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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 multicoloured 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

the low-frequency spatial information that is important in detecting the centre of the subsequent word (see Slattery & Rayner, 2013), the initial landing position will be closer to the beginning of the word in unspaced alternating colour sentences than in spaced sentences. Finally, given that there is closer spatial proximity in adjacent words in unspaced alternating colour sentences than in spaced sentences, this may maximize the chances of obtaining parafoveal-on-foveal effects (i.e., shorter fixations on the N-1 fixation when the target word is of high-frequency than when it is of low-frequency).

2. Method

2.1. Participants

Twenty-four students from the University of Valencia took part in the experiment for course credit. All of them were native speakers of Spanish and had normal vision—none of them was colour blind.

2.2. Materials

We employed the 120 sentences from the Perea and Acha (2009) experiment. These materials included 60 high-frequency target words (mean frequency: 87 per million in the B-Pal Spanish database [Davis & Perea, 2005], mean number of letters = 7.3 [5–9]) and 60 low-frequency target words (mean frequency: 4.5 per million, mean number of letters = 7.3 [5–9]). Specifically, there were two sentence frames for each high-frequency and low-frequency word pair of the same length (e.g. [jardín$^{\text{high-frequency}}$, cerezo$^{\text{low-frequency}}$]), as in "El niño observa el [jardín, cerezo] desde su ventana" and "El abuelo cuida su [jardín, cerezo] a diario con mucho esmero", the Spanish for "The child is watching the [garden, cherry tree] from his window" and "On a daily basis, the grandfather takes care of his [garden, cherry tree] with great care"). The sentences were considered as readily intelligible, and the target word was not predictable, as deduced from a cloze task (see Perea & Acha, 2009, for details). Presentation of the sentences was counterbalanced across spacing (unspaced regular, unspaced alternating colour, spaced alternating colour) and word-frequency conditions. The sentences were presented in 14-pt Times New Roman font. Red (RGB [208, 0, 0]) and green (RGB [0, 208, 94]) colours were chosen to be equally bright.

2.3. Apparatus

An Eyelink-II eyetracker (SR Research Ltd, Canada) was employed to register the participants' eye movements. This device samples pupil location at a rate of 500-Hz frequency and the average gaze position error is less than 0.5°. Although vision was binocular, only the eye movements of the right eye were registered. A chin rest was used to reduce head motion.

2.4. Procedure

The session took place individually in a silent, weakly lit lab. Participants were seated 60 cm from the computer screen. They were told that they would be presented a sentence on each trial, which they had to read for comprehension. They were asked to press a button on a game pad once they had read the sentence. They were also told that they would be presented with a yes/no comprehension question on 25% of the trials—they had to press the right ("yes") or left ("no") button on the game pad. The scenario of each trial was as follows. A black square on the left side of the computer screen was presented until the participant looked at the square. Then, the sentence appeared on a single line of text. The location of the first letter of the sentence corresponded to the black square. Nine practice sentences preceded the 120 experimental sentences. Before starting each trial, calibration was verified and the system was recalibrated when necessary. The order of the experimental sentences was different for each participant.

3. Results

Accuracy data in the comprehension questions was above 93%, with no differences across conditions (the percentages across conditions ranged from 93% [unspaced one-colour sentences] to 95% [spaced alternating colour sentences). The raw eye-tracking data were initially processed with EyeDoctor software (http://www.psych.umass.edu/eyelab/software/). A small proportion of sentences (66 out of 2880 sentences; 2.29%) were removed because there was track loss during the trial because participants were not fixating at the initial part of the sentence when it appeared. Subsequently, all fixation durations shorter than 80 ms that were within one letter of the following or previous saccade were merged into that fixation. In addition, to avoid the influence of extreme data, all individual fixations shorter than 80 ms or longer than 800 ms were excluded from the statistical analyses (e.g., see Slattery & Rayner, 2013). In the "global" analyses, type of sentence (unspaced regular, unspaced with alternating colour, spaced with alternating colour) was the fixed effect factor. The dependent variables were sentence reading time, mean fixation duration, and number of progressive/regressive saccades. In the local analyses, type of sentence (unspaced regular, unspaced with alternating colour, spaced with alternating colour) and word-frequency (high-frequency vs. low-frequency) were the factors in the design. The dependent variables in the "local" analyses on the target word were first-fixation duration (i.e., the duration of the initial fixation on the target word), gaze duration (i.e., the sum of fixation durations on the target word before leaving it), total time, percentage of fixations on the target word, and initial landing position. To examine the existence of parafoveal-on-foveal effects, we also examined the duration of the (progressive) fixation before reaching the target word. The descriptive eye movement measures are displayed in Tables 2 and 3. The analyses were conducted over-subjects ($F1$) and over items ($F2$) as random effects — note that the pattern of data was the same if linear mixed-effects models were conducted instead.

