Research Article

Does *Viotin* Activate *Violin* More Than *Viocin*?

On the Use of Visual Cues During Visual-Word Recognition

Manuel Perea and Victoria Panadero

ERI-Lectura and Departamento de Metodología, Universitat de València, Valencia, Spain

Abstract. The vast majority of neural and computational models of visual-word recognition assume that lexical access is achieved via the activation of abstract letter identities. Thus, a word's overall shape should play no role in this process. In the present lexical decision experiment, we compared word-like pseudowords like *viotín* (same shape as its base word: *violín*) vs. *viocín* (different shape) in mature (college-aged skilled readers), immature (normally reading children), and immature/impaired (young readers with developmental dyslexia) word-recognition systems. Results revealed similar response times (and error rates) to consistent-shape and inconsistent-shape pseudowords for both adult skilled readers and normally reading children – this is consistent with current models of visual-word recognition. In contrast, young readers with developmental dyslexia made significantly more errors to viotín-like pseudowords than to viocín-like pseudowords. Thus, unlike normally reading children, young readers with developmental dyslexia are sensitive to a word's visual cues, presumably because of poor letter representations.

Keywords: visual-word recognition, lexical decision, reading development

The process of learning to read in alphabetic languages is commonly regarded as evolving from an initial stage in which peripheral visual features alone (e.g., problem) produce semantic activation to a more efficient letter-based reading stage in which visual-word recognition is mediated by abstract letter representations (e.g., see Ehri, 1995; Frith, 1985; Webb, Beech, Mayall, & Andrews, 2006). Current neural, biologically plausible, proposals of how letters and words are processed involve the activation of the word's abstract letter representations, regardless of their visual characteristics (i.e., a, *a*, A, or 𝔄 would activate the letter detectors corresponding to the abstract letter unit "a"; see Dehaene, Cohen, Sigman, & Vinckier, 2005; Grainger, Rey, & Dufau, 2008). Likewise, the most influential computational models of visual-word recognition and reading assume that the process of visual-word identification is based on the activation of the abstract letter representations rather than on peripheral visual cues such as a word's outline shape (e.g., spatial coding model, Davis, 2010).

A conclusive demonstration that the cognitive system rapidly converts the visual characteristics of the words to abstract representations comes from masked priming experiments – note that this technique taps into the early stages of word processing (Forster & Davis, 1984; see Grainger, 2008, for review; see also Paap, Newsome, & Noel, 1984; Rayner, McConkie, & Zola, 1980, for early empirical evidence using other procedures). In an influential study, Bowers, Vigliocco, and Haan (1998) found that the magnitude of the masked identity priming effect in lexical decision and semantic categorization for adult skilled readers, relative to an unrelated priming condition, was equivalent for pairs that were nominally and physically the same (e.g., *kiss-KISS*) and for pairs that were nominally the same but physically different (*edge-EDGE*) (see also Dehaene et al., 2003, for a parallel finding using fMRI). Likewise, in a recent series of experiments, Perea, Abu Mallouh, and Carreiras (2013) found that, using a very intricate orthography (Arabic), the magnitude of masked priming effects relative to an unrelated priming condition (طيلر- كتاب transliterated as [Tylr- ktAb]) was comparable for one-letter different pairs that were physically similar (e.g., كتزب - كتاب [ktzb-ktAb]) and for one-letter different pairs that were physically dissimilar (كتخب- كتاب [ktxb-ktAb]). Importantly, Perea et al. (2013) found this pattern of data not only with adult skilled readers but also with developing readers (3rd and 6th Graders). This finding suggests that normally-developing readers (at least from Grade 3 onwards) have a fast access to the abstract representation of a word's constituent letters and that visual peripheral cues such as outline envelope play (if any) a minor role during the recognition of visually presented words.

