants.* 26 French monolingual normal young adults (students from the University of Geneva, Switzerland), without visual, cognitive and motor troubles, participated in Experiment 1.

*Materials.* Stimuli consisted of 36 monosyllabic monomorphemic French nouns (experimental items) and 18 monosyllabic French-like nonwords (fillers). Words had a CVC or CCVC phonological syllabic structure. Eighteen words had an embedded word at their onset (for instance TRIQUE/cudgel begins with the embedded word TRI/sorting -- E for "Embedded" Condition). Eighteen words had no lexical embedding at their onset (C for "Control" Condition). Words from the two conditions were strictly matched phonologically and graphically to form pairs. In each pair, the two words differed by one grapheme only (1 or 2 letters), in such a way that only the vocalic core changed (TRAQUE/tracking is the matching control condition for TRIQUE. TRA is not a word; the vocalic core of the syllable is changes from /i/ to /ɑ/ by switching the letter I to the letter A). Embedded words were semantically unrelated to the carrier word except for two words. Table 1 summarizes word characteristics, taken from the lexical database LEXIQUE (New, Pallier, Ferrand, & Matos, 2001).

INSERT TABLE 1

Table 1 shows that the experimental material is highly controlled. Words from the two conditions match perfectly concerning graphic and phonologic length. The graphical uniqueness point position is very similar between both conditions, as well as the phonological uniqueness point position. Few words had homographs and homophones. However, their repartition across conditions was similar. Graphic neighborhood is also approximately similar. The slight difference between two conditions was tested and was not significant, $F(1, 34) = 1$; $p = .32$. Finally, the percentage of superimposition quantifies the experimental factor in formal terms.

Word frequency was not controlled during the selection phase, to avoid supplementary restrictions that would have prevented finding enough items. Table 1 shows that the control condition has a mean frequency approximately twice that of the experimental condition. The consequence would be to decrease reaction times for words from the control condition, compared to the experimental condition, eventually masking any facilitation effect of lexical embedding. Therefore, we included this factor in the statistical model to part its influence on reaction times from that of the experimental factor. We also modeled its interaction with the experimental factor. It is worth mentioning here that we used a particular statistical technique for the analyses, which allowed for such a control -- see “Statistical procedure”.

The 18 nonwords were built with a structure similar to that defined by the experimental factor for the words: 9 nonwords started with an embedded word, 9 nonwords had no embedded word. Nonwords strictly matched words with respect to their syllabic structure and number of characters. The 9 embedded words included in nonwords had no semantic, graphic or phonological relation to experimental words and were not related to the embedded words of the E condition.

Words were divided into two complementary lists, to avoid a formal priming between the E and C conditions (N = 18 words per list, 9 E and 9 C). The 18 nonwords were the same in the two lists. Power limitation that usually results from a small set of items in statistical analyses was bypassed by the statistical technique we used -- see “Statistical procedure”.

*Task and procedure.* Stimuli were presented in the centre of a 19’’ cathode ray tube monitor at about 85 cm from the eyes’ participant. Words were written in lower case letters, font Verdana, size 16, in white on a black background. The maximal height of letters was about 0.6 degrees of visual angle.

A ‘go, no-go’ lexical decision task was used to measure word recognition latency. Participants were asked to press a button using the index of their dominant hand when the stimulus they saw was a word, and to restrain from doing so if it was a non-word. They had to answer as fast as possible, and avoid making errors. Each participant was tested once, randomly with the 18 words and the 18 non-words, after a detailed instruction and a training session on training items.

The sequence of events in a trial was as follows. A small cross was first displayed for 1 second at the position where the first character of the word was about to appear. Participants were instructed to fixate this position. This cross disappeared when the stimulus appeared. The stimulus remained on the screen until the participant gave an answer, or until 2.5 seconds had passed if no answer was given. Then, a new trial was started. The testing part of the experiment took about 2 minutes. 13 * 2 * 18 = 468 measures were collected in Experiment 1.

**Results**

*Data filtering.* A ±3 standard deviation filter was applied for each subject and item, to exclude an eventual outlier subject or item, and to remove outlier reaction times.

*Error rate.* 60 missing values were counted, due to missed responses and filtered outliers (12.82% of all responses; E condition: 14.1%; C condition: 11.51%).

*Statistical procedure.* Instead of an ANOVA, we used the multilevel modeling technique (MLM) to analyze data with the software MLwiN (Rasbash, Browne, Healy, Cameron, & Charlton, 2001). For details about this technique see for instance Snijders and Bosker (1999), Hox (2002), or Lachaud & Renaud (submitted).

MLM was preferred to ANOVA for its higher reliability and flexibility (Lachaud & Renaud, submitted). This technique is particularly adapted for analyzing incomplete designs, as in the experiments of this study. The influence of a list is actually modeled as residual variance at the trial level, a level resulting from crossing items and subjects. Consequently, this variance is not conflated with the variance due to the experimental factor, and the small number of items per list is no longer a limitation for significance estimation of the experimental factor.

The model crossed items and subjects as random factors, integrating the experimental factor (embeddedness) and logarithm of word frequency (controlled variable) as fixed predictors of reaction times (Rasbash, Steele, Browne, & Prosser, 2005). The analysis was carried out without replacing missing data. Factor significance was estimated with an $F$ test or with a large sample $\chi^2$ test depending on the analysis.

*Reaction times.* Table 2 gives characteristics of reaction times per condition.

INSERT TABLE 2

While taking into account the influence of lexical frequency, the statistical model's estimates show that participants responded 40 ms faster in the experimental condition (523 ms) than in the control condition (563 ms), $\chi^2(1, N = 408) = 5.56$, $p < .02$, without making more mistakes, $F(1, 34) = 0.14$; $p = .72$. The effect of frequency was significant, $\chi^2(1, N = 408) = 9.92$, $p < .002$. Words were recognized 47 ms faster per each additional logarithmic unit of frequency. There was no interaction between frequency and embeddedness, $\chi^2(1, N = 408) = 1.58$, $p < .22$.

**Discussion**

Experiment 1 demonstrates that a lexical embedding at the beginning of a monomorphemic monosyllabic written noun decreases reaction times in a lexical decision task, compared to graphically and phonologically matched control words. Therefore, lexical competition and the subsequent slowing of word recognition predicted by TRACE for written words starting with a lexical embedding were not observed.

Experiment 1 replicates with written words the facilitation effect observed with spoken words in the same lexical configuration. The effect is not only robust across tasks and languages, but across modalities. Furthermore, its amplitude is in the same range as that reported by previous studies (Lachaud, 2005; Luce & Lyons, 1999).

Critics have argued that facilitation was due to inter-conditions bigram (sequence of two letters) and trigram (sequence of three letters) frequency variations: Bigram and trigram frequencies could actually be higher in the E condition because of the experimental factor. An analysis was run to check this point. Bigram and trigram frequencies were obtained from the database LEXIQUE (Surface -- Lexique 2). Analysis could only be run on 20 words, 10 in each condition, because the index was not available for all 36 words in LEXIQUE. It was however a large enough random sample to get differential effects of bigram and trigram frequencies between conditions, if such differences existed. There was no relation between bigram frequency and lexical embeddedness, $F(1, 34) = 0.55$, $p = .47$, as well as between trigram frequency and lexical embeddedness, $F(1, 34) = 0.25$, $p = .62$. Consequently, variations in bigram and trigram frequencies between the two experimental conditions could not explain the facilitation effect.

This effect could not be due to word frequency either; first because frequency is higher for control words, second because variance due to word frequency was parted from the variance due to the experimental factor in the statistical analysis. Critics also argued that the effect of facilitation we found was due to task demands. Actually, if the “go” answer gets twice the amount of activation in the E condition, once from the embedded word and once from the carrier word, it is natural that reaction times be faster than in the C condition, where the “go” answer receives activation only from the stimulus word. However, this explanation also implies that two lexical representations are activated simultaneously. Therefore, if this task demands explanation were true, one would have to wonder if the lexical decision task, though widely used, is not causing many biases in psycholinguistic theories, because of the proportion of words containing embedded words. Furthermore, if simultaneous lexical activations were producing faster reaction times, facilitation would be a product of dense neighborhoods in lexical decision tasks. Neighborhood is usually considered as impairing lexical processing speed (Goldinger, Luce, & Pisoni, 1989; Luce & Pisoni, 1998), though the literature sometimes shows that a dense neighborhood facilitates word recognition (Forster & Shen, 1996). Further investigations about effects of neighborhood showed that facilitation resulted from increased phonotactic probabilities or familiarity (Grainger, Muneaux, Farioli, & Ziegler, 2005; Ziegler, Muneaux, & Grainger, 2003). Facilitation would therefore be a sublexical effect (Vitevitch & Luce, 1999), and not a task effect. However, because the materials used in Experiment 1 showed no neighborhood density difference due to the lexical variable, because we found no relation between bigram or trigram frequencies and the lexical variable, because the effect size of lexical embedding is large, and because TRACE implements sublexical facilitatory effects via the lexicon, we suggest that the facilitation we observed was not sublexical nor task dependent, but lexical.

## EXPERIMENT 2

Experiment 2 had two goals: first, to replicate the facilitation effect obtained in Experiment 1, second to investigate this facilitation effect further with eye-tracking. Therefore, we used the same materials and task as in Experiment 1 with a new set of participants, and measured eye movements while participants read words. This additional index was used to find clues for understanding the origins of faster reaction times.

The reaction time hypothesis was the same as for Experiment 1. The oculomotor hypothesis was that landing position in words would be attracted towards the word beginning in the E condition compared to the C condition. This drift of the landing position would depend on the presence of an embedded word, varying the “center of gravity” of the carrier word by adding some “lexical weight” at the beginning of the carrier word. This gravitational-like effect can be hypothesized on the basis of previous studies (Beauvillain, 1996; Beauvillain et al., 1996). A landing drift is supposed to be the visual counterpart of the facilitation observed with a chronometric measurement, both resulting from a distortion in the perceptual space due to the presence of a lexical embedding.

### Method

*Participants.* 64 French monolingual normal young adults (students from the University of Geneva, Switzerland), without visual, cognitive and motor troubles, participated in Experiment 2.

*Materials.* The same material as in Experiment 1 was used. In order to counterbalance the laterality of stimulus presentation on the screen, each list of words had to be presented to two groups of participants. Four groups of participants were therefore needed.

Participants were asked to perform the same task as in Experiment 1. While doing so, their eye movements were recorded with a head-mounted video-based eye-tracker (EyeLink 2, SR-Research, Canada) at a frequency of 250 Hz. A velocity threshold of 22 deg/s and an acceleration threshold of 4000 deg/s$^2$ were used to detect saccades. Stimuli were presented on a 21-inch screen at a refresh rate of 100 Hz. Head movements were restrained by a chin rest. Viewing distance was about 46 cm. At this distance, one pixel subtended 0.036 deg. Words were written in lower case letters using the equidistant font “Courrier New”. Each letter was 11 pixels wide (0.4 deg) and was presented in white (60 cd/m$^2$) on a black background (0.1 cd/m$^2$).

*Task and procedure.* Participants practiced the experimental task (“go, no-go” lexical decision task) on a set of training items before the eye tracker was calibrated. Only the horizontal eye position was recorded. Testing started after successful calibration. Each participant was tested once with the 18 words and the 18 nonwords, randomly drawn from the list.

Words appeared randomly in the left or right half of the screen, to avoid strategic behavior and to help participants systematically fixate the central mark appearing on the screen before each stimulus. The last letter of a word presented on the left and the first letter of the word presented on the right were 3 letters (33 pixels) away from the center of the screen.

The sequence of events in each trial was as follows. A small vertical line appeared for 650 ms at the centre of the screen. Participants were instructed to fixate this line. The central fixation mark disappeared when the stimulus was presented. The stimulus was presented for 800 ms, and the program waited another 300 ms for participant’s response. Then, a new trial started. The testing part of the experiment took about 2 minutes. 16 * 4 * 18 = 1152 trials were collected in Experiment 2.

