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# The effects of inter-letter spacing in visual-word recognition: Evidence with young normal readers and developmental dyslexics

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ABSTRACT

Recent research has demonstrated that slight increases of inter-letter spacing have a positive impact on skilled readers' recognition of visually presented words. In the present study, we examined whether this effect generalises to young normal readers and readers with developmental dyslexia, and whether increased inter-letter spacing affects the reading times and comprehension of a short text. To that end, we conducted a series of lexical decision and continuous reading experiments in which words were presented with the default settings or with a small increase in inter-letter spacing. Increased spacing produced shorter word identification times not only with adult skilled readers (Experiment 1), but also with young normal readers (Grade 2 and Grade 4 children; Experiment 2) and, even to a larger degree, with readers with dyslexia (Experiments 3 and 4). These experiments suggest that slight increases in inter-letter spacing would improve the readability of texts aimed at children, especially those with dyslexia.



## 1. Introduction

E-book readers and tablets are becoming more and more popular in the classrooms as a result of the incoming information society. When reading an e-book (or a digital document), we usually take for granted the default typographical settings offered by the publishing companies. Indeed, e-book users are offered only a limited set of choices, such as background/text colour, letter size, and (in some cases) font type. In the present study, we focus on yet another perceptual factor which may affect the ease of reading: inter-letter spacing (e.g., compare c a s i n o vs. the default casino).

When examining the readability of textbooks for children, Woods, Davis, and Scharff (2005) indicated the following: "Publishing companies have guidelines, but these are often based on font types and sizes most frequently used by other publishing companies rather than on empirical data" (p. 86). Thus, one fair question to ask is whether or not the choice of the parameters for children books, and more specifically, the choice of the default inter-letter spacing, is optimal. Indeed, it would be rather surprising if the default settings (not based on empirical data) were optimal. The vast majority of experiments with developing readers has focused on the impact of sublexical/lexical factors in visual-word recognition and reading (e.g., length, neighbourhood size, orthographic consistency, regularity, word-frequency age-of-acquisition, etc; see Defior, Jimenez-Fernandez, & Serrano, 2009; Manolitsis, Georgiou, & Parrila, 2011; Manolitsis, Georgiou, Stephenson, & Parrila, 2009; Verhoeven, Schreuder, & Baayen, 2006; Wang, Castles, Nickels, & Nation, 2011), whereas – as occurs with adult skilled readers – much less attention has been paid to the influence of perceptual factors such as font, letter size, or inter-letter spacing (see Tinker, 1963, for early research on typographical factors during reading; see also Sanocki & Dyson, 2012, for a recent review). The present study represents a modest effort to shed some light on role of a potentially important parameter such as inter-letter spacing during visual-word recognition and reading with developing readers.

Clearly, a factor such as inter-letter spacing may play a relevant role in the process of visual-word recognition. In alphabetical languages, words are composed of an ordered succession of letters. It is well known that the perception of a given letter is impaired when there are other letters located nearby – due to lateral masking between these neighbouring letters: this is the effect of crowding (see Bouma, 1970). Importantly, a slight increase of inter-letter spacing relative to the default settings, as in c a s i n o

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(compare with the default casino), may reduce the detrimental effects of crowding without affecting the whole word's integrity (i.e., c a s i n o would still be perceived as a single unit).[1] Furthermore, a small increase of inter-letter spacing may not just reduce the effect of crowding, it may also aid in the process of letter position coding: if letter position coding were not attained, we could not distinguish between words like casual and causal (see Perea & Lupker, 2003, 2004). Recent theories of orthographic processing assume that there is some degree of "position uncertainty" on a letter's position within a word (see Chung & Legge, 2009; Davis, 2010; Gomez, Ratcliff, & Perea, 2008). Thus, increasing the space among letters within a word can reduce a letter's position uncertainty within a word and have a beneficial impact on lexical access.

Two recent studies with adult skilled readers in Spanish (Perea & Gómez, 2012; Perea, Moret-Tatay, & Gómez, 2011a), using a lexical decision task ("is the stimulus a word?") reported shorter response times for words presented with a slight increase of inter-letter spacing than for words presented with the default spacing (i.e., c a s i n o faster than casino; see Latham & Whitaker, 1996; Tai, Sheedy, & Hayes, 2009, for similar findings with other paradigms and languages). Importantly, the effect of inter-letter spacing occurred to a similar degree for high-frequency words and low-frequency word (Perea, Moret-Tatay, & Gómez, 2011a). This suggests that the effect of inter-letter spacing occurs very early in processing, before a lexical factor such as word-frequency starts playing a role. Furthermore, Perea and Gómez (2012) reported fits from Ratcliff's (1978) diffusion model to their empirical data and showed that the beneficial effect of inter-letter spacing in visual-word recognition occurs at an early (letter) encoding level. This finding is consistent with the "crowding" and the "perceptual uncertainty" accounts indicated above.

The central questions under scrutiny in the present paper are: i) whether or not the beneficial effect of increasing inter-letter spacing (relative to the default settings) generalises across different levels of reading development to young readers, and ii) whether or not these effects (which have been reported in visual-word identification tasks) can be generalised to a continuous reading task. The effects of inter-letter spacing were examined not only with young normal readers, but also with young readers with developmental dyslexia. If we use the definition from DSM-IV, readers with developmental dyslexia are characterised by difficulty in accuracy or fluency of reading beyond the individual's chronological age which cannot be explained in terms of the individual's intellectual abilities or lack of educational opportunities (see Gabrieli, 2009, for a recent review). Although a comprehensive discussion of the literature on dyslexia would go beyond the scope of the present paper, the traditional view regarding dyslexia is related to a phonological deficit (e.g., see Liberman, Shankweiler, Fischer, & Carter, 1974). Nonetheless, more recent research has qualified this view by indicating that the deficit would occur when accessing these phonological representations (i.e., the phonological representations per se of individuals with developmental dyslexia may be intact; see Ramus & Szenkovits, 2008) and that developmental dyslexia may be characterised on the basis of abnormal, parallel letter coding as visual objects rather than as letters (e.g., see Whitney & Cornelissen, 2005).

According to the "crowding" and "perceptual uncertainty" mechanisms, there are several reasons why young readers (and particularly those with dyslexia) may benefit from small increases in inter-letter spacing, even more than adult skilled readers. On the one hand, crowding effects tend to be greater for young readers than for adults (see Jeon, Hamid, Maurer, & Lewi, 2010) and they tend to be greater for readers with dyslexia than for their controls (see Atkinson, 1991; Geiger & Lettvin, 1987; Hawelka & Wimmer, 2005; Martelli, Di Filippo, Spinelli, & Zoccolotti, 2009; Spinelli, de Luca, Judica, & Zoccolotti, 2002). Indeed, it has been suggested that "visual crowding may be a factor contributing to the genesis of developmental dyslexia" (Spinelli et al., 2002, p. 197). On the other hand, it has been claimed that orthographic development in young readers goes "from a fairly loosely tuned system for the coding of the position of letters within words towards a more precisely tuned system" (Castles, Davis, Cavalot, & Forster, 2007, p. 168). This is consistent with the presence of larger transposed-letter effects (i.e., jugde being processed as judge) with beginning readers than for intermediate readers or adult skilled readers (see Acha & Perea, 2008; Castles et al., 2007; Perea & Estévez, 2008). In this light, it has been suggested that, among young readers, perceptual uncertainty may be larger for readers with dyslexia than for normal readers (see O'Brien, Mansfield, & Legge, 2005). Indeed, failures in letter position coding may produce a specific form of developmental dyslexia (i.e., the so-called "letter position" dyslexia, see Friedman & Rahamim, 2007).