Clearly, a comprehensive model of visual-word recognition and reading should be able to accommodate not only the data from a fully developed visual-word recognition

DOI: 10.1027/1618-3169/a000223

system but also how it develops in time and how it is affected by reading impairments (e.g., see Share, 2004; Thompson, 2009; Wang, Castles, Nickels, & Nation, 2011, for evidence of orthographic learning in young readers). In this respect, two recent studies have shown that adult readers with dyslexia (i.e., a learning disability that harms a person's ability to read with fluency; see Gabrieli, 2009, for review) may be overly sensitive to a word's visual peripheral information. Lavidor (2011) found similar response times in a lexical decision task for words composed of neutral/ascending/descending letters (''non-flat'' words like *bishop*) and for words created exclusively with neutral letters (''flat'' words like *camera*) with adult skilled readers – note that this is entirely consistent with all current models of visual-word recognition that assume that there is fast access to abstract letter representations. But the remarkable finding in the Lavidor experiment is that, using the same materials, she found faster response times for *bishop*-like words than *camera*-like words in a group of adult individuals with developmental dyslexia (mean age = 22 years). In addition, Friedmann and Haddad-Hanna (2012) reported that college-aged participants with ''letter position'' dyslexia made a large number of transposed-letter errors in a word naming task when the physical appearance of the target word and its potential competitor was similar. For instance, the word تمهل *slowed* [tmhl] was frequently misread as its transposed-letter neighbor تهمل *neglect* [*thml*]. In contrast, this type of transposed-letter error was very infrequent when the potential competitor was physically different (e.g., the word ترغب *to want* [trjb], was not read as *sunset* تغرب [tjrb]) – note that Friedmann and Haddad-Hanna study did not include a control group of skilled adult readers. Therefore, the mentioned studies suggest that the process of visual-word recognition in adult individuals with dyslexia may be affected by nonrelevant visual cues in the stimuli (see Lachmann & van Leeuwen, 2004, 2007, 2008, for extensive discussion on feature integration of letters and non-letters in skilled adult readers, normally reading children, and children with dyslexia). One limitation of the Lavidor (2011) and Friedmann and Haddad-Hanna (2012) experiments, however, is that the participants were adult readers so that the obtained effects could have been a consequence rather than a cause of dyslexia.

The main aim of the present lexical decision experiment was to examine the role of visual cues during visual-word recognition, using exactly the same materials/procedure, in three separate groups of participants: (i) a group of individuals with a well-developed visual-word recognition system (college-aged students; Experiment 1a); (ii) a group of individuals with a well-developed but (somewhat) immature visual-word recognition system (Grade 4 children; around 9–10 years; Experiment 1b); and (iii) a group of individuals with an immature/impaired visual-word recognition system (young readers with developmental dyslexia; Experiment 1c).[1] The key visual factor manipulated in the experiment was straightforward: we replaced a consonant letter from a familiar high-frequency word (e.g., ''*violín*'' [*violin*, in English]) with a consonant letter which kept the same outline shape (consistent-shape pseudoword; e.g., *viotín*; i.e., the ascending letter ''l'' was replaced with another ascending letter, ''t'') or with a consonant letter which altered the outline shape of the baseword (inconsistent-shape pseudoword; e.g., *viocín*; ''c'' is a neutral letter). If visual cues (e.g., outline shape) play a role during visual-word recognition, responses to the consistent-shape pseudoword ''*viotín*'' should be more errorprone (and/or slower) in a word/nonword discrimination task (i.e., lexical decision) than the responses to the inconsistent-shape pseudoword ''*viocín*'' – note that current neural and computational models of visual-word recognition predict no difference. For control purposes, the items were also presented in uppercase. There are no obvious visual cues of outline shape available in uppercase items, and hence no differences are expected between the lexical decision responses to *VIOTÍN* and *VIOCÍN*.

Importantly, the manipulation of case also allows the examination of the overall differences between lowercase and uppercase words in mature/immature visual-word recognition systems. Prior studies with adult skilled readers have revealed that, for high-frequency words, lexical decision times are similar for lowercase and uppercase words (i.e., *house* and *HOUSE* produce similar response times and error rates) whereas, for low-frequency words, lexical decision times are faster for lowercase than for uppercase words (i.e., *diurnal* faster than *DIURNAL*; English: Mayall & Humphreys, 1996; Spanish: Perea & Rosa, 2002; Portuguese: Perea, Comesaña, & Soares, 2012). The lack of an effect of case for high-frequency words in adult skilled readers is entirely consistent with models of visual-word recognition that assume an early activation of abstract letter representations, but the lowercase advantage in low-frequency words requires an explanation. To explain the Case × Frequency interaction, Perea and Rosa (2002) employed an adaptive resonance framework (Stone & Van Orden, 1993; Van Orden & Goldinger, 1994), in which stable percepts are more easily attained in a familiar format than in an unfamiliar format – note that lowercase letters/words appear in more frequently in print than uppercase letter/words. The lack of an effect of case with highly familiar words would be due to the fact that, unlike infrequent words, they form stable percepts very quickly (i.e., they would not be dramatically affected by the format of bottom-up information). This explanation is compatible with the neural accounts of visual-word recognition. Indeed, Dehaene et al. indicated that ''feedback and lateral connections are numerous in the visual system, and probably contribute to shaping the neurons'' (p. 338) (i.e., the Dehaene et al. account is not purely feedforward). The present set of word stimuli was of high frequency ($M = 55$ per

