Lexical Predictability Exerts Robust Effects on Fixation Duration, but not on Initial Landing Position During Reading

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Abstract. An eye movement experiment was conducted to examine effects of local lexical predictability on fixation durations and fixation locations during sentence reading. In the high-predictability condition, a verb strongly constrained the lexical identity of the following word, while in the low-predictability condition the target word could not be predicted on the basis of the verb. The results showed that first fixation and gaze duration on the target noun were reliably shorter in the high-predictability than in the low-predictability condition. However, initial fixation location was not affected by lexical predictability. As regards eye guidance in reading, the present study indicates that local lexical predictability influences *when* decisions but not *where* the initial fixation lands in a word.

Keywords: eye movements, reading, lexical predictability, fixation, saccade

Introduction

There is ample evidence demonstrating that sentence-level or paragraph-level semantic predictability affects fixation times on words during reading (Ashby, Rayner, & Clifton, 2005; Balota, Pollatsek, & Rayner, 1985; Calvo, 2001; Calvo, Estevez, & Dowens, 2003; Calvo & Meseguer, 2002; Calvo, Meseguer, & Carreiras, 2001; Drieghe, Brysbaert, Desmet, & De Baecke, 2004; Drieghe, Rayner, & Pollatsek, 2005; Ehrlich & Rayner, 1981; Frisson, Rayner, & Pickering, 2005; Hyönä, 1993; Kliegl, Grabner, Rolfs, & Engbert, 2004; Morris, 1994; Rayner, Ashby, Pollatsek, & Reichle, 2004; Rayner & Well, 1996; White, Rayner, & Liversedge, 2005). Contextually predictable words are read with shorter fixation times than less predictable words.

In the present study, we examined the processing of nouns whose lexical identity is predicted by the verb immediately preceding the noun phrase, as in *The TV news showed how the men hunched their back while the judge announced the verdict*. In this sentence the noun phrase *their back* is lexically predicted by the preceding verb *hunch*, whereas the preceding context is neutral. On the other hand, in the sentence *The TV news showed how the men greeted their friend while the judge read the indictment*, the noun phrase *their friend* is not predicted by the preceding verb *greeted*. Thus, the present study examines effects of lexical predictability. The study was conducted in Finnish where the aforementioned noun phrases appear as single words (i.e., *selkää+nsä* = "back+theirs"; *kaveria+an* = "friend+theirs").

To our knowledge, there is only one eye-tracking study (Schustack, Ehrlich, & Rayner, 1987) that has investigated the effects of lexical predictability between verb-noun pairs in a sentence context. This study showed that gaze duration and fixation probability were smaller for the noun appearing after a restrictive than a general verb. However, the target noun was also mentioned earlier in the text (see also Hyönä, 1993); thus, the observed effects are not restricted to the verb constraints. The novel aspect of the present study is that the effects of lexical predictability were examined in sentence contexts where the contextual constraint is restricted to the main verb.

The effects of local lexical predictability were studied by recording readers' eye movements during sentence processing. During reading, readers need to constantly make two types of decisions: When to terminate a fixation and where to fixate next. These "when" and "where" decisions are assumed to be made independently from each other (Findlay & Walker, 1999; Rayner & McConkie, 1976; Rayner & Pollatsek, 1981). *When* decisions are under cognitive control (reflecting process monitoring), while *where* decisions are primarily made on the basis of lower-level factors (but see below for word skipping) such as spacing and word length (e.g., Morris, Rayner, & Pollatsek, 1990; O'Regan, 1979; Pollatsek & Rayner, 1982; Rayner, 1979), and orthographic regularity (Beauvillain, Doré, & Baudouin, 1996; Hyönä, 1995; White & Liversedge, 2006). The distinction between *when* and *where* decisions is also utilised when modelling readers' eye movement patterns: The E-Z Reader model

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(Pollatsek, Reichle, & Rayner, 2006; Reichle, Pollatsek, Fisher, & Rayner, 1998), SWIFT (Engbert, Longtin, & Kliegl, 2002; Engbert, Nuthmann, Richter, & Kliegl, 2005; Kliegl, Nuthmann, & Engbert, 2006), Glenmore (Reilly & Radach, 2003, 2006), the Competition-Inhibition theory (Yang & McConkie, 2001), and SHARE (Feng, 2006).

