Writing impairments in Spanish children with developmental dyslexia

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Author's Note

This study was funded by grant PSI2015-64174P from the Ministry of Economy and Competitiveness, Spanish Government to Fernando Cuetos.

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Abstract

This study investigated which components of the writing production process are impaired in Spanish children with developmental dyslexia (DD) aged 8-12 years. Children with and without dyslexia (n = 60) were assessed in their use of the lexical and the sublexical routes of spelling as well as the orthographic working memory system by manipulating lexical frequency, phonology-to-orthography (P-O) consistency and word length in a copying task and a spelling-to-dictation task. Results revealed that children with dyslexia produced longer written latencies than chronological age-matched (CA) controls, more errors than CA and reading age-matched (RA) controls and writing durations similar to CA controls. Latencies were more affected by frequency, consistency and length in the DD group and the RA group than in CA controls. Children in the DD and RA groups produced longer written latencies in the copying than in the spelling-to-dictation task, while controls in the CA group were not affected by the task. Results indicate that spelling impairments in Spanish children with dyslexia affect the relative involvement of lexical and sublexical information during handwriting. Meanwhile effects on writing speed seem to be related to deficits in reading ability, accuracy scores seem to be poorer than expected by children's reading skill.

Keywords: developmental dyslexia; spelling; handwriting; phonology-to-orthography; lexical processing.

Developmental dyslexia (henceforth, DD) is characterized by impaired performance in both reading and writing tasks (Lyon, Shaywitz, & Shaywitz, 2003; Tops, Callens, Bijn, & Brysbaert, 2014). Although reading difficulties have been extensively studied, writing problems have received considerably less attention (Berninger, Nielsen, Abbott, Wijsman, & Raskind, 2008). Previous findings indicate that most children with DD exhibit poor spelling (Wimmer & Mayringer, 2002), a difficulty that is still present in adulthood (Afonso, Suárez-Coalla, & Cuetos, 2015; Di Betta & Romani, 2006; Holmes & Castles, 2001). They produce more and longer pauses than typically developing children during handwriting (Afonso et al., 2015; Sumner, Connelly, & Barnett, 2013). However, there is no agreement about the nature of the impairment that may cause these difficulties.

In the frame of dual-process theories, there are at least two different processing routes that can be followed to spell a word. The sublexical or assembled route makes use of knowledge about phonology-to-orthography (henceforth, P-O) correspondences existing in the language and provides phonologically plausible spellings for non-words or low-frequency words (Caramazza, 1991; Tainturier & Rapp, 2001). The so-called lexical route gives access to the spelling of whole-words from long-term memory and thus would be used when spelling familiar words. Regardless of the route followed to access the orthographic representation, this representation must be held in a short-term memory store, the orthographic working memory (OWM) system, in which the abstract graphemic units are kept for subsequent production (Cuetos, 1991; Tainturier & Rapp, 2003). The orthographic sequences computed by lexical or sublexical processes would be maintained by this short-term memory system during the time needed for the sequential assignment of format-specific information depending on the output modality (for example, letter name in oral spelling or letter shape in handwriting).

Dual-route accounts of spelling have been developed from a symbolic (rule-based) perspective (Coltheart & Rastle, 1994) but also from a connectionist perspective. Houghton & Zorzi (2003) described a dual-route connectionist model in which one route mapped phonemes onto graphemes and the other route is mediated by a frequency-sensitive lexical level of representation. This model was proposed as an alternative to "single-route" connectionist models in which only one route maps phonemes onto graphemes mediated by a layer of "hidden units" that would make possible the learning of nonlinear mappings. One important limitation of this type of model is their inability to model some of the patterns of errors repeatedly observed in acquired dysgraphia. Acquired dysgraphia refers to a difficulty in producing written language following neurological damage. Evidence from cognitive neuropsychology has contributed to identify two differentiated dysgraphic profiles. In *surface dysgraphia* errors appear in words with non-predictable spellings (inconsistent and irregular words). In the case of *phonological dysgraphia* word spelling is spared, but nonword spelling is affected. Although this double dissociation is difficult to model with a single-route architecture, dual-route models can easily explain these findings by claiming selective damage to the lexical and sublexical route in surface and phonological dysgraphia respectively.

Although there is extensive agreement about the presence of spelling difficulties in DD, authors substantially differ in their assumptions about the process/es that might be impaired. Evidence from previous studies has been largely inconsistent. As a consequence, deficits affecting lexical processes (Angelelli, Judica, Spinelli, Zoccolotti, & Luzzatti, 2004; Di Betta & Romani, 2006), sublexical processes (Angelelli, 2004; Caravolas & Volín, 2001; Yatabe, Goto, Watanabe, Kaga, & Inagaki, 2012) and the OWM system (Beneventi, Tønnessen, Ersland, & Hugdahl, 2009; Ramus & Szenkovits, 2008; Szmalec, Loncke, Page, & Duyck, 2011) have been claimed to underlie the poor writing performance observed in individuals with DD.