**Results**

*Data filtering.* Outliers were removed by excluding observations beyond ±3 standard deviations of the mean. The filter was applied separately for each subject and each item, on the reaction times as well as on each parameter of the oculomotor behavior. Considering that reliable trials were only those with a consistent pattern of information, we additionally filtered trials providing reaction times but no oculomotor data for the first saccade, and those providing refixation data but no first saccade data.

*Statistical procedure.* Errors were analyzed with a by items ANOVA-type model (reaction times, oculomotor data). Reaction times and oculomotor data were analyzed with MLM. Missing values were not replaced.

Models crossed subjects and items as two random factors, and used “lexical embeddedness”, “laterality of stimulus presentation”, the interaction between these two factors, and “logarithm of words frequency” (statistical control in the model) as fixed factors. Separate models were done for reaction times and each parameter of each saccade category (first saccade, refixation), one model per dependent variable. Significance of fixed factors was estimated with a large sampled $\chi^2$ test.

Laterality effects being known and documented in the literature on eye movements (see for instance Ducrot and Pynte, (2002)), and not being the focus here, they will be summarily documented. Same for the interaction between laterality of stimulus presentation and the lexical factor, as no hypothesis was made concerning this interaction in Experiment 2. Only the main effect of the lexical factor will be discussed. Reaction times and the oculomotor data are presented in two separate sections.

*Reaction times.* Table 3 shows Reaction time (RT) and Error rate (Er) as a function of lexical embedding (C/E) and laterality of stimulus presentation (L/R).

INSERT TABLE 3

Error rates did not vary as a function of lexical embedding, $F(1, 31) = 0.01$; $p = .92$, or as a function of laterality of stimulus presentation, $F(1, 31) = 0.06$; $p = .81$, and there was no interaction of both factors, $F(1, 31) = 0.08$; $p = .78$. Estimates provided by the statistical model show that words with initial lexical embedding tended to be recognized 44 ms faster than words with no initial lexical embedding, $\chi^2(1, N = 740) = 3.6$, $p = .058$. Words presented on the right part of the screen were processed slightly faster than on the left, but this 30 ms difference was marginally significant, $\chi^2(1, N = 740) = 2.9$, $p = .089$. Lexical embedding did not interact with laterality of presentation, $\chi^2(1, N = 740) = 0.13$, $p = .72$.

*Oculomotor data: Error rate.* Error rate refers to the missing observations due to filtering or blinks. Table 4 gives the Error rate for first saccades and refixations, depending on the presence of a lexical embedding (C/E) and the laterality of stimulus presentation (L/R).

INSERT TABLE 4

First saccades showed 1.1 more errors in the embedded condition than in the control condition, $F(1, 31) = 6.4$; $p = .017$, no difference as a function of laterality of item presentation, $F(1, 31) = 1$; $p = .32$, and no interaction between lexical embedding and laterality of item presentation, $F(1, 31) = 0.2$; $p = .66$.

Refixations did not show error rate differences depending on a lexical embedding, $F(1, 31) = 1.2$; $p = .29$. However, there were 1.9 more refixations for a stimulus presented on the right compared to the left, $F(1, 31) = 7.3$; $p = .01$. The interaction between lexical embedding and laterality of stimulus presentation was marginally significant, $F(1, 31) = 3.47$; $p = .07$.

The error rate differences between left and right tended to be larger in case of control words (1.9) than in case of words with lexical embeddings (0.6).

*Oculomotor data: Saccade characteristics.* Table 5 synthesizes saccade characteristics, for first saccades (Sacc.: S1) as well as for refixations (S2), for each parameter (Param.: latency and duration in ms, position in letters). Coefficients (Coeff.) and standard errors (SE) provided by models are given for the grand mean (Mean), and for predictors (Pred.) E (reference = C), R (reference = L), and interaction E*R (reference = C*L). Information is completed with values of test statistics ($\chi^2(1, N = 740)$) and significance level $p$.

INSERT TABLE 5

There was no effect of the lexical factor on initial saccades and refixation characteristics. Laterality of stimulus presentation was significant for all three parameters of first saccades, but produced no effect on refixations. The latency of first saccades was 5.9 ms longer for stimuli on the right compared to stimuli on the left, saccade duration was 1.5 ms faster with stimuli presented on the right, and eyes landed 0.85 nearer from the screen center with stimuli presented on the right. See for instance Ducrot & Pynte (2002) for a review and study about effects of stimulus presentation laterality on saccades characteristics. The interaction of lexical embedding and laterality of stimulus presentation was not significant.

**Discussion**

Experiment 2 tended to replicate the chronometric behavioral pattern observed in Experiment 1: recognition of carrier words was facilitated in the experimental compared to the control condition. The effect, though of the same size as in Experiment 1, had a higher $p$ value, slightly above the .05 threshold. However, mean reaction times were 210 ms longer in Experiment 2 than in Experiment 1. Once corrected by subtracting the latency and duration of the first saccade, this mean reaction time difference falls to 38 ms, showing still slower reaction times in Experiment 2 than in Experiment 1. Possibly, the data in Experiment 2 are noisier and the increase of variance could have resulted in a drop of significance. Among the factors explaining noise are degraded visibility of the text (font size was 0.2 degrees of visual angle smaller in Experiment 2 than in Experiment 1, words appeared parafoveally instead of foveally), visual fatigue (smaller fonts, use of the eye-tracking paradigm causing visual fatigue), and distraction from the lexical decision task (eye-tracker on the head). We therefore tentatively concluded that the behavioral effect of Experiment 1 was replicated in Experiment 2.

Although Experiment 2 showed 1.1 more errors in the embedded condition than in the control condition for first saccades, it failed to reveal any effect of the lexical factor on saccade parameters, for first saccades as well as for refixations. From error rates, we can however think that the response of the lexical/oculomotor system was somewhat different because of the presence of lexical embeddings, but without significant effects on saccade characteristics.

It may be that the monosyllabic format was causing this absence of lexical embedding effect in saccade characteristics. If the advantage of short words was to control the graphical and phonological match between conditions in Experiment 1, the drawback of this format was to reduce the discriminating visual properties of experimental materials in Experiment 2. The probability of shifting the landing position was certainly low with monosyllabic words, because short words can be processed parafoveally more easily and foveally in a single fixation. For these reasons and because we obtained encouraging indications with the error rate, we conceived Experiment 3 to test longer words.

## EXPERIMENT 3

Although we replicated the facilitation effect, results of Experiment 2 suggest that monosyllabic stimuli are an inappropriate format for finding oculomotor effects depending on lexical embeddedness. Therefore, Experiment 3 used disyllabic words instead of monosyllabic words. However, this word format came with a higher probability of an embedded word in the stimulus, making it more difficult to find control words. Consequently, Experiment 3 contrasted words with an initial embedding (I) to words with a final embedding (F), instead of words with vs. without an initial lexical embedding. In this new situation, we hypothesized that the eyes' landing position would be attracted towards the lexical embedding because the higher lexical weight of the lexical embedding attracts the perceptual center of gravity of the word. The eyes would land nearer to the beginning of the carrier word in the case of an initial lexical embedding, and nearer to the end of the carrier word in the case of a final lexical embedding, compared respectively to the F and I conditions. Comparing the two lexical conditions would therefore result in a measurable difference in landing position.

As in Experiment 2, words were either presented on the left (L) or on the right (R) of the screen, resulting in four conditions (IL, IR, FL, and FR). The experimental task in Experiment 3 was the same as in the two previous experiments ('go, no-go' lexical decision task) and eye movements were recorded following the protocol of Experiment 2.

We hypothesized that reaction times would be identical in both lexical conditions. First, Experiment 3 compared written words containing a lexical embedding in both conditions. Second, because a visual stimulus can be sensed fully at once, the position of the lexical embedding is not supposed to be an influential factor as it is in the auditory modality, where the sensory input is sequential.

We formulated two oculomotor hypotheses predicting modulations of the eyes' landing position. The first oculomotor hypothesis states that the eyes' landing position will deviate towards the lexical embedding (Landing Position Hypothesis) according to the “gravitational” mechanisms described previously. Modulations of the eyes’ landing position would come with changes of saccadic duration and saccadic latency, but we did not make any prediction for these parameters. The second oculomotor hypothesis, concerning the interaction between lexical embedding position and stimulus position (Interaction Hypothesis), states that landing position would deviate with a higher amplitude towards the embedded word in the Initial/Right and Final/Left conditions than in the Final/Right and Initial/Left conditions respectively. Actually, the embedded word will be more activated in the Initial/Right and Final/Left conditions than respectively in the Final/Right and Initial/Left conditions, because the embedded word’s image is projected nearer to the fovea during the latency period of the first saccade. Consequently, the embedded word has higher chance to be pre-processed parafoveally, and to influence the processing of the carrier stimulus word, therefore to influence oculomotor behavior. Though this may also result in measurable modulations of saccadic latencies (shorter latencies for Initial/Right and Final/Left than for Final/Right and Initial/Left), we did not make any predictions for this parameter. We did not formulate any hypothesis for saccade duration as well, as modulations of this parameter are possibly being caused by variations of landing position.

**Method**

*Participants.* 64 French monolingual normal young adults (students from the University of Geneva, Switzerland), without visual, cognitive and motor troubles, participated in Experiment 3. Two groups of participants were used to counterbalance laterality of stimulus presentation.

*Materials.* Stimuli were 60 disyllabic monomorphemic French nouns (words) and 60 disyllabic French-like nonwords (fillers). The disyllabic format was used instead of monosyllabic items in order to increase our chances to find effects in oculomotor behavior as a function of lexical embedding. Furthermore, as it is difficult to find disyllabic words without lexical embeddings, the contrast was not between initial embedding and no embedding, but between initial embedding and final embedding.

Thirty words had an initial lexical embedding, referred to as I condition (FAUTEUIL [armchair] begins with the embedded word FAUTE [mistake]). Thirty words had a final lexical embedding, referred to as F condition (BÉQUILLE [crutch] ends with the embedded word QUILLE [skittle]). Embedded words were semantically unrelated to the carrier word.

Table 6 summarizes word characteristics, taken from LEXIQUE.

INSERT TABLE 6

The two lexical conditions were balanced for word length (graphical and phonological), for uniqueness point position (graphical and phonological), and for phonological superimposition rate. Word frequency was not controlled during the selection phase, to avoid supplementary restrictions. Despite a mean difference between the two conditions, it did not vary significantly, $F(1, 58) = 0.77$; $p = .38$.

The graphical superimposition rate between the embedded word and the carrier word (percentage of letters of the carrier word corresponding to the embedded word) was 8% larger for the final embedding condition than for the initial embedding condition, $F(1, 58) = 13$, $p = .001$. This should result in a slightly larger weight of the perceptual/lexical space in favor of the final lexical embeddings. However, a greater superimposition rate for the final embeddings condition also means that the beginning of a final embedded word is nearer to the beginning of the carrier word than the end of an initial embedded word is from the end of the carrier word. Consequently, the deviation of landing positions towards final embeddings should be finally slightly smaller than with initial embeddings. However, we did not control for this factor in the statistical analyses. The first reason is that the amplitude difference in superimposition is only 8% between conditions, which should probably cause a deviation in landing position smaller than 8%. The second reason is that this difference does not alter the experiment's sensitivity, because this set of items still allows detecting different saccadic behavior depending on embeddings position.

The number of orthographic neighbors (LEXIQUE), not controlled during selection of the stimulus material, was not statistically different between conditions, $F(1, 58) = 2.3$, $p = .13$. Sixty nonwords were built according to the experimental factor: 30 nonwords started with an embedded word, 30 nonwords ended with an embedded word. Nonwords strictly matched words on number of letters. Embedded words were formally and semantically unrelated to experimental carrier words as well as to their embedded words.

*Task and procedure.* Procedure was the same as described in Experiment 2. Each participant was tested once with every word and every non-word, items being drawn in random order from the list, and presented on the right or on the left part of the screen according to counterbalanced lists. The testing part, including resting pauses, was about 10 minutes long. 60 * 2 * 32 = 3840 trials were collected.

