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Eye movements guided by morphological structure: Evidence from the Uighur language ☆

Ming Yan [a,*], Wei Zhou [b], Hua Shu [b], Rizwangul Yusupu [b], Dongxia Miao [c], André Krügel [a], Reinhold Kliegl [a,*]

[a] Department of Psychology, University of Potsdam, Germany
[b] State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, PR China
[c] Department of Chinese Minority Language and Literature, Minzu University of China, PR China

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ABSTRACT

It is generally accepted that low-level features (e.g., inter-word spaces) are responsible for saccade-target selection in eye-movement control during reading. In two experiments using Uighur script known for its rich suffixes, we demonstrate that, in addition to word length and launch site, the number of suffixes influences initial landing positions. We also demonstrate an influence of word frequency. These results are difficult to explain purely by low-level guidance of eye movements and indicate that due to properties specific to Uighur script low-level visual information and high-level information such as morphological structure of parafoveal words jointly influence saccade programming.

1. Introduction

During reading, the eyes of a reader are sent to different positions in the text to acquire lexical and semantic information. Research on eye-movement control in reading alphabetic scripts has reached the generally accepted conclusion that the center of the word which is to be fixated serves as the intended landing position for the next saccades because word processing is assumed to be optimal at this location (McConkie, Kerr, Reddix, Zola, & Jacobs, 1989; O'Regan & Lévy-Schoen, 1987). Word centers are calculated on the basis of word lengths. Therefore, a major cue to determine where to fixate next is the low spatial-frequency information (i.e., spaces between words) in parafoveal or peripheral vision. One of the topics debated recently is whether or not variables other than low-level visual information can influence where the eyes initially fixate in a word in reading (see Rayner, 2009; for a review). In the present study, we provide clear evidence that saccade-target selection in eye-movement control is also influenced by the morphological structure of words and by word frequency in at least one writing system.

Fixation landing-positions are not always precisely at the intended locations (i.e., word centers). Due to random oculomotor error and the saccadic range effect which was explained as either a systematic range-error (McConkie, Kerr, Reddix, & Zola, 1988) or an error occurring at the perceptual level (Engbert & Krügel, 2010), first-fixation landing-positions (FLPs) form a Gaussian distribution peaking slightly to the left of word centers, labeled the preferred

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* Corresponding authors. Address: Department of Psychology, University of Potsdam Karl-Liebknecht-Str. 24/25, 14476 Potsdam-Golm, Germany. Tel.: +49 03319772127.

E-mail addresses: mingyan@uni-potsdam.de (M. Yan), kliegl@uni-potsdam.de (R. Kliegl).

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viewing location (PVL; Rayner, 1979). Rayner's (1979) observation of a PVL effect has been replicated in a number of studies; they are consistent with the original observation that initial fixations are primarily driven by low-level visual information. FLPs also depend on the launch site of the saccade (i.e., the distance of the last fixation to the beginning of the currently fixated word): The peak of the Gaussian distribution moves towards the beginning of words as launch sites increase (Engbert & Krügel, 2010; McConkie et al., 1988; Nuthmann, Engbert, & Kliegl, 2005).

Such PVL curves and their underlying mechanism of word-based saccade-target selection in reading require knowledge of the beginning and end of the target word as indicated by spaces between words. For example, if spaces are removed from English texts, the PVL curve no longer follows a Gaussian shape, but decreases sharply and linearly from the beginning to the end of a word (Rayner, Fischer, & Pollatsek, 1998; Rayner & Pollatsek, 1996). Similar PVL curves were also observed during reading Chinese texts (Li, Liu, & Rayner, 2011; Yan, Kliegl, Richter, Nuthmann, & Shu, 2010). Conversely, Nuthmann, Engbert, and Kliegl (2007) reported little difference in PVLs between normal reading and so-called mindless reading of Z-strings with spaces.