Empirical work concerning the effects of inter-letter spacing in visual-word recognition with young readers is very scarce, but it does suggest a beneficial effect of a slight increase in inter-letter spacing relative to the default settings. Spinelli et al. (2002) employed five-letter Italian words in a naming task with young normal readers and with readers with developmental dyslexia (12 year-olds in both groups). For the dyslexic group, they found substantially shorter response times (around 40 ms; overall RTs around 900 ms) when there was a slightly wider inter-letter spacing (e.g., bordo) than with the default settings (e.g., b o r d o). For the control group, Spinelli et al. reported a nonsignificant 7–8 ms advantage for the words with the slightly wider inter-letter spacing – the overall RTs were around 550 ms. Not surprisingly, a substantial increase in inter-letter spacing (e.g., b o r d o) produced slower naming times in both groups – note that an increase in inter-letter spacing beyond certain limits destroys the word's integrity (see Chung, 2002). In addition, McLeish (2007), in a sample of young readers (10–15 years old) with low vision, found that increasing letter spacing increased reading speed in a continuous reading task in English. McLeish concluded that "increased letter spacing may be beneficial to most low-vision readers whatever their visual condition" (p. 141).

In sum, previous evidence suggests that inter-letter spacing has a beneficial effect in the process of visual-word recognition. The theoretical explanations, in terms of "crowding" and "perceptual uncertainty", would hypothesise an effect of similar (or probably larger) magnitude with developing readers, especially for those readers with developmental dyslexia. The present study also has obvious implications at a practical level: if a slightly wider inter-letter spacing produces faster word identification times (or reading times) than the default inter-letter spacing settings with young readers, then publishing companies, e-books, etc. should slightly modify (i.e., increase) the default inter-letter spacing values in children books. Or at the very least, the option of modifying inter-letter spacing should be offered in e-book applications – this is already an option in most word-processing software (e.g., MS-Word, OpenOffice Writer, among others).

### 1.1. Overview of the experiments

We present four experiments that explored the effects of inter-letter spacing in visual-word recognition and reading. In all the experiments, words were presented with the default inter-letter

[1] Unsurprisingly, a large increase in inter-letter spacing (e.g., as in the word c a s i n o) has a deleterious effect on the process of lexical access because the words are no longer perceived as a single entity (see Chung, 2002; Perea, Moret-Tatay, & Gómez, 2011a, for discussion).

settings (e.g., hotel) or with a slight increase in inter-letter spacing (+1.2 in MS-Word: h o t e l, using a 14-pt Times New Roman font). These conditions were the same as in the Perea, Moret-Tatay, and Gómez (2011a) experiments.

In Experiments 1–3, we employed an online word identification task which is highly sensitive to small effects, namely, the lexical decision task (see Dufau et al., 2011, for a recent review). We should note here that the findings obtained with the lexical decision task have typically been generalised to normal silent reading (e.g., see Davis, Perea, & Acha, 2009; Johnson, Perea, & Rayner, 2007; Perea & Pollatsek, 1998). Indeed, in his influential review on eye movement research, Rayner's (1998) indicated that "researchers can have some confidence that results obtained with standard naming and lexical decision tasks generalize to word recognition processes while reading" (p. 392). We employed the go/no-go variant of the lexical decision task ("if it is a word, press 'yes'; if not, refrain from responding") rather than the yes/no procedure ("if it is a word, press 'yes'; if not, press 'no'") because it produces faster responses and fewer errors than the standard yes/no variant with developing readers, without altering the process of interest (Moret-Tatay & Perea, 2011; Perea, Moret-Tatay, & Panadero, 2011b; see also Gomez, Ratcliff, & Perea, 2007, for a mathematical model of the go/no-go task).

Experiment 1 was designed to replicate Perea, Moret-Tatay, and Gómez's (2011a), Perea and Gómez (2012) findings with adult skilled readers (i.e., university students) using a different set of materials – the new materials were composed of (frequent) words which were familiar to first-grade children. The purpose of this replication (which was accomplished) was to show that the effects of inter-letter spacing could be generalised to the materials that were used with children in Experiments 2 and 3. Experiments 2 and 3 were parallel to Experiment 1, except that Grade 4 and Grade 2 children participated in Experiment 2, whereas young readers with developmental dyslexia participated in Experiment 3. Finally, to examine whether the effects obtained in Experiments 2 and 3 could be generalised beyond the recognition of isolated words, Experiment 4 employed a continuous reading task with young normal readers and with young readers with developmental dyslexia.

## 2. Experiment 1 (adult skilled readers)

Together with inter-letter spacing, in Experiments 1–3 we also manipulated word length (four vs. six-letter words). The rationale of this manipulation was to examine whether the effect of inter-letter spacing could interact with this relevant sublexical factor. Perea, Moret-Tatay, and Gómez (2011a) found a similar pattern of data for five- and eight-letter words with adult skilled readers. However, the effect of word length is usually very small (and nonsignificant) with adult readers, whereas it is quite robust with young readers (e.g., see Acha & Perea, 2008). Thus, in the case of young readers, it may be the case that inter-letter spacing affects differently four- and six-letter words (i.e., it could be argued that crowding effects would play a larger role with longer words rather than with shorter words).

Although the critical manipulation in the present study was inter-letter spacing, we also tested another spacing manipulation in Experiments 1–3: the word/nonword could have an extra spacing after each syllable (syllable-based spacing; as in ca si no). This manipulation may be potentially relevant because it has been claimed that syllables may be fundamental units of processing, in particular for Romance languages with well-defined syllable boundaries (see Carreiras, Álvarez, & de Vega, 1993; Perea & Carreiras, 1998). The evidence with respect to syllable-based spacing in visual-word recognition is, however, very scarce. Splitting the word into syllables (e.g., BUR DEN) has been shown to produce longer response times than presenting the whole word with no extra spacing between syllables (BURDEN) in a lexical decision task in English with adult skilled readers (660 vs. 627 ms, respectively; see Lima & Pollatsek, 1983). Nonetheless, leaving aside that syllabic effects in English tend to be less reliable than in Romance languages (see Macizo & Van Petten, 2007), the extra spacing between syllables in the Lima and Pollatsek experiment was greater than that used here, and it might have hindered the whole word's integrity.

In sum, in this experiment with adult skilled readers, we predict that a small increase in inter-letter spacing will significantly reduce response times in the lexical decision task (Hypothesis 1) –similarly to previous reports with other sets of items (e.g., Perea & Gómez, 2012; Perea, Moret-Tatay, & Gómez, 2011a).

### 2.1. Method

#### 2.1.1. Participants

The participants were 24 undergraduate and graduate students from the University of Valencia (16 female; mean age: 23 years). All participants had normal or corrected-to-normal vision and were native speakers of Spanish. None of them had sensory, neurological, or other problems traditionally used as exclusionary criteria for learning disabilities.