If lexical predictability affects the ease of word identification (i.e., when to terminate a fixation), high-constraint words should be read with shorter fixation times than low-constraint words. Whether lexical predictability also influences saccadic programming during reading (i.e., where decisions) is less clear. It is generally agreed that predictability influences word skipping such that predictable words are skipped more often than less predictable words (Balota et al., 1985; Rayner & Well, 1996). However, whether word skipping represents the only instance of moment-to-moment cognitive control of saccadic programming is under dispute. Lavigne, Vitu, and d'Ydewalle (2000) observed that the eyes landed further into a highly predictable than a nonpredictable word (see also Kennedy, Murray, & Boissiere, 2004; McDonald & Shillcock, 2003b). This finding challenges the widely held view that the fine-tuning of saccadic amplitude is determined only by visual and oculomotor factors. However, Rayner, Binder, Ashby, and Pollatsek (2001) and Vonk, Radach, and van Rijn (2000) obtained no evidence in support of the view that the initial landing position would vary as a function of sentence-level predictability.

A possible explanation for the different results between the Lavigne et al. (2000) study and those of Rayner et al. (2001) and Vonk et al. (2000) is that the strength in predictability varied between them. The predictability in the high-constraint condition was 40%, 64%, and 94% in the Vonk et al., Rayner et al., and Lavigne et al. studies, respectively. Thus, a high constraint may be needed to obtain an effect in saccadic amplitude. If fine-tuning of saccadic amplitude is prone to lexical-semantic guidance, our locally strong predictability manipulation should exert an influence on fixation location. As Finnish words are generally longer than, for example English words, possible effects in saccadic programming were not expected in word skipping (for the importance of word length in skipping, see e.g., Rayner, Sereno, & Raney, 1996; White et al., 2005), but only in the initial landing position on the target with or without the saccadic extent into the target.

We wanted to ensure that local lexical predictability is not confounded with the co-occurrence frequency of the verb-noun pairs, because co-occurrence frequency might affect lexical predictability (MacDonald, 1993). This inevitably leads to the frequency of the nonconstraining verbs to be higher than that of the constraining verbs. However, this works against finding a predictability effect in fixation time, because a possible frequency effect may spill over from verb to noun (Rayner & Duffy, 1986); besides, it should not affect the initial fixation location on the target (White & Liversedge, 2006). Had we controlled for verb frequency, we would have needed to use very low-frequency verb-object pairs in the nonconstraining condition, which would have resulted in a comparison between very typical and slightly odd verb-noun pairs.

A strong local lexical predictability manipulation is necessarily confounded with transitional probability (TP; McDonald & Shillcock, 2003a, 2003b). TP is the frequency of a given verb-object combination in a corpus, divided by the frequency of the verb. To differentiate TP from general predictability, the studies examining the *independent* effect of TP (see, however, Frisson, Rayner, & Pickering, 2005) have used materials with low cloze predictability values ($p < .09$). In contrast, we wanted to maximise the difference in local lexical predictability between the constraining ($p = .80$) and nonconstraining ($p < .01$) verb conditions.

Method

Participants

Twenty-four native speakers of Finnish (university students) participated in the experiment. All participants had normal or corrected-to-normal vision.

Apparatus

Eye movements were collected by the EyeLink I eyetracker manufactured by SR Research Ltd. (Canada). There are two cameras mounted on a headband (one for each eye) including two infrared LEDs for illuminating each eye. The cameras sampled pupil location and size at the rate of 250 Hz. The data were collected from the right eye by placing the camera 4–6 cm away from the eye. The spatial accuracy was better than 0.5°. Head position with respect to the computer screen was tracked via a head-tracking camera; possible head motion was compensated for online.

