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Can colours be used to segment words when reading?☆

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ABSTRACT

Rayner, Fischer, and Pollatsek (1998, Vision Research) demonstrated that reading unspaced text in Indo-European languages produces a substantial reading cost in word identification (as deduced from an increased word-frequency effect on target words embedded in the unspaced vs. spaced sentences) and in eye movement guidance (as deduced from landing sites closer to the beginning of the words in unspaced sentences). However, the addition of spaces between words comes with a cost: nearby words may fall outside high-acuity central vision, thus reducing the potential benefits of parafoveal processing. In the present experiment, we introduced a salient visual cue intended to facilitate the process of word segmentation without compromising visual acuity: each alternating word was printed in a different colour (i.e., youwillbeabletoreadthissentenceveryeasily). Results only revealed a small reading cost of unspaced alternating colour sentences relative to the spaced sentences. Thus, present data are a demonstration that colour can be useful to segment words for readers of spaced orthographies.

1. Introduction

Classical Greek and Latin texts were commonly written without spaces between words (i.e., the so-called *scriptio continua*). Around 1000 A.D., spaces were added between words to help the process of word segmentation (see Saenger, 1997, for a detailed historical review). Indeed, modern-day readers of Indo-European languages find it quitechallengingtoreadunspacedsentences. In an influential study, Rayner, Fischer, and Pollatsek (1998) demonstrated that the lack of spaces between words in English hinders the process of word identification (e.g., lexical effects such as word-frequency are magnified in unspaced sentences relative to spaced sentences) as well as eye movement guidance (e.g., landing sites are closer to the beginning of the word than to the centre of the word [i.e., the preferred viewing location; see Rayner, 1979] in unspaced sentences).

As noted by Slattery and Rayner (2013), spaces between words may provide low-spatial frequency information that help signal the centre of the following orthographic chunk (i.e., the following word), thus serving to guide saccade planning. Indeed, in one of the leading models of eye movement control in reading, the EZ Reader model (Reichle, Pollatsek, Fisher, & Rayner, 1998), a basic assumption is that "all saccades are directed towards the centres of the intended word target (though they typically land short of the centre; Rayner, 1979) using the low-spatial frequency information that is available from parafoveal vision to identify word boundaries" (Pollatsek, Rayner, & Reichle, 2006, p. 15). Note that lexical processing proceeds more rapidly when this central location is achieved. A similar assumption was made in the SWIFT model (Engbert, Nuthmann, Richter, & Kliegl, 2005) where the authors stress the critical role that "clear orthographical word boundaries (i.e., low spatial frequency information)" play (Yan, Kliegl, Richter, Nuthmann, & Shu, 2010, p. 720).

The addition of spaces between words comes with a cost, though: nearby words are located farther away from the fixated word, and thereby, these words may fall outside high-acuity central vision, which reduces the potential benefits from parafoveal processing during reading. Indeed, while parafoveal-on-foveal effects during sentence reading (i.e., an effect of the parafoveal word [e.g., as a function of its lexical frequency] on the fixation time on the currently fixated word) are difficult to detect in spaced orthographies (see Drieghe, 2011, for review), they have generally been obtained in unspaced writing systems (e.g., see Yan, Zhou, Shu, & Kliegl, 2012, for evidence in Chinese; see also Winskel & Perea, 2014, for partial evidence in Thai).

Thus, a fair question to ask is whether it is possible to find another visual cue that helps the process of word segmentation during sentence reading without compromising visual acuity. To fulfil this objective, Perea and Acha (2009) employed an alternating**bold** manipulation in a spaced writing system (Spanish), so that alternating words in the sentence

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were emphasized (e.g., "the**child**is**watching**the**garden**from**his**house"). Under these conditions, it is straightforward to determine where a given word begins/ends (i.e., the word's boundaries are well defined) with the advantage that nearby words are spatially closer (i.e., in a region with greater visual acuity) than in standard spaced sentences. In their experiment, Perea and Acha registered the participants' eye movements while they read normally spaced sentences, unspaced sentences, and alternating**bold** sentences. They found that alternating**bold** sentences did produce a reading benefit over the unspaced sentences (mean sentence reading time = 2708 vs. 3343 ms, respectively). However, there was still a substantial reading cost relative to the standard spaced sentences (mean total time = 1856 ms; i.e., a 31% reading cost). Although the word-frequency effect was similar in magnitude for the target words embedded in alternating**bold** sentences and in regular sentences (i.e., the "word identification" stage did not seem to be hindered; see Inhoff & Rayner, 1986, for early evidence of word-frequency effects in reading), the initial landing position on the target word was closer to the beginning of the words in alternating**bold** sentences than in spaced sentences, thus suggesting that the alternating**bold** condition was not distinctive enough to provide the appropriate word segmentation cues. It may be important to note here that, in an unspaced alphabetic writing system (Thai), Winskel, Perea, and Ratitamkul (2012) found that the standard unspaced sentences in Thai produced faster reading times and fewer fixations than the alternating**bold** sentences. Importantly, Bai, Yan, Liversedge, Zang, and Rayner (2008) employed another visual cue to segment words by marking their background. They conducted a sentence reading experiment in Chinese (i.e., an unspaced nonalphabetic writing system) in which the background of each other word was presented highlighted (e.g., 科学技术的飞速发展给社会带来了巨大的变化。) or not (科学技术的飞速发展给社会带来了巨大的变化。). Results revealed a remarkably similar pattern of eye movement measures for the sentences with highlighted words and the unmarked unspaced sentences. Bai et al. (2008) also included a condition in which the highlighted characters did not form words in Chinese, and these sentences produced a reading cost. Taken together, the Winskel et al. (2012) and the Bai et al. (2008) experiments suggest that skilled adult readers of unspaced writing systems (e.g., Thai, Chinese) use quite different strategies to segment words when compared to readers of Indo-European languages.