#### 2.1.2. Materials

We selected a set of 108 Spanish words from the B-Pal database (Davis & Perea, 2005). These words were divided into two groups as a function of their length: four-letter bisyllabic words were labelled as short words, and six-letter trisyllabic words were labelled as long words. The mean word-frequency per million was 60 (range: 1–352) for short words and 57 (range: 1–210) for long words. All these words were familiar to young readers: they appeared in the Spanish word-frequency count for first-grade children of Corral, Goikoetxea, and Ferrero (2009; the frequencies in this corpus for short and long words were 56 and 55, respectively). The mean number of 'orthographic neighbours' (i.e., one-letter different words) was 11.4 for short words (range: 0–26) and 1.7 for long words (range: 0–6).[2] An additional set of 108 orthographically legal nonwords was created for the lexical decision task (64 'short' nonwords and 64 'long' nonwords). Nonwords were created by changing several letters of Spanish words (vowel by vowel, and consonant by consonant), so that both length and orthographic structure was the same as in the target words (e.g., socade, bido). The list of words and nonwords is available in Appendix A. Word and nonword stimuli were counterbalanced across three experimental lists so that if a letter string was presented with the default inter-letter spacing in the first list, it would be presented with a slightly wider inter-letter spacing in the second list, and with a slightly wider syllabic spacing in the third list. Stimuli were presented in 14-pt Times New Roman. The condition with a slightly wider inter-letter spacing consisted in a +1.2 extra inter-letter spacing (e.g., compare the default animal with a n i m a l), and the condition with a syllabic spacing consisted in a parallel spacing as the previous condition but only between each syllable (e.g., compare the default hotel with ho tel).

[2] Because of the restrictions at selecting the words for the children, we could not equate the short and long words in terms of $N$. Nonetheless, there is no particular reason why $N$ would have an interacting effect with inter-letter spacing. Furthermore, we must keep in mind that $N$ may not have a genuine effect in visual-word recognition (see Davis, 2010) and that the children may not know many of a word's neighbours in the general corpus from which $N$ is derived. Indeed, post hoc analyses on Experiments 1–3 failed to find any signs of an interaction between $N$ and the obtained effects of inter-letter spacing when length was controlled.

#### 2.1.3. Procedure

Participants were tested individually in a quiet room. Presentation of the stimuli and recording of response times were controlled by a Windows computer running DMDX (Forster & Forster, 2003). On each trial, a fixation point ("+") was presented at the centre of the screen for 500 ms. Next, the target stimulus was presented in lowercase and remained on the screen until the participant's response or until 2500 ms had elapsed (see Moret-Tatay & Perea, 2011, for a similar procedure). Participants were told that words and nonwords would be displayed on the monitor in front of them, and that they should press one button to indicate if the stimulus was a Spanish word, and refrain from responding if the stimulus was not a word. They were instructed to respond as rapidly as possible without making too many mistakes. Each participant received a different random order of stimuli. Each participant received a total of 24 practice trials prior to the experimental phase. The session lasted approximately 15 min.

### 2.2. Results and discussion

Incorrect responses and reaction times less than 250 ms or greater than 1800 ms (.08%) were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in Table 1. Although the key comparison is the default inter-letter spacing condition vs. the slightly wider inter-letter spacing condition, the syllable-based spacing condition was also included in the ANOVAs. For word stimuli, RTs and percent errors were submitted to separate ANOVAs with a 2 (Length: 4 letters, 6 letters) × 3 (Spacing: default, wide, syllabic) × 3 (List: list 1, list 2, list 3) design. For nonword stimuli, participants' error rates (there were no RTs for nonwords because this was a go/no-go task) were submitted to an ANOVA with a 2 (Length: 4 letters, 6 letters) × 3 (Spacing: normal, wide, syllabic) × 3 (List: list 1, list 2, list 3) design.

**Table 1**
Mean lexical decision times (in ms) and percentage of errors (in parentheses) for words and pseudowords in Experiments 1–3.

| | Spacing | | |
|---|---|---|---|
| | Default | Slightly wider | Syllabic |
| Adult Readers (Exp.1) | | | |
| *Words* | | | |
| Short | 592 (1.6) | 567 (.7) | 576 (1.6) |
| Long | 596 (.5) | 554 (.2) | 591 (.2) |
| *Nonwords* | | | |
| Short | – (3.0) | – (2.3) | – (3.0) |
| Long | – (1.4) | – (3.9) | – (2.5) |
| 4th Graders (Exp. 2) | | | |
| *Words* | | | |
| Short | 806 (1.9) | 795 (2.3) | 811 (2.3) |
| Long | 854 (1.6) | 821 (1.6) | 860 (2.5) |
| *Nonwords* | | | |
| Short | – (10.6) | – (9.5) | – (11.1) |
| Long | – (10.0) | – (7.9) | – (8.3) |
| 2nd Graders (Exp. 2) | | | |
| *Words* | | | |
| Short | 931 (2.9) | 937 (3.7) | 941 (3.7) |
| Long | 1021 (3.7) | 989 (5.1) | 1038 (4.1) |
| *Nonwords* | | | |
| Short | – (8.1) | – (9.3) | – (7.9) |
| Long | – (6.7) | – (6.0) | – (5.1) |
| Readers with dyslexia (Exp. 3) | | | |
| *Words* | | | |
| Short | 917 (9.9) | 906 (8.0) | 981 (6.8) |
| Long | 1180 (25.6) | 1051 (11.1) | 1242 (25.9) |
| *Nonwords* | | | |
| Short | – (6.8) | – (5.2) | – (4.9) |
| Long | – (1.5) | – (3.4) | – (2.8) |

List was included in the ANOVAs to extract the error variance due to the counterbalancing lists (see Pollatsek & Well, 1995).

The main effect of spacing on the latency data was significant, $F1(2,42) = 3.98$, $MSE = 3480$, $\eta^2 = .16$, $p < .05$, $F2(2,204) = 13.96$, $MSE = 2104.2$, $\eta^2 = .12$, $p < .001$. Consistent with Hypothesis 1, this reflected faster response times for the words with a slightly wider inter-letter spacing than for the words with the default inter-letter settings (560 ms vs. 594 ms, respectively), $F1(1,21) = 4.75$, $MSE = 5564.3$, $\eta^2 = .18$, $p < .05$; $F2(1,102) = 29.59$, $MSE = 1895.5$, $\eta^2 = .23$, $p < .001$, while the pairwise comparison between the inter-syllable spacing and the default condition was not significant (584 vs. 594 ms, respectively), $F1(1,21) = .96$, $MSE = 2651.2$, $\eta^2 = .05$, $p > .30$; $F2(1,102) = 2.85$, $MSE = 1906.7$, $\eta^2 = .03$, $p = .094$. Word length, however, did not yield significant effects on the latency data: The mean response time to six-and four-letter words was remarkably similar (578 vs. 580 ms, respectively; both $Fs < 1$). Finally, the interaction between length and spacing was not significant, $F1(2,42) = 1.45$, $MSE = 1203$, $\eta^2 = .10$, $p > .15$; $F2(2,204) = 2.56$, $MSE = 2104.2$, $\eta^2 = .02$, $p = .080$.

The error rate data only revealed a significant effect of word length: Participants made more errors on four-letter words than on six-letter words (1.3 vs. .3%, respectively), $F1(1,21) = 6.76$, $MSE = 5.36$, $\eta^2 = .24$, $p < .02$; $F2(1,102) = 5.00$, $MSE = 16.31$, $\eta^2 = .05$, $p < .03$. The other effects (for both word and nonword stimuli) did not approach significance (all $ps > .2$).