3.1. Global analyses

3.1.1. Total reading times

The effect of type of sentence on total reading times was significant, $F1(2,46) = 106.0$, $p < .001$; $F2(2,238) = 51.9$, $p < .001$. Reading times were substantially longer in unspaced one-colour sentences (3701 ms) than in the unspaced alternating colour sentences (2293 ms; $F1(1,23) = 94.76$, $p < .001$; $F2(1,119) = 574.6$, $p < .001$) and, in turn, reading times were longer in unspaced alternating colour sentences than in the spaced sentences (2188 ms) ($F1(1,23) = 9.65$, $p = .005$; $F2(1,119) = 10.35$, $p = .002$).

To examine whether the reading cost in the unspaced alternating colour sentences relative to the spaced sentences is affected by experience, we computed the differences in reading times between the spaced vs. unspaced alternating colour sentences in the first half of the experiment and in the second part of the experiment. Given that the number

Table 2
Global measures for each of the conditions: total sentence reading time (in ms), mean fixation duration (in ms), and number of progressive and regressive saccades. Standard errors are presented between brackets.

Type of sentence	Total reading time	Mean fixation duration	Number of saccades	
			Progressive	Regressive
Spaced, alternating colour	2188 (139)	234 (6.4)	7.3 (0.3)	2.1 (0.2)
Unspaced, alternating colour	2293 (135)	247 (6.7)	7.3 (0.3)	2.0 (0.1)
Unspaced, one-colour	3701 (245)	289 (9.7)	9.8 (0.5)	2.9 (0.2)

Table 3
Local measures on the target word for each of the conditions: first fixation duration (FFD, in ms), gaze duration (GD, in ms), total time (TT, in ms), percentage of fixation on the target word (%Fix, in %), initial landing position on the target words (Initial Land.P.), and parafoveal-on-foveal effects (Fix.Dur, in ms). Standard errors are presented between brackets.

Type of sentence	FFD		GD		TT		%Fix		Initial Land.P.		Fix.Dur N-1	
	LF	HF	LF	HF	LF	HF	LF	HF	LF	HF	LF	HF
Spaced, alternating colour	234 (8)	221 (6)	279 (13)	253 (12)	342 (23)	303 (19)	90.4 (1.3)	83.8 (2.3)	2.2 (0.1)	2.1 (0.1)	213 (7)	214 (7)
Unspaced, alternating colour	248 (8)	235 (8)	325 (14)	279 (11)	385 (19)	320 (17)	93.9 (1.9)	87.8 (2.7)	1.8 (0.1)	2.0 (0.1)	248 (10)	225 (6)
Unspaced, one-colour	295 (8)	269 (7)	476 (23)	393 (16)	668 (38)	552 (36)	96.1 (1.0)	94.6 (1.5)	1.7 (0.1)	1.7 (0.1)	280 (10)	279 (9)

of words per sentence was not exactly the same in the initial/final part of the experiment, we computed the words per minute (wpm). In the first half of the experiment, participants were on average 13.7 wpm faster in the spaced than in the unspaced alternating colour sentences (263.6 vs. 249.9 wpm, respectively), whereas in the second half of the experiment, participants were 11.1 wpm faster in the spaced than in the unspaced alternating colour sentences (286.5 vs. 275.4 wpm, respectively).