Materials

The experiment was conducted in Finnish. Thirty-two nouns (16 predictable and 16 nonpredictable) were used as the targets. Each target noun was embedded in a sentence, where it was preceded either (a) by a verb, which strongly constrained the target's lexical identity or (b) by a verb that did not lexically predict the following word. In both conditions the target noun was the syntactic object of the verb. An example sentence pair, with an English translation, is presented below (the critical verb is in bold; the target noun is in italics).

High-constraint Condition

Uutiskatsauksessa nähtiin, kuinka miehet **köyristävät** *selkäänsä* tuomarin julistaessa tuomion.

"The TV news showed how the men **hunched** *their back* ('back+theirs') while the judge announced the verdict".

Low-constraint Condition

Uutiskatsauksessa nähtiin, kuinka miehet **tervehtivät** *kaveriaan* tuomarin lukiessa syytekirjelmää.

"The TV news showed how the men **greeted** *their friend* ('friend+theirs') while the judge read the indictment".

The paired sentences were identical up to the critical verb; also the word after the target ($N + 1$) was the same in both versions (average per-million frequency of $N + 1$ was 930 and its average word length 8.8 characters). The sentence end was different in 12 pairs; in four sentence pairs also $N + 2$ was identical. The target nouns were matched for base and surface frequency, length, and average bigram frequency (see Table 1). All the differences in the target noun characteristics reported in Table 1 were nonsignificant (ps > .213), but verb's base and surface frequency differed between the conditions (ps < .01). The initial trigram frequency of the target was marginally higher in the high-constraint condition ($p = .097$), but this difference was nonsignificant ($p > .2$) for the subset of 11 items used in the saccade analyses.

The target sentences were mixed with 112 filler sentences of different grammatical structures. The sentences were written in black on a white background. They were presented in Courier font left-justified one at the time in the middle of the screen. Reading was self-paced; after reading a sentence the reader pushed a button in a gamepad to advance to the next sentence. Forty-five characters fitted on a text line. The sentence position of the verb-noun pairs varied due to the sentence length. In eight sentence pairs, it appeared on the first line, in seven sentence pairs on the second line, and in one sentence pair on the third line. The sentence length varied from two to four lines. A short practice session preceded the experiment. The critical verb-noun pair never appeared in the beginning or end of a text line. With a viewing distance of about 65 cm, one character space subtended approximately 0.5° of visual angle. The sentences were presented in two blocks, so that the paired sentences never appeared in the same block. The order of blocks was counterbalanced across participants; within a block the sentence order was individually randomised.

Norming of Materials

The materials were selected and normed using the following procedure.

Word Association Task 1

We first intuitively chose 20 highly constraining verbs. Then, 11 university students who did not participate in the experiment proper received a personally randomised list of these verbs together with 41 filler verbs. Their task was to fill in a word that could follow the verb. On the basis of this task, 16 most constraining verb-target noun pairs were chosen. Their average predictability was 72.2% (SD = 28.6; range: 45.5–100%).

Corpus Analysis

In order not to create anomalous verb-noun pairs, we used verb-noun pairs that exist in a 22.7-million word token newspaper corpus (Laine & Virtanen, 1999; Virtanen & Pajunen, 2000). Moreover, we wanted to equate the verb-noun co-occurrence frequency across the conditions. This led the mean co-occurrence frequencies (per million) to be quite low, 0.18 (SD = 0.14) and 0.06 (SD = 0.03) for the constraining and nonconstraining conditions, respectively. This in turn meant that the lexical frequency of the constraining verb was significantly lower than that of the nonconstraining verb (see Table 1). However, a lower lexical frequency of the verb should lead to longer fixation durations on the target noun in the constraining condition (due to a spill-over effect of frequency, due to

Table 1. Mean (per million) base frequency, surface frequency, bigram frequency, initial trigram frequency, and length (in letters) of the verbs and target nouns, and their standard deviations (SD)