The results of the present go/no-go lexical decision experiment replicated the main findings reported by Perea, Moret-Tatay, and Gómez (2011a) and Perea and Gómez (2012) with adult skilled readers using a yes/no lexical decision task: small increases of inter-letter spacing lead to faster word identification times than the default settings (Hypothesis 1). Likewise, as in the experiments of Perea and colleagues, neither the effect of length nor the interaction between inter-letter spacing and length was significant; Perea et al. employed words of five vs. eight letters. Finally, even though there were some hints that the syllabic-based spacing condition could lead to faster response times than the default spacing condition (a 10-ms difference), the difference did not approach significance; that is, increasing the inter-syllable spacing did not have a beneficial/deleterious effect on identification times to word stimuli relative to the default settings.

Once the benefit of a small increase of inter-letter spacing was established with this set of items, the question became whether this effect also generalises to young readers. In Experiment 2, we employed the same conditions/procedure as in Experiment 1, except that this time the sample was composed of young readers of second and fourth grade. Thus, in Experiment 2, we predict that – similarly to adult skilled readers – small increases in inter-letter spacing will reduce lexical decision times with young normal readers (Hypothesis 2).

## 3. Experiment 2 (young normal readers)

### 3.1. Method

#### 3.1.1. Participants

The participants were 24 second grade children (12 female; mean age: 7.8 years; range: 7–8) and 24 fourth graders (12 female; mean age: 9.7 years; range: 9–10). All participants had normal or corrected-to-normal vision and were native speakers of Spanish. These children came from above-average socioeconomic backgrounds in a private school in Valencia, Spain. As in Experiment 1, participants were excluded if they had sensory, neurological, or other problems traditionally used as exclusionary criteria for learning disabilities. The experiment took place at the end of the academic year.

*3.1.2. Materials and procedure*

The design, materials and procedure were the same as in Experiment 1.

*3.2. Results and discussion*

Incorrect responses and reaction times less than 250 ms or greater than 1800 ms (.8 and 1.7% for the fourth and second graders, respectively) were excluded from the latency analysis. The mean response times for correct responses and the error rates are presented in Table 1.

*3.2.1. Word data*

The ANOVA on the latency data showed that 4th graders responded to words more rapidly than 2nd graders (824 vs. 976 ms, respectively), $F1(1,42) = 20.93$, MSE = 79174.5, $\eta^2 = .33$, $p < .001$; $F2(1,102) = 448.9$, MSE = 7891.5, $\eta^2 = .82$, $p < .01$, and that six-letter words were responded to more slowly than four-letter words (930 vs. 870 ms, respectively), $F1(1,42) = 26.79$, MSE = 9788.4, $\eta^2 = .39$, $p < .01$; $F2(1,102) = 15.15$, MSE = 35801.3, $\eta^2 = .13$, $p < .01$. The effect of length was larger for 2nd graders than for 4th graders, as deduced from the interaction between length and grade in the item analysis (and marginally in the participant analysis), $F1(1,42) = 2.74$, MSE = 9788.4, $\eta^2 = .10$, $p = .10$; $F2(1,102) = 7.29$, MSE = 7981.5, $\eta^2 = .07$, $p < .01$. More important for the present purposes, the main effect of spacing was significant, $F1(2,84) = 5.69$, MSE = 3159.3, $\eta^2 = .12$, $p < .01$; $F2(2,204) = 6.63$, MSE = 6623.5, $\eta^2 = .06$, $p < .01$, as was the interaction between Length and Spacing, $F1(2,84) = 4.00$, MSE = 15868, $\eta^2 = .10$, $p < .05$; $F2(2,204) = 3.30$, MSE = 6623.5, $\eta^2 = .03$, $p < .01$. This interaction reflected a significant effect of spacing for the six-letter words, $F1(2,85) = 8.55$, MSE = 2914.6, $\eta^2 = .17$, $p < .03$; $F2(2,102) = 8.69$, MSE = 7181.3, $\eta^2 = .15$, $p < .01$, with faster response times for the words with a slightly wider inter-letter spacing than for the words presented with the default settings (905 vs. 937 ms, respectively; i.e., consistent with Hypothesis 2), $F1(1,42) = 7.96$, MSE = 3213.3, $\eta^2 = .10$, $p < .01$; $F2(1,51) = 6.13$, MSE = 9446.1, $\eta^2 = .11$, $p < .02$, while there were no differences between the inter-syllable spacing and the default conditions (949 vs. 937 ms, respectively), both $ps > .30$. In contrast, there were no signs of an effect of inter-letter spacing for the four-letter words (slightly wider inter-letter spacing: 866 ms; default spacing: 868 ms), both $Fs < 1$.

The ANOVAs on the error data revealed (restricted only to the item analyses) that 2nd graders made more omission errors than 4th graders (word stimuli; 3.9 vs. 2.0% of omission errors; $F1(1,42) = 2.91$, MSE = 84.72, $\eta^2 = .07$, $p = .095$; $F2(1,102) = 16.40$, MSE = 33.87, $\eta^2 = .14$, $p < .01$). The other effects did not approach significance, all $Fs < 1$.

*3.2.2. Nonword data*

The ANOVA on the accuracy data to nonwords revealed that participants committed more false alarms for four-letter nonwords than for the six-letter nonwords (9.4 vs. 7.3%, respectively), $F1(1,42) = 12.22$, MSE = 25.57, $\eta^2 = .23$, $p < .002$; $F2(1,102) = 4.47$, MSE = 157.3, $\eta^2 = .04$, $p < .04$. The other effects did not approach significance, all $Fs < 1$.

As occurred with adult skilled readers in Experiment 1, there is a benefit from small increases in inter-letter spacing (relative to the default settings) in the visual recognition of words for both second and fourth graders (Hypothesis 2). Not surprisingly, word identification latencies were overall longer for Grade 2 children than for Grade 4 children and, as expected, we found a length effect with young readers. This effect of length was greater for beginning readers (Grade 2) than for intermediate readers (Grade 4) (see also Acha & Perea, 2008). Finally, one difference with respect to Experiment 1 with adult skilled readers is that the effect of inter-letter spacing with young readers was restricted to six-letter word. We found a similar trend in Experiment 1 with adult skilled readers but that interaction was not significant. (We defer an interpretation of this interaction until the General Discussion.)

As in Experiment 1, the syllable-based spacing behaved similarly to the default spacing condition (i.e., it did not produce a significant benefit on lexical access, but it did not have a deleterious effect either). Finally, it is important to note that the error rates were quite low, not only for fourth graders, but also for second graders. This reinforces the use of the go/no-go procedure as the most appropriate variant of the lexical decision task when conducting experiments with children (see Moret-Tatay & Perea, 2011; Perea, Moret-Tatay, & Panadero, 2011b).