Caravolas and Volín (2001) reported results that seem to be in line with the sublexical route being impaired in DD. These authors observed that children with dyslexia produced higher rates of phonologically non-plausible errors than controls, suggesting the existence of a deficit in the correct application of the P-O correspondences. Moreover, Angelelli (2004) described a case of phonological dysgraphia in an Italian child with dyslexia. This child had special difficulties in nonword spelling and produced a high rate of minimal distance errors. This type of error consists of the substitution of one letter by another that differs only in one phonetic feature. The presence of minimal distance errors is thought to be consistent with impairment in the sublexical route. In contrast, some evidence suggests that dysgraphia in DD may emerge as a consequence of poor orthographic lexical representations (Afonso, Suárez-Coalla, et al., 2015; Angelelli et al., 2004; Di Betta & Romani, 2006; Goulandris & Snowling, 1991; Hanley, Hastie, & Kay, 1992). Angelelli et al. observed that the major problem for children with dyslexia was to write words with inconsistent P-O correspondences. Since inconsistent words cannot be successfully spelled via the sublexical route, the authors concluded that the main impairment to the spelling abilities of individuals with dyslexia is in the lexical route. Finally, it has been proposed that there might be a deficit involving the OWM system in DD (Afonso, Suárez-Coalla, et al., 2015; Menghini, Finzi, Carlesimo, & Vicari, 2011; Ramus & Szenkovits, 2008), or the ability to process and/or access temporal order information (Beneventi et al., 2009; Szmalec et al., 2011). Szmalec et al. suggested that a difficulty in creating serial-ordered long-term representations from a sequence in short-term memory may be the cause of the spelling difficulties associated with DD. However, some findings are not in line with this idea (Di Betta & Romani, 2006; Tops et al., 2014). For example, Tops and colleagues observed that adolescents with dyslexia did not make more transposition errors than controls. The authors interpreted this result as evidence of preservation of letter order information. In Spanish, Suárez-Coalla, Villanueva, González-Pumariega, and González-Nosti (2016) tested 7-to-11 year-old children with dyslexia in a spelling-to-dictation task. They observed that these children made more errors in P-O irregular than regular words, suggesting difficulties to develop/access orthographic lexical representations.

These previous studies have focused on the analysis of the writing product rather than on the analysis of the writing process. For several decades, the analysis of errors has provided abundant and interesting evidence about the characteristics of the impaired writing process. However, it is now possible to obtain detailed information of the time-course of the written response by using digital writing tablets. This procedure allows for the analysis of a wide range of chronometric measures of the handwriting process and it is been increasingly used in the field of writing development (Afonso, Suárez-Coalla, González-Martín, & Cuetos, 2017; Kandel & Perret, 2015; Kandel & Valdois, 2005; Lambert, Alamargot, Larocque, & Caporossi, 2011; Prunty, Barnett, Wilmut, & Plumb, 2014; Sumner et al., 2013). In the present study we used this methodology, which provides a unique opportunity to detect potential differences between individuals with and without DD even when they produce correct spellings.

Afonso and colleagues (2015) analysed several measures of the online writing process in a study conducted with Spanish adults with dyslexia. These authors manipulated word frequency, P-O consistency and word length in a spelling-to-dictation task and a direct copy transcoding task in order to evaluate the lexical and sublexical routes of spelling as well as the OWM system. They found that adults with dyslexia showed larger word frequency effects in written latencies and larger word length effects in both written latencies and inter-letter interval durations than a control group. However, both groups exhibited similar P-O consistency effects. The authors concluded that writing difficulties in DD involve deficits at the orthographic lexicon and OWM levels, and that the sublexical route of spelling was relatively spared.

As stated above, phonological impairments affecting spelling have been previously observed in children with dyslexia (Angelelli, 2004; Caravolas & Volín, 2001). Of course, DD is a heterogeneous deficit that might be more related to lexical deficits in some cases and to phonological impairments in others. Moreover, Spanish is a language with a relatively transparent orthography. This is a crucial point that has been often linked to the higher prevalence of surface dyslexia compared to phonological dyslexia in Spanish-speaking populations (Jiménez-González & Ramírez-Santana, 2002; Rack, Snowling, & Olson, 1992). It might well be the case that even Spanish children with DD are able to eventually learn the fairly consistent relationship between phonemes and graphemes of their language. Thus, Afonso et al. (2015) suggested that initial deficits affecting the sublexical route in DD during childhood may have been overcome in adulthood as a result of the repeated exposure to written language. In the present study, we manipulated the same variables studied in this previous study and we asked participants with DD, chronological age-matched (CA) peers and reading-ability matched (RA) peers to perform the same tasks, to see whether or not the same spelling deficits arise in Spanish children with DD. Namely, we address the following research questions:

1. Are impairments to the orthographic output lexicon and to the orthographic working memory system evident in Spanish children with dyslexia?
2. Do children with dyslexia exhibit difficulties with the application of P-O correspondences when compared to chronological age-matched (CA) peers?

3. If present, are spelling difficulties experienced by children with dyslexia linked to their level of reading development? To address this question we also compared the performance of children with DD to that of a group of reading age-matched (RA) controls.

