Psychon Bull Rev (2011) 18:736–741
DOI 10.3758/s13423-011-0105-x

BRIEF REPORT

The influence of number of syllables on word skipping during reading

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Introduction

During reading, saccadic eye movements are necessary to move words into the center of the visual field, the fovea, where word recognition is enabled by high visual acuity. However, there is one exception where word recognition seems to be accomplished exclusively on the basis of parafoveal processing. When a word does not receive a direct fixation during first-pass reading, the word has been skipped. And if the word does not receive a regression after it has been skipped, the identity of the word has to have been established exclusively on the basis of parafoveal processing, possibly in combination with the predictability of the word from the surrounding context. Word skipping is far from being a rare phenomenon. On average, one third of all words are initially skipped (for reviews, see Rayner, 1998, 2009).

The two factors that have the most substantial impact on word skipping during reading are word length and predictability. Short words are skipped more often than long words, and words that are predictable from the preceding context are skipped more often than unpredictable words (e.g., Balota, Pollatsek, & Rayner, 1985; Drieghe, Rayner, & Pollatsek, 2005). High-frequency words are also skipped slightly more often than low-frequency words, although this effect is numerically smaller than the effects of word length and predictability (Brysbaert, Drieghe, & Vitu, 2005). Even though current models of eye movements in reading (e.g., E-Z Reader, Reichle, Rayner, & Pollatsek, 2003; SWIFT, Engbert, Nuthmann, Richter, & Kliegl, 2005) uphold diverging opinions on some fundamental issues (e.g., serial vs. parallel lexical processing), all of them incorporate word length, frequency, and predictability as the main factors for the system to decide whether or not to skip the next word.

These influencing factors show that the word that is skipped was processed up to a certain extent when the oculomotor system decided to skip it. Indeed, research has shown that the level of processing is quite high during average reading conditions. Drieghe et al. (2005) observed that even in a sentence where the word *cake* is very predictable, the visually similar nonword *cahe* will not be skipped more often than the nonword *picz*, indicating that readers picked up the difference between the predictable word and the visually similar nonword. However, research has also shown that when necessary, skipping can occur on the basis of incomplete word identification, such as that for very long words, where the end of the word will fall outside the letter identification span (Rayner, Slattery, Drieghe, & Liversedge, 2011).

Because skipping is influenced by how much information can be extracted from the parafoveal word, as well as by how

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Electronic supplementary material The online version of this article (doi:10.3758/s13423-011-0105-x) contains supplementary material, which is available to authorized users.

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easy it is to process that word, it is tempting to assume that manipulations of parafoveal preview that result in reduced fixation durations when the eyes do land on the target word (e.g., correct vs. incorrect orthographic information as a preview) also result in increased skipping of the preview. However, the relationship between skipping rates and fixation times of words is not as straightforward. Parafoveal processing of a word can occur right up to the moment the saccade is launched toward the target word (or the word after it), but the decision to skip a word needs to be made considerably earlier. This is due to the time it takes to program a saccade after the target has been decided upon (e.g., in the E-Z Reader model, this is estimated to be about 125 ms; Reichle et al., 2003). In other words, finding an effect on skipping of a target word means that the word was processed up to a certain extent in the parafovea quite some time before the saccade was launched. This also makes an effect on skipping rates one of the earliest effects possible in the eye-tracking record for word processing during reading.

One of the types of information that is extracted from the parafovea is phonological information. Pollatsek, Lesch, Morris, and Rayner (1992) used a boundary change paradigm and found a parafoveal preview benefit for a homophone, as compared with a visually similar non-homophonic control (e.g., *sent* vs. *rent* as a preview for *cent*). Ashby and Rayner (2004) extended these findings by showing shorter fixation times for targets when syllabic congruent previews (e.g., *de_πx* was a preview for *device*) were presented, as compared with syllabic incongruent previews (e.g., *dev_πx* as a preview), even though the incongruent preview shared more letters with the target word (see also Ashby & Martin, 2008, for a replication in a display change lexical decision task). This shows that prosodic information is extracted from the parafovea by the reader and is used to facilitate word recognition (see also Ashby, Treiman, Kessler, & Rayner, 2006, for evidence of parafoveal vowel processing).

To examine potential phonological influences on word skipping, we manipulated the number of syllables in our target words. New, Ferrand, Pallier, and Brysbaert (2006) found a significant effect of number of syllables while examining lexical decision times acquired in the English Lexicon Project (Balota et al., 2007). This effect was independent of other influencing factors, such as frequency, number of neighbors, and word length. Their regression model showed that increasing the number of syllables in a word increased lexical decision times by 32 ms. Returning to reading, if information concerning the syllabic structure of the parafoveal word comes into the oculomotor system early enough to influence word skipping, this would translate into a higher chance of skipping a monosyllabic over a disyllabic word.