In sum, the present experiment has revealed that there is a beneficial effect of small increases of inter-letter spacing (relative to the default settings) with young normal readers (Hypothesis 2). Experiment 3 was designed to examine the effects of inter-letter spacing with young readers with developmental dyslexia, using the same materials and procedure as in the previous experiments. As indicated in the Introduction, Spinelli et al. (2002) found substantially faster naming latencies for words presented with a slightly wider inter-letter spacing (e.g., b o r d o) than with the default settings (e.g., bordo) in a sample of young readers with developmental dyslexia. In their experiment, the effect of inter-letter spacing on naming latencies for normal readers was small and nonsignificant. If the effects of crowding (or perceptual uncertainty) are larger in dyslexics than in normal young readers (as suggested by O'Brien et al., 2005 and Spinelli et al., 2002, among others), we would expect a larger effect of inter-letter spacing for individuals with developmental dyslexia than that obtained with young normal readers. The present experiments were conducted in Spanish and the Spinelli et al. experiments were conducted in Italian, another shallow orthography. Nonetheless, as we discuss in the General discussion an explanation in terms of "crowding" or letter position coding (i.e., "perceptual uncertainty") should be independent of a language's orthographic depth (see Davis et al., 2009; Serrano & Defior, 2008).

We originally intended to recruit the group with developmental dyslexia from Grades 4 and 2 – to keep the age level similar to Experiment 2. However, the initial testing revealed that even the go/no-go variant of the lexical decision task was very difficult for the vast majority of these children: both error rates and latencies were too high to allow a reasonable comparison with the normal readers. For that reason, we recruited children diagnosed with developmental dyslexia from the final year of primary school (i.e., Grade 6) and from the two initial years of compulsory secondary education in Spain (i.e., Grades 7 and 8 in the US system). We must keep in mind that the goal of the present study is to examine whether slight increases in inter-letter spacing benefit lexical access in developing readers –normal readers and readers with developmental dyslexia– rather than a direct comparison of a group of readers with dyslexia vs. a control group.

## 4. Experiment 3 (young readers with developmental dyslexia)

Based on previous research on crowding effects – and based on the findings of Experiments 1 and 2 – small increases in inter-letter spacing will considerably reduce response times with young readers with developmental dyslexia (Hypothesis 3).

### *4.1. Method*

*4.1.1. Participants*

The participants were 18 children (7 female) from the province of Valencia, Spain (mean age: 12.1 years: range: 11–13) which had been diagnosed with dyslexia. All of the participants were native speakers of Spanish and met the following criteria: normal or above normal intelligence, standard educational opportunities, normal or corrected-to-normal vision, no gross sensory deficits or behavioural problems, and no history of neurological disease. To further verify that the children had reading problems, we administered to all of the participants the PROLEC-SE standardised battery of reading tests in Spanish (Ramos & Cuetos, 1999) and the diagnosis of developmental dyslexia was confirmed. At the time of the experiment, all the participants were receiving individual remediation training (two 45-min sessions per week) in private centres or at their own schools—this included training in phonological awareness tasks, attention/memory tasks, reading tasks (speed, accuracy, comprehension), writing asks (dictation, spontaneous writing, copying), and breathing exercises.

#### *4.1.2. Materials and procedure*

The design, materials and procedure were the same as in Experiments 1 and 2.

### *4.2. Results and discussion*

Incorrect responses and reaction times less than 250 ms or greater than 1800 ms (5.5%) were excluded from the latency analysis. The mean latencies for correct responses and error rates are presented in Table 1.

#### *4.2.1. Word data*

The ANOVA on the latency data showed that six-letter words were responded to more slowly than the four-letter words (1158 vs. 935 ms, respectively), $F1(1,15) = 73.39$, MSE = 18325, $\eta^2 = .83$, $p < .01$; $F2(1,102) = 96.43$, MSE = 34171.9, $\eta^2 = .49$, $p < .01$. The main effect of spacing was also significant, $F1(2,30) = 12.11$, MSE = 13247, $\eta^2 = .45$, $p < .01$; $F2(2,204) = 13.56$, MSE = 26263.3, $\eta^2 = .12$, $p < .01$. As in Experiment 2 (young normal readers), the interaction between Length and Spacing was significant, $F1(2,42) = 4.10$, MSE = 9979, $\eta^2 = .22$, $p < .01$; $F2(2,204) = 2.87$, MSE = 26263.3, $\eta^2 = .03$, $p = .059$. This reflected that there was a significant effect of spacing for the six-letter words, $F1(2,30) = 9.28$, MSE = 18489, $\eta^2 = .38$, $p < .01$; $F2(2,102) = 9.69$, MSE = 37330.8, $\eta^2 = .16$, $p < .01$, with faster response times for the wider inter-letter spacing condition than for the default spacing condition (1051 vs. 1180 ms, respectively; i.e., consistent with Hypothesis 3), $F1(1,21) = 13.76$, MSE = 10845, $\eta^2 = .48$, $p < .01$; $F2(1,102) = 9.81$, MSE = 38081.3, $\eta^2 = .03$, $p < .01$, whereas there were no differences between the syllable-based spacing and the default conditions (1240 vs. 1180 ms, respectively), both $ps > .20$; in contrast, there were no signs of an effect of inter-letter spacing for the four-letter words (default spacing: 917 ms; wider inter-letter spacing: 906 ms), both $Fs < 1$.

The ANOVA on the error data showed that participants committed more errors to six-letter words than to four-letter words (20.9 vs. 8.2%, respectively), $F1(1,15) = 22.22$, MSE = 194.6, $\eta^2 = .60$, $p < .01$; $F2(1,102) = 34.61$, MSE = 374.9, $\eta^2 = .25$, $p < .01$. The main effect of spacing was also significant, $F1(2,30) = 6.82$, MSE = 101.1, $\eta^2 = .31$, $p < .01$; $F2(2,204) = 12.90$, MSE = 160.3, $\eta^2 = .11$, $p < .01$, as well as the interaction between Length and Spacing, $F1(2,42) = 11.14$, MSE = 57.8, $\eta^2 = .43$, $p < .01$; $F2(2,204) = 12.05$, MSE = 160.3, $\eta^2 = .11$, $p < .01$. This interaction reflected that there was a significant effect of spacing for the six-letter words, $F1(2,30) = 12.25$, MSE = 105.3, $\eta^2 = .45$, $p < .01$; $F2(2,102) = 17.17$, MSE = 225.4, $p < .01$, with substantially more errors to the default inter-letter spacing condition than in the slightly wider inter-letter spacing condition (25.6 vs. 11.1%, respectively), $F1(1,15) = 16.22$, MSE = 116.8, $\eta^2 = .52$, $p < .01$; $F2(1,102) = 20.24$, MSE = 178.5, $\eta^2 = .17$, $p < .01$. In contrast, there was no significant effect of inter-letter spacing for four-letter words (default spacing: 9.9%; wider inter-letter spacing: 8.0%), both $Fs < 1$.

#### *4.2.2. Nonword data*

The ANOVA on the accuracy data to nonwords revealed that participants committed more false alarms for the four-letter nonwords than for the six-letter words in the analysis by participants (5.7 vs. 2.6%, respectively), $F1(1,15) = 7.84$, MSE = 32.81, $\eta^2 = .34$, $p < .02$; $F2(1,102) = 2.59$, MSE = 298.4, $\eta^2 = .03$, $p = .11$. The other effects/interactions were not significant (all $ps > .30$).