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[1] It may be important to note that we were interested in examining the potential role of outline shape in the three groups rather than in the direct comparison of the group of readers with dyslexia versus a control group (see Perea, Panadero, Moret-Tatay, & Gómez, 2012, for a similar procedure when examining the effects of letter spacing in visual-word recognition [e.g., *casino* vs. *c a s i n o*] with normally reading children, children with dyslexia, and adult skilled readers).

million), so that a reduced/null effect of case is expected in the group of adult skilled individuals – consistent with prior experiments. With respect to the young readers with/without dyslexia, since attaining a stable percept will take significantly more cycles than in a fully developed system (i.e., the quality of lexical information is smaller than in skilled readers), an advantage of the more common format (i.e., lowercase) over the less common format (i.e., uppercase) is expected – as happens with low-frequency words in adult skilled readers.

Method

Participants

The participants were 16 undergraduate students from the Universitat de València in Experiment 1a (12 female; mean age = 20.3 years; range: 19–22), 36 fourth grade children from a private school in Valencia in Experiment 1b (19 female; mean age = 9.7 years; range: 9–10), and 20 children with developmental dyslexia who were recruited from different schools in Valencia in Experiment 1c (seven female, mean age = 11.6 years; range: 11–13). None of the participants in Experiment 1a or 1b had any problems traditionally used as exclusionary criteria for learning disabilities. At the time of the experiment, all the participants in Experiment 1c were receiving individual remediation training for developmental dyslexia either at their own schools or in private centers. To further verify their diagnosis of developmental dyslexia, we administered the PROLEC-SE battery of reading tests (Ramos & Cuetos, 1999) – this is a widely used standardized test for children older than 10 years. All participants were below 2 standard deviations from the mean of their age in a combined measure of the word and nonword reading tasks (both accuracy and speed) of the PROLEC-SE test (i.e., the diagnosis of dyslexia was confirmed in all cases) – note that the participants' IQ was within the normal range, as measured by the Spanish adaptation of the intelligence test WISC-R (Wechsler, 2001). All the participants were native speakers of Castilian Spanish and had normal (or corrected-to-normal) vision.

Materials

A set of 100 words (mean length = 6.6 letters, range: 6–7) was selected to be the base words for the pseudowords in the experiment. The mean frequency of these words was 61 per million (range: 1–474) in the Spanish B-Pal database (Davis & Perea, 2005) – it was 44 (range: 18–206) in the Spanish children database (LEXIN: Corral, Ferrero, & Goikoetxea, 2009). The mean number of one-letter substitution neighbors for these words was 0.7 (range: 0–6). The pseudowords were created by changing an interior consonant of the base words: the modified letter (in lowercase) could have the same shape (in terms of ascending/descending/neutral form) as the original letter or not (e.g., *viotín* vs. *viocín*; the base word was *violín*) – syllable structure was kept in all cases. The critical letter was an ascending/descending letter in 53 words (*violín*: viotín, viocún), while it was a neutral letter in the remaining 43 words (e.g., *música*: músira, músifa). To increase the "saliency" of the base word, there were no other word neighbors in that letter position (i.e., vio#in matched only one base word: violin). The mean log bigram frequency in the two sets of pseudowords was virtually the same (2.21 in each set, $p > .50$). In addition, 100 Spanish words were selected from the B-Pal database for the purposes of the lexical decision task (mean frequency: 55 per million, range: 1–743; mean length = 6.6 letters, range: 6–7). The list of words is available at http://www.uv.es/mperea/outlineshape.pdf. The words/pseudowords were presented in lowercase or uppercase. Four lists of counterbalanced items were created for the pseudowords in a Latin square manner (e.g., *viotín* would be presented in list 1, *viocín* in List 2, *VIOTÍN* in List 3, and *VIOCÍN* in List 4) – two lists were created for the words (e.g., *general* would be presented in Lists 1 and 2, while *GENERAL* would be presented in Lists 3 and 4).