Methods

Participants

Twenty children with DD (ages 8;0 to 12;0, mean age 9;35), twenty CA-matched controls (ages 8;0 to 12;0, mean age 9;7) and twenty RA-matched controls (ages 7;6 to 9;9, mean age 8;2) participated in this study. Across groups, they were matched by gender (7 females and 13 males per group). Participants were recruited from several public primary schools in Oviedo and Gijón (Asturias, Spain), two areas of similar socioeconomic status. In these schools, handwriting was not formally taught at the grades tested and spelling instruction focuses on the learning of orthographic rules of Spanish and exception words. All the participants were native Spanish speakers and had no known motor or perceptual disorders. All of them had an intelligence quotient (IQ) of 85 or higher according to the Wechsler Intelligence Scale for Children (WISC). Children were considered for inclusion in the group with DD if they appeared in the school's counsellor register as having developmental dyslexia. For each child included in the group with DD, a child attending the same class and considered by the counsellor not to suffer from reading disabilities was considered for inclusion the CA group. Children in the RA group were recruited from the same school to match the RA and gender of each child included in the group with DD.

A battery designed to assess reading, "Batería de Evaluación de los Procesos Lectores – Revisada", (PROLEC-R, Cuetos, Rodríguez, Ruano, & Arribas, 2014), was administered to all participants to confirm their correct allocation to each group. PROLEC-R provides scores for word and pseudoword reading and good reliability (α = .79) and construct validity (GFI = .97; AGFI = .93; RMSEA = .07). Accuracy scores and total reading times were recorded for both sections. The word reading section includes 40 Spanish words (α = .74), half of them high-frequency words and the other half low-frequency words. For each half, 10 words are short words and 10 are long words. The pseudoword reading section consists of 40 pseudowords (α = .68), half of them short and the other half long. Children were included in the DD group if both their accuracy and reading speed score were two standard deviations below the age mean in both sections according to age norms provided by PROLEC-R. Children were included in the CA group if they had an age appropriate score in both sections. Younger children with the same reading age as children in the DD group were selected to be included in the RA group. Means, standard deviations and *p* values for demographic characteristics and scores obtained in reading assessment tests are provided in Table 1. None of the participants with dyslexia had received systematic treatment from a speech or occupational therapist for their reading impairment.

Table 1 here: see below

Materials

Thirty-two Spanish common nouns were selected as experimental stimuli. Among them, phoneme-to-grapheme consistency (consistent vs. inconsistent), word frequency (high vs. low) and word length (short vs. long) were orthogonally varied. Inconsistent words started with a grapheme with at least one alternative spelling. For example, the word VESTIDO ([bes'tido], dress) is inconsistent because it starts with the phoneme /β/, which in Spanish could be spelled V instead of B. Consistent words only included phonemes with unambiguous spellings (e.g., SORPRESA, [sor'presa], surprise). For the lexical frequency manipulation, words with a frequency above 150 occurrences within a corpus of 2,600,000 words according to the values provided by ONESC (Martínez & Pérez, 2008) were considered high-frequency words and those with a frequency below 25 occurrences were considered low-frequency words. Regarding word length, short words had 4 to 5 letters and long words had 7 to 9 letters. Across all conditions, words were controlled by orthographic neighbourhood. Excepting those conditions in which these variables were manipulated, word frequency, P-O consistency and word length (number of letters and syllables) were also controlled across different conditions. The full set of experimental stimuli with the values for manipulated and controlled variables is given in Appendix A. For each word, a visual and an auditory stimulus were created for the direct copy transcoding and the spelling-to-dictation task respectively.

Procedure

Stimuli presentation and digital recording of the responses were controlled by Ductus (Guinet & Kandel, 2010). The experiment was run on an HP Mini laptop. A WACOM Intuos 5 graphic tablet connected to the computer and an Intuos Inking Pen were used to register the participants' responses. Auditory stimuli were recorded by a female speaker with a Plantronics microphone and edited with Audacity. The procedure of this experiment was approved by the Ethics Committee of the Department of Psychology of the University of Oviedo. The experimental sessions were conducted for each participant individually in a quiet room. For all the participants the spelling-to-dictation task was conducted before the direct copy transcoding task. We choose this method instead of counterbalancing the administration of the tasks to avoid some children (those children performing the copying task in the first place) being exposed to the orthographic representations of the words before the spelling-to-dictation task.

The first author tested all participants in a quiet room at their school. In the spelling-to-dictation task, each trial started with the simultaneous presentation of an auditory signal and a 500-millisecond fixation point. The auditory stimulus was presented 500 milliseconds after the offset of the fixation point. Participants had to write the word in lower case on a lined sheet of paper placed over the digitizer as quickly and as accurately as possible. When they finished a response, participants were instructed to hold the pen over the next line of the response sheet, but without making any contact with the paper. Then the tester clicked the left button of the mouse to start a new stimulus. In the direct copy transcoding task, a trial started with the same auditory signal and fixation point as in the spelling-to-dictation task and was followed by a 500-milisecond white screen. Then, the visual stimulus was presented in black upper-case Calibri 60 point font on a white background and it remained onscreen until the next trial started. The instructions given to the participants were the same as in the spelling-to-dictation task. Their attention was called to the fact that they had to write the words in lower case, in spite of the fact that they would see the stimulus in upper case. The experiment lasted around 20 minutes.