The main findings of the present experiment are straightforward. Leaving aside the vast effect of length − which occurred in both response times (223 ms) and error data (12.7%) to word stimuli − there was a substantial reading benefit from small increases of inter-letter spacing relative to the default settings (Hypothesis 3). This benefit occurred both in the word identification data and in the error data. Indeed, the vast majority of participants showed a beneficial effect from inter-letter spacing: seventeen out of the eighteen participants. Furthermore, as occurred in the group of normal young readers, the effect was restricted to six-letter words. This finding argues against the idea that increasing the length of the stimulus (via increasing inter-letter spacing) may be beyond the visual span of the participants in a visual-word recognition task, at least for six-letter words.

One relevant question now is whether or not the effects of inter-letter spacing obtained with a laboratory word identification task (i.e., lexical decision) can be generalised to normal reading. Experiments 1 and 3 offer clear evidence in favour of a foveal advantage of inter-letter spacing during the recognition of visually presented words. However, in a normal reading situation, neighbouring words would be farther away when using a slightly wider inter-letter spacing and this may lead to less parafoveal preview benefits. This potential trade-off may cancel the advantage in foveal processing from small increases in inter-letter spacing.

We believe that is important to examine whether young readers also show a benefit of small increases in inter-letter spacing when reading a text. To that end, we conducted Experiment 4 with both a group of young normal readers (Grade 4 students) and a group of young readers with developmental dyslexia. Participants were presented with two texts composed each of several paragraphs. In one text, inter-letter spacing was slightly increased (+1.2, as in Experiments 1–3) and, in the other text, we employed the default spacing. The critical dependent variable was the overall reading time, but we also collected data from comprehension questions on the text. We acknowledge that monitoring the participants' eye movements would provide much finer measures than measuring the total reading time, but we believe that the present experiment can be used as an initial approach to assessing normal reading. If the benefits from small increases in inter-letter spacing extend to normal reading, this should be particularly robust for the readers with dyslexia since this is the group that presented the largest effect of inter-letter spacing in the visual-word identification task (i.e., lexical decision).

## 5. Experiment 4 (text reading)

If the findings observed in Experiments 2 and 3 with isolated words can be generalised to a normal reading situation, reading times will be shorter when the text is presented with a slight increase in inter-letter spacing relative to the default settings, both with young normal readers (Hypothesis 4) and young readers with developmental dyslexia (Hypothesis 5).

### *5.1. Method*

#### *5.1.1. Participants*

The group of normal readers was composed of 20 fourth graders (7 female; mean age: 9.3 years) from the same school as in Experiment 2; the test took place during the initial quarter of the academic year and none of them had participated in the previous experiment. None of them had sensory, neurological, or other problems traditionally used as exclusionary criteria for learning disabilities. The group with developmental dyslexia was composed of the 18 individuals from Experiment 3 as well as two additional participants from the same population. The test took place several months after Experiment 3.

### 5.1.2. Materials

We selected two stories ("The snowman" and "The wind"; see Appendix B) from a Spanish website which includes text readings for children. We made very minor changes in the wording of these texts because the original texts used a few dialectal words from the Canary Islands. The two texts were originally intended for Grade 4 children. We prepared two versions for each story: one with the default inter-letter spacing and another with a small increase in inter-letter spacing. Half of the children were initially presented with the story "The snowman" and then "The wind", while the order was reversed for the other half. In addition, the spacing condition (default spacing vs. slightly wider spacing) was also counterbalanced across participants. Half of the children were presented initially with one text presenting the default spacing, and then with the text with slightly wider spacing. The order was reversed for the other half. To obtain a comprehension score for each story, we created five open questions for each text (included in Appendix B). All the questions were surface comprehension questions (e.g., "What are they playing?"; the story indicated "John and Anne are at home, playing pirates").

### 5.1.3. Procedure

Participants were tested individually in a quiet room. Prior to the experiment, they were instructed to read the short story aloud. They were also told that they would be presented with a few questions after reading each text. Presentation of the stimuli and recording of response times were controlled by a Windows computer running DMDX (Forster & Forster, 2003). At the beginning of each trial, the participants were presented with a screen with the instructions. After they pressed the "SPACE" button, the text appeared on the screen and the participants read the text aloud. Participants had to press a button to end the trial. Then, they were asked five (open) comprehension questions – the list of questions (see Appendix B).

### 5.2. Results and discussion

The overall reading times (in words per minute) and the reading comprehension scores for young normal readers and readers with developmental dyslexia are displayed in Table 2. We conducted paired *t*-tests on the participants' reading times and on the mean percentage of correct responses in the open comprehension questions based on the following comparison: default inter-letter spacing vs. slightly wider inter-letter spacing.

### 5.2.1. Young normal readers

Overall reading times (in words per minute) were only marginally faster when the text was presented with a slightly wider inter-letter spacing (122.2 words per minute) than when it was presented with the default inter-letter spacing (120.2 words per minute); this difference was not significant, $t(19) = -.92$, $\eta^2 = .05$, $p > .20$, hence this finding does not confirm Hypothesis 4. (13 out of 20 participants [i.e., 65% of the sample] showed faster reading times in the slightly wider inter-letter spacing condition than with the default settings.) The comprehension score was virtually the same in the two spacing conditions ($|t| \langle 1$; 84% of correct responses in the two spacing conditions).

**Table 2**
Overall reading times (in words/minute) and comprehension score (percent correct) in Experiment 4.

| | Interletter spacing | | | |
|---|---|---|---|---|
| | Default | | Slightly wider | |
| | Reading time | Accuracy | Reading time | Accuracy |
| Normal children | 120.2 | 84.0 | 122.2 | 84.0 |
| Readers with dyslexia | 74.1 | 46.3 | 81.9 | 56.3 |

### 5.2.2. Readers with developmental dyslexia

Overall reading times (in words per minute) were substantially faster when the text was presented with a slightly wider inter-letter spacing (81.9 words per minute) than when it was presented with the default inter-letter spacing (74.1 words per minute), $t(19) = -3.49$, $\eta^2 = .39$, $p < .01$, thus confirming Hypothesis 5. The reading comprehension scores were higher in the condition when the text was presented with a slightly wider inter-letter spacing (56.3%) than when it was presented with the default inter-letter spacing (46.3%), $t(19) = -2.33$, $\eta^2 = .22$, $p < .05$.

The findings from the present experiment are clear-cut. The beneficial effect of small increases in inter-letter spacing (relative to the default settings) also occurs in a continuous reading task in the case of readers with dyslexia (Hypothesis 5). Furthermore, this beneficial effect occurred not only in terms of reading speed, but also in terms of comprehension scores. In contrast, the effect of inter-letter spacing was much weaker with young normal readers (i.e., not confirming Hypothesis 4): we found a nonsignificant difference of 2 words per minute in the reading rate (it was nearly 8 words per minute for the readers with developmental dyslexia), and virtually no effect in the comprehension scores.

## 6. General discussion

The main findings of the present series of experiments can be summarised as follows. Firstly, a small increase in inter-letter spacing relative to the default spacing (i.e., h o t e l vs. hotel) produces faster word identification times not only with adult skilled readers (Experiment 1; Hypothesis 1), but also with young normal readers (Experiment 2; Hypothesis 2) and – to an even larger degree – with young readers with developmental dyslexia (Experiments 3 and 4; Hypotheses 3 and 5). Secondly, the effect of inter-letter spacing was modulated by word length with young readers (both normal readers and readers with dyslexia): the effect occurred for six- rather than for four-letter words. Thirdly, there was a robust effect of word length for young normal readers (41 ms for 4th Graders, 80 ms for 2nd Graders) and for young readers with developmental dyslexia (223 ms) but not for adult skilled readers (2 ms). Fourthly, increasing the spacing between the syllables did not produce any beneficial or detrimental effects relative to the default inter-letter settings. Fifthly, the facilitative effect of small increases of inter-letter spacing also occurred in a continuous reading task with young readers with developmental dyslexia (Experiment 4; Hypothesis 5) both in the reading times and in the comprehension scores. The effect in the reading time for young normal readers was in the same direction but it was not significant (i.e., Hypothesis 4 was not confirmed by the data). In the following paragraphs we examine the implications of the present data, both at a theoretical level and at an applied level.