Procedure

Participants were tested individually in a quiet room. DMDX software (Forster & Forster, 2003) was employed to present the stimuli and record the participants' responses in a Windows computer. On each trial, a fixation point (+) was presented for 500 ms in the center of the screen. Then, the word (or pseudoword) was presented in 14-pt Times New Roman until the participant's response – or until 2,500 ms had elapsed. Participants were instructed that words and pseudowords would be displayed on the monitor in front of them, and that they should press the "sí" [*yes*] button if the stimulus was a Spanish word and the "no" button if the stimulus was not a word. Participants were instructed to respond as fast as possible while trying to avoid making too many mistakes. The order of the stimuli was randomized for each participant. Twenty practice trials preceded the 200 experimental trials. The session lasted approximately 10–12 min.

Results

Incorrect responses and response times shorter than 250 ms or longer than 2,400 ms were excluded from the latency data (less than 0.1, 0.7, and 0.6% in the subexperiments 1a, 1b, and 1c, respectively). The mean lexical decision times for correct responses and error rates are presented in Table 1. For the word stimuli, RTs and percent errors were submitted to separate ANOVAs with a 3 (Group: adult readers, normally reading children, children with dyslexia) × 2 (Case: lowercase, uppercase) × 2 (List: list 1, list 2) design. For the nonword stimuli, RTs and percent errors were submitted to separate ANOVAs with a 3

Table 1. Mean lexical decision times (in ms) and percentage of errors for words and pseudowords in the experiment. The standard errors are presented between parentheses

Case	Lowercase		Uppercase	
	RT	%E	RT	%E
Adult Readers				
Words	662 (20.1)	4.0 (0.8)	668 (21.4)	4.0 (1.0)
Pseudowords				
Consistent shape	749 (29.1)	2.8 (0.9)	773 (24.9)	2.5 (0.7)
Inconsistent shape	751 (25.4)	3.0 (1.0)	779 (29.1)	2.5 (0.9)
Normally reading children				
Words	1056 (29.0)	7.8 (1.0)	1119 (35.4)	10.7 (1.2)
Pseudowords				
Consistent shape	1314 (40.6)	13.8 (1.7)	1378 (41.6)	13.9 (2.1)
Inconsistent shape	1319 (40.8)	14.1 (1.8)	1377 (43.9)	16.3 (2.4)
Children with dyslexia				
Words	1388 (83.1)	15.4 (2.2)	1242 (63.8)	9.7 (1.5)
Pseudowords				
Consistent shape	1363 (70.5)	30.2 (4.4)	1397 (76.1)	24.2 (3.8)
Inconsistent shape	1360 (71.3)	16.6 (2.5)	1401 (77.8)	20.2 (2.5)

(Group: adult readers, normally reading children, children with dyslexia) × 2 (Pseudoword type: similar, dissimilar) × 2 (Case: lowercase, uppercase) × 4 (List: list 1, list 2, list 3, list 4) design. List was included in all the ANOVAs as a dummy factor just to extract the error variance due to the counterbalancing lists (see Pollatsek & Well, 1995, for further details).

Word Data

As expected, there was a robust effect of Group, $F1(2, 66) = 44.21$, $MSE = 85{,}892$, $\eta^2 = .57$, $p < .001$; $F2(2, 194) = 1{,}233.9$, $MSE = 14{,}893$, $\eta^2 = .93$, $p < .001$, which reflected faster RTs for adult skilled readers than for normally reading children (665 vs. 1,087 ms, respectively) and faster RTs for normally reading children than for young readers with dyslexia (1,087 vs. 1,315 ms, respectively) (all *p*s < .001). The main effect of Case approached significance in the analysis by subjects, $F1(1, 66) = 3.71$, $MSE = 5{,}217$, $\eta^2 = .05$, $p = .059$; $F2(1, 97) = 6.60$, $MSE = 8{,}438$, $\eta^2 = .06$, $p = .012$. More important, the interaction between Group and Case was significant, $F1(2, 66) = 27.30$, $MSE = 5{,}217$, $\eta^2 = .45$, $p < .001$; $F2(2, 194) = 54.02$, $MSE = 8{,}259$, $\eta^2 = .36$, $p < .001$. This interaction reflected that, for adult skilled readers, there was a nonsignificant 6-ms advantage of lowercase over uppercase words, both *F*s < 1, thus replicating the Perea and Rosa (2002; Perea, Comesaña, et al., 2012) findings with high-frequency words. But remarkably the finding here is that while for normally-developing readers, words presented in lowercase were responded to 63 ms faster than the words presented in uppercase, $F1(1, 34) = 27.17$, $MSE = 2{,}621$, $\eta^2 = .44$, $p < .001$; $F2(1, 98) = 24.10$, $MSE = 5{,}571$, $\eta^2 = .20$, $p < .001$, whereas for the young readers with dyslexia, lowercase words were responded to 146 ms more slowly than lowercase words, $F1(1, 18) = 15.99$, $MSE = 13{,}418$, $\eta^2 = .47$, $p = .001$; $F2(1, 97) = 52.55$, $MSE = 15{,}115$, $\eta^2 = .35$, $p < .001$.