	Constraining verb condition		Nonconstraining verb condition	
	M	*SD*	*M*	*SD*
Verb				
Base frequency	0.9	1.2	130	192
Surface frequency	0.1	0.1	7.5	14.0
Bigram frequency[a]	7.19	2.30	7.56	2.72
Initial trigram frequency[b]	0.12	0.12	0.74	0.73
Word length	9.8	1.1	9.1	1.5
Target noun				
Base frequency	112	272	119	289
Surface frequency	3.2	4.2	3.2	4.5
Bigram frequency[a]	7.55	2.24	7.15	2.05
Initial trigram frequency[b]	1.04	1.15	0.37	0.11
Word length	7.81	1.11	7.88	1.26

[a]Average bigram frequency per 1000.
[b]Average initial trigram frequency per 1000.

reduced parafoveal preprocessing, or both). Thus, this frequency difference works against finding a predictability effect. Moreover, the difference should not affect the initial fixation location on the target (White & Liversedge, 2006). Note that the transitional probability (the frequency of a verb-noun pair in the corpus, divided by the frequency of the verb; McDonald & Shillcock, 2003a, 2003b) also necessarily differed between the conditions: TP was 36.47% (SD = 27.1) for the constraining and 0.33% (SD = 0.48) for the nonconstraining verb conditions, respectively.

Word Association Task 2

This task was undertaken to ensure that there was a clear difference in lexical predictability between the two conditions. Thus, 14 university students were asked to write down 5–6 first words that could follow the verb (see Lavigne et al., 2000). The verb lists were individually randomised. In the constraining condition, the target noun was listed in 80.8% (SD = 17.8; range: 42.9–100%), whereas it was mentioned only once with a nonconstraining verb; the difference was significant, $t(15) = 18.19$, $p < .001$. Our lexical predictability manipulation was similar in strength to that of Lavigne et al. in their high-predictability condition (75%).

Sentence Cloze Task

The selected verb-noun pairs were embedded in sentences so that each target sentence beginning was used twice, once for the constraining and once for the nonconstraining condition. To confirm that target predictability was not affected by the sentence context, a cloze test was conducted where 20 university students were presented with the sentences up to the critical verb. Their task was to fill in a word that could appear next in the sentence (see Lavigne et al., 2000; Rayner et al., 2001; Vonk et al., 2000). Two counterbalanced lists were created; only one member of each sentence pair appeared in each list. The sentences in each list were individually randomised with 38 filler sentences. The participants mentioned the target noun in 79.3% (SD = 18.4; range: 27.3–100%) of the time in the constraining condition, but only 2.5% (SD = 4.5; range: 0–10%) of the time in the nonconstraining condition; the difference was significant, $t(15) = 14.51$, $p < .001$. Thus, this task yielded comparable predictability estimates to word association task 2 (79.3% vs. 80.8%, respectively). Moreover, the close task yielded comparable results with those of Lavigne et al. (94% vs. 3%), but our predictability manipulation is stronger than that of Rayner et al. (64% vs. <1%) and Vonk et al. (40% vs. 12.5%). Note also that in the materials of Lavigne et al. predictability increased in sentence context in comparison to word associations (94% vs. 75% in the high-predictability condition).

Sentence Plausibility Task

Following Rayner et al. (2001) we matched the sentences for plausibility. The sentences were presented up to the target, and a group of 20 university students were asked to rate (using a 7-point Likert scale) how well the final noun fitted in the sentence. Again, two counterbalanced and individually randomised lists were created; the two members of each sentence pair appeared in separate lists. The plausibility ratings revealed no difference ($t(15) < 1$) for the two sentence sets. The mean ratings were 5.4 (SD = 1.1; range: 3.0–7.0) and 5.3 (SD = 1.1; range: 3.5–6.7) for the constraining and nonconstraining conditions, respectively.

All in all, the pretests demonstrate that our predictability manipulation was strong and restricted to lexical predictability induced by the verb.

Procedure

Prior to the experiment, the eye-tracker was calibrated using a 9-point calibration grid that extended over the entire computer screen. Prior to each sentence, the calibration was checked by presenting a fixation point on the centre-left corner of the screen; if needed, the calibration was automatically corrected.