At a theoretical level, how can we explain the presence of a facilitative effect of inter-letter spacing in visual-word recognition relative to the default settings with young readers? As indicated in the Introduction, Perea and Gómez (2012) recently demonstrated that small increases of inter-letter spacing facilitate the encoding of letters in words – rather than late word-identification processes –

using fits of Ratcliff's (1978) diffusion model. The absence of a difference between the default condition and the syllable-based spacing condition in Experiments 1–3 is consistent with the idea that these effects operate at an early letter-encoding level rather than at a (higher) sublexical level (e.g., the syllable). As indicated in the Introduction, there are two non mutually-exclusive reasons for the advantage of a slight increase in inter-letter spacing in the encoding of words. On the one hand, lateral masking (i.e., crowding effects) may be reduced for words with a slightly wider inter-letter spacing. Importantly, this mechanism may affect to a less degree very short words (e.g., four-letter words) and this may explain why the effect of inter-letter spacing was larger for six-letter than for four-letter words – in particular for young readers. On the other hand, letter position encoding can be more accurate with an increased inter-letter spacing (i.e., there would be less perceptual uncertainty on a letter's position within a word) and this may affect differently four-letter words and six-letter words (see Davis & Andrews, 2001, for evidence of greater transposed-letter effects for longer than for shorter stimuli). These effects may have affected to a larger degree the immature system of letter/word recognition of developing readers than the letter/word recognition system of adult skilled readers – note that even with adult skilled readers (Experiment 1) we found a numerically larger effect of inter-letter spacing for six-letter words as well.[3] Dissociating between the two mechanisms underlying the effect of inter-letter spacing (i.e., crowding vs. perceptual uncertainty) would be considerably beyond the scope of the present data set, and we would rather not enter in a purely speculative debate.

In Experiments 1–3, we focused on the recognition of individually presented words. We acknowledge that even though the recognition of isolated words provides useful information (e.g., when reading traffic signs, product names, etc.), it is important to examine whether or not the effect of inter-letter spacing can be generalised to a normal reading situation. Indeed, the generalization may not be completely straightforward. On the one hand, a small increase in inter-letter spacing may produce a benefit during the encoding of individual words in the fovea (as Experiments 1–3 demonstrated; see also Perea & Gómez, 2012). On the other hand, there may be a reading cost when these words with an increased inter-letter spacing are presented in a sentence: neighbouring words with small increases in inter-letter spacing will farther away from the fixation than in the default settings (e.g., compare a rows is a rose vs. a r o w s  i s  a  r o s e) and this may limit the information attained while the words are in the parafovea because of less acuity. Experiment 4 was an initial step to examine the effects of inter-letter spacing during normal reading. Specifically, inter-letter spacing was manipulated during a continuous reading task in which we measured the overall reading time and a comprehension score. Results revealed that, for young readers with dyslexia, there were faster reading times when the text had a small increase in inter-letter spacing relative to the default settings; furthermore, this was also accompanied by higher comprehension scores. That is, the benefits from small increases of inter-letter spacing from encoding words at the fovea level surpassed the potential cost of having the nearby words more separated. Although we failed to find a parallel effect for normal young readers, this null effect with young readers must be taken with some caution, since the task employed in Experiment 4 only offers global measures and cannot be used to explore the time course of the effect of inter-letter spacing (e.g., fixation durations might have been shorter but participants might have also made more fixations, and these two opposing effects could have produce a global null effect). Clearly, one question for future research is to examine in detail how inter-letter spacing modulates the pattern of eye movements during reading in developing readers – both with young normal readers and with young readers with developmental dyslexia. In this light, it would be important to use a parametric approach (i.e., employing several levels of inter-letter spacing; see Perea & Gómez, 2012) to shed some light on which one is the "optimal" letter spacing for young readers and how (and why) it may vary across individuals. And last but not least, it is important to examine how this effect is modulated by other potentially relevant factors such as print size (e.g., see O'Brien et al., 2005).

The large effect of inter-letter spacing found in the group of young readers with developmental dyslexia both in lexical decision (Experiment 3) and in continuous reading (Experiment 4) is remarkable. This extends the findings reported from Spinelli et al. (2002) in a naming task, who indicated that "one-third of the dyslexics showed a clear-cut advantage with spacing. In these subjects, improvement with increased letter distance was substantial (on the average 130 ms)" (p. 196). Crucially, the present data has shown that small increases in inter-letter spacing in the group of developmental dyslexics lead not only to beneficial effects in the identification of isolated words (Experiment 3), but also produce faster reading time in a brief story and higher comprehension levels (Experiment 4). It is important to note here that the questions in Experiment 4 were surface comprehension questions. Future research should focus not only on surface comprehension questions but also on deep comprehension questions as they may provide relevant information about the nature and relevance of the questions and what they reveal about local and global text comprehension (see Graesser & McNamara, 2011, for a recent review). Thus, the practical implications of the present study for the written materials for children (in particular, for young readers with dyslexia) are clear: the present data suggest that words in e-books or digital documents should be presented with a slightly wider inter-letter spacing than the current default settings.

In the present experiments, the effect of inter-letter spacing had substantially larger effects on the reading speed of participants with dyslexia than on normal readers – both 2nd and 4th graders. Given that, on average, the data from dyslexic participants were slower and/or less accurate than Grade 2 children, one could hypothesize that effect of inter-letter spacing might be associated with reading age.[4] To further examine this issue, it would be important to examine the impact of inter-letter spacing during visual-word recognition and reading at the very initial stages of learning to read.

The present experiments were conducted in a shallow orthography (Spanish). Can the obtained findings be generalised to other languages? Given that the effects of inter-letter spacing should occur in an early encoding stage, they should be independent of a language's orthographic depth. We must bear in mind that there is evidence of a beneficial effects of slight increases of inter-letter spacing not only in other shallow orthographies (e.g., Italian; Spinelli et al., 2002) but also in deep orthographies (e.g., English; see Latham & Whitaker, 1996). Furthermore, prior experiments on letter position coding and/or on crowding effects have yielded similar results when conducted in an opaque orthography or a shallow orthography (e.g., see Davis et al., 2009; Spinelli et al., 2002).

[3] In addition, it may be important to consider that four-letter words may be processed differently than longer words (e.g., in terms of initial fixation position; see O'Regan & Jacobs, 1992, for eye movement evidence comparing four-letter words with longer words).

[4] We thank an anonymous reviewer for suggesting this reasoning.