3.1.2. Average fixation times

The effect of type of sentence on the average fixation times was significant, $F1(2,46) = 86.9$, $p < .001$; $F2(2,238) = 263.2$, $p < .001$. Fixation durations were longer for the unspaced one-colour sentences (289 ms) than for unspaced alternating colour sentences (247 ms; $F1(1,23) = 75.75$, $p < .001$; $F2(1,119) = 305.7$, $p < .001$). In addition, fixation durations were longer for unspaced alternating colour sentences than for spaced alternating colour sentences (234 ms) $F1(1,23) = 60.2$, $p < .001$; $F2(1,119) = 28.35$, $p < .001$.

3.1.3. Number of progressive and regressive saccades

The effect of type of sentence on the number of progressive and regressive saccades was significant (progressive saccades: $F1(2,46) = 94.42$, $p < .001$; $F2(2,238) = 375.1$, $p < .001$; regressive saccades: $F1(2,46) = 26.52$, $p < .001$; $F2(2,238) = 91.78$, $p < .001$). This reflected more saccades in the unspaced one-colour sentences (progressive saccades: 9.8; regressive saccades, 2.9) than in the unspaced alternating colour sentences (progressive saccades: 7.3, $F1(1,23) = 90.24$, $p < .001$; $F2(1,119) = 465.8$, $p < .001$; regressive saccades: 2.0, $F1(1,23) = 33.5$, $p < .001$; $F2(1,119) = 129.2$, $p < .001$). Importantly, the number of saccades (progressive/regressive) did not differ between spaced alternating colour sentences (progressive saccades: 7.2; regressive saccades, 2.1) and the unspaced alternating colour sentences (progressive saccades: both $Fs < 1$; regressive saccades: $F1(1,23) = 1.85$, $p = .18$; $F2(1,119) = 2.59$, $p = .11$).

3.2. Local analyses

3.2.1. First fixation duration

The analyses on the first fixation durations revealed a main effect of word-frequency (i.e., shorter fixation durations [around 16 ms] for high-frequency words than for low-frequency words), $F1(1,23) = 26.07$, $p < .001$; $F2(1,116) = 12.69$, $p = .001$, and a main effect of Type of sentence, $F1(2,46) = 61.64$, $p < .001$; $F2(2,238) = 74.24$, $p < .001$. This reflected longer first-fixation durations for the target words embedded in unspaced one-colour sentences than in unspaced alternating colour sentences (282 vs 241 ms, respectively; both $ps < .001$) and longer first-fixation durations for the target words embedded in unspaced alternating colour sentences than in the spaced sentences (241 vs. 227 ms, respectively: both $ps < .001$). There were no signs of an interaction between the two factors, both $ps > .20$.

3.2.2. Gaze duration

The analyses on the gaze durations on the target words revealed a main effect of word-frequency, $F1(1,23) = 36.76$, $p < .001$; $F2(1,116) = 15.97$, $p = .001$, a main effect of type of sentence, $F1(2,46) = 100.52$, $p < .001$; $F2(2,238) = 163.4$, $p < .001$ (unspaced one-colour = 435 ms; unspaced alternating colour = 302; spaced alternating colour = 266 ms; all $ps < .001$), and an interaction between the two factors, $F1(2,46) = 6.36$, $p = .004$; $F2(2,238) = 3.57$, $p = .03$. This reflected that the magnitude of the word-frequency effect was larger for target words when embedded in unspaced one colour sentences (85 ms) than when embedded in unspaced alternating colour sentences or in spaced sentences (45 and 27 ms, respectively)—if the unspaced alternating colour sentence and the spaced sentences were only included, the magnitude of the word-frequency effect for the target words when embedded in unspaced alternating colour sentences and when embedded in spaced sentences did not differ (both $ps > .14$).