Participants were instructed to read sentences for comprehension at their own pace. They were further told that periodically they would be asked to paraphrase the last sentence they have just read to make sure that they attended to what they read. However, it was emphasised that the task was to comprehend, and not to memorise the sentences. Participants were asked to paraphrase the sentence approximately after every ten sentences. The experimental session lasted a maximum of 45 min.

Results

All trials with a track loss were excluded and so were trials where the critical verb or the target noun was skipped during the first-pass reading. We also excluded trials in which the saccade from the verb did not directly land on the target noun. The excluded data amounted to 7.9% for the constraining and 5.6% for the nonconstraining verb condition. As effects of local lexical predictability are not likely to be considerably delayed, we also excluded from the analyses all rereadings that were made after fixating beyond word $N + 1$. All the relevant statistical analyses were computed both by participants (henceforth t_1 or F_1) and by items (henceforth t_2 or F_2).

Reading Measures

Four fixation time measures were calculated for the critical verb and the target noun: *first fixation duration*, *gaze duration* (the sum of all first-pass fixations until leaving the word), *probability of rereading*, and *total fixation time* (the sum of gaze duration and rereading time prior to reading beyond word $N + 1$). We also calculated *first fixation duration* and *gaze duration* for the word following the target (word $N + 1$). Early effects of predictability may be detected by first fixation duration and gaze duration on the target noun; somewhat delayed effects are observed in the measures of word $N + 1$; the latest recorded effects may be seen in probability of rereading and total fixation time of the target noun. The means and standard deviations of the fixation time measures are presented in Table 2.

Verb

Paired sample t tests were computed on the data. The t tests did not show an effect of verb type in first fixation duration, $t_1(23)$, $t_2(15) < 1$, or in the probability of rereading, t_1, $t_2 < 1$, but a significant effect emerged in gaze duration, $t_1(23) = 5.15$, $SEM = 10.22$, $p < .001$; $t_2(15) = 2.18$, $SEM = 24.01$, $p = .046$, and in total fixation time, $t_1(23) = 4.47$, $SEM = 13.90$, $p < .001$; $t_2(15) = 1.50$, $SEM = 38.43$, $p = .154$). The constraining verbs were read with a longer gaze duration and total fixation time than the nonconstraining verbs. This reflects either a frequency difference or a memory retrieval effect (an increase in fixation time due to retrieving from memory the upcoming word; Kliegl et al., 2006).

Target Noun

A reliable effect of verb constraint was observed in: first fixation duration, $t_1(23) = 2.67$, $SEM = 5.59$, $p = .013$; $t_2(15) = 2.67$, $SEM = 5.29$, $p = .018$); gaze duration, $t_1(23) = 4.95$, $SEM = 10.37$, $p < .001$; $t_2(15) = 4.16$, $SEM = 11.48$, $p = .001$; total fixation time, $t_1(23) = 5.62$, $SEM = 14.46$, $p < .001$; $t_2(15) = 5.05$, $SEM = 15.04$, $p < .001$; and in the probability of rereading, where the effect remained marginal in the item analysis, $t_1(23) = 2.80$, $SEM = .024$, $p = .010$; $t_2(15) = 1.79$, $SEM = .035$, $p = .094$. The target nouns in the constraining verb condition were read with shorter fixation times than those in the nonconstraining verb condition; the differences were as follows: first fixation duration = 16 ms, gaze duration = 53 ms, total fixation time = 88 ms, and probability of second-pass fixations = 9.1%.

Word $N + 1$

The effect of verb type was marginal in first fixation duration, $t_1(23) = 1.78$, $SEM = 7.38$, $p = .088$; $t_2(15) = 2.02$, $SEM = 7.46$, $p = .062$; but yielded significance in gaze duration, $t_1(23) = 2.92$, $SEM = 18.47$, $p = .008$; $t_2(15) = 2.58$, $SEM = 21.08$, $p = .021$. First fixation duration was 15 ms and gaze duration 54 ms faster in the constraining than in the nonconstraining verb condition.

To sum up the fixation time results, lexical predictability produced both an immediate effect, as indexed by first fixation duration and gaze duration of the target, and an effect that spilled over to subsequent processing, as indexed by the probability of rereading and total fixation time of the target, and first fixation duration and gaze duration of word $N + 1$.