The ANOVA on the error data also revealed a main effect of Group, $F1(2, 66) = 9.91$, $MSE = 66.0$, $\eta^2 = .23$, $p < .001$; $F2(2, 196) = 22.71$, $MSE = 163.6$, $\eta^2 = .19$, $p < .001$: adult readers committed fewer errors than normally reading children (4.0 vs. 9.3%, respectively) and, in turn, normally reading children committed fewer errors than the young readers with dyslexia (9.3 vs. 12.6%, respectively) (all *p*s < .001). The main effect of Case was not significant, both *p*s > .15. More important, as occurred in the latency data, there was a significant interaction between Group and Case, $F1(2, 66) = 14.03$, $MSE = 16.9$, $\eta^2 = .30$, $p < .001$; $F2(2, 196) = 17.39$, $MSE = 54.9$, $\eta^2 = .15$, $p < .001$. This interaction reflected the same pattern of effects as the latency data: (i) college-aged adults did not show an effect of case (4.0% of errors in lowercase and uppercase words); (ii) normally reading children committed 2.9% more errors on uppercase than on lowercase words, $F1(1, 34) = 9.22$, $MSE = 16.3$, $\eta^2 = .21$, $p = .005$; $F2(1, 98) = 10.15$, $MSE = 41.1$, $\eta^2 = .09$, $p = .002$; and (iii) young readers with dyslexia committed, on average, 5.7% of more errors on lowercase words than on uppercase words, $F1(1, 18) = 12.49$, $MSE = 26.0$, $\eta^2 = .41$, $p = .002$; $F2(1, 98) = 16.07$, $MSE = 101.1$, $\eta^2 = .14$, $p < .001$.

Pseudoword Data

The ANOVA on the latency data revealed an effect of Group $F1(2, 60) = 35.34$, $MSE = 251{,}060$, $\eta^2 = .54$, $p < .001$; $F2(2, 180) = 1129.39$, $MSE = 30{,}643$, $\eta^2 = .93$, $p < .001$. This reflected faster RTs for adult readers than for both normally reading children (763 vs. 1,347 ms, respectively) and young readers with dyslexia (763 vs. 1,380 ms, respectively) (all *p*s < .001). In addition, responses to the pseudowords in lowercase were faster than the responses to the pseudowords in uppercase, $F1(1, 60) = 23.72$, $MSE = 4{,}638$, $\eta^2 = .28$, $p < .001$, $F2(1, 90) = 19.36$, $MSE = 19{,}868$, $\eta^2 = .18$, $p < .001$. None of the other effects/interactions was significant (all *p*s > .19) – it may be important to note here that there were no signs of a viotín-viocín difference in any of the groups (adult skilled readers: 549 vs. 551 ms, respectively; normally reading children: 1,314 vs. 1,319 ms, respectively; young readers with dyslexia: 1,360 vs. 1,363 ms, respectively; $F < 1$ for all contrasts).