**Results**

*Data filtering.* Data filtering followed the same protocol as described in Experiment 2. Missing values were not replaced in the MLM analyses. All presented results were obtained with filtered data.

*Statistical procedure.* Error rates were analyzed with a by items ANOVA-type model. Reaction times and oculomotor data were analyzed with MLM. Statistical models crossed items and subjects as random factors, and included as fixed factors "position of lexical embeddedness", "laterality of stimulus presentation", the interaction between these two factors, and "logarithm of word frequency" (statistical control). Separate models were done for reaction times, for each parameter of first saccades, and for each parameter of refixations, one model per dependent variable. For the sake of verification, the reaction times model also included an additional predictor: the number of words of the same length as the stimulus (in number of letters), having the same trigram in the same position as the trigram which central letter was targeted during refixations. According to Pynte (2000), lexical access in reading could occur from foveal fixation in the same way as it occurs from the word beginning in spoken word recognition. Foveal lexical neighborhood might therefore be important to control. We did not control lexical neighborhood for the position targeted by first saccades, as initial landing positions seemed to be mainly computed based on the parafoveally captured physical characteristics of stimuli. For information, the mean number of words sharing foveal trigrams with stimuli (refixations) was 18.8 (1-96; SD = 21.9).

Statistical significance was estimated with a large sampled $\chi^2$ test. Results for words and non-words are presented separately. For words, reaction times and reaction time error rate, first saccades, refixations, and saccade error rate (outlier saccades + blinks) are reported and analyzed, depending on the laterality of stimulus presentation (reported but not discussed -- see justification in Experiment 2), the lexical factor (Landing Position Hypothesis), and the interaction between laterality of stimulus presentation and lexical factor (Interaction Hypothesis). For non-words, only first saccades and refixations characteristics are presented, as no lexical decision reaction times were collected for them in this experiment.

*Words: Reaction times.* Table 7 gives the characteristics of reaction time (RT) and error rate (Er) observed, depending on lexical embedding position (I/F) and laterality of stimulus presentation (R/L).

INSERT TABLE 7

Error rate for lexical decision reaction times did not vary depending on the position of the lexical embedding, $F(1, 115) = 0.68$; $p = .41$, laterality of stimulus presentation, $F(1, 115) = 0.55$; $p = .46$, and the interaction between these two factors, $F(1, 115) = 0.36$; $p = .55$. Taking into account the influence of lexical frequency and foveal neighborhood (statistical controls) showed that words were not recognized at a different speed depending on the position of the lexical embedding, $\chi^2(1, N = 2828) = 0.006$; $p = .94$. Words were recognized 32 ms faster when presented in the right half of the screen compared to a presentation on the left, $\chi^2(1, N = 2828) = 29$; $p < .001$. The interaction between the two factors was marginally significant, $\chi^2(1, N = 2828) = 3.17$; $p = .075$. Reaction time differences between two lexical conditions tended to be greater if words were presented on the right (16 ms) than if they were presented on the left (1 ms). The difference between conditions RI and RF was not significant, $\chi^2(1, N = 2828) = 1.7$; $p < .20$. Word frequency was significant, $\chi^2(1, N = 2828) = 44.9$, $p < .001$, words being recognized 56 ms faster per additional unit of logarithmic frequency. The effect of foveal neighborhood was not significant, $\chi^2(1, N = 2828) = 0.1$; $p < .80$.

*Words: Saccade error rate.* Table 8 gives the Error rate for first saccades and refixations depending on the position of the lexical embedding (I/F) and laterality of stimulus presentation (L/R).

INSERT TABLE 8

There was no effect of lexical embedding position on error rates for first saccades, $F(1, 55) = 0.4$; $p = .55$, no effect of stimulus presentation laterality, $F(1, 55) = 0.01$; $p = .95$, and no interaction between these two factors, $F(1, 55) = 0.4$; $p = .55$. Words beginning with an initial lexical embedding did not induce more refixations than words with a final lexical embedding, $F(1, 55) = 1.5$; $p = .23$. There were 2.5 more refixations in words presented on the left than in words presented on the right, $F(1, 55) = 5.9$; $p = .02$. The interaction between lexical embedding position and laterality of stimulus presentation was not significant, $F(1, 55) = 2.1$; $p = .16$.

*Words: Saccade characteristics.* Table 9 synthesizes saccade characteristics, for first saccades (Sacc.: S1) as well as for refixations (S2), for each parameter (Param.: latency and duration in ms, position in number of letters). Coefficients (Coeff.) and standard errors (SE) provided by models are given for mean (Mean), and for predictors (Pred.) I (reference = F), R (reference = L), and interaction I*R (reference = F*L). Information is completed with values of test statistics ($\chi^2$) and significance $p$.

INSERT TABLE 9

First saccades: There was no effect of lexical embedding position on saccade latency, saccade duration, and landing position. Presentation of stimuli on the right part of the screen resulted in an increase of saccade latency (+5 ms), a decrease of duration (-3 ms), and a decrease of landing position (-1.5 letters). There was no interaction between lexical embedding position and laterality of stimulus presentation on saccade parameters.

Refixations: There was no effect of lexical embedding position on latency and on duration of refixations. However, words beginning with a lexical embedding induced refixations landing 0.322 characters further away from the beginning of carrier words, than for words ending with a lexical embedding. Presentation of stimuli on the right part of the screen resulted in an increase of refixation latency (+27 ms), in an increase of saccade duration (+1 ms), and in an increase of landing position (+1.2 letters). There was no interaction between lexical embedding position and laterality of stimulus presentation, on refixation duration and on landing position. However, this interaction was significant for refixation latency, a parameter equivalent to the first fixation duration. The difference between left and right hemi-screen presentation was 16 ms smaller with the initial embedding condition (11 ms) than the difference observed with the final embedding condition (27 ms).

*Nonwords: Saccade error rate.* Table 10 gives the error rate for first saccades and refixations depending on the position of the lexical embedding (I/F) and laterality of stimulus presentation (L/R).

INSERT TABLE 10

There was no effect of lexical embedding position on error rates for first saccades, $F(1, 55) = 0.1$; $p = .77$, no effect of stimulus presentation laterality, $F(1, 55) = 3.1$; $p = .09$, and no interaction between these two factors, $F(1, 55) = 1.2$; $p = .28$. For refixations, there were no effects of lexical embedding position, $F(1, 55) = 0.3$; $p = .61$, laterality of stimulus presentation, $F(1, 55) = 2.2$; $p = .15$, or interaction between these two factors, $F(1, 55) = 1$; $p = .33$.

*Nonwords: Saccade characteristics.* Table 11 synthesizes saccade characteristics, for first saccades (Sacc.: S1) as well as for refixations (S2), for each parameter (Param.: latency and duration in ms, position in number of letters). Coefficients (Coeff.) and standard errors (SE) provided by models are given for mean (Mean), and for predictors (Pred.) I (reference = F), R (reference = L), and interaction I*R (reference = F*L). Information is completed with values of test statistics ($\chi^2$) and significance $p$.

INSERT TABLE 11

There was no effect of lexical embedding's position on any saccade parameter, and no interaction between lexical embedding's position and laterality of stimulus presentation. This is true for all characteristics of first saccades (latency, duration and landing position) as well as for the characteristics of refixations. Laterality of stimulus presentation produced effects on all saccade parameters for first saccades, and on latency and position for refixations.

**Discussion**

We failed to obtain a main effect of lexical embeddings' position on the characteristics of first saccades, including first saccades error rate. This implies that lexical embeddings were not processed parafoveally in our experience, but needed a deeper analysis of the stimulus, which was probably done during the first fixation in the word. Indeed, a parafoveal effect would imply that the system has already recognized the stimulus at a lexical level within 130 ms and a refixation saccade is run for confirmatory purposes. It is more probable that the parafoveal analysis of stimuli is partial and mainly sensory/sublexical. Because we found a marginal interaction between the lexical factor and the task factor on first fixation duration, a significant effect of this interaction on refixation latencies, and an effect of the lexical factor on refixation position, but none of these effects with non-words, we concluded that all the effects for words arose from a lexical level. The absence of further effects on first saccade landing position and error rate with words were probably due to the early measurement in the lexical processing.

Though we found a landing position shift in refixations due to the position of the lexical embedding, the Landing Position Hypothesis was invalidated. Actually, the refixation pattern was the reverse of what we predicted: The eyes were moving away from the lexical embedding instead of being attracted to it. Therefore, a lexical embedding did not prove to attract the fovea, but repelled it. The observation is somehow disturbing, for it means that our hypothesis, stating that a weighting of the perceptual space by a lexical embedding causing facilitation in chronometric measures and attraction in oculomotor measures, is wrong. The observed behavior seems to be more related to selection processes of lexical representations.

As suggested by Pynte's findings (1996), what we observed as repulsion of the eyes could only occur if the eyes targeted the most informative part of the word, i.e. the part that allowed selection by disambiguating the carrier word from the embedded word, instead of the most confusing part, i.e. lexical embedding. However, one may also argue that the eyes will not target the position from which information is easily processed, but the position from which information is more difficult to process. Findings from Experiment 3 do not allow parting these two opposite statements. Therefore, we designed Experiment 4 to test if viewing position located in the embedded word facilitated the recognition of the carrier word, or made it more difficult.

## EXPERIMENT 4

Experiment 3 revealed that lexical embeddings had a repulsive effect on gaze refixation. However, Experiment 3 did not show reaction time facilitation, as it was the case with Experiments 1 and 2. Indeed, Experiment 3 compared two lexical conditions both having embedded words, making the situation non-contrastive for a reaction time measurement. Because an initial lexical embedding caused the same oculomotor reaction as a final lexical embedding, they could also have facilitated the recognition of the carrier word equivalently. However, the lack of chronometric effect was possibly due to some physical causes, making the influence of embedded words on the processing of the carrier word smaller than expected. First, Experiment 3 was not forcing the foveal inspection of embedded words, contrary to Experiment 1, where fixation mark and the first letter of the carrier word were located in the same display position. Second, it was more difficult to process lexical embeddings from the landing position in Experiment 3 than it was in Experiment 2, because of differences in the size of the carrier.

To create a situation similar to Experiment 1 with the materials of Experiment 3, one would have to force subjects to inspect a specific location in the word by controlling the viewing position. The viewing positions of interest are inside the embedded word versus outside the embedded word. The processing of the embedded word should be enhanced when the subject looks at the embedded word. As a result, interference between the lexical embedding and the processing of the carrier word is expected to increase. Consequently, recognition times for the carrier word should increase.

Because we were interested in testing the impact of lexical embeddings on reaction times, we needed to control the visual input by suppressing exploration of the word. Word exploration would have added noise to reaction times, and would have allowed selection processes by providing disambiguating inputs to the lexical system. Therefore, we presented words at duration inferior to saccade latency.

**Method**

*Participants.* 48 French monolingual normal young adults (students from the University of Geneva, Switzerland), without visual, cognitive and motor troubles, participated in Experiment 4. Three groups of participants were used to counterbalance laterality of stimulus presentation.

*Materials.* Words and non-words from Experiment 3 were used. We varied foveal or viewing position in the carrier word by modulating word eccentricity around the central fixation mark preceding each trial. Three foveal positions were adopted: Beginning (B), Middle (M) and End (E). According to the foveal position and the lexical condition, the fovea could be located at a position favoring or not the lexical processing of the initial or the final embedded words. The three foveal positions were precisely defined for each stimulus with Equation 1.

$$f(x) = p + (s * x/c) \quad (1)$$

with x the number of letters composing a stimulus word; p the position given as letter rank in the sequence of letters composing a word (p1 = 1, p2 = x/2, p3 = x); s a corrective constant for p (s = 1 for p1, s = -1 for p2, s = -3 for p3); c a constant equal to 8. The value of the constant c was defined through pre-tests in which we intended to quantify the visibility of extreme viewing positions by measuring the performance of one subject doing the task.