Data Analytic Methods

The statistical analyses were conducted on written latencies, whole-word writing durations, in-air pen durations, in-air pen trajectories and errors. Only correct responses were included in these analyses. Responses containing misspellings, self-corrections or those in which a recording error occurred were considered errors and removed from these analyses (11.87%). Latencies above and below two standard deviations from the mean by participant and word were also excluded from the analysis (3.91%). For written latencies, whole-word writing duration, in-air pen duration and in-air pen trajectories, ANOVAs were run with mixed-effects analyses (Baayen, 2008) using R-software (RStudio, RStudio Team, 2015) with participants and items as random-effect variables and group, word frequency, P-O consistency, word length and task as fixed-effect variables. The most complex adjustment model (adjustment on the by-participants and by-item intercepts and by-participant slopes) was included in all the analyses (Barr, Levy, Scheepers, & Tily, 2013). Stepwise model comparisons were conducted from the most complex to the simplest model and the one with the most complex adjustment but the smallest Bayesian information criterion (BIC) and significant χ^2 test for the log-likelihood was retained (Schwarz, 1978). *F* values from the ANOVAs of type III with Satterthwaite approximation for degrees of freedom are reported for fixed-effects. When the effect of group or significant interactions were significant t-tests were performed and the *p*-values were adjusted via the Holm-Bonferroni method. For the analyses of errors, we used a Generalised Mixed-effect model with a binomial distribution. χ^2 values are reported for fixed-effects. For significant effects, estimates are reported in milliseconds.

The analyses conducted resulted in many significant results, several of them of no interest for the present discussion. For the sake of conciseness, only the significant interactions involving group (DD vs. CA vs. RA) are reported for the measures of written latencies, writing durations and in-air pen durations. In-air pen trajectories (measured as the total length -in centimeters- of the trajectory drawn by the pen in the absence of contact with the tablet) are not reported since none of the manipulated variables produced a significant effect. A *p*-value $\leq .05$ was adopted as level of significance.

Results

Written Latencies

Written latencies were measured as the time between the presentation of the stimulus and the occurrence of the first contact of the pen with the digitizer. Table 2 shows the means and standard deviations for written latencies in each condition for the three groups. The main effects of group, $F(2, 56.83) = 8.25$; $MSE = 1,497,776$; $p < .001$ (Estimate = 591.10), type of task, $F(1, 56.61) = 6.44$; $MSE = 1,169,672$; $p < .05$ (Estimate = -117.21), word frequency, $F(1, 26.89) = 26.25$; $MSE = 4,762,718$; $p < .001$; (Estimate = 22.84), P-O consistency, $F(1, 23.6) = 10.33$; $MSE = 1,874,755$; $p < .005$ (Estimate = 117.47), and word length, $F(1, 34.85) = 24.71$; $MSE = 4,483,519$; $p < .001$ (Estimate = 205.63), were significant. Pairwise comparisons showed that the CA group initiated the response significantly faster than the DD group, $t(25.2) = 3.56$, $p < .005$, and the RA group, $t(27.85) = 4.3$, $p < .005$. Longer written latencies were observed in the direct copy transcoding task than in the spelling-to-dictation task. Low-frequency words were slower than high-frequency words, P-O inconsistent words were slower than consistent words and long words were slower than short words. However, several significant interactions modulated these effects. The interaction between P-O consistency and group was significant, $F(2, 3,047.52) = 12.05$; $MSE = 2,187,235$; $p < .001$ (Estimate = 166.22). This interaction was also modified by a marginally significant three-way interaction Task x P-O consistency x Group, $F(2, 3,044.12) = 2.98$; $MSE = 540,408$; $p = .051$ (Estimate = 24.92). Pairwise comparisons revealed P-O consistency effects were significant in the spelling-to-dictation task for the DD group, $t(19) = 3.23$, $p < .005$, and the RA group, $t(19) = 3.19$, $p < .005$. The CA group was not affected by P-O consistency in either of the tasks, all *t*s< 1. The interaction between word frequency and group was also significant, $F(2, 99.1) = 6.64$; $MSE = 1,204,291$; $p < .005$ (Estimate = 417.00). The word frequency effect was smaller in the CA group than in the DD group, $t(22.91) = 2.89$, $p < .01$ and the RA group, $t(27.51) = 5.11$, $p < .005$. There was not a significant difference in the word frequency effect between the DD and the RA group, $t < 1$. The interaction between group and word length was significant, $F(2, 57.27) = 57.27$; $MSE = 1{,}039{,}967$; $p < .01$ (Estimate = -243.08), but it was subsumed by the significant three-way interaction Task x Group x Word length, $F(2, 71.84) = 3.36$; $MSE = 610{,}673$; $p < .05$ (Estimate = 292.39). Pairwise comparisons revealed that the word length effect had a significantly larger effect in the copying task for all the groups. For the CA group this difference was smaller than for the RA group, $t(25.62) = 3$, $p < .05$ and (marginally) the DD group, $t(23.88) = 2.2$, $p = .08$.

Table 2 here: see below

Writing Durations and In-air Pen Durations

Writing durations refer to the time between the first pen down produced in a word and the last pen lift in the same word. In air-pen durations refer to the total time within a word that the pen did not make contact with the tablet. The main effects of word length and P-O consistency were significant and marginally significant respectively in the analysis conducted on writing durations. Word length was also significant when only in-air pen time was considered. However, these effects involve comparisons between different words, so they are likely to reflect differences in the duration of the hand movements required to produce different letters. The most obvious example is the word length effect, which it is clearly related to the fact that more letters have to be produced in long words. We will only comment on those effects arising from the comparison of the same words to ensure effects are not due to differences in the motor patterns required to produce those words.