The ANOVA on the error data also revealed an effect of Group, $F1(2, 60) = 18.22$, $MSE = 393.1$, $\eta^2 = .38$, $p < .001$; $F2(2, 192) = 117.31$, $MSE = 346.2$, $\eta^2 = .55$, $p < .001$. This reflected that adult readers committed fewer errors than the normally reading children (2.7 vs. 14.5%, respectively) and, in turn, the normally reading children committed fewer errors than the young readers with dyslexia (14.5 vs. 22.8%, respectively) (all *p*s < .001). More important, the three-way interaction between Group, Case, and Pseudoword type was significant, $F1(2, 60) = 3.93$, $MSE = 33.9$, $\eta^2 = .12$, $p = .025$; $F2(2, 192) = 3.93$, $MSE = 174.7$, $\eta^2 = .04$, $p = .021$. Thus, we examined how the interaction between Case and Pseudoword type varied across Group). For college-aged students and the normally reading children, there were no main/interaction effects of Case or Pseudoword type (all *p*s > .25). Importantly, for the young readers with dyslexia, the interaction between Case and Pseudoword type was significant, $F1(1, 16) = 8.50$, $MSE = 54.2$, $\eta^2 = .35$, $p = .01$; $F2(1, 96) = 7.05$, $MSE = 326.7$, $\eta^2 = .07$, $p = .009$: when presented in lowercase, children with dyslexia committed more errors on viotín-type pseudowords than on viocín-type pseudowords, $F1(1, 16) = 16.00$, $MSE = 115.6$, $\eta^2 = .50$, $p = .001$; $F2(1, 90) = 18.59$, $MSE = 497.5$, $\eta^2 = .16$, $p < .001$, whereas this difference was absent (or at least severely diminished) when the pseudowords were presented in uppercase, $F1(1, 16) = 2.54$, $MSE = 63.0$, $\eta^2 = .13$, $p = .13$; $F2(1, 90) = 1.45$, $MSE = 548.5$, $\eta^2 = .02$, $p = .23$.

Discussion

The three main findings of the present experiment can be summarized as follows. First, for adult skilled readers (college-aged individuals; Experiment 1a) and normally reading children (Grade 4 children: 9–10-year-olds; Experiment 1b), the response times (and error rates) to word-like pseudowords that kept the same outline shape as their base words (e.g., *viotín*) were remarkably similar to those of the word-like pseudowords that altered the base-word's outline shape (e.g., *viocín*). This is consistent with the view that a normally-developing visual-word recognition system (at least from Grade 4 and onwards) relies mainly on abstract letter representations. Second, unlike normally-developing readers, young readers with developmental dyslexia revealed a sensitivity to the word's visual elements: pseudowords that kept the same outline shape as their base words (e.g., *viotín*) were more word-like, as deduced from the error data, than the pseudowords which altered the outline shape of their base words (e.g., *viocín*) – note that this difference did not occur when the information on outline shape was lacking (i.e., when the pseudowords were presented in uppercase). And third, lexical decision times were faster on lowercase than in uppercase words with normally reading children; in contrast, young readers with dyslexia showed the opposite pattern (i.e., faster response time on uppercase words) – as in earlier research with high-frequency words, adult skilled readers did not show an effect of case on word stimuli (e.g., Perea & Rosa, 2002).

The lack of a difference between the responses to pseudowords like *viotín* and *viocín* in normally reading children and in college-aged skilled readers adds further empirical evidence to the view that a normally developing system of visual-word recognition relies mainly on the activation of a word's abstract letter representations (see also Perea et al., 2013, for similar evidence with a masked priming paradigm). But the critical finding of the present experiment is that young readers with dyslexia committed more "word" responses to consistent-shape pseudowords (e.g., *viotín*) than to inconsistent-shape pseudowords (e.g., *viocín*). This does suggest that these individuals may be using a route to visual-word recognition that takes into account some peripheral visual cues, despite its obvious inefficiency/inaccuracy (as deduced from the large error rates and long latencies).[2] Thus, these data generalize the findings reported by Lavidor (2011) and Friedmann and Haddad-Hanna (2012) with college-aged students to a population of young readers with dyslexia.