To allow word recognition in a glimpse, the fovea must be located around the optimal viewing position at the center of a word (O'Regan, Lévy-Schoen, Pynte, & Brugaillère, 1984). Positions p1 and p3 did not allow the recognition of the stimulus words at short exposure durations. Furthermore, the landing position is usually a little left to the center of the word (Ducrot & Pynte, 2002). It is therefore the role of the second term of Equation 1, (s * x/c), to shift p to the left and to contract the inter-p interval linearly around the middle position.

Viewing positions were located at 8% before the end of first third of the stimulus (B), 6% before middle of the stimulus (M corresponding approximately to the preferred landing position) and 4% before the beginning of last third (E), respecting equidistance between the three positions (M – B = E – M). Table 12 gives details on the fovea-positioning plan, depending on stimulus length (N letters) and B/M/E position. Positions are given in number of letters from the beginning of the stimulus.

INSERT TABLE 12

*Task and procedure.* Experiment 4 used a “go, no-go” lexical decision task to measure recognition latency of stimulus words. Eye movements were not recorded.

Participants had to look a vertical line (fixation mark) at the center of the screen, appearing 650 ms at the beginning of each trial. As soon as this fixation mark was disappearing, a stimulus (word or non-word) was presented for 130 ms. This very short time was sufficient to recognize the stimulus words, whatever the viewing position. The eccentricity of each stimulus was adjusted as defined by Equation 1 so that the fixation mark located at B, M or E when the stimulus appeared. Thanks to this procedure, the viewing position in the stimulus was controlled. The stimulus disappeared before any saccade could be initiated, assuring a lexical processing from the only input predefined by the position of the fovea.

After a training session on a set of training items, subjects were tested once with every word and every non-word, items being drawn randomly, and presented with one of the three eccentricities according to counterbalanced lists. The testing part was about 10 minutes including pauses. 60 * 3 * 16 = 2880 trials were collected.

**Results**

*Data Filtering.* Data filtering was following the same protocol as described in Experiment 1. Missing values were not replaced.

*Statistical procedure.* Error rates were analyzed with a by items ANOVA-type model. Reaction times were analyzed with MLM in two separate analyses. The first analysis considered the experimental situation according to the experimental plan. The statistical model crossed items and subjects as random factors, and included as fixed factors “position of lexical embeddedness”, “eccentricity of viewing position”, the interaction between these two factors, and “logarithm of word frequency” (statistical control).

The second analysis used the independent variable “Fovea: inside the embedded word”. This independent variable derived from the experimental variable “eccentricity of viewing position” by recoding the B, M and E viewing positions into “Inside” if the fovea was located in an embedded word and “Outside” if this was not the case. The need for this recoding appeared during the first analysis, which revealed a lot of variance: The viewing position was sometimes located in the initial lexical embedding, sometimes in the final lexical embedding, and sometimes in none of them, independently of the condition. This situation was unfortunate considering the contrast we were trying to test in Experiment 4. However, recoding did not produce a symmetrical distribution across conditions either. All 30 words containing an initial lexical embedding allowed a foveal position inside the embedded word, but only 9 of them allowed for a foveal position outside the embedded word. All 30 words containing a final lexical embedding allowed a foveal position outside the embedded word, but only 29 of them allowed for a foveal position inside the embedded word. This asymmetrical situation between the initial and final embedding carriers resulted from the second term of Equation 1, (s * x/c), which shifted the viewing position to the left of the word in order to preserve readability in the extreme viewing position E. We controlled this potential problem with two additional analyses. The first one considered the restricted subset of 9 items comparing readers' performance with foveal view of the initial embedded word to the performance with a parafoveal view. The second one considered the subset of 29 items and compared readers' performance with their fovea directed inside the final embedded word to their performance with fovea directed outside the final embedded word.

The statistical model used in the second analysis of Experiment 4 crossed items and subjects as random factors, and included as fixed factors "position of lexical embeddedness", "In Fovea", the interaction between these two factors, and "logarithm of word frequency" (statistical control). Significance was estimated with a large sampled $\chi^2$ test.

*Presentation of Reaction times and Error rates.* Table 13 gives characteristics of observed reaction times and error rate repartition per condition (first analysis).

INSERT TABLE 13

Table 14 gives the number of cases per recoded condition and the corresponding characteristics of observed reaction times and error rate (second analysis).

INSERT TABLE 14

*First analysis: Error rate.* Error rate did not vary depending on lexical embedding position, $\chi^2(1, \underline{N} = 360) = 0.55$; $\underline{p} = .46$. It did not vary depending on viewing position, respectively for B and E as compared to M $\chi^2$s(1, $\underline{N}$ = 360) = 0.64 and 2.06; $\underline{p}$s = .43 and .15. It did not vary depending on interaction between lexical embedding position and viewing position, respectively for I*B and I*E as compared to I*M $\chi^2$s(1, $\underline{N}$ = 360) = 0.07 and 0.14; $\underline{p}$s = .79 and .71.

*First analysis: Reaction time.* Figure 1 shows the estimated means provided by the model for each condition.

INSERT FIGURE 1

Reaction times did not vary significantly depending on the position of the lexical embedding, $\chi^2(1, \underline{N} = 2143) = 0.01$; $\underline{p} = .91$. Reaction times tended to be 12 ms longer for a B viewing position than for a M viewing position, $\chi^2(1, \underline{N} = 2143) = 3.1$; $\underline{p} = .08$, and were 23 ms longer for an E viewing position than for a M viewing position, $\chi^2(1, \underline{N} = 2143) = 11.1$; $\underline{p} = .001$. This advantage of M over B and E is a pure effect of optimal viewing position. Though Figure 1 reveals what seems to be an interaction between viewing position and the position of lexical embedding, it was not significant, respectively for I*B and I*E as compared to I*M, $\chi^2$s(1, $\underline{N}$ = 2143) = 1.3 and 0.5; $\underline{p}$s = .26 and .50. Reaction times also varied as a function of word frequency (controlled factor), words being recognized 62 ms faster per additional logarithmic unit of frequency, $\chi^2(1, \underline{N} = 2143) = 44.3$; $\underline{p} = .001$.

*Second analysis: Error rate.* Error rate varied depending on lexical embedding position, $\chi^2(1, \underline{N} = 2700) = 45.7$; $\underline{p} < .0001$. The number of missing values was 25.3% larger with words containing an initial lexical embedding than with words having a final lexical embedding. Error rate varied depending on viewing position, $\chi^2(1, \underline{N} = 2700) = 5.6$; $\underline{p} = .018$. Missed trials were 5.2% more frequent when looking at the embedded word than when looking outside the embedded word. Error rate varied depending on the interaction between lexical embedding position and viewing position, $\chi^2(1, \underline{N} = 2700) = 37.2$; $\underline{p} < .0001$. The percentage difference of missing values between Initial and Final embeddings was -25.9% between the Inside and the Outside viewing conditions.

*Second analysis: Reaction time.* Figure 2 shows the estimated means provided by the model for each condition.

INSERT FIGURE 2

Reaction times were 35 ms slower for words with an initial lexical embedding than for words with a final embedding, $\chi^2(1, \underline{N} = 2143) = 3.9$; $\underline{p} = .048$. Reaction times did not vary depending on the recoded viewing position, $\chi^2(1, \underline{N} = 2143) = 1.8$; $\underline{p} = .18$. The interaction between these two factors was however significant, $\chi^2(1, \underline{N} = 2143) = 7.9$; $\underline{p} = .005$, showing that the difference between initial and final embeddings was smaller when the embedded word was in the fovea (-5 ms) than when the embedded word was not in the fovea (+35 ms). When the embedded word was not in the fovea, there was a clear disadvantage for initial embeddings compared to final embeddings (661 vs. 626 ms). Reaction times varied depending on word frequency (controlled factor), words being recognized 60 ms faster per additional logarithmic unit of frequency, $\chi^2(1, \underline{N} = 2143) = 41.5$; $\underline{p} = .001$.

The additional analysis on the subset of 9 initial embedding words comparing inside and outside viewing positions confirmed the previous results. Subjects were 32 ms slower to process the same words when looking outside the initial lexical embedding (703 ms) than when looking inside (671 ms), $\chi^2(1, \underline{N} = 263) = 7.6$; $\underline{p} = .006$. The same additional analysis on the subset of 29 final embedding words showed a non-significant 9 ms difference between the Inside (614 ms) and the Outside (623 ms) viewing conditions, $\chi^2(1, N = 263) = 2$; $p = .16$.

**Discussion**

The first analysis based on viewing position in the carrier word and embedding location only revealed an effect of optimal viewing position. It did not reveal any interaction between these two factors, although Figure 1 shows a lengthening in mean reaction times when the viewing position was in the embedded word (B and I, E and F) compared to when the viewing position was outside the embedded word (respectively B and F, E and I). However, because the situation was noisy for the M viewing position, as explained in the Statistical procedure section, statistical estimations may have missed the real effect.

The second analysis based on recoded viewing position and embedding location showed an interaction effect between the two factors. This interaction seemed to result from reaction times 40 ms slower in the Outside/Initial condition than in the three other conditions. The error percentage in this particular condition (41.5%) was almost twice as high as in the other three conditions (20.7, 21.3 and 16.13%). This confirmed the higher processing difficulty. Additional analyses also confirmed that words with an initial lexical embedding were more difficult to process when subjects were not looking inside the embedded word, which was not the case with words containing a final lexical embedding. Equation 1 defined viewing positions identically in both cases.

At this point, it is important to recall the predictions of TRACE for written words. Lexical competition due to an initial embedded word should have the same dynamic impact on the recognition of the stimulus carrier word as lexical competition due to a final embedded word, because in both cases, lexical competition starts at the beginning of the recognition process. While this prediction is consistent with the chronometric findings of Experiment 3, it is, at first glance, inconsistent with what we found in the second analysis of Experiment 4. According to TRACE, we should have found longer reaction times when participants looked at the embedded words than when they did not. Therefore, main effect of viewing position should have resulted.

The behavioral pattern we observed with recoded variables (Second analysis) may be explained in two different ways. The first explanation is that words were more difficult to recognize only in the Outside/Initial condition, the three other conditions being equally easier to process. According to this point of view, though no lexical competition is observed in the Inside/Initial and Inside/Final conditions, no facilitation is measured either. On the contrary, we observed what seems to be a baseline, common to three conditions. Longer reaction times and higher error rates in the Outside/Initial condition would therefore be due to lexical confusion between the embedded word and the carrier word, which suggests that word beginnings are more important than word endings (no confusion between the embedded word and the carrier word in the Outside/Final condition). Consequently, not looking at an initial embedded word would impair processing of the carrier word, and looking at it would not interfere, while final embeddings would never cause any interference. This explanation is consistent with predictions of TRACE for spoken words, but not for written words.

The second explanation, more plausible, is a little more complex. It considers that the recoded viewing position is conflated with another factor: viewing position in the carrier word (left half vs. right half). The new model is therefore based on viewing position in the embedded word, embedding position, and viewing position in the carrier word. Let us suppose that the main effect of the position of the lexical embedding would be as suggested by the second analysis of Experiment 4: Words with an initial lexical embedding would be more difficult to process than words with a final lexical embedding. This phenomenon could result from the structure of the mental lexicon, built on the experience of spoken language rather than on the experience of written language, therefore integrating something of the temporal directionality of speech in its structure. In addition, let us suppose that viewing position in the embedded word would not be non-significant as it appears in the results from the second analysis. Let us suppose that non-significance resulted from the conflation of two factors cancelling their respective effect: Viewing position in the embedded word and viewing position in the carrier word. Let us suppose that looking at the left half of the carrier word makes the recognition easier than looking at the right half. This phenomenon, reported in the literature (Ducrot & Pynte, 2002), is found in our data, which show a 10 ms difference (average over the B and M conditions for the left half viewing position = 609 ms; average over the F condition for the right half = 618 ms). The behavioral pattern provided by the second analysis makes only sense if viewing inside an embedded word facilitates the lexical processing of the carrier word (dashed arrow in Figure 3) and viewing outside impairs the processing (plain arrow). Figure 3 shows the behavioral pattern predicted by a main effect of viewing position in the carrier word combined with a main effect of lexical embedding position (grey dashed lines), and how this pattern evolves straightforwardly to the observed pattern when adding the main effect of viewing position in the embedded word (black plain lines).