3.2.3. Total time

The analyses on the total times on the target words revealed a main effect of word-frequency, $F1(1,23) = 31.88$, $p < .001$; $F2(1,116) = 11.6$, $p = .001$, and type of sentence, $F1(2,46) = 96.20$, $p < .001$; $F2(2,238) = 205.8$, $p < .001$ (unspaced one-colour = 610 ms; unspaced alternating colour = 353 ms; spaced alternating colour = 323 ms; all $ps < .001$). The interaction between the two factors was also significant, $F1(2,46) = 5.94$, $p = .005$; $F2(2,238) = 2.96$, $p = .054$. This reflected that the magnitude of the word-frequency effect was greater on the target words when embedded in unspaced one-colour sentences (116 ms) than when embedded in unspaced alternating colour or spaced sentences (65 and 39 ms, respectively)—if the unspaced alternating colour sentence and the spaced sentences were only included, the interaction between type of sentence and word-frequency approached significance in the by-subjects analyses, $F1(1,23) = 3.95$, $p = .059$; $F2(1,118) = 1.13$, $p = .289$.

3.2.4. Percentage of first-pass fixations on the target word

The analyses on the proportion of first-pass fixations on the target words revealed main effects of word-frequency, $F1(1,23) = 20.87$, $p < .001$; $F2(1,118) = 8.12$, $p = .004$ (i.e., a higher percentage of first-pass fixations for low- than for high-frequency words; 93.4 vs. 88.7%, respectively) and type of sentence, $F1(2,46) = 11.96$, $p < .001$; $F2(2,238) = 5.93$, $p = .003$ (unspaced one-colour = 87.1% ms; unspaced alternating colour = 89.8%; spaced alternating colour = 95.3%). The interaction between the two factors was not significant, $F1(2,46) = 1.69$, $p = .196$; $F2 < 1$.

3.2.5. Initial landing position on the target word

As in prior research, and to make the measures from words of different length equivalent, each target word was divided into five fixation zones (e.g., Rayner et al., 1998; see also Perea & Acha, 2009, for a similar procedure). The analyses on the initial landing position only revealed a main effect of type of sentence, $F1(2,46) = 22.68$, $p < .001$; $F2(2,136) = 10.07$, $p < .001$, which indicated that initial landing position was closer to the beginning of the target word in the unspaced one-colour sentences than in unspaced alternating colour sentences (1.7 vs. 1.9, respectively, $F1(1,23) = 14.93$, $p = .001$; $F2(1,118) = 6.43$, $p = .013$) and that it was closer to the beginning of the word in alternating colour sentences than in the spaced sentences (1.9 vs. 2.2, respectively, $F1(1,23) = 9.70$, $p = .005$; $F2(1,118) = 3.81$, $p = .053$).

3.2.6. Duration of the (progressive) fixation previous to the target word

The analyses on the duration of the fixation previous to the target word revealed main effects of word-frequency, $F1(1,23) = 6.10$, $p = .021$; $F2(1,118) = 2.38$, $p = .126$, type of sentence, $F1(2,46) = 115.4$, $p < .001$; $F2(2,136) = 87.17$, $p < .001$, and an interaction between the two factors, $F1(2,46) = 4.37$, $p = .018$; $F2(2,136) = 3.78$, $p = .024$. This interaction reflected a word-frequency effect (i.e., shorter fixation when the following fixation was on a high- than a low-frequency word) in the unspaced alternating colour sentences (23 ms, $F1(1,23) = 13.23$, $p = .001$; $F2(1,118) = 9.80$, $p = .002$) but not in spaced sentences (−1 ms, both $Fs < 1$) or unspaced one-colour sentences (1 ms, both $Fs < 1$).