In agreement with the view that initial fixations are primarily driven by low-level visual information, Beauvillain (1996) demonstrated that morphological structure in French words (suffixed and prefixed words) had little influence on FLP when word length was matched. Hyönä and Pollatsek (1998) varied the lengths of the component morphemes (i.e., constituent words constructing the compound word) of two-morpheme Finnish words of constant overall word length. They found no effect of morpheme length on FLP. Their result is consistent with a purely visual guidance-mechanism. Similarly, Deutsch and Rayner (1999) compared FLP between single and plural Hebrew words of the same lengths (varying from 5 to 8 letters), and no effect of morphological structure was observed. Finally, Inhoff, Briihl, and Schwartz (1996) found no difference in FLP between bimorphemic suffixed (e.g., *ceaseless*) and monomorphemic words (e.g., *arthritis*), but fixations were slightly closer to the center when bimorphemic compound-words were fixated (e.g., *blueberry*).

Underwood, Clews, and Everatt (1990) hypothesized that eye-movement guidance can also be based on high-level semantic parafoveal information processing. They observed that readers' saccades took their eyes further into the word if decisive information was located in the second half (i.e., *superstore*), as opposed to those words with decisive information located in the first half of the word (i.e., *engagement*), underscoring the view that the eye guidance system has knowledge of the information density of the word to be fixated before its fixation actually takes place (see also Hyönä, Niemi, & Underwood, 1989). However, Underwood et al.'s (1990) critical finding was not replicated in later studies (e.g., Hyönä, 1995; Rayner & Morris, 1992).

Lavigne, Vitu, and d'Ydewalle (2000) reported a shift of the initial fixation-location towards the end of words for highly frequent and predictable target words when prior fixations were located close to the beginning of the target word. These results suggest that the decision where to send the eyes next in reading might be affected by ongoing linguistic processes. Rayner, Binder, Ashby, and Pollatsek (2001) found that, compared to unpredictable words, readers skipped predictable words more often and spent less time processing them when they did fixate them; however, there was only a very small influence of predictability on FLP and this result could be explained as being due to skipping-related mislocated fixations (see also Vainio, Hyönä, & Pajunen, 2009 and Rayner, Reichle, Stroud, Williams, & Pollatsek, 2006, who found no influence of lexical predictability on FLP at all).

Finally, Hyönä (1995) reported that irregular letter combinations at word beginnings attracted a fixation closer to the word beginning, indicating that word length is not the only type of information that will influence the decision where to fixate next. Similarly, White and Liversedge (2004) also found that initial fixation positions shifted towards word beginnings when the first letters of target words were misspelled. These results are in agreement with the view that abstract letter-codes for the first few letters are activated parafoveally (Rayner, Mcconkie, & Zola, 1980). It is perhaps worth noting that the FLP modulation, observed in both studies, was mainly due to low-level visual/orthographic information. This modulation effect only took place when the irregular/misspelled letters were close to the fovea.

Summing up, the studies reviewed above indicate clearly that low-level features are primarily responsible for FLP, whereas there is a lack of strong evidence supporting the hypothesis that saccade-target selection (as indexed by FLP) is also influenced by high-level information such as the morphological structure of parafoveal words. One possible reason for the absence of positive evidence is that affixes are generally much shorter than root morphemes in Indo-European languages. This may reduce the relevance of affixes in saccade-target selection. Alternatively, researchers may choose orthogonal designs using target words with short root-morphemes as experimental materials, so that the lengths of root morphemes and affixes are roughly the same. However, this in turn limits both the amount of available material and the number of observations.

The Uighur language is well suited to demonstrate an effect of affixes (in fact, suffixes). Uighur, formerly known as Eastern Turki, became a written language in the fifth century. Today, an Arabic-derived alphabet is the official graphemic system used for Uighur in the Xinjiang Uighur Autonomous Region, under the administration of the People's Republic of China. Uighur is an agglutinative alphabetic language. This means that many suffixes serving different functions can be attached to the end of a word; they denote, among others, person, number, direction, tense, case, and voice. For example, the word بولمايدىغانلىقىنى (*impossibility*) is composed of one root بول (meaning *able*) and 5 suffixes: ى ,لىق ,يدىغان ,ما and نى, which indicate negation, tense, part of speech, person and ablative, respectively. Some of the letters look different in the whole word than in isolated forms or suffixes, because they are written in successive strokes (so-called closing letters) in the whole word; each letter has up to four different forms (Engesæth, Yakup, & Dwyer, 2009; Hahn, 1991). Fig. 6 contains a few example sentences.