INSERT FIGURE 3

This little demonstration shows how Experiment 4 succeeded in measuring two opposite phenomena occurring in written word recognition: Lexical competition due to initial embeddings and lexical facilitation due to an embedded word.

We asked in the discussion of Experiment 3 as a premise for Experiment 4 whether the foveal shift away from a lexical embedding corresponded to a behavior of search for disambiguating information, or if it was the correlate of an easier processing caused by lexical embeddings. Because the same oculomotor behavior of repulsion was observed for initial and for final lexical embeddings in Experiment 3, we considered that lexical embeddings were processed the same way, whatever their embedding position. We showed with Experiment 4 that looking inside a lexical embedding facilitated processing of the carrier word. Consequently, readers were probably scanning the most difficult parts of the stimulus word, by looking away from lexical embeddings in Experiment 3.

Before entering the general discussion, we had to check one more point concerning the relation between lexical variables and eye landing positions in Experiments 2 and 3. Actually, we observed across these two experiments a weak relation between the lexical embedding factors and oculomotor behavior. Recall that Experiment 2 did not reveal any effect of lexical embedding on landing position and Experiment 3 showed the opposite effect of what we predicted with refixations. We needed a theoretical and practical tool linking lexical factors with behavior. We used the split-fovea model (Shillcock et al., 2000) to reanalyze our oculomotor data.

## ANALYSIS OF OUR OCULOMOTOR DATA IN THE LIGHT OF THE SPLIT-FOVEA MODEL

Using the split-fovea model (Shillcock et al., 2000), we aimed at clarifying whether the absence of oculomotor differences observed between the two lexical conditions in Experiment 2, and the differences observed for refixation positions in Experiment 3, were due to lexical factors (e.g., small size of items, position of lexical embedding) or to the visual lexical neighborhood of split words. The split-fovea model is based on anatomical constraints determining visual information pathways towards the cortex, which affect lexical processing because the retinal image of a word is split in two, each half being processed in a cerebral hemisphere. The image of a word projected on the retina can be divided into a central zone (fovea), corresponding to the fixation point in the word, and two peripheral zones, the right and the left hemi-retina, respectively receiving the projection of the left and the right parts of the word split by the fixation point. The left hemi-retina projects in the left hemisphere, and the right hemi-retina projects in the right hemisphere. Therefore, the part of a word situated to the left of the fixation point is processed by the right hemisphere, and the right part of the word is processed by the left hemisphere. This splitting configuration raises the problem of communication inside the lexical processor. According to Shillcock, Ellison et al. (2000), “one way of optimizing the necessary communication between the two halves of the processor is to ensure that each half has an equal probability of identifying the word being presented, the aim being to maximize the sum of the information on both sides” (p. 827).

MacDonald and Shillcock (2005) explored this hypothesis and showed that division of visual input determines a target point corresponding to the optimal split of the word in terms of probability to identify it from each half. The confusability of each part of the word is determined by each part’s lexical neighborhood. If the lexical neighborhood is larger for the left part of the word than for the right part, the fixation position will be shifted towards the right to balance the two lexical neighborhood sizes. The system looks for the viewing position offering the best compromise in terms of statistical accuracy.

We used this model to compute the theoretical fixation target for each one of the stimulus words. This analysis did not consider all the possible neighbors, but only those having the length of the stimulus. Actually, “two types of orthographic information can be employed in discriminating a word from its visual competitors: its length and its component letters” (McDonald & Shillcock, 2005).

The computation of the theoretical fixation point was done as follows, adapted from descriptions of the split-fovea model given by McDonald and Shillcock (2005). For each rank n or letter position in a given string of letters forming a word, the number x of words having the length of the stimulus and sharing the same sequence of letters until that rank were counted, separately from the beginning of the word and from the end of the word. For instance, the word CHEMISE (shirt) has seven letters. According to the database LEXIQUE, 613 words of 7 letters start with the letter C, 79 words of 7 letters start with the sequence of letters CH, 7 words of 7 letters start with CHE, etc. and 2130 words of 7 letters end with E, 185 words of 7 letters end with SE, 23 words of 7 letters end with ISE, etc. We thereby obtained two series of numbers for each word. For each rank, the sum of the two values was computed, resulting in a new series of values (for instance, for the word CHEMISE, this series is 614, 80, 8, 5, 24, 186, and 2131). From that series, the fixation position f(x), expressed in letters, was computed as the sum of the ratios n/x at each rank n, divided by the sum of the ratios 1/x at each rank, resulting in the formula given in Equation 1:

$$f(x) = \sum_{1}^{n}(n/x) \Big/ \sum_{1}^{n}(1/x) \qquad (1)$$

With n being the rank and x being the sum of neighbors for this rank. For the word CHEMISE, the fixation position f(x) predicted by the model will therefore be 3.74 characters.

**Reanalysis of the oculomotor data from Experiment 2**

The null effect of initial lexical embedding on eye landing position in Experiment 2 could result from similar theoretical fixation points for words with and without initial embedding, instead of resulting from item size as initially thought. We computed the theoretical landing position for each word used in Experiment 2, following the procedure explained previously. We used these theoretical landing position values as dependent variable in a by items ANOVA-like statistical analysis, in which the experimental variable “presence of an initial lexical embedding” was used as predictor. This analysis revealed no difference between the theoretical viewing position in words with a lexical embedding (2.762) and in words without a lexical embedding (2.763), $\chi^2(1, N = 36) = 0$, $p = 1$. Consequently, the absence of effect of lexical embedding on oculomotor behavior in Experiment 2 could also be due to identical theoretical landing positions in the two conditions.

**Reanalysis of the oculomotor data from Experiment 3**

The same analysis was run on the experimental materials of Experiment 3. Statistical analyses revealed that the theoretical fixation point differed significantly between the two lexical conditions of Experiment 3. Words beginning with a lexical embedding have a theoretical fixation point (4.18 letters) located 0.57 letters further from the beginning of the word than words ending with a lexical embedding (3.61 letters), $\chi^2(1, \underline{N} = 60) = 14.4$, $\underline{p} = .0001$. Therefore, the 0.322 letters difference observed between the two lexical conditions for the landing position of refixations appears to fit the predictions of the split-fovea model. A multilevel analysis was run to test if theoretical landing positions were a good predictor of landing position of refixations, instead of the lexical factor manipulated in Experiment 3. The model crossed two random factors (subjects and items), the dependent factor being the observed landing position of the eyes in refixations, the predictor being the theoretical fixation point. Missing values were not replaced. For each additional character of the theoretical fixation point, the observed landing position was increased by 0.55 characters. This relation was highly significant, $\chi^2(1, \underline{N} = 2408) = 70$, $\underline{p} = 6.10^{-17}$.

These analyses reveal that differences in refixation landing position observed in Experiment 3 can be explained by the lexicon’s structure as well as by the lexical factor manipulated in Experiment 3. Because theoretical landing position is congruent with oculomotor data from Experiments 2 and 3, the lexical neighborhood of split words appears as a good predictor of oculomotor behavior, making it ambiguous whether our observations were finally due to lexical embeddings in Experiment 3, or to other parameters. To help choosing between two alternatives, we ran a confirmatory analysis by studying the relation of the lexical embedding factors from Experiment 2 and Experiment 3 with the theoretical fixation point. To this end, we selected “randomly”, provided they respected the criteria defining the categories described hereafter, 30 disyllabic 8 to 9 letters length monomorphemic French nouns from LEXIQUE. Ten had no lexical embedding (C), 10 had an initial lexical embedding (B), and 10 had a final lexical embedding (F). We computed for each word the theoretical landing position following the procedure described above. Two by items ANOVA-like analysis were run. The first one contrasted words from the categories C and B to test a similar situation as in Experiment 2, the second one contrasted words from the categories B and F to test a similar situation as in Experiment 3. Both included theoretical landing position as dependent variable. The first analysis included the independent lexical variable of Experiment 2 as predictor (“presence of an initial lexical embedding”), the second analysis included the independent lexical variable of Experiment 3 as predictor (“lexical embedding position”). We found no significant relation between theoretical landing position and presence of an initial lexical embedding in the first analysis, $F(1, 18) = 0.2$ ; $p = .68$. We found no significant relation between theoretical landing position and lexical embedding position in the second analysis, $F(1, 18) = 0.2$ ; $p = .63$. We concluded that there was no relation between theoretical landing position and existence or position of a lexical embedding, while a strong relation existed between theoretical landing position and oculomotor behavior, i.e. between lexical neighborhood of split words and oculomotor behavior. The consequence is that none of the oculomotor results from this study say anything about the processing of lexical embedding configurations.

## GENERAL DISCUSSION

Experiments 1, 2 and 4 measuring reaction times with a lexical decision task revealed that in reading, non-morphological lexical embeddings facilitate the recognition of their carrier words, compared to control words. We concluded, after controlling lexical neighborhood, bigram and trigram frequencies, lexical frequency and foveal viewing position, that this phenomenon could not be explained in terms of sublexical processes and lexical frequency. It could not be explained acceptably by task demands as well, facilitation having been found in other studies with other tasks, including a non-linguistic task measuring the interference of computational demands (non-linguistic target detection in the auditory modality). We arrived at the conclusion that facilitation caused by lexical embeddings was due to unknown lexical processes taking advantage of the superimposing structure of the lexicon. We also concluded that contrary to spoken words, this advantage was not depending on the position of the lexical embedding in written words.

The chronometric part of the study also revealed that the dynamics of an acoustical stimulus was not masking the lexical competition, as previously suggested from results obtained with spoken words. If the lexical competition that TRACE predicts between the carrier word and the embedded word was an early phenomenon difficult or impossible to measure with spoken words because of the delayed input, longer reaction times should have been observed with written words instead of faster reaction times. Because an inverse effect to lexical competition was observed in Experiments 1 and 2, we first concluded that lexical competition between the carrier and the embedded word was absent during the processing of this lexical configuration, or was of marginal impact compared to other processes. However, the second analysis of Experiment 4 showed that lexical competition was probably occurring in the case of initial lexical embeddings, a fact compatible with TRACE predictions for spoken words, but not for written words. Consequently, two opposite phenomena may occur at the same time, lexical competition and facilitation, the first one being masked by the second one. Furthermore, lexical competition may not always be required during the recognition of a word containing an initial lexical embedding.

Word recognition would therefore rely on unknown processes favoring lexical targeting and activation thanks to lexical enhancement of the carrier by the embedded word. This could be the case if the mental lexicon was a layered structure in which the bottom levels contain the simpler lexical units and the top levels contain the most complex lexical units. Because of this organization, the path to access the representation of a long word containing an initial embedded word would automatically go through the layer where the representation of the lexical embedding is stored, and from there jumps to the next layer. Contrary to a cohort system in which lexical units are unrelated except by the mediation of the sublexical layer, the superimposing relation between the embedded word and the carrier word would allow an activation transfer from the lexical embedding to the carrier. No competition would occur if words were not stored in the same layer. Instead of conflicting, the long word would benefit from the activation of the lower lexical level.

We thought that investigating oculomotor behavior would allow us to find an effect expressing a curvature of the perceptual space due to lexical embeddedness, the same way it seemed to be expressed in the chronometric dimension as facilitation. This was not the case. Experiment 2 failed to reveal any effect of lexical embedding on oculomotor behavior, despite a chronometric effect. While the null effect may be due to items size, the neighborhood of split words was most probably causing it. Experiment 3 showed that lexical embeddings acted as repulsing magnets for the eyes, when we predicted the opposite. We concluded that the eyes were probably targeting the most informative part of the word, which is also the most difficult part to process, therefore neglecting the easiest part to process: Lexical embedding. However, a reanalysis of the data from Experiment 3 in the light of the split-fovea model showed that eyes targeted the most informative part of the word defined by the neighborhood of split words. Further analysis of the relation between the theoretical landing position defined by the split-fovea model and the presence or the position of a lexical embedding showed that lexical embedding factors did not cause the oculomotor behaviors in Experiment 3.