Saccade Measures for Items Where Verb Length was Identical

As the average verb length was 0.7 character spaces greater in the constraining condition, we report below the saccadic analyses for the subgroup of 11 sentence pairs, for which verb length was equated (9.4 character spaces, $SD = 1.0$). The target length was identical between the conditions (7.6 character spaces, $SD = 1.0$).

The following results include trials where there was a maximum of two fixations on the verb with no within-word regressions, followed by a saccade to the target word. A total of 70.5% of the constraining and 81.4% of the nonconstraining items were used in the analyses. The means and standard deviations of the saccade measures, as well as first fixation duration and gaze duration of the target noun are given in Table 3.

Initial Landing Position

The location of initial fixation on the target noun was not affected by lexical predictability, $t_1(23)$, $t_2(10) < 1$. This

Table 2. Mean (in ms) first fixation duration, gaze duration, total fixation time, probability of rereading (in %), and their standard deviations (*SD*), for the verb, target, and word $N + 1$

Word	Measure	Constraining verb condition		Nonconstraining verb condition	
		M	*SD*	*M*	*SD*
Verb	First fixation duration	245	39	244	40
	Gaze duration	389	99	345	91
	Probability of rereading	15.2	14.0	15.9	9.8
	Total fixation time	449	117	387	99
Target	First fixation duration	239	28	254	32
	Gaze duration	273	32	324	54
	Probability of rereading	13.7	12.6	20.0	12.2
	Total fixation time	304	34	385	80
$N + 1$	First fixation duration	226	29	240	37
	Gaze duration	393	64	447	124

Table 3. Mean (in character spaces) initial landing position, incoming saccade length, launch site of the incoming saccade, first fixation duration, gaze duration of the target noun, and their standard deviations (*SD*), for the items for which verb length was equated

	Constraining verb condition		Nonconstraining verb condition	
	M	*SD*	*M*	*SD*
Initial landing position	3.66	0.86	3.74	0.90
Saccade length	8.92	0.92	9.00	0.69
Launch site	5.25	0.99	5.25	0.94
First fixation duration	227	35	261	34
Gaze duration	255	33	320	63

Note. Initial landing position and launch site are calculated from the end of the verb.

was also true for the analysis of the complete item set, $t_1(23)$, $t_2(15) < 1$.

Saccade Length

The length of the saccade launched from the verb to the target was not affected by verb type, $t_{1,2} < 1$.

Launch Site

There was no significant effect of verb type in the launch site of the saccade launched from the verb to the target noun, $t_{1,2} < 1$.

Note that also in this subset of data, first fixation duration of the target noun was 33 ms shorter, $t_1(23) = 3.81$, $SEM = 8.78$, $p = .001$; $t_2(10) = 2.69$, $SEM = 9.11$, $p = .023$, and gaze duration 65 ms shorter, $t_1(23) = 4.47$, $SEM = 14.46$, $p < .001$; $t_2(10) = 3.15$, $SEM = 15.89$, $p = .010$, in the constraining than in the nonconstraining verb condition.

Saccade Measures Separately for the Near and Far Launch Sites

As Lavigne et al. (2000) obtained a predictability effect in the initial landing position only for trials where the incoming saccade was launched from a near distance, we analysed the data separately for the near and far launch sites. For each participant and item, we divided the trials into two subgroups (near and far) by a median split. A set of 2 (verb type: constraining vs. nonconstraining) × 2 (launch distance: close vs. far) ANOVAs was computed on the data with both variables being within-participants and within-items variables. The means and standard deviations of these analyses are reported in Table 4.

Initial Landing Position

A significant main effect emerged for launch distance, $F_1(1, 23) = 13.83$, $MSE = 0.305$, $p = .001$; $F_2(1, 10) = 56.47$, $MSE = 0.212$, $p < .001$. However, there was no main effect of verb type, $F_{1,2} < 1$. Moreover, the Launch Distance × Verb Type interaction was nonsignificant, $F_1 < 1$; $F_2(1, 10) = 1.82$, $p = .207$.