Experiment

Method

Participants Twenty-six native English speakers with normal or corrected-to-normal vision from the University of Southampton participated for £4.50 or course credit.

Apparatus Eye movements were measured with an SR Research Eyelink 1000 system. Viewing was binocular, but eye movements were recorded from the right eye only. Sentences were displayed on a single line with a maximum length of 85 characters, and all letters were lowercase (except when capitals were appropriate) and in monospaced Courier font. The display was 73 cm from the participant's eye, and at this distance, three characters equalled 1° of visual angle.

Materials Sixty monosyllabic or disyllabic target words (e.g., *grain* vs. *cargo*) were embedded in neutral sentences (e.g., *The workers were quick at loading the grain/cargo onto the ship*; see the Appendix). Thirty students from the University of Southampton who did not participate in the eye-tracking experiment were presented with the sentence frames up to the target word and were asked to produce the next word in the sentence. No significant differences were observed in sentence completion ratio between the monosyllabic (1%) and disyllabic (3%) target words, $t(59) = -1.58$, $p > .10$, indicating that they were equally (un)predictable from the preceding context. A counterbalanced design was used in which each participant read all 60 sentences, half containing the monosyllabic and half the disyllabic target words, resulting in 30 sentences per condition, per participant. The monosyllabic and disyllabic words were all five-letter words and were matched on word frequency, orthographic neighbors, and mean bigram frequency, all *t*s < 1, n.s. (see Table 1), according to the norms collected in the HAL corpus (Burgess & Livesay, 1998). These 60 sentences were mixed with 60 filler items and were displayed in a pseudorandom order preceded by 12 practice sentences.

Table 1 Lexical statistics for the target words (with standard deviations in parentheses)

	Log Frequency	Orthographic Neighbors	Log Mean Bigram Frequency
Monosyllabic	8.53 (1.33)	3.60 (2.64)	3.40 (0.21)
Disyllabic	8.53 (1.15)	3.67 (2.99)	3.55 (0.17)

Procedure Participants were first given a description of the experimental procedure and were told that they would be reading sentences on the monitor. They were instructed to read for comprehension and were told that they would be asked comprehension questions about the sentences. The participant's head was stabilized using a head-/chinrest. The initial calibration of the eyetracker required approximately 5 min. At the beginning of each trial, the participant had to look at a fixation point on the screen. When the eyetracker registered a stable fixation on the dot, the sentence was displayed, ensuring that the fixation fell at the beginning of the sentence. When participants had finished reading a sentence, they moved to the next trial by pressing a button on the response box. Each participant first read 12 practice sentences to become familiar with the procedure. Comprehension questions were presented on 25% of the trials; accuracy in answering them was 93%. The experiment lasted approximately 30 min.

Results

Trials on which there was a blink or tracker loss on the target word or during an immediately adjacent fixation to the target word were removed prior to analysis (0.5% of the trials). Fixations shorter than 80 ms, which were within one character of a previous or subsequent fixation, were combined with that fixation. All other fixations that were less than 80 ms were removed prior to analysis, as were any fixations longer than 800 ms. Additionally, when the eye movement measures were calculated, any data points that were more than 2.5 standard deviations above the mean within a condition for a specific participant were removed. Data loss affected both conditions similarly.

Four eye movement measures were computed: *skipping probability*, which is the probability that the target word was skipped on first-pass reading; *first-fixation duration*, which is the duration of the first fixation on a word; *single-fixation duration*, where the reader made only one first-pass fixation on the target word; and *gaze duration*, which is the sum of all first-pass fixations on the target word before moving to another word. To ensure that our manipulations did not affect the eye movement behavior prior to reaching the target word, we will also report the *launch site* of the saccade that either skipped the target word or landed on it. The latter measure is expressed in number of characters from the launch position to the space in front of the target word. A series of pairwise *t*-tests were undertaken, with participants (t_1) and items (t_2) as random variables.

Table 2 shows the means for all the eye movement measures. There was no difference for the launch site distance, $t_1(25) = -1.39$, $p > .10$; $t_2(58) = -1.31$, $p > .10$). However, monosyllabic words were skipped 5.6% more often than disyllabic words, $t_1(25) = 2.17$, $p < .05$; $t_2(59) = 3.34$, $p < .01$. There were no differences present in any of the fixation duration measures on the target word, all *t*s < 1, n.s.