The conclusion we came to was that the eyes' behavior depended in no way on the lexical factors we manipulated in Experiments 2 and 3. Our oculomotor results rather found a satisfactory explanation in terms of neighborhood size of split words, while the neighborhood of split words did not depend strictly on lexical embedding. Consequently, eye movements were not expressing the perceptual space curvature we hypothesized as an underlying common phenomenon to chronometric and oculomotor aspects of the behavior. Eye movements did not prove to be a good index for studying the problem we investigated. However, manipulating the viewing position was very useful. It allowed confirming the positive effect of lexical embeddings on the carrier word recognition. The auditory modality could in no way reveal this kind of results.

**Speculations about the underlying lexical process causing facilitation**

Presently, we can only speculate about unknown lexical processes causing facilitation when a word contains a lexical embedding. We do not think, with respect to the observations we collected, that these processes rely on sublexical phenomena. We rather think that their origin is in the structure of the lexicon and the way sublexical units are represented and linked to the lexicon. We have already suggested that the mental lexicon could have a layered structure organizing lexical complexity. However, a structure with more levels would probably generate more constraints in the system. A model like TRACE, for instance, is structurally and dynamically unable to produce the facilitation we measured (Lachaud, submitted-b). It can only produce less competition, never facilitation. This limitation is mainly due to its localist architecture causing separate levels and a strict hierarchy in the processing through levels. We suggest, after authors like (Derthick & Plaut, 1986; Gaskell & Marslen-

Wilson, 1997; Hinton, McClelland, & Rumelhart, 1986; Plate, 1994), that distributed lexical representations ground the word recognition system rather than localist representations, which allows new properties to emerge. That is, compounds of sublexical units and phonemic primitives, as well as of lexical units, organized in such a way that the superimposition relations between words are also implemented in the structure of this distributed lexicon, all representational levels being possibly collapsed into the same physical layer. A localist alternative to this schema would be to adapt TRACE-like systems by adding a post-lexical layer in charge to model the relations between lexemes, as it was suggested with the LEXSS metaphor by Lachaud (2005; Submitted-a).

The discovery of facilitation effects due to the lexical superimposition of the lexicon is an exciting challenge if it is confirmed by other teams. It may help us improve our understanding of the lexical processor architecture and functioning, and open to new automatic speech recognition systems.

## CONCLUSION

Results from the present study, in combination with results from existing studies on lexical processing of words containing embedded words draw a picture suggesting that lexical embeddings facilitate the processing of their carriers, instead of impairing it as suggested by the theoretical framework of lexical competition. Our results also suggest that these effects are probably generated at a lexical level by unknown phenomena: It implies that the mechanisms taking advantage of the massive superimposing organization of the lexicon are still to be discovered.

**FOOTNOTES**

Footnote 1. A non-linguistic target is a 10 ms non-linguistic sound inserted in the sound wave of the stimulus word. The task consisted in detecting these targets as fast as possible without mistaking it with a distracting non-linguistic resembling sound. This task allowed measuring the computational load in the system through the interference between the detection processes and the linguistic processing of word recognition occurring automatically during the monitoring of the stimulus.

## REFERENCES


Allopenna, P. D., Magnuson, J. S., & Tanenhaus, M. K. (1998). Tracking the Time Course of Spoken Word Recognition Using Eye Movements: Evidence for Continuous Mapping Models. *Journal of Memory and Language, 38,* 419-439.

Baayen, H., Pipenbrook, R., & Guilikers, L. (1995). The Celex lexical database (v2.5).

Baccino, T. (1999). Exploring the flicker effect: the influence of in-flight pulsations on saccadic control. *Ophthalmic and Physiological Optics, 19*(3), 266-273.

Beauvillain, C. (1996). The integration of morphological and whole-word form information during eye fixations on prefixed and suffixed words. *Journal of Memory and Language, 35,* 801-820.

Beauvillain, C., & Doré, K. (1998). Orthographic codes are used in integrating information from the parafovea by the saccadic computation system. *Vision Research, 38*(1), 115-123.

Beauvillain, C., Doré, K., & Baudouin, V. (1996). The 'Center of gravity' of words: evidence for an effect of the word-initial letters. *Vision Research, 36*(4), 589-603.

Content, A., Mousty, P., & Radeau, M. (1990). BRULEX. Une base de données lexicales informatisée pour le français écrit et parlé. *L'année Psychologique*, *90*(4), 551-566.

Cutler, A., McQueen, J. M., Jansonius, M., & Bayerl, S. (2002). *The lexical statistics of competitor activation in spoken-word recognition.* Paper presented at the 9th Australian International Conference on Speech Science and Technology, Melbourne.

Dahan, D., Magnuson, J. S., & Tanenhaus, M. K. (2001). Time course of frequency effects in spoken-word recognition: evidence from eye movements. *Cognitive Psychology, 42*(4), 317-367.

Davis, M. H. (2000). *Lexical segmentation in spoken word recognition.* University of London, London.

Derthick, M., & Plaut, D. C. (1986). *Is distributed connectionism compatible with the Physical Symbol System Hypothesis?* Paper presented at the 8th Annual Conference of the Cognitive Science Society.

Ducrot, S., & Pynte, J. (2002). What determines the eyes' landing position in words? *Perception & Psychophysics, 64*(7), 1130-1144.

Forster, K. I., & Shen, D. (1996). No Enemies in the Neighborhood: Absence of Inhibitory Neighborhood Effects in Lexical Decision and Semantic Categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22*(3), 696-713.

Gaskell, M. G., & Marslen-Wilson, W. D. (1997). Integrating form and meaning: A distributed model of speech perception. *Language and Cognitive Processes, 12*(5-6), 613-656.

Goldinger, S. D., Luce, P. A., & Pisoni, D. B. (1989). Priming lexical neighbors of spoken words: effects of competition and inhibition. *Journal of Memory and Language, 28*, 501-518.

Grainger, J., Muneaux, M., Farioli, F., & Ziegler, J. C. (2005). Effects of phonological and orthographic neighborhood density interact in visual word recognition. *The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology, 58A*(6), 981-998.

Grossberg, S. (1968). Some physiological and biochemical consequences of psychological postulates. *Proceedings of the National Academy of Sciences USA, 60*(3), 758-765.

Hinton, G. E., McClelland, J. L., & Rumelhart, D. E. (1986). Distributed representations. In D. E. Rumelhart & J. L. McClelland (Eds.), *Parallel Distributed Processing:*

*Explorations In The Microstructure of Cognition* (pp. 77-109). Cambridge, MA: MIT Press.

Hox, J. (2002). *Multilevel analysis: techniques and applications*. London: Lawrence Erlbaum Associates, Publishers.

Kennedy, A. (2000). Parafoveal processing in word recognition. *The Quarterly Journal of Experimental Psychology A, 53*(2), 429-455.

Lachaud, C. M. (1997). *Les effets perturbateurs liés au scintillement subliminal des écrans cathodiques, sur le contrôle oculomoteur lors du déplacement saccadique des yeux.* Université de Nice-Sophia Antipolis

Université de Provence-Aix Marseille I, Nice

Aix-en-Provence.

Lachaud, C. M. (2005). *La prégnance perceptive des mots parlés: une réponse au problème de la segmentation lexicale?* (Doctoral Dissertation). Genève, GE: Université de Genève, Suisse.

Lachaud, C. M. (Submitted-a). Challenging the generic model of spoken word recognition with the general superimposition principle: another direction with the LEXSS metaphor. *Cognitive Psychology*.

Lachaud, C. M. (submitted-b). How can embedded words facilitate their carrier recognition: Simulations with TRACE.

Lachaud, C. M., & Renaud, O. (submitted). A tutorial for analyzing reaction times: how to filter data, to manage missing values, and to chose a statistical model? *Journal of Memory and Language*.

Luce, P. A., & Lyons, E. A. (1999). Processing lexically embedded spoken words. *Journal of Experimental Psychology: Human Perception and Performance, 25*(1), 174-183.

Luce, P. A., & Pisoni, D. B. (1998). Recognizing spoken words: the neighborhood activation model. *Ear and Hearing, 19*(1), 1-36.

Marslen-Wilson, W. D., & Welsh, A. (1978). Processing interactions and lexical access during word recognition in continuous speech. *Cognitive Psychology, 10*(1), 29-63.

McClelland, J. L., & Elman, J. L. (1986). The TRACE model of speech perception. *Cognitive Psychology, 18*(1), 1-86.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: I. An account of basic findings. *Psychological Review, 88*(5), 375-407.

McDonald, S. A., & Shillcock, R. (2005). The implications of foveal splitting for saccade planning in reading. *Vision Research, 45*, 801-820.

New, B., Pallier, C., Ferrand, L., & Matos, R. (2001). Une base de données lexicales du français contemporain sur internet: LEXIQUE. *L'année Psychologique, 101*(3), 447-462.

O'Regan, J. K., Lévy-Schoen, A., Pynte, J., & Brugaillère, B. (1984). Convenient fixation location within isolated words of different length and structure. *Journal of Experimental Psychology: Human Perception and Performance, 10*(2), 250-257.

Plate, T. A. (1994). *Distributed representations and nested compositional structure.* Unpublished phd, Toronto, Toronto.

Pynte, J. (1996). Lexical Control of Within-Word Eye Movements. *Journal of Experimental Psychology: Human Perception and Performance, 22*(4), 958-969.

Pynte, J. (2000). Words likely to activate many lexical candidates are granted an advantage: evidence from within-word eye-movements. In A. Kennedy, R. Radach, D. Heller & J. Pynte (Eds.), *Reading as a perceptual process* (pp. 47-64). Amsterdam

New-York: Elsevier Science Ltd.

Pynte, J., & Frenck-Mestre, C. (1997). Syntactic Ambiguity Resolution While Reading in Second and Native Languages. ***The Quarterly Journal of Experimental Psychology A***, *50*(1), 119-148.

Rasbash, J., Browne, W., Healy, M., Cameron, B., & Charlton, C. (2001). MLwiN (Version 1.1): Multilevel Models Project, Institute of Education, London, UK.

Rasbash, J., Steele, F., Browne, W., & Prosser, B. (2005). *A user's guide to MLwiN version 2.0*: Centre for Multilevel Modelling, University of Bristol.

Shillcock, R., Ellison, T., & Monaghan, P. (2000). Eye-Fixation Behavior, Lexical Storage, and Visual Word Recognition in a Split Processing Model. *Psychological Review, 107*(4), 824-851.

Snijders, T., & Bosker, R. (1999). *Multilevel analysis: an introduction to basic and advanced multilevel modeling*. London, UK: SAGE Publications Ltd.

Taft, M., & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior*, *15*(6), 607-620.

Vitevitch, M. S., & Luce, P. A. (1999). Probabilistic phonotactics and neighborhood activation in spoken word recognition. *Journal of Memory and Language, 40*, 374-408.

Ziegler, J. C., Muneaux, M., & Grainger, J. (2003). Neighborhood effects in auditory word recognition: Phonological competition and orthographic facilitation. *Journal of Memory and Language, 48*, 779-793.

**TABLES**

Table 1.

Word characteristics per condition for Experiment 1

| | | Frq. | Length | | U.P. | | Homo. | | Gr. | % Superimp. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Gr | Pho | Gr | Pho | Gr | Pho | Neigh | Gr | Pho |
| E | Mean | 1519 | 5.1 | 3.4 | 5.6 | 4.3 | 0.1 | 0.3 | 8.1 | 65 | 72 |
| | Min | 34 | 4 | 3 | 4 | 3 | 0 | 0 | 1 | 50 | 67 |
| | Max | 7389 | 7 | 4 | 7 | 5 | 1 | 3 | 17 | 80 | 100 |
| | SD | 2305 | 0.8 | 0.5 | 0.8 | 0.6 | 0.3 | 0.8 | 5.4 | 11 | 8 |
| C | Mean | 2978 | 5.1 | 3.4 | 5.4 | 4.4 | 0.2 | 0.4 | 6.6 | 0 | 0 |
| | Min | 38 | 4 | 3 | 4 | 4 | 0 | 0 | 0 | 0 | 0 |
| | Max | 13550 | 7 | 4 | 8 | 5 | 2 | 3 | 18 | 0 | 0 |
| | SD | 3735 | 0.8 | 0.5 | 1.0 | 0.5 | 0.5 | 0.8 | 4.0 | 0 | 0 |

Note. E Embedded condition, C Control condition; Frq. Formal frequency of words; U.P. uniqueness point; Homo. Number of homo- graphs (Gr)/phons (Pho); Gr. Neigh number of graphic neighbors; % Superimp. Percentage of sublexical components of the carrier word corresponding to the embedded word; Gr graphic; Pho phonemic.