Saccade Length

The main effect of launch distance was significant, $F_1(1, 23) = 157.24$, $MSE = 0.701$, $p < .001$; $F_2(1, 10) = 66.58$, $MSE = 0.478$, $p < .001$. However, the main effect of verb type and the Launch Distance × Verb Type interaction remained nonsignificant, all $F_{1,2} < 1$.

Launch Site

Naturally, the main effect of launch distance was significant, $F_1(1, 23) = 309.73$, $MSE = 0.529$, $p < .001$; $F_2(1, 10) =$

Table 4. Mean (in character spaces) initial landing position, incoming saccade length, and launch site of the incoming saccade for the target words, and their standard deviations (*SD*), separately for close and far launch distance

	Constraining verb condition				Nonconstraining verb condition			
	Launch distance				Launch distance			
	Close		Far		Close		Far	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Initial landing position	3.95	0.78	3.45	1.10	3.92	0.94	3.57	1.01
Saccade length	7.82	1.28	9.99	0.94	7.90	0.97	10.02	0.64
Launch site	3.87	1.39	6.58	0.89	3.99	1.09	6.51	0.91

Note. Initial landing position and launch site are calculated from the end of the verb.

79.62, $MSE = 0.165$, $p < .001$. Neither the main effect of verb type nor the Launch Distance × Verb Type interaction proved significant, all $F_{1,2} < 1$.

Saccade Measures for Trials Where There was a Single Fixation on the Verb

Our final analyses were computed for trials where there was only a single fixation on the verb prior to fixating the target (see Kennedy et al., 2004). This was the case for 45.1% of the trials in the constraining and for 56.4% of trials in the nonconstraining condition. The means and standard deviations are presented in Table 5.

The pairwise *t* tests showed no effect of verb type in the initial landing position, saccade length, or launch site of the critical saccade, all $t_{1,2} < 1$.

However, there was a reliable effect of verb constraint in gaze duration of the target noun, $t_1(22) = 4.31$, $SEM = 13.42$, $p < .001$; $t_2(10) = 2.67$, $SEM = 17.20$, $p = .024$, and a tendency in first fixation duration, $t_1(22) = 2.30$, $SEM = 9.57$, $p = .032$; $t_2(10) = 1.51$, $SEM = 12.25$, $p = .161$. Gaze duration was 58 ms and first fixation duration 22 ms shorter in the constraining verb condition. There was no effect of verb type in the single fixation duration on the verb, $t_1 < 1$; $t_2(10) = 1.11$, $p = .293$. This last finding suggests that the shorter fixation time on the target in the constraining verb condition is not due to a trade-off; that is, a shorter fixation time on the target was not traded off with a longer fixation time on the verb.

Discussion

The present study is to our knowledge the first where effects of local lexical predictability between two consecutive words were studied in normal reading using the eye-tracking methodology. In our high-constraint condition, the verb predicted the lexical identity of the following noun with a $p = .8$, while in the low-constraint condition the lexical identity of the target noun was unpredictable. The predictability manipulation was entirely localised in the verb, as the preceding sentence context was neutral. Moreover, the target noun's syntactic role was the same in both conditions.

During reading, readers need to constantly make decisions about when to terminate a fixation and move on to the next text region, and where to fixate next in the text. It is widely accepted (see Rayner, 1998, for a review) that *when* decisions are governed by the ongoing cognitive processes related to extracting meaning from text, while *where* decisions are primarily governed by oculomotor factors and low-level visual features of the upcoming text (particularly word length information). It is well established that a word's global predictability in a sentence or discourse has a robust effect on the time readers spend fixating the word (see the references in the Introduction). Highly predictable words are fixated for less time than less predictable words. However, it is less clear to what extent predictability exerts an effect on *where* decisions. On the one hand, it is well established that saccade target selection may be affected by predictability, as indexed by contextually highly predictable words being skipped more often than unpredictable words (e.g., Balota et al., 1985; Rayner & Well, 1996). On the other hand, it is controversial whether also saccadic amplitude may be fine-tuned by the predictability of the upcoming word. While Lavigne et al. (2000) provided evidence in support of this view (saccade landing further into a predictable than a nonpredictable word), Rayner et al. (2001) and Vonk et al. (2000) failed to find a predictability effect.