We were surprised to see that the effect of number of syllables was observed in skipping rate but was not reflected in fixation times on the target. To ensure that the presence or absence of the effect was not due to factors that we had not controlled for, we ran a linear mixed-effects model (lme) using R (R Development Core Team, 2009), specifying participants and items as crossed random effects. The significance values and standard errors reported reflect both participant and item variability. These analyses have the advantage that they result in considerably less loss of statistical power for designs that are unbalanced due to missing values than do traditional ANOVAs. Especially for fixation times, where trials on which the target word was skipped are counted as missing data, this could have affected the results. The *p*-values were estimated using posterior distributions for model parameters obtained by Markov chain Monte Carlo sampling. All the patterns observed in the models were identical whether they were run on log-transformed or untransformed fixation durations, allowing us to present the data run on the untransformed fixation durations in order to increase transparency. Unlike the regression weights for the fixation durations, the regression weights for the skipping probabilities cannot be directly interpreted as effect sizes, because they originate from a logistic lme model that is better suited for the binomial nature of skipping rates.

As fixed factors, we included number of syllables and launch distance. Model comparisons showed that the interaction between the fixed factors had to be removed from the models because it did not contribute significantly to the fit of the data, with the exception of the model for the *skipping* data. All the fixed effects estimates are shown in Table 3. As in the pairwise *t*-tests, the effect of number of syllables was significant only for skipping rates, but not for the fixation times. A numerically small but significant effect was observed from launch distance

Table 2 Launchsite of the saccade landing on or skipping the target word, skipping percentage of the target word, and first-fixation duration, single-fixation duration, and gaze duration on the target word (with standard deviations in parentheses)

	LaunchSite (Characters)	Skipping %	First Fixation (ms)	Single Fixation (ms)	Gaze Duration (ms)
Monosyllabic	4.27 (1.16)	20.00 (15.50)	218 (44)	221 (42)	237 (61)
Disyllabic	4.45 (1.30)	14.40 (14.80)	219 (33)	220 (36)	235 (49)

Table 3 Fixed effect estimates for skipping percentage of the target word and first-fixation duration, single-fixation duration, and gaze duration

	Skipping Percentage	First-Fixation Duration	Single-Fixation Duration	Gaze Duration
Intercept	-.59	205***	206***	215***
Number of syllables	-.85**	-0.33	-1.20	-4.35
Launch distance	-.48***	2.63***	3.01***	4.55***
Number of syllables × launch distance	.13*			

* $p < .05$

** $p < .01$

*** $p < .001$

on all measures. This effect shows reduced parafoveal processing when the launch distance increased, due to reduced visual acuity, leading to less skipping and longer fixation times. Finally, an interaction was observed in the skipping model between launch site distance and number of syllables. This interaction shows an increased effect of number of syllables when the eyes were close to the target word. Again, this could be expected, given that it is reasonable to assume that it would be difficult to pick up syllabic information from a far launch site, due to reduced visual acuity.

Discussion

Our experiment explored whether information concerning syllabic structure could be extracted from the parafoveal word early enough to influence how often it would be skipped. Our results clearly show that this is the case,since monosyllabic words were skipped 5% more often than disyllabic words. Even though this effect is comparable in magnitude to that of skipping a high-frequency word versus a low-frequency word (Brysbaert et al., 2005)–in other words, it is a nontrivial effect size–it was not reflected in the fixation times when the target word was fixated.

Skipping rates and fixation times for a word are often considered correlated measures of the same phenomenon, with both reflecting the amount of preceding parafoveal processing. However, the time window in which parafoveal processing can build up to impact word skipping or fixation times is slightly different. To influence saccade target selection, information needs to enter the system before the start of saccadic programming. If information comes in at a later point, it can still affect fixation durations on the target word after the eyes have landed on it, but this new information can no longer influence skipping rates. Moreover, a number of experimental manipulations have been shown to differentially impact word skipping and fixation durations (Drieghe, 2008), indicating that different underlying mechanisms drive these phenomena. And indeed, the present study can be added to this list.

Likewise, the decision as to which word to target and where to target within a word is influenced by different factors. Whereas predictable words are skipped more often than unpredictable words, there is usually no difference in landing positions when the words are not skipped (e.g., Rayner, Ashby, Pollatsek, & Reichle, 2004). Similarly, in the present study, there was no difference between the landing position in a monosyllabic versus disyllabic word (both 1.8 characters into the word). All these factors indicate that saccade target selection is a process during reading that is distinctively different from other processes related to saccade programming and can be influenced by factors related to lexical processing that are distinct from those that are reflected in fixation durations.