Table 2.

Reaction Time and Error Rate characteristics per condition for Experiment 1

| | C | | E | |
|---|---|---|---|---|
| | RT | Er | RT | Er |
| Mean | 546 | 1.5 | 523 | 1.8 |
| SD | 108 | 2.6 | 91 | 3.0 |

Note. C Control condition. E Embedded condition. RT reaction time. Er errors. SD standard deviation.

Table 3.

Reaction time and Error rate characteristics for Experiment 2

| | C | | | | E | | | |
|---|---|---|---|---|---|---|---|---|
| | L | | R | | L | | R | |
| | RT | Er | RT | Er | RT | Er | RT | Er |
| Mean | 771 | 2.67 | 730 | 2.56 | 739 | 2.39 | 724 | 2.72 |
| SD | 144 | 3.61 | 132 | 3.24 | 151 | 2.99 | 147 | 3.82 |

Note. C Control condition. E Embedded condition. L presentation to the left side of the screen. R to the right. RT reaction time. Er error rate. SD standard deviation.

Table 4.

First saccade and refixation Error Rate characteristics for Experiment 2

| | First saccade | | | | Refixation | | | |
|---|---|---|---|---|---|---|---|---|
| | C | | E | | C | | E | |
| | L | R | L | R | L | R | L | R |
| Mean | 3.56 | 3.11 | 4.67 | 3.94 | 9.78 | 11.72 | 10.56 | 10.61 |
| SD | 1.58 | 1.23 | 1.08 | 1.47 | 2.10 | 2.24 | 2.33 | 2.17 |

Note. C Control condition. E Embedded condition. L presentation to the left side of the screen. R to the right. SD standard deviation.

Table 5.

Saccade Characteristics for Experiment 2

| Param. | Sacc. | Mean | Pred. | Coeff. | SE | $\chi^2$ | p |
|---|---|---|---|---|---|---|---|
| Latency (ms) | S1 | 130.33 | E | 1.7 | 2.5 | 0.5 | .50 |
| | | | R | 5.9 | 2.4 | 6.1 | .013 |
| | | | E*R | -5.4 | 4.3 | 1.6 | .21 |
| | S2 | 301.77 | E | -10.2 | 16.7 | 0.4 | .54 |
| | | | R | -11.8 | 15.3 | 0.6 | .44 |
| | | | E*R | 18.6 | 24.6 | 0.6 | .45 |
| Duration (ms) | S1 | 25.59 | E | -0.02 | 0.6 | 0.0 | .96 |
| | | | R | -1.5 | 0.6 | 7.4 | .006 |
| | | | E*R | 0.7 | 1.1 | 0.4 | .52 |
| | S2 | 15.79 | E | -1.9 | 1.8 | 1.1 | .30 |
| | | | R | -1.5 | 1.6 | 0.9 | .35 |
| | | | E*R | 0.4 | 2.3 | 0.03 | .87 |
| Position (letter) | S1 | 2.76 | E | -0.1 | 0.2 | 0.9 | .34 |
| | | | R | -0.9 | 0.1 | 60.3 | <.001 |
| | | | E*R | 0.3 | 0.2 | 2.2 | .14 |
| | S2 | 2.59 | E | -0.2 | 0.2 | 1.2 | .28 |
| | | | R | 0.3 | 0.2 | 2.4 | .12 |
| | | | E*R | 0.3 | 0.3 | 1.7 | .19 |

Note. Param. Saccade Parameters. Sacc. Saccade. S1 first saccade. S2 Refixation. Pred. Predictor. E Embedded condition (reference: Control condition). R presentation to the right side of the screen (reference: Left). E*R interaction. Coeff. Coefficient provided by the model. SE standard error of the estimation. $\chi^2$ value of Chi square. p significance level.

Table 6.

Word characteristics by condition for Experiment 3

| | | Frq. | Length | | U.P. | | Gr. | % Superimp. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Gr | Pho | Gr | Pho | Neigh | Gr | Pho |
| I | Mean | 27.41 | 7.47 | 5.37 | 6.47 | 4.83 | 1.43 | 57 | 57 |
| | Min | 0.14 | 6 | 3 | 5 | 3 | 0 | 43 | 33 |
| | Max | 304.67 | 10 | 7 | 9 | 6 | 10 | 67 | 100 |
| | SD | 63.09 | 1.07 | 0.89 | 1.04 | 0.83 | 2.62 | 08 | 15 |
| F | Mean | 16.85 | 7.47 | 5.30 | 6.60 | 4.90 | 0.67 | 65 | 58 |
| | Min | 0.01 | 6 | 4 | 2 | 3 | 0 | 50 | 40 |
| | Max | 91.42 | 10 | 7 | 10 | 6 | 3 | 83 | 80 |
| | SD | 22.48 | 1.14 | 0.70 | 1.67 | 0.80 | 0.84 | 08 | 09 |

Note. Fq. Lexical frequency (occurrence per million). Gr written form in number of letters. Pho phonological form in number of phonemes. U.P. uniqueness point. Gr. Neigh graphical neighborhood. % Superimp the percentage of the carrier word that corresponds to the embedded word. I Initial embedding condition. F final embedding condition. SD standard deviation.

Table 7.

Reaction Time and Error Rate characteristics per condition for Experiment 3

| | I | | | | F | | | |
|---|---|---|---|---|---|---|---|---|
| | R | | L | | R | | L | |
| | RT | Er | RT | Er | RT | Er | RT | Er |
| Mean | 774.5 | 8.83 | 793.2 | 8.67 | 762.6 | 7.53 | 796.0 | 8.70 |
| SD | 146.5 | 6.75 | 151.2 | 6.68 | 140.2 | 5.73 | 142.8 | 5.66 |

Note. I Initial embedding condition. F Final embedding condition. R stimulus presentation on the right. L on the left. RT reaction time. Er error rate. SD standard deviation.

Table 8.

Saccade error rate per condition for word stimuli in Experiment 3

| | First saccade | | | | Refixation | | | |
|---|---|---|---|---|---|---|---|---|
| | I | | F | | I | | F | |
| | L | R | L | R | L | R | L | R |
| Mean | 4.63 | 4.50 | 4.60 | 4.93 | 9.57 | 12.87 | 12.03 | 13.27 |
| SD | 2.06 | 2.35 | 2.18 | 2.15 | 3.09 | 4.09 | 4.34 | 4.35 |

Note. I Initial embedding condition. F Final embedding condition. L stimulus presentation on the left. R on the right. SD standard deviation.

Table 9.

Saccade Characteristics per condition for word stimuli in Experiment 3

| Param. | Sacc. | Mean | Pred. | Coeff. | SE | $\chi^2$ | p |
|---|---|---|---|---|---|---|---|
| Latency (ms) | S1 | 132 | I | -0.4 | 0.8 | 0.3 | .60 |
| | | | R | 5.3 | 0.8 | 39.8 | < .001 |
| | | | I*R | -0.03 | 1.2 | 0.01 | .97 |
| | S2 | 259 | I | 8.6 | 5.8 | 2.2 | .14 |
| | | | R | 27 | 4.4 | 38.1 | < .001 |
| | | | I*R | -16 | 6.1 | 6.9 | .008 |
| Duration (ms) | S1 | 28 | I | -0.1 | 0.2 | 0.2 | .62 |
| | | | R | -3 | 0.2 | 261 | < .001 |
| | | | I*R | 0.5 | 0.3 | 3 | .08 |
| | S2 | 16 | I | 0 | 0.3 | 0 | 1 |
| | | | R | 0.8 | 0.2 | 19 | < .001 |
| | | | I*R | -0.1 | 0.2 | 0.2 | .64 |
| Position (letters) | S1 | 3.87 | I | -0.1 | 0.1 | 0.1 | .92 |
| | | | R | -1.5 | 0.1 | 825 | < .001 |
| | | | I*R | 0.1 | 0.1 | 0.3 | .60 |
| | S2 | 2.88 | I | 0.3 | 0.1 | 6.4 | .01 |
| | | | R | 1.2 | 0.1 | 264 | < .001 |
| | | | I*R | -0.1 | 0.1 | 0.6 | .43 |

Note. Param. Saccade Parameters. Sacc. Saccade. S1 first saccade. S2 Refixation. Pred. Predictor. E Embedded condition (reference: Control condition). R presentation to the right side of the screen (reference: Left). E*R interaction. Coeff. Coefficient provided by the model.

SE standard error of the estimation. $\chi^2$ value of Chi square. p significance level. $\chi^2(1, N = x)$, with x = 3285 for first saccades, x = 2408 for refixations.

Table 10.

Saccade error rate per condition for non-word stimuli in Experiment 3

| | First saccade | | | | Refixation | | | |
|---|---|---|---|---|---|---|---|---|
| | I | | F | | I | | F | |
| | L | R | L | R | L | R | L | R |
| Mean | 7.70 | 7.57 | 7.50 | 6.30 | 10.70 | 13.30 | 10.23 | 11.57 |
| SD | 2.88 | 2.51 | 2.89 | 2.52 | 2.64 | 4.39 | 3.27 | 3.75 |

Note. I Initial embedding condition. F Final embedding condition. L stimulus presentation on the left. R on the right. SD standard deviation.

Table 11.

Saccade Characteristics per condition for non-word stimuli in Experiment 3

| Param. | Sacc. | Mean | Pred. | Coeff. | SE | $\chi^2$ | p |
|---|---|---|---|---|---|---|---|
| Latency (ms) | S1 | 132 | I | 0.7 | 0.9 | 0.7 | .41 |
| | | | R | 4.3 | 0.9 | 24.5 | < .001 |
| | | | I*R | -1.1 | 1.2 | 0.8 | .37 |
| | S2 | 275 | I | -1.1 | 5.5 | 0.1 | .84 |
| | | | R | 15.4 | 4.8 | 10.5 | .001 |
| | | | I*R | 0.6 | 6.8 | 0.0 | .93 |
| Duration (ms) | S1 | 27.7 | I | -0.2 | 0.3 | 0.4 | .54 |
| | | | R | -2.3 | 0.2 | 144 | < .001 |
| | | | I*R | 0.2 | 0.3 | 0.8 | .37 |
| | S2 | 16.8 | I | -0.3 | 0.4 | 0.3 | .56 |
| | | | R | 0.3 | 0.3 | 1.4 | .24 |
| | | | I*R | 0.2 | 0.4 | 0.1 | .71 |
| Position (letters) | S1 | 3.9 | I | 0.03 | 0.1 | 0.1 | .77 |
| | | | R | -1.5 | 0.05 | 1070 | 0 |
| | | | I*R | 0.07 | 0.07 | 1.2 | .28 |
| | S2 | 3.2 | I | 0 | 0.1 | 0 | 1 |
| | | | R | 1.1 | 0.07 | 224 | 0 |
| | | | I*R | -0.06 | 0.1 | 0.4 | .52 |

Note. Param. Saccade Parameters. Sacc. Saccade. S1 first saccade. S2 Refixation. Pred. Predictor. E Embedded condition (reference: Control condition). R presentation to the right side of the screen (reference: Left). E*R interaction. Coeff. Coefficient provided by the model.

SE standard error of the estimation. $\chi^2$ value of Chi square. p significance level. $\chi^2(1, N = x)$, with x = 2968 for first saccades, x = 2466 for refixations.

Table 12.