4. Discussion

The current experiment examined whether colours could be used to effectively segment words during reading in a spaced writing system (Spanish). The rationale is that word boundaries can be effectively delimited by colour (e.g., as in the sentence "youwillbeabletoreadthissentenceveryeasily") with the potential advantage that nearby words would be closer to high-acuity visual regions in unspaced sentences than in spaced sentences. The critical, and novel, finding of the experiment was that there was only a small reading cost in the unspaced alternating colour sentences when compared to the spaced sentences (see Table 1 for depiction). Indeed, the number of saccades (both progressive and regressive) was very similar in the two types of sentences. Fixation durations were slightly longer for the unspaced alternating colour sentences, and consequently, the overall reading time revealed a small reading cost (2293 ms in unspaced alternating colour sentences vs. 2188 ms in the spaced sentences; i.e., a 4.7% reading cost). Thus, colour information is more useful to segment words than the bold information employed by Perea and Acha (2009)—the alternating bold manipulation produced a 31% reading cost relative to the spaced sentences. In addition, results revealed that reading unspaced regular (one-colour) sentences had a large reading cost relative to spaced sentences (i.e., more [progressive, regressive] saccades, longer fixation durations, greater word-frequency effects, and initial landing positions close to the word beginning) (e.g., Rayner et al., 1998; see also Perea & Acha, 2009).

We now examine whether the alternating colour manipulation affected the process of word identification. If the alternating colour manipulation did not hinder the process of word identification, the size of the word-frequency effect on the target words should have been similar to that of target words embedded in spaced sentences. Results revealed that the magnitude of the word-frequency effect on the target word was only slightly greater in the unspaced alternating colour sentences than in the spaced sentences—note that the magnitude of the word-frequency effect was substantially greater for target words embedded in unspaced one-colour sentences (see also Rayner et al., 1998, for early evidence). This finding suggests that word identification processes were not severely hindered by lack of spaces between words. An explanation why the magnitude of the word-frequency effect was slightly greater for target words when embedded in unspaced colour sentences than when embedded in spaced sentences is that spacing not only diminishes lateral masking (crowding) of letters, but it may also increases the visibility of linguistically informative letters even though they occupy slightly more eccentric positions.

We now examine whether eye control guidance was affected by the unspaced alternating colour manipulation. At the global level, the number of progressive and regressive saccades was similar for unspaced alternating sentences and for spaced sentences. This finding may be taken to suggest that colour information did not hinder eye movement guidance when compared to spaced sentences—note that, unsurprisingly, unspaced one-colour sentences received more and longer fixations. However, this is not the whole story. At the local level, the initial landing position on the target word was slightly closer to the beginning in the unspaced alternating colour sentences than in the spaced sentences, and fixation durations were slightly longer in unspaced alternating colour sentences than in the spaced sentences—note that the initial landing position on the target words was closer to the beginning of the word in unspaced one-colour sentences than in spaced alternating colour sentences. Therefore, lack of spaces affected the low-frequency spatial information that is typically employed to programme the saccades towards the centre of the following word, as the EZ Reader model or the SWIFT model would predict. Keep in mind that when the landing position falls too close to the beginning of a word, there would be a reading cost (e.g., longer fixation durations and/or more refixations on the word; see Rayner et al., 1998), as actually occurred.

The apparent divergence between the global data (similar number of progressive/regressive saccades for unspaced alternating colour sentences and spaced sentences) and the local data (initial landing positions are closer to word onsets in unspaced alternating colour sentences than in spaced sentences) may be due to different reading strategies, as the words in alternating colour unspaced sentences (in particular, the short words) may benefit more from parafoveal processing. Keep in mind that nearby words are located closer from the fixated word in unspaced alternating colour sentences than in spaced sentences. Some support for this interpretation comes from the presence of a parafoveal-on-foveal effect with unspaced alternating colour sentences: the duration of the fixation prior to the target word was shorter when the target word was a high-frequency word than when the target word was a low-frequency word. As is usually the case in Indo-European languages, there were no trends of this effect in spaced sentences or in unspaced one-colour sentences (e.g., Rayner et al., 1998). Thus, this finding is consistent with the idea that adjacent nonfixated words are closer to the fovea in unspaced alternating colour sentences, thus (allegedly) maximizing the chances of obtaining parafoveal-on-foveal effects or a parafoveal preview benefit. To examine whether or not this parafoveal-on-foveal effect could be due to mislocated fixations (i.e., fixations may have undershot the intended word; see Drieghe, Rayner, & Pollatsek, 2008), we excluded the final letter of the N-1 word from the analyses, as this would reduce the chances of parafoveal-on-foveal effects as due to an undershoot of the intended target. Results revealed that the significant 25 ms effect of the original analyses was reduced to a nonsignificant 3 ms effect when this restriction was applied. Therefore, we prefer to be cautious with respect to this finding. Indeed, if parafoveal processing had played a more important role in unspaced alternating colour sentences than in spaced sentences, the rate of word skipping for target words would be expected to be higher in this condition, which was not found to be the case—note however that shortest target words in the current experiment were five-letters long and it may be the case that this effect occurs mostly with shorter (i.e., 2–4 letters) words. Further research should explore in greater detail this issue in normal reading experiments (e.g., using Rayner's, 1975, boundary technique) or in experiments with parafoveal flanking letters (see Grainger, Mathôt, & Vitu, 2014).