An alternative possibility for why the number of syllables of the target word influenced the skipping rates, but not the fixation times, could lie in fact that these two measurements are not independent.[1] If easier words are skipped more often than difficult ones, the remaining monosyllabic words could be as difficult, on average, as the disyllabic words. As such, a difference in processing ease between mono- and disyllabic words could be obscured in the fixation times because skipped words are counted as missing values for calculating fixation times. However, a strong indication that our fixation times are not obscuring any difference in processing ease comes from lexical decision times on the specific items we presented to our participants. Lexical decision times available from the English Lexicon Project averaged 561 ms for our monosyllabic words and 572 ms for the disyllabic words. This 11 ms was only marginally significant, $t(57) = -1.66$, $p = .10$, and as such indicative that our lack of effect in fixation times was not due to a subset of the stimuli (i.e., the ones that were not skipped), since these lexical decision times were collected on all the stimuli.

It would also be interesting to compare the observed skipping rates (and fixation times) with those for multisyllabic and/or longer words. If no difference is

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[1] We are grateful to Marc Brysbaert for this suggestion.

observed between the skipping rates of a disyllabic and a trisyllabic word, this would have important implications for oculomotor control. It would mean that the effect we observed of number of syllables is due to the oculomotor system having learned that it is usually not problematic for text understanding to skip a monosyllabic word. Alternatively, a more quantitative effect would result in monosyllabic words being skipped more often than disyllabic words and disyllabic words, in turn, being skipped more often than trisyllabic words. However, such an experiment would be prone to floor effects for the skipping rates.

The idea that phonological information can be extracted very early from a word is also compatible with research conducted by Jane Ashby and colleagues, who showed, in a masked priming experiment with EEG recording, that phonological feature congruency (nonword primes were congruent or incongruent with target words in voicing and vowel duration) started modulating the amplitude of brain potentials after 80 ms (Ashby, Sanders, & Kingston, 2009). Syllable priming using stimuli similar to the *device* example discussed in the Introduction, influenced ERPs at 100 ms (Ashby, 2010). Moreover, Ashby and Rayner (2004) found evidence that initial syllables are processed in the parafoveaduring reading to facilitate word recognition speed. The present study extends these findings by showing that the syllable layer of the phonological representation also has an impact on saccade target selection. A first indication that prosodic phonological information could affect saccade planning was reported by Ashby and Clifton (2005), who showed that the number of stressed syllables influenced the number of fixations on high- and low-frequency words. Our data indicate that such an influence is not limited to within-word saccades but can also affect the planning of between-word saccades.

Further research will be necessary to establish how fine-grained the phonological processing from the parafoveal word is when the system decides to skip the next word or land on it. Even though syllabic structure seems to be extracted and we matched our words, to a very high extent, on different measures of orthographic familiarity, we cannot yet be certain that our participants did, in effect, obtain detailed phonological information. One of the alternative possibilities is that participants used a nonphonological shortcut to deduce syllabic structure, since orthographic information can often be used as a fairly reliable predictor of number of syllables. For example, in our materials, all the target words were five-letter words. Of these targets words, 95% of the disyllabic target words presented to participants had a consonant in the middle (e.g., *music*), while 82% of the monosyllabic target words had a vowel in the middle (e.g., *phone*). It may therefore be the case that this difference was the cause of the increased skipping rates that we observed between monosyllabic and disyllabic words, rather than being a purely phonological effect. It is important to note, however, that both explanations reflect the importance of syllabic structure (or indications thereof) for the decision of whether to skip or not.

To summarize, we observed that a monosyllabic word was skipped more often than a disyllabic word, indicating very early extraction of syllabic structure (or indications thereof) from the parafoveal word. This effect was not present in the fixation times on the target. This differential impact on skipping rates and fixation times is compatible with the view that skipping rates and fixation durations cannot always be considered to be correlates of the same underlying phenomenon—that is, amount of preceding parafoveal processing (Drieghe, 2008). Moreover, the present findings provide novel insights into the decision process of saccade target selection and, as such, are very informative for models of eye movement control during reading. Models such as E-Z Reader (Reichle et al., 2003) and SWIFT (Engbert et al., 2005) predict skipping rates mostly on the basis of contextual predictability, frequency, and word length, even though the present data indicate an important role for syllabic structure. Focusing on the E-Z Reader model, this model assumes that the oculomotor system decides to skip the next word when a distinct step (i.e., *L*1) in its lexical processing has been completed. This step corresponds to the point at which the processing system, from prior experience, estimates that full lexical identification (i.e., *L*2) is likely to be achieved shortly. The present findings point toward phonological complexity being an important factor in this process of deciding whether or not to skip the next word. When the system needs to make an estimation of whether the next word is easy enough to skip, it uses early indications of phonological complexity in this process.

Author Note We are grateful to Jane Ashby, Marc Brysbaert, and an anonymous reviewer for many helpful comments on an earlier draft of the manuscript.

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