The second remarkable finding of the present study is that the overall effect of case for word stimuli differed in the three subexperiments. First, for adult skilled readers, there was only a nonsignificant 6-ms advantage of lowercase words over uppercase words, thus replicating the pattern of data reported in previous studies with high-frequency words in adult skilled readers (e.g., Mayall & Humphreys, 1996; Perea, Comesaña, et al., 2012; Perea & Rosa, 2002). Given that lowercase words are more frequent in the print environment than uppercase words, the lack of an effect of case for high-frequency words strongly suggests that there is a fast access to abstract letter/word representations in adult skilled readers. Second, for normally reading children, there was an advantage of lowercase over uppercase words in the latency data (on average, 63 ms) and in the error data (2.9%). This can be readily explained in an adaptive resonance framework

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[2] One might argue that the *viotín-viocín* differences found in error rates should have also occurred in the latency data as well. However, we must take into account that "word" responses (e.g., an incorrect "word" response to the pseudoword *viotín*) and "nonword" responses (e.g., a correct "nonword" response to the pseudoword *viotín*) imply different thresholds in the decision-making process (e.g., see Ratcliff, Gomez, & McKoon, 2004, for a mathematical account of the lexical decision task).

(see Perea & Rosa, 2002): a stable percept in an immature (normally-developing) system requires more processing cycles than in a fully developed system, and this would magnify the advantage of the more familiar format (lowercase) over the less familiar format (uppercase) – that is, the findings with high-frequency words in normally reading children would be parallel to the findings with low-frequency words in adult skilled readers. And third, we found the opposite pattern of data in the young readers with developmental dyslexia: lexical decision times were, on average 146 ms faster for uppercase than for lowercase words – similarly, error rates were 5.7% lower for uppercase than for lowercase words. One interpretation for this unexpected finding is that dyslexic children are less confident with lowercase than uppercase words, and conceivably they may have less robust representations of what lowercase letters look like (e.g., common errors of these individuals in the remediation sessions are naming *eloro* instead of *cloro* [chlorine], or bospe instead of bosque [wood]). This is consistent with the fact that normally reading children who are learning to read find it easier to name/write uppercase letters rather than lowercase letters (e.g., see Worden & Boettcher, 1990). This uppercase advantage has been attributed to "greater visual simplicity and distinctiveness of uppercase letters" (Worden & Boettcher, 1990, p. 288; see also Thompson, 2009, for discussion). Furthermore, lowercase letters tend to have more variability across contexts than uppercase letters (e.g., note that when filling in an application forms, "capital letters" are typically required to avoid letter confusion), and this variability may make it more difficult to initially build strong representations for lowercase words – in particular in those children with a reading impairment. To further examine this issue, it may be important to test word naming times and word naming errors in young readers with/without dyslexia in both lowercase vs. uppercase formats – note that lexical decisions could be made more on the basis of global lexical activity rather than on unique word identification.

The present experiments can be taken to suggest that visual-word recognition may be attained using different pathways, not just via purely abstract letter representations. Specifically, young readers with dyslexia seem to have poor representations of lowercase letters, and this would make them more likely to use visual peripheral cues when reading (e.g., consistent-shape pseudowords like *viotín* would be perceived as *violín*). This adds up to the previous evidence of the use of visual cues during visual-word recognition in adults with developmental dyslexia (e.g., Friedmann & Haddad-Hanna, 2012; Lavidor, 2011) and adults with acquired dyslexia (e.g., Howard, 1987). As Davis (1999) noted, it is important to distinguish between the processes we usually employ during visual-word recognition – mostly based in abstract letter presentations in skilled readers – and the processes we are capable of using – as happens with the use of a word's visual cues in dyslexics. Thus, future neural/computational models of visual-word recognition should go beyond the existence of a single route to the mental lexicon – it may be worth noting here that Davis (1999) included a nonimplemented "logographic" route in the SOLAR model of visual-word recognition.

In sum, the present experiment has revealed that, unlike normally reading children or adult skilled readers, young readers with developmental dyslexia are overly sensitive to a word's visual cues, probably because of poor lowercase letter representations (see also Perea, Panadero, Moret-Tatay, & Gómez, 2012, for a demonstration that dyslexics are also more sensitive than normally reading children to a perceptual factor such as letter spacing). Future research should examine in greater detail how abstract letter representations are built in the process of learning to read in children with/without dyslexia.

Acknowledgments

This research has been supported by Grant No. PSI2011-26924 from the Spanish Government. We would like to thank Wouter Braet, Iring Koch, Thomas Lachmann, and an anonymous reviewer for very helpful comments on an earlier version of this paper.

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Received December 25, 2012
Revision received May 22, 2013
Accepted May 22, 2013

Manuel Perea

Departamento de Metodología
Av. Blasco Ibáñez, 21
46010-Valencia
Spain
Fax +34 96 3864697
E-mail mperea@valencia.edu