Taken together, the present findings suggest that at some processing level, there is a benefit from the nearby alternating colour words (i.e., parafoveal-on-foveal effects in unspaced alternating colour sentences, but not in spaced sentences), but this comes with an associated cost (i.e., landing positions closer to the beginning of the word). That is, removal of inter-word spaces may not only convey benefits (moving words closer to high acuity vision) but also incur costs (e.g., increased lateral masking). Further research should be conducted to examine in greater detail the extent to which parafoveal preview benefits can be obtained with alternating colour sentences as well as to examine whether the initial landing position on the target words is closer to the centre of the word when participants are trained with unspaced alternating colour texts (i.e., whether eye movement guidance is flexible enough with extensive training). We must keep in mind that readers are used to reading spaced (not unspaced) sentences in their daily lives and that with appropriate training, alternating colour sentences could also provide low/medium spatial information that may be useful in guiding saccades.[1]

To sum up, present data are a demonstration that colour can be useful to segment words for readers of spaced orthographies. The alternating colour manipulation (without spaces) helps segment the words in a spaced orthography, Spanish, and is certainly a better option than bold information. We believe that this finding can have practical applications. Given that infants use colour information to segregate different objects early in life (e.g., see Needham, 1998), an important question for further research is whether children's reading benefits from the use of unspaced sentences with alternating colour words (e.g., when learning unspaced languages: Chinese, Thai), in particular this could have benefits for poor readers or readers with dyslexia.[2] Similarly, given that colour improves object recognition in individuals with low vision (see Boucart, Despretz, Hladiuk, & Desmettre, 2008), one relevant question is whether these individuals may benefit from reading sentences with an alternating colour format. Furthermore, the unspaced alternating colour format is a viable option to present URL addresses or hashtags as well as (relatively brief) texts in small screen devices. Finally, an issue that deserves additional research is whether visual fatigue increases with the unspaced alternating colour format (see Benedetto, Drai-Zerbib, Pedrotti, Tissier, & Baccino, 2013, for an examination of visual fatigue in e-readers).

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[1] To further examine this issue, we conducted an additional experiment which involved more extensive training with unspaced alternating colour sentences. 24 participants, all of them native speakers of Spanish, read a long story (close to 3,000 words) in unspaced alternating colour format before reading an experimental text that was in unspaced or unspaced alternating colour (around 500 words). Results revealed only a small (but significant) advantage of the spaced over the unspaced alternating colour texts (around 9 words per minute).

[2] One remaining issue is whether the present findings can be generalised to unspaced writing systems. To that end, we conducted a preliminary experiment in which 33 skilled Thai readers read the sentences employed by Winskel et al. (2012). The sentences were presented in unspaced alternating colour sentences, in unspaced (standard) sentences, and in spaced sentences. We acknowledge that this alternating colour experiment must be taken with some caution, as eye movements were not registered. Results revealed a reading cost when the sentences were presented with spaces in one colour (see Winskel, Radach, & Luksaneeyanawin, 2009), while sentence reading was not affected by the alternating colour manipulation. This suggests that skilled adult Thai readers use quite different strategies to segment words when compared to readers of Indo-European languages (e.g., the relative frequency of characters in word-initial/final positions could be acting as word-boundary cues; see Kasisopa, Reilly, Luksaneeyanawin, & Burnham, 2013).