Characteristics of viewing positions per condition in Experiment 4

| N letters | B | M | E | M-B | E-M |
|---|---|---|---|---|---|
| 6 | 1.75 | 2.75 | 3.75 | 1 | 1 |
| 7 | 1.875 | 3.125 | 4.375 | 1.25 | 1.25 |
| 8 | 2 | 3.5 | 5 | 1.5 | 1.5 |
| 9 | 2.125 | 3.875 | 5.625 | 1.75 | 1.75 |
| 10 | 2.25 | 4.25 | 6.25 | 2 | 2 |

Note. N letters size of the stimulus in number of letters. B beginning foveal position (in number of letters). M middle. E end. M-B and E-M difference of foveal position between M and B, between E and M, in number of letters.

Table 13.

Reaction time and Error rate per condition observed in Experiment 4

| | I | | | | | | F | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | | M | | E | | B | | M | | E | |
| | RT | Er | RT | Er | RT | Er | RT | Er | RT | Er | RT | Er |
| Mean | 615.1 | 1.75 | 601.1 | 1.38 | 613.6 | 2.00 | 610.8 | 1.40 | 607.1 | 1.15 | 622.4 | 1.60 |
| SD | 125.4 | 1.93 | 123.8 | 1.62 | 125 | 1.89 | 120.6 | 1.84 | 120 | 1.23 | 131 | 1.79 |

Note. I Initial embedding condition. F Final embedding condition. B word beginning foveal position. M middle. E end. RT reaction time. Er error rate. SD standard deviation.

Table 14.

Number of cases, observed Reaction time and Error rate, per recoded condition in Experiment 4

| | Initial | | Final | |
|---|---|---|---|---|
| | Inside | Outside | Inside | Outside |
| N | 1215 | 135 | 600 | 750 |
| Nv | 963 | 79 | 472 | 629 |
| Er | 20.7 | 41.4 | 21.3 | 16.1 |
| RT | 605 | 668 | 615 | 612 |

Note. N Number of cases or measurements. Nv number of values used in the analysis. Er Error rate meaning missing values (%). RT Reaction time (ms).

## FIGURES

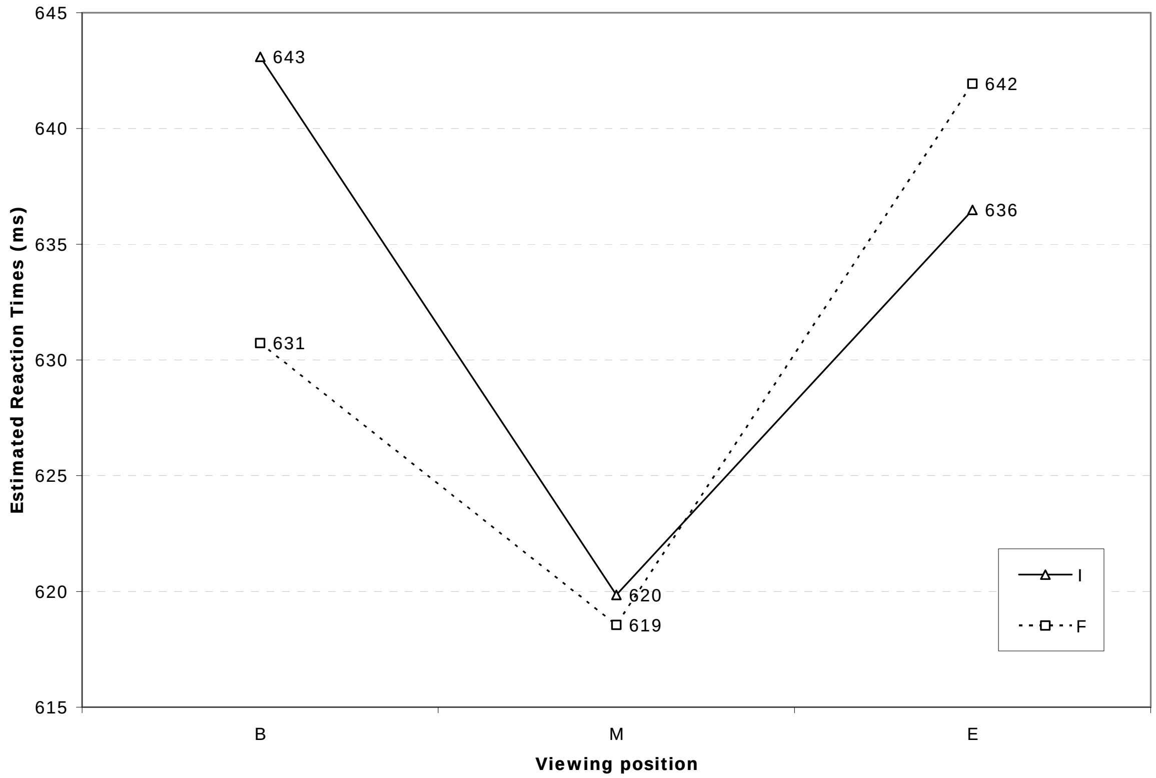


Figure 1. Estimated mean reaction time per condition provided by the first model, as a function of position of lexical embedding (I Initial vs. F Final) and viewing position (B Beginning, M Middle, E End).

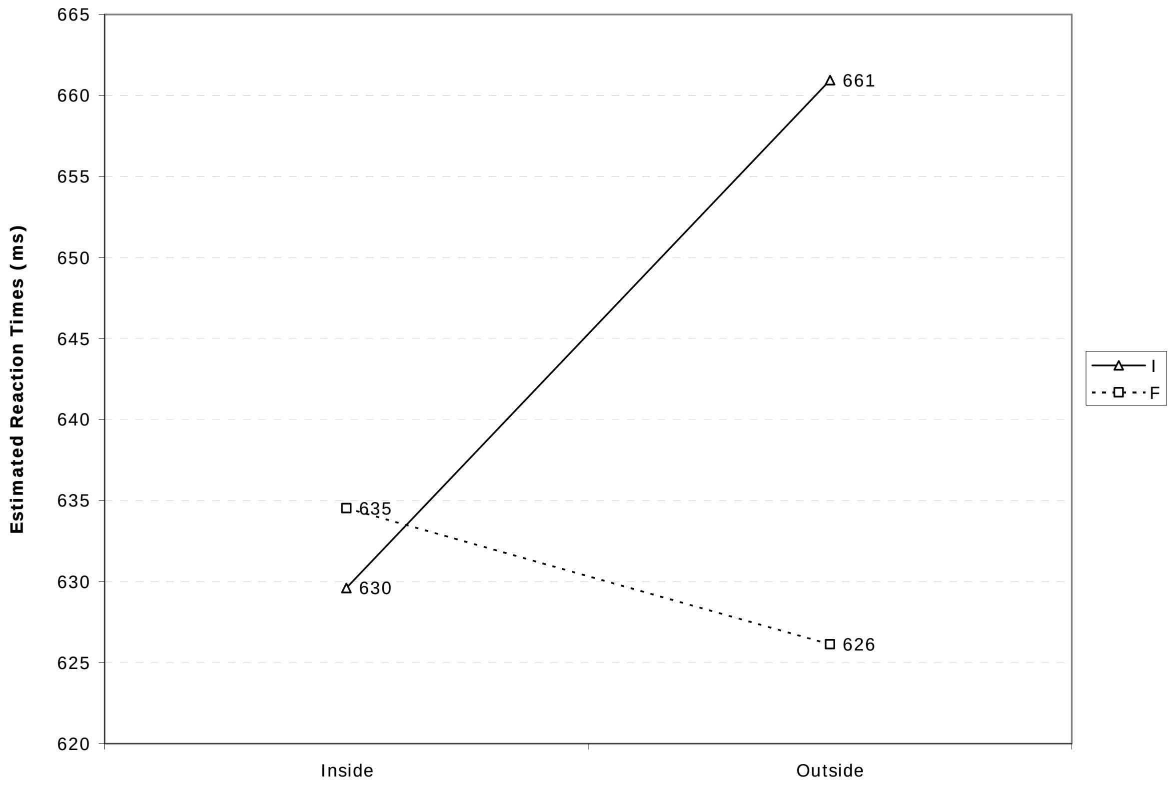


Figure 2. Estimated mean reaction time per condition provided by the second model, as a function of position of lexical embedding (I Initial vs. F Final) and viewing position ("Inside" the embedded word vs. "Outside" the embedded word).

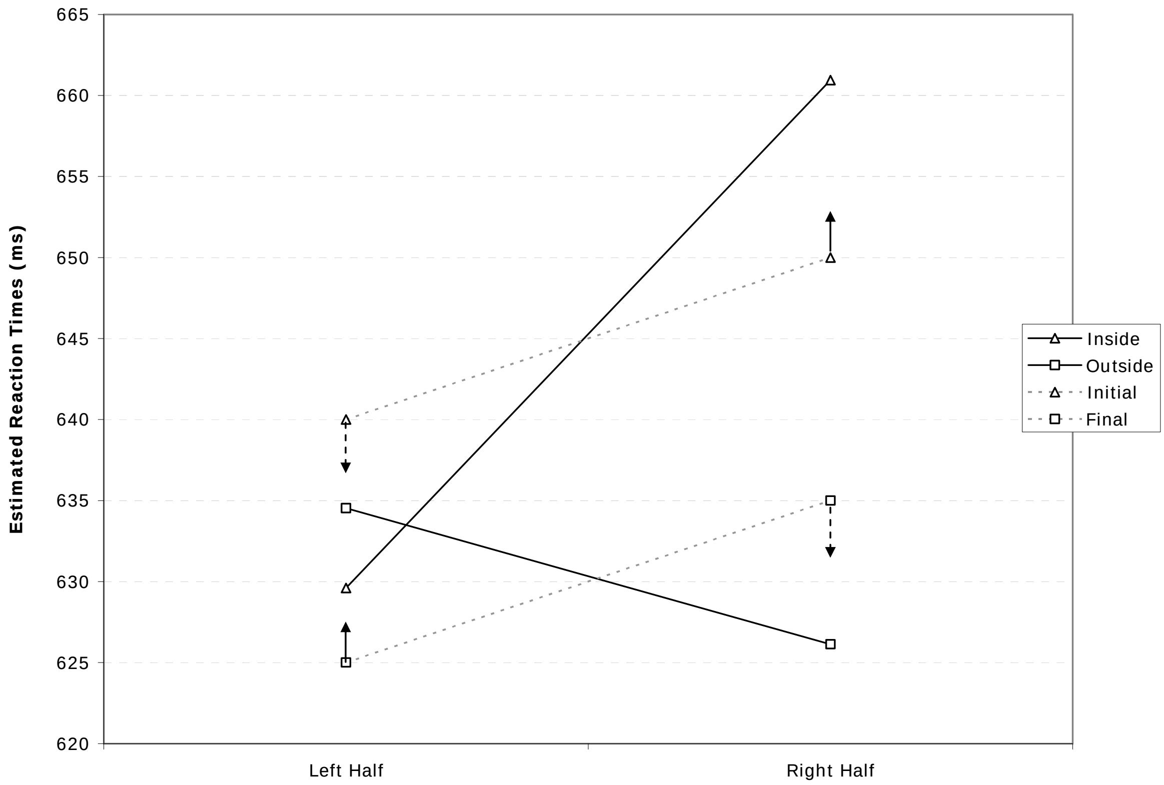


Figure 3. Reaction times predicted for main effects of “viewing position in the carrier word” (left half vs. right half) and “embedding position” (initial vs. final, corresponding to squares vs. triangles, both with dashed lines), in the situation of Experiment 4 which conflated “viewing position in the carrier word” and “viewing position in the embedded word” (inside vs. outside, corresponding to squares vs. triangles, both with solid lines). Generally, words are processed more rapidly when the viewing position is in the left half of the word. The slope of the dotted lines, increasing from left to right, depicts this. Further, words are processed more slowly, if they have an initial embedding. This is indicated by the shift of the triangles dotted line above the squares dotted line. Under the hypothesis that looking inside an embedded word facilitates the lexical processing of the carrier word (dashed arrow) and viewing outside impairs the processing (plain arrow), we arrive at the data pattern observed in Experiment 4.