The main effect of group significantly affected writing durations, $F(2, 57) = 16.19$; $MSE = 6{,}112{,}989$; $p < .001$ (Estimate = 1,169.82). Children in the RA group produced longer writing durations than children in the CA group, $t(34.4) = 5.73$, $p < .001$ and children in the DD group, $t(38) = 3.64$, $p < .001$. There was not a significant difference between the CA and the DD group in this variable, $t < 1$. Group did not differ in in-air pen durations, $F = 1.27$. The main effect of task was significant in the writing durations' analysis, $F(1, 3{,}286.1) = 114.31$; $MSE = 43{,}169{,}369$; $p < .001$ (Estimate = 64.07) and marginally significant in the in-air pen durations analysis, $F(1, 3{,}020.08) = 3.06$; $MSE = 1.14$; $p = .06$ (Estimate = -.055). Writing and in-air pen durations were longer in the spelling-to-dictation task than in the copying task. P-O consistency interacted with group, $F(2, 3{,}285.7) = 6$; ; $MSE = 2{,}264{,}883$; $p < .001$ (Estimate = 92.58). Pairwise comparisons showed that only the RA group showed a significant effect of P-O consistency in both writing durations, $t(19) = 2.42$, $p < .05$ and in-air pen durations, $t(19) = 3.93$, $p < .001$. A significant interaction between word length and group was found on the writing durations analysis, $F(2, 60.3) = 16.73$; $MSE = 6{,}317{,}007$; $p < .001$ (Estimate = 459.52).

Although the word length effect involves comparing different words, we will comment on the interaction between this effect and group because it reflects a significant difference between groups in the extent they are affected by this variable. Writing durations produced by the RA group were more affected by word length than those produced by the CA group, $t(19) = 6.17$, $p < .001$ and the DD group, $t(19) = 3.82$, $p < .001$. The three-way interaction Task x Word frequency x Group significantly affected writing durations, $F(2, 3{,}285.3) = 3.31$; $MSE = 1{,}251{,}300$; $p < .001$ (Estimate = -227.50). The CA group showed a significant effect of word frequency on writing durations in both the direct copy transcoding task, $t(19) = 5.54$, $p < .001$ and the spelling-to-dictation task, $t(19) = 5.33$, $p < .001$. For the RA group this effect was significant in the copying task, $t(19) = 2.36$, $p < .001$ but not in the spelling-to-dictation task, $t < 1$. The DD group showed a significant word frequency effect on copying, $t(19) = 3.05$, $p < .01$ and a marginally significant effect in spelling-to-dictation, $t(19) = 1.95$, $p < .07$.

Table 3 here: see below

Number of Errors

Table 4 shows the mean percentage of errors for each condition and group. The main effect of group was significant, $\chi^2(16) = 46.47$, $p < .001$ (Estimate = -0.453). Pairwise comparisons showed that the CA group made fewer errors than the DD group, $t(25.92) = 6.33$, $p < .001$ and the RA group, $t(27.49) = 3.29$, $p < .01$. Moreover, the DD group made more errors than the RA-matched controls, $t(37.54) = 2.51$, $p < .001$. The main effects of P-O consistency, $\chi^2(10) = 48.98$, $p < .001$ (Estimate = -.000) and task, $\chi^2(10) = 98.55$, $p < .001$ (Estimate = .006). were also significant. More errors were made in P-O inconsistent words and in the spelling-to-dictation task. There was a significant interaction between these effects, $\chi^2(4) = 20.49$, $p < .001$ (Estimate = .019), revealing that the P-O consistency effect was significant only in the spelling-to-dictation task, $t(37.54) = 2.71$, $p < .001$. No other effect was significant.

Table 4 here: see below

Discussion

The present study aimed to better characterize the spelling difficulties often experienced by children with DD. The performance of a group of Spanish children with DD in two writing tasks (a copying task and a spelling-to-dictation task) was compared to that of two control groups: one matched by chronological age and one matched by reading age. Written latencies, writing durations, in-air pen durations and accuracy were analysed. The results showed that the group with DD showed a pattern of results identical to that observed for the RA-matched controls. However, analyses on writing and in air-pen durations revealed largely similar results in the DD group and the CA-matched group.

In relation to our research questions, the results indicate that impairment to the orthographic lexicon and the orthographic working memory system can be detected in children with dyslexia, and that they show additional problems in the application of more complex P-O correspondences. The group with DD produced longer written latencies than the CA and larger effects of lexical frequency, P-O consistency and word length in this measure. This pattern confirms that Spanish children with dyslexia experience spelling problems affecting the three main components of the spelling system.

The larger word frequency effect for the DD group points to difficulties affecting lexical processes in children with DD compared to typically-developing children of the same age. Namely, it seems that children with DD have particular problems with low frequency words. The presence of impairment to the lexical route for spelling in individuals with dyslexia has been previously proposed by several authors (Afonso, Suárez-Coalla, et al., 2015; Angelelli et al., 2004; Di Betta & Romani, 2006; Goulandris & Snowling, 1991; Hanley et al., 1992). Although our findings regarding word frequency effects on latencies seem to be in line with this claim, we also observed larger effects of P-O consistency and word length in the DD group than in the CA group. In the case of P-O consistency, this variable reliably affected the written latencies produced by the DD only in the spelling-to-dictation task, suggesting a marked sublexical strategy to perform this task in this group. This interpretation also fits the larger effect of word length obtained for these children.