In the current experiment, we introduced a highly salient cue of visual distinctiveness in a spaced writing system (Spanish): alternate colours were used to segment the words in sentences (e.g., "youwillbeabletoreadthissentenceveryeasily"). The rationale here is that colour information helps detect, identify, recognise, and classify objects (Livingstone & Hubel, 1987; Treisman & Gelade, 1980; see also Gegenfurtner & Rieger, 2000; Tanaka, Weiskopf, & Williams, 2001). Indeed, similarities in colour facilitate composing an object from several parts, whereas differences in colour facilitate segregating stimuli as different objects (see Goldfarb & Treisman, 2011). In a recent (spaced) text reading experiment conducted by Pinna, Uccula, and Tanca (2010), reading times were faster when the text was written with words in different colours than when written in grey or in multi-coloured letters. Pinna et al. concluded that "color contributes to determining the phenomenal wholeness" (p. 592). Thus, alternating the colour among contiguous words may provide a highly salient visual cue for word segmentation. At an anecdotal level, it is worth noting that alternating colour phrases (or pairs of words) are often seen in advertisements (e.g., from the GameStop store), TV series (e.g., modernfamily) or brand names, including those from academic contexts (e.g., SCHOLARONE). Furthermore the use of colours as word delimiters when presenting Internet addresses is also common — note that hashtags and URLs are commonly written in *scriptio continua* and this may lead to ambiguous sentences (e.g., the URL address www.teacherstalking.org could be parsed as teacherstalking or teacherstalking).

The words of the sentences used in the current experiment were either in red, or green, or both colours. Red–green discrimination is generally good even at eccentricities in the retina that are quite far from the fovea (see Nagy & Doyal, 1993). We registered the participants' eye movements while they read three types of sentences (see Table 1 for an illustration): i) sentences written without spaces in which each alternate word was in green or red (i.e., unspaced alternating colour sentences); ii) sentences written without spaces (either in green or red) (i.e., standard unspaced sentences); and iii) sentences written with spaces in which each alternate word was in green or red (i.e., spaced sentences). That is, we used two different control conditions that could be compared with the unspaced alternating colour condition: an unspaced condition which was expected to severely impair word segmentation due to lack of any perceptual cue (i.e., neither spacing nor colour alternation), and another condition with both spacing and colour alternation (i.e., this condition only differed in spacing from the unspaced alternating colour condition). Because the focus of the experiment was on the role of colours as cues for word segmentation, we did not include a condition with sentences written with spaces in which each word was in the same colour, as these words are already segmented by blank spaces (see Pinna et al., 2010, for a comparison of spaced one-colour vs. spaced multi-colour texts in reading aloud).

In the present experiment, we obtained several "global" reading measures, including number of saccades (progressive and regressive), mean fixation duration, and total reading time (see White, Johnson, Liversedge, & Rayner, 2008, for a similar analysis). To obtain finer eye movement measures for each sentence, a target word (either a high-frequency or a low-frequency word) was embedded in each sentence (e.g., "El niño observa el [jardín$^{\text{high-frequency}}$, cerezo$^{\text{low-frequency}}$] desde su ventana", the Spanish for "The child is watching the [garden, cherry tree] from his window"). This word-frequency manipulation allowed us to examine whether: i) the process of lexical identification is hindered by the alternating colour manipulation (i.e., whether there is a magnification of the word-frequency effect in unspaced alternating colour sentences in first-fixation durations, gaze durations [sum of fixations on the target word before leaving it], and total time); and ii) whether eye movement guidance is hindered by the alternating colour manipulation (i.e., whether the initial landing positions are closer to the initial letters of the word in unspaced alternating colour sentences).

The predictions of the experiment are straightforward. If the alternating colour manipulation facilitates the processes of word segmentation and word identification, then at a global level, the reading time per sentence as well as the number of saccades (both progressive and regressive) on the unspaced alternating colour sentences should be similar to those of spaced sentences. At the local level, if the word-identification stage is not hindered in the unspaced alternating colour sentences, the magnitude of the word-frequency effect on the target words in unspaced alternating colour sentences should be similar to that of the spaced sentences—note that prior research has revealed that the magnitude of the word-frequency effect is substantially greater for target words embedded in unspaced one-colour sentences than in spaced sentences (Rayner et al., 1998; see also Perea & Acha, 2009). In addition, if the unspaced alternating colour manipulation can be used to effectively segment words, then one would expect that the initial landing position in the target words would be similar in alternating colour sentences and spaced sentences (i.e., close to the centre of the word). Alternatively, if inter-word space information is key in providing

Table 1
Illustration of the sentences in the experiment.

Type of sentence	
Spaced, alternating colour	El niño observa el jardín desde su ventana
Unspaced, alternating colour	Elniñoobservaeljardíndesdesuventana
Unspaced, one-colour	Elniñoobservaeljardíndesdesuventana