In sum, the present set of experiments with young readers provide a modest, initial step to study typographic factors during visual-word recognition and reading in a systematic way, by revealing that small increases of inter-letter spacing have a beneficial effect on the visual identification of words for young readers (Hypotheses 1–3) and, importantly, also in text comprehension –at least for children with developmental dyslexia (Hypothesis 5). We believe that future implementations of e-book apps should offer the user the option to modify not just the background/ink colour or font size/type, but also the inter-letter spacing – as currently occurs with word processors. Further research is necessary to study how inter-letter spacing may be used in the classroom context to (potentially) improve the ease of reading.

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## Appendix A. Words/nonwords in Experiments 1–3

Word stimuli: maleta, helado, equipo, muñeca, pájaro, payaso, animal, alegre, dibujo, arriba, pomada, gorila, patata, conejo, moneda, tomate, cometa, mañana, dinero, abuelo, camisa, escoba, enorme, regalo, música, camino, médico, tejado, maceta, verano, molino, último,águila, gusano, bonito, sábado, bañera, muñeco, azúcar, sandía, señora, debajo, zapato,cabeza, cocina, paloma, abrigo, pirata, madera, encima, comida, pelota, seguro, sonido, rosa,nube, dedo, boca, suma, humo, aire, agua, mago, hijo, lupa, goma, vino, peso, boda, cara, ropa,copa, cubo, caja, pata, malo, roto, tela, café, vela, risa, paso, pavo, hada, loro, ramo, lobo, nata,taxi, zumo, cena, bola, sapo, rojo, foca, moto, cola, pupa, saco, lago, piña, hora, pato, país, cine, lata, león, baño.

Nonword stimuli: socade, pirefa, jaredo, catune, tebino, fogori, metuna, petudi, tanadi, ronedo, mojuca, lebeto, operco, pearza, ansuco, tureso, actate, astozo, orgara, cotesa, buneto, surugo, daciso, toluto, renuno, arnino, mirive, busaja, bosama, aspele, dulajo, aperga, pocuza, cagiro, ovator, sájuta, mogine, benoje, vibego, éngoro, untofa, navisa, poresu, danade, temati, empaga, sileda, ambote, gelabo, nidere, nucilo, estari, temaje, ronosi, dagu, fagu, gagu, ladi, jotu, sagu, potu, bubí, judu, veru, tenu, leri, rici, puen, lazi, jabu, bido, leru, nubi, sufe, bifa,obón, sace, dulu, sili, venu, oste, mulu, nití, febu, feba, nide, fasi, radi, inde, bebu, ince, úpir,fuge, jere, beco, endo, pazi, odil, pufí, jabe, soje, vagu, dotu, tine, nuen, sofe, gasi, ribe.

## Appendix B

Texts presented to the young readers in Experiment 4. The texts were taken from the following web sites:

http://www.rinconmaestro.es/lengua/actividades/actividades05.pdf
http://www.rinconmaestro.es/lengua/actividades/actividades11.pdf

*Defaul inter-letter spacing. Text 1*

*EL MUÑECO DE NIEVE*

Es invierno. En el pueblo, todas las calles se han cubierto de nieve. Cuando los niños salen del colegio, se van corriendo al parque a hacer un muñeco.

Con las manos, juntan toda la nieve que pueden y poco a poco forman una gran bola. Luego, hacen otra más pequeña y la colocan encima.

Uno de los niños ha cogido de su casa dos botones para los ojos del muñeco. Otro ha encontrado una zanahoria para hacerle la nariz. El más pequeño de todos ha traído de su casa un sombrero de su padre, y por supuesto, no falta quien se quita la bufanda para ponérsela al muñeco.

Finalmente, con las ramas los árboles le han hecho los brazos. En unos de ellos, alguien le ha puesto una escoba que ha encontrado en un patio cercano.

¡Nunca se había visto en el pueblo un muñeco de nieve tan bonito!

*Slightly wider inter-letter spacing. Text 1*

*EL MUÑECO DE NIEVE*

Es invierno. En el pueblo, todas las calles se han cubierto de nieve. Cuando los niños salen del colegio, se van corriendo al parque a hacer un muñeco.

Con las manos, juntan toda la nieve que pueden y poco a poco forman una gran bola. Luego, hacen otra más pequeña y la colocan encima.

Uno de los niños ha cogido de su casa dos botones para los ojos del muñeco. Otro ha encontrado una zanahoria para hacerle la nariz. El más pequeño de todos ha traído de su casa un sombrero de su padre, y por supuesto, no falta quien se quita la bufanda para ponérsela al muñeco.

Finalmente, con las ramas los árboles le han hecho los brazos. En unos de ellos, alguien le ha puesto una escoba que ha encontrado en un patio cercano.
¡Nunca se había visto en el pueblo un muñeco de nieve tan bonito!

*Defaul inter-letter spacing. Text 2*

*EL VIENTO*

Es domingo y el viento sopla fuertemente. Las calles y los parques están desiertos. Juan y Ana están en casa, jugando a los piratas.
Con unas sillas, han construido un barco y con un gorro de papel, unas espadas de madera y un parche en el ojo, se han disfrazado de piratas.

Al cabo de un rato, se cansaron de jugar y se asomaron por la ventana para ver el jardín. Allí, las ramas de los árboles se balancean movidas por el viento.

Entre la hierba, ven una paloma. Casi no se mueve. Debe estar herida. Juan y Ana salen a verla. Se ha caído de un árbol y se ha roto una patita.

Los niños la cogen y la llevan a su casa. Allí le lavan la herida y le vendan la patita rota.

Durante unos días, la cuidan y la alimentan. Pero pronto se recupera y comienza a caminar. Entonces, le quitan la venda y la dejan volar.

*Slightly wider inter-letter spacing. Text 2*

*EL VIENTO*

Es domingo y el viento sopla fuertemente. Las calles y los parques están desiertos. Juan y Ana están en casa, jugando a los piratas.

Con unas sillas, han construido un barco y con un gorro de papel, unas espadas de madera y un parche en el ojo, se han disfrazado de piratas.

Al cabo de un rato, se cansaron de jugar y se asomaron por la ventana para ver el jardín. Allí, las ramas de los árboles se balancean movidas por el viento.

Entre la hierba, ven una paloma. Casi no se mueve. Debe estar herida. Juan y Ana salen a verla. Se ha caído de un árbol y se ha roto una patita.

Los niños la cogen y la llevan a su casa. Allí le lavan la herida y le vendan la patita rota.
Durante unos días, la cuidan y la alimentan. Pero pronto se recupera y comienza a caminar. Entonces, le quitan la venda y la dejan volar.

*Comprehension questions in Experiment 4*

Note: The approximate English translations are presented in italics.

*"El muñeco de nieve" [The snowman]*

1. ¿Qué estación del año es? [*What season of the year is it now?*]
2. ¿Qué hacen los niños cuando salen del colegio? [*What do children do when they leave school?*]
3. ¿Con qué hacen los ojos del muñeco? [*How do they make the eyes of the snowman?*]
4. ¿Quién ha traído de su casa un sombrero? [*Who has brought a hat from home?*]
5. ¿Dónde han encontrado la escoba? [*Where have they found the broom?*]

*"El viento" [The wind]*

1. ¿Cómo se llaman los niños? [*What are the names of the children?*]
2. ¿A qué están jugando? [*What game are they playing?*]
3. ¿Con qué han construido el barco? [*What have they built the boat with?*]
4. ¿Qué ven por la ventana? [*What do they see out of the window?*]
5. ¿Por qué se ha roto una pata? [*Why has (the pigeon) broken a leg?*]

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