In relation to our third research question, identical effects of the three variables on written latencies were found in the DD group and the RA group. It seems that the deficits observed in the DD group when compared to the CA group are related to the reduced reading ability of these children. In other words, increased times to initiate the response and atypical effects of linguistic variables on the written latencies of Spanish children with dyslexia seem to be a by-product of reading difficulties rather than a manifestation of an additional deficit specifically affecting the spelling system. This pattern of results strongly supports the idea that the use of lexical and sublexical information made by children with DD is similar to that made by typically-developing children with comparable reading skills.

However, accuracy results were poorer for the group of children with DD than for typically-developing CA-matched children and the younger RA-matched children. These findings may be in line with the idea that children with DD have a reduced number of lexical orthographic representations stored compared to children of the same chronological age (CA) and the same reading age (RA). Although the pattern of results obtained on written latencies suggests that children with DD retrieve the words they know how to spell (correct words) as fast as any typically-developing children with the same reading ability, it seems that they are able to correctly spell fewer words. In other words, these results may be reflecting specific difficulties for storing orthographic representations while access to stored representations is normal for the level of development of the orthographic lexicon.

Evidence reported here can be easily integrated in the context of a dual-route model of spelling. An orthographic lexicon underdeveloped in the case of DD may result in increased effects of word frequency (reflecting special difficulties with low frequency words) and overreliance on the sublexical route. This is true for both symbolic and connectionist dual-route models (Houghton & Zorzi, 2003). It is less clear how a “single-route” connectionist model would accommodate the evidence obtained in the present study. Although lesion to these models usually produce variations replicating enhanced P-O consistency effects, it is not obvious how word frequency effects would be produced (Houghton & Zorzi, 2003). It must be nevertheless noted that most of the connectionist accounts of spelling have focused on modelling accuracy scores, with assumptions of latencies mirroring the pattern observed on errors (Bullinaria, 1994) or no specific mention to response latencies (Brown & Loosemore, 1994; Olson & Caramazza, 1994). The dual-route model of Houghton and Zorzi produced variations for both latencies and errors, but it is not evident to us whether a “dyslexic” version of this model would produce larger effects on accuracy than on written latencies.

Children with DD did not seem to have difficulties with the motor aspects of writing. The group with dyslexia wrote as fast as the group of CA-matched peers and significantly faster than children on the RA-matched group. Moreover, both the DD and the CA groups showed comparable P-O consistency and word length effects on writing durations, which were larger in the RA-group. It seems that RA-matched children were still in the process of increasing their writing speed, while the group with DD and CA have a comparable level of development of this aspect of written production. As to writing durations, all the manipulated variables produced a similar effect in the DD and the RA groups, with the exception of word frequency. Neither children with DD and RA-matched controls showed a significant effect of word frequency on writing durations in the spelling-to-dictation task. It has been recently suggested that word frequency affects writing durations during writing acquisition, reflecting a close interrelationship between lexical and motor processes during this period (Afonso et al., 2017). As suggested above, both the DD and the RA groups seem to have used a sublexical strategy to resolve the spelling-to-dictation task. Thus, the absence of a word frequency effect on writing durations is not surprising. Although lexical information was also used by these groups to retrieve/generate the written response (as reflected by significant word frequency effects on written latencies), this lexical information may not be strong enough to cascade into writing durations, at least for most of the stimuli. In sum, we interpret this particular effect as being related to lexical rather than to motor processes and thus, as confirmation of the existence of difficulties at the lexical level of processing in children with DD as compared to CA-matched peers.

The fact that writing speed was not affected in children with DD is in line with the findings reported Sumner and colleagues (2013). These authors found that increased writing times observed in individuals with DD were due to the production of more frequent and longer pauses rather than to slower writing movements. Our findings seem to confirm that although children with DD need more time than CA controls to initiate their response, they are not slower once writing has been initiated. Difficulties with word production in DD seem to be related to spelling rather than to writing difficulties.

Regarding the effect of task, children with DD and RA-matched controls initiated the responses faster in the spelling-to-dictation task than in the direct copying transcoding task. CA-matched controls were not affected by the task in written latencies. This pattern of results is likely to be related to differences in reading ability between groups. CA children were actually faster in the copying task when only short words were considered, suggesting they were able to rapidly recognize short words. However, children with DD and RA-matched controls required less time to initiate the response in spelling-to-dictation for all kinds of words. This pattern suggests that their reading speed is particularly slow, so they cannot rapidly recognize short words either. The three groups of children produced longer writing durations and in-air pen durations in the spelling to dictation task, confirming that the response is initiated as soon as the initial segments are recognized in this task (Bonin, Peereman, & Fayol, 2001), and that the rest of the letters of the word are retrieved immediately before their actual production (Afonso, Suárez-Coalla, et al., 2015).