The present study demonstrates that, similarly to global predictability, local lexical predictability exerts a robust effect on fixation times. The effect is immediate in the sense that it was observed in first fixation and gaze duration on the target noun. The effect is not short-lived as it was also observed in gaze duration of the subsequent word and in the probability of rereading the target. We conclude that local lexical predictability exerts a robust effect on fixation times in reading. One possible explanation for these results is the cued memory retrieval account proposed by Kliegl et al. (2006). According to this account, the immediate effect in fixation time is a result of activating the target word's identity already while fixating on the previous verb. This activation would not lead to full lexical access of the upcoming word but this partial activation would decrease the time needed to complete the lexical and meaning access when the word is fixated.

Table 5. Mean (in character spaces) initial landing position, incoming saccade length, and launch site of the incoming saccade for the target noun, first fixation duration, gaze duration on the target noun, and single fixation duration on the verb, and their standard deviations (*SD*), when there was only one fixation on the verb

	Constraining verb condition		Nonconstraining verb condition	
	M	*SD*	*M*	*SD*
Initial landing position	3.53	1.05	3.60	0.97
Saccade length	9.54	0.96	9.59	0.76
Launch site	6.01	0.80	5.98	0.98
First fixation duration	227	33	249	42
Gaze duration	257	32	315	60
Single fixation duration on verb	264	50	263	54

Note. Initial landing position and launch site are calculated from the end of the verb.

On the other hand, we found no evidence to support the view that local lexical predictability would affect the fine-tuning of saccade amplitudes. Most importantly, the location of initial fixation on the target was not influenced by lexical predictability. Thus, we were unable to find support (see also Rayner et al., 2001; Vonk et al., 2000) for the result of Lavigne et al. (2000), who reported the initial fixation to land further into a predictable than a less predictable word. We failed to find such an effect even when we restricted the analysis to the saccades launched from a position close to the target or to trials where only a single fixation was made on the prior verb (see Kennedy et al., 2004). Rayner et al. suggest that Lavigne et al.'s finding may be interpreted as a saccadic undershoot (see also Nuthmann, Engbert, & Kliegl, 2005): Readers intend to skip the target word but the critical saccade falls short and lands instead on the target. In other words, what appears to be an effect on fine-tuning of saccadic amplitude may in fact be an effect on saccade target selection (cf. Radach & McConkie, 1998). In sum, we conclude that even a strong lexical predictability manipulation does not influence the location of initial fixation in the predicted word. However, this does not preclude a predictability effect in saccade target selection. Had we used short target words, the skipping rate may well have been affected by local lexical predictability.

In conclusion, the present study demonstrates that local lexical predictability has a robust effect on fixation times in reading. However, despite the strong predictability manipulation and sizeable effects in fixation times, local lexical predictability does not exert an effect on fine-tuning of saccade amplitudes. Thus, as regards eye guidance in reading, the present study indicates that lexical predictability influences *when* to terminate a fixation but not *where* in the word to fixate. This finding is generally in line with models of eye guidance in reading that subscribe to the functional independence of when and where decisions (Engbert et al., 2005; Feng, 2006; Reichle, Rayner, & Pollatsek, 2003).[1] More specifically, all these models assume that the initial landing position in words is determined by low-level visual features and oculomotor constraints. These models differ from each other in the principles that govern saccade target selection (i.e., what word to saccade next). However, what is important in the present context, once the target for the next saccade is selected, is that the saccadic amplitude is assumed to be governed by low-level factors with no cognitive control. On the other hand, the Glenmore model of Reilly and Radach (2006) allows cognitive factors (as indexed e.g., by word frequency or predictability) to influence saccade amplitudes – a finding not observed in the present study.

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[1] Note that the E-Z Reader model (Reichle et al., 2003) departs from the complete independence principle in one respect: If a word is skipped, the duration of the preceding and following fixation is elevated.

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