Limitations and Further Research

It is important to note that other factors may explain the pattern of results obtained here. For example, the different pattern obtained for errors and written latencies in the present study may be due to subtle differences in reading ability between the RA and the DD group, which may have not been captured by our measure of reading ability. These undetected differences might have enabled younger children to spell slightly better than the DD group. It is also possible that our study lacks the necessary statistical power to detect differences between these two groups in written latencies. In any case, more research is necessary to elucidate how measures of the writing process (written latencies, writing durations) and the writing product (spelling errors) relate to each other. Moreover, it is unclear if at least some of our findings can be explained by the high level of transparency of Spanish orthography. Further studies need to be conducted in more opaque orthographies (for example, English) to elucidate to what extent and for how long the application of phonology-to-orthography correspondences is altered in developmental dyslexia. It may well be the case that the more complex conversion procedures existing in

English are not mastered by individuals with dyslexia even in adulthood. Studies using a methodology similar to that used in this study in languages with a more opaque orthography are missing in the literature. However, previous evidence coming from the analysis of errors made by adults with dyslexia seems to support that difficulties experienced in childhood with the application of phonology-to-orthography conversion rules are overcome in adulthood also for English-speaking individuals (Di Betta & Romani, 2006). Differences in transparency between orthographies could also affect the relationship between spelling and reading abilities. The pattern of results obtained here might be at least partially due to the fact that in Spanish phonology-to-orthography (spelling) correspondences have a comparable level of transparency than orthography-to-phonology (reading) correspondences. However, transparency in English is higher for reading than for spelling. This fact could lead to a higher dissociation between the levels of reading and spelling ability in children with dyslexia. This interesting possibility should be explored in future studies.

Implications

The findings reported here have several implications for how to teach more effectively spelling and writing to children with dyslexia. Compared with their typically developing classmates, children with dyslexia will require more time to successfully produce writing tasks, especially if the task demands rapid access to difficult-to-spell words, infrequent words or long words. Accommodations may be necessary in order to ensure that children with dyslexia are not penalised in their assignments by this need for extra time to be as productive in their writing as their peers. It is important to notice that differences in speed observed here emerged for correctly spelled words, so accuracy should not be considered the only indicator of the severity of spelling problems in these students. Moreover, the fact that poor reading skills seems to be strongly related to the level of spelling ability may suggest that remediation focusing on improving reading ability may have a positive impact on spelling development. Finally, attention should be called to the fact that children with dyslexia performed more slowly when copying from a model than when spelling to dictation. Thus, this finding advises against using copying tasks in the class if productivity or speed are considered an important factor to establish success in the assignment.

Conclusion

In summary, evidence gained in the present experiment confirms the presence of spelling impairments affecting the relative involvement of lexical orthographic information and phonology-to-orthography relationships in Spanish children with DD compared to typically-developing children of the same age. Slow initiation of words that exert greater demands on the spelling system (such as low-frequency words, P-O inconsistent words and long words) appears to be connected to reading ability. However, spelling errors made by Spanish children with dyslexia exceeded what might be expected given their reading ability. It seems that the spelling system in children with dyslexia functions following the same principles than the spelling system of typically-developing children, although it may be underdeveloped. This delay in orthographic knowledge development affects the relative contribution made by lexical and sublexical information to spelling tasks.

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Table 1

Means and Standard Deviations (in parenthesis) for Demographic Characteristics and Reading Scores of children in the DD, CA, and RA Groups.

Variable	CA	DD	RA	*p* values
Age (in years)	9.7 (1.34)	9.35 (1.35)	8.17 (.71)	*CA-DD* = .98*; CA-RA* < .001; *DD-RA* < .001
Education (in years)	4.3 (1.3)	4.2 (1.32)	2.55 (.69)	*CA-DD* = .95*; CA-RA* < .001; *DD-RA* < .001
Reading				
Words				
Accuracy	39.55 (0.6)	35.5 (5.76)	37.95 (2.44)	*CA-DD* < .001*; CA-RA* < .005; *DD-RA* = .09
Speed (s)	34.67 (6.96)	72.6 (22.84)	40 (13.8)	*CA-DD* < .001*; CA-RA* < .15; *DD-RA* < .001
Pseudowords				
Accuracy	38.2 (1.44)	32.7 (5.51)	32.95 (3.8)	*CA-DD* < .001*; CA-RA* < .001; *DD-RA* < .95
Speed (s)	60.18 (14.3)	95.2 (30.45)	73.5 (27.31)	*CA-DD* < .001*; CA-RA* < .05; *DD-RA* < .01

Note. CA = chronological age-matched controls; DD = developmental dyslexia; RA = reading-age matched controls.

Table 2

Mean Written Latencies (in milliseconds) and Standard Deviations (in parentheses) for each Condition for the DD, CA, and RA Groups.

		P-O consistent				P-O inconsistent			
		Short		Long		Short		Long	
Group	Task	HF	LF	HF	LF	HF	LF	HF	LF
CA	Copy	1251 (262)	1331 (271)	1448 (390)	1415 (370)	1289 (316)	1284 (297)	1334 (334)	1389 (399)
	STD	1296 (310)	1443 (416)	1331 (298)	1404 (340)	1365 (252)	1464 (343)	1338 (328)	1455 (369)
DD	Copy	1604 (602)	1815 (858)	2023 (725)	2257 (1031)	1749 (782)	1876 (819)	2030 (859)	2155 (954)
	STD	1450 (744)	1523 (683)	1433 (560)	1549 (553)	1532 (692)	1605 (608)	1546 (538)	1819 (736)
RA	Copy	1508 (406)	1670 (553)	1877 (720)	2268 (916)	1647 (555)	1824 (725)	1928 (749)	2137 (807)
	STD	1474 (372)	1642 (518)	1585 (423)	1669 (437)	1641 (491)	1997 (1078)	1733 (798)	1959 (945)

Note. CA = chronological age-matched controls; DD = developmental dyslexia; RA = reading-age matched controls; P-O = phonology-to-orthography; STD = spelling-to-dictation; HF = high frequency; LF = low frequency.

Table 3

Mean Writing Durations (in milliseconds) and Standard Deviations (in parentheses) for each Condition for the DD, CA, and RA Groups.

		P-O consistent				P-O inconsistent			
		Short		Long		Short		Long	
Group	Task	HF	LF	HF	LF	HF	LF	HF	LF
CA	Copy	1867 (575)	1793 (542)	3012 (815)	3266 (1112)	1914 (545)	2158 (650)	3135 (853)	3352 (1063)
	STD	1856 (455)	1898 (393)	3067 (642)	3245 (806)	2031 (528)	2318 (712)	3166 (868)	3386 (859)
DD	Copy	1917 (609)	1989 (701)	3455 (1118)	3429 (1066)	2232 (906)	2339 (1039)	3487 (1412)	3636 (1117)
	STD	2100 (679)	2129 (677)	3601 (1083)	3621 (1044)	2347 (990)	2433 (936)	3535 (1222)	3745 (1066)
RA	Copy	2376 (547)	2492 (767)	4105 (1048)	4439 (1385)	2717 (677)	2917 (804)	4378 (1111)	4797 (1372)
	STD	2797 (755)	2717 (821)	4795 (1550)	4790 (1266)	3167 (1158)	3326 (930)	4842 (1527)	5051 (1491)

Note. CA = chronological age-matched controls; DD = developmental dyslexia; RA = reading-age matched controls; P-O = phonology-to-orthography; STD = spelling-to-dictation; HF = high frequency; LF = low frequency.

Table 4

Mean Percentage of Error and Standard Deviations (in parentheses) for each Condition for the DD, CA, and RA Groups.

		P-O consistent				P-O inconsistent			
		Short		Long		Short		Long	
Group	Task	HF	LF	HF	LF	HF	LF	HF	LF
CA	Copy	2.50% (.18)	0% (0)	1.25% (.11)	1.25% (.11)	0% (0)	1.25% (.11)	1.25% (.11)	1.25% (.11)
	STD	1.25% (.11)	10% (.3)	1.25% (.11)	0% (0)	5% (.22)	15% (.36)	3.75% (.19)	8.75% (.28)
DD	Copy	1.25% (.11)	2.50% (.18)	7.5% (.26)	3.75% (.11)	1.25% (.11)	10% (.3)	5% (.22)	6.25% (.24)
	STD	10% (.3)	16% (.37)	6.25% (.24)	5% (.22)	41% (.49)	43.7% (.5)	28.7% (.45)	28.7% (.45)
RA	Copy	1.25% (.11)	2.50% (.18)	1.25% (.11)	5% (.22)	0% (0)	1.25% (.11)	0% (.11)	2.50% (.18)
	STD	2.50% (.18)	15% (.36)	0% (0)	2.5% (.18)	26.2% (.44)	33.7% (.47)	15% (.36)	22.5% (.42)

Note. CA = chronological age-matched controls; DD = developmental dyslexia; RA = reading-age matched controls; P-O = phonology-to-orthography; STD = spelling-to-dictation; HF = high frequency; LF = low frequency.

Appendix A

Experimental stimuli used in the writing tasks.

Words	WF	NL	NS	N
Consistent				
High-frequency				
Short				
Color	791.4	5	2	4
Edad	329.9	4	2	0
Radio	290.4	5	2	0
Susto	187.8	5	2	3
Long				
Contento	335.0	8	3	8
Escalera	332.4	8	4	0
Resultado	343.8	9	4	1
Sorpresa	326.0	8	3	0
Low-frequency				
Short				
Coral	21.07	5	2	5
Emir	0.83	4	2	0
Rigor	6.62	5	2	1
Senda	14.22	5	2	3
Long				
Contrato	14.17	8	3	6
Estacada	4.14	8	4	1
Remolacha	13.91	9	4	0
Senador	5.41	7	3	3
Inconsistent				
High-frequency				
Short				
Bolsa	346.5	5	2	4
Vapor	157.2	5	2	1
Venir	294.3	5	2	2
Viejo	689.2	5	2	2
Long				
Bicicleta	280.1	9	4	0
Ventana	673.0	7	3	2
	203.0	9	4	1
Vestido	279.6	7	3	2
Low-frequency				
Short				
Bingo	5.40	5	2	2
Vaina	6.42	5	2	0
Vigor	7.89	5	2	2
Virus	18.19	5	2	1
Long				
Bailarina	15.17	9	4	0
Vencedor	9.99	8	3	1
Vendida	1.44	5	3	5
Visitante	22.58	9	4	2

Note. WF = word frequency; NL = number of letters; NS = number of syllables; N = orthographic neighbourhood.