Handwriting production in Spanish children with dyslexia: spelling or motor difficulties?

(Spelling and motor difficulties in children with dyslexia)

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Abstract

Spelling and handwriting are different processes; however, they are learned simultaneously, and numerous studies have shown that they interact. Besides the commonly reported presence of a spelling deficit, previous studies have indicated that handwriting difficulties can also be detected in children with dyslexia. Despite this, this issue has not been sufficiently explored. The goal of the study was to investigate the potential handwriting difficulties met by children with dyslexia and how they might relate to spelling difficulties and to basic graphic skills. Twenty children with dyslexia were compared with a chronological age-matched group and reading level-matched group. Participants completed a spelling-to-dictation task of words and pseudowords, an alphabet writing task, and two graphic tasks. Results showed that children with dyslexia were less accurate and slower in preparing and executing the written response than typically developing peers, but they showed the spelling level expected given their reading ability. Children with dyslexia also performed similarly to children with the same reading level in the alphabet and graphic tasks, with both groups being slower and less fluent than the control age group. Altogether, the results suggest the existence of a delay in the development of handwriting and graphic fluency related to the level of reading and spelling skills rather than the presence of a core deficit affecting fine motor skills in dyslexia. In this sense, it seems that reduced literacy skills can affect the development of other skills that are usually enhanced with handwriting practice, such as fine motor skills.

Keywords: Dyslexia – Handwriting – Spelling – Writing – Fine motor difficulties

Introduction

Most influential models of writing assume that spelling and handwriting are different processes but closely related (Hayes & Flower, 1980, 1986; Hayes, 1996; Van Galen, 1995). The spelling module involves the retrieval and maintenance of the orthographic representation of words; and the motor modules are engaged in allograph selection, size control and muscular adjustment. From a developmental point of view, the importance of automating both spelling and handwriting processes has been highlighted (Berninger & Amtman, 2003; Juel, Griffith, & Gough, 1986), in order to ensure that resources are available for higher-order processes (Bourdin & Fayol, 1994; McCutchen, 2011).

Handwriting is a sophisticated ability which takes time to acquire (Graham, Berninger, Weintraub & Schafer, 1998; Van Galen, 1995). Such skill is often understood in terms of legibility or readability (how readable the production is) and fluency or speed (number of letters or words produced within a period of time) (Abbott & Berninger, 1993; Barnett, Henderson, Scheib, & Schulz, 2007; Graham et al., 2008; Kandel, Lassus-sangosse, Grosjacques & Perret, 2017; Prunty, Barnett, Wilmut & Plumb, 2013; Rosenblum, Weiss & Parush, 2003; Sumner, Connelly & Barnett, 2013, 2014). It has been reported that readability and fluency grow at different rates, which indicates that they are separable skills (Graham et al., 1998). However, there is no consensus about the moment at which handwriting becomes an automated skill and the basic skills that are necessary to master it are fully developed. Some authors consider that handwriting automation is achieved in the early years of elementary school (Overvelde & Hulstijn, 2011); while others have claimed it to occur around 12 (Graham et al., 1998; Thibon, Gerber, & Kandel, 2018) or 15 years old (Accardo, Genna, & Borean, 2013). In addition, it should be considered that variability exists, due to several factors, such as instruction, practice or exposure (Caravolas, Downing, Hadden & Wynne, 2020; Graham et al., 2008; Graham & Harris, 2005; Vander Hart, Fitzpatrick & Cortesa, 2010).

At school, spelling and handwriting are learned simultaneously, and numerous studies have shown that they interact during writing production (Abbott, Berninger & Fayol, 2010; Berninger, Mizokawa & Bragg, 1991; Bourdin, Cogis & Foulin, 2010; Fayol & Miret, 2005; Graham, Berninger, Abbott, Abbott, & Whitaker, 1997; Medwell, Strand & Wray, 2007; Palmis, Danna, Velay, & Longcamp, 2017; Treiman & Kessler, 2014). Some studies have shown that children's handwriting skills have an influence on writing and spelling (Graham, Harris & Fink, 2000; Wicki, Lichtsteiner, Geiger & Müller, 2015), while other studies have investigated the opposite direction, namely, the influence of spelling on handwriting fluency and speed (Kandel & Perret, 2015).

Otherwise, the development of transcription skills can be hindered by several reasons such as reduced opportunity for instruction, socioeconomic factors and especially the occurrence of neurodevelopmental disorders including dyslexia (Caravolas et al., 2020). Specifically, children with dyslexia experience both spelling difficulties (Bernstein, 2009; Snowling, 2000), and difficulties in handwriting skills (Cheng-Lai, Li-Tsang, Chan, & Lo, 2013; Martlew, 1992; Søvik & Arntzen, 1986; Søvik, Arntzen, & Thygesen, 1987).

In dyslexia, the existence of a spelling deficit (Angelelli, Notarnicola, Judica, Zoccolotti, & Luzzatti, 2010; Callens, Tops, & Brysbaert, 2012; Kemp, Parrila, & Kirby, 2009; Swanson & Hsieh, 2009) has been demonstrated through error analysis (Angelelli, Judica, Spinelli, Zoccolotti & Luzzatti, 2004; Angelelli, et al., 2010; Bruck & Treiman, 1990; Caravolas & Volín, 2001; Friend & Olson, 2010; Romani, Olson & Di Betta, 2005; Suárez-Coalla, Villanueva, González-Pumariega & González-Nosti, 2016). Phonologically non-plausible errors reflect difficulties in the acquisition of phoneme-tographeme (P-G) correspondences, whereas plausible errors indicate overreliance on the sublexical route and therefore difficulties in developing precise orthographic representations. In Spanish, Suárez-Coalla, et al. (2016) concluded that children with dyslexia rely more on a sublexical strategy to write and have difficulties to develop orthographic lexical representations. Chronometric studies have also suggested that spelling difficulties in dyslexia are reflected in longer written latencies and writing durations (Afonso, Suárez-Coalla, & Cuetos, 2015; 2020). Besides, it is important to point out that some authors have recently proposed that spelling deficits in dyslexia may be also related to deficits affecting the orthographic working memory system (Afonso et al., 2015, 2020; Menghini, Finzi, Carlesimo, & Vicari, 2011; Szmalec, Loncke, Page, & Duyck, 2011). This claim has been recently supported by the finding that both adults and children with dyslexia are disproportionally affected by word length effects when compared with typically developing peers (Afonso et al., 2015; 2020).

Regarding handwriting difficulties, some studies have suggested the existence of handwriting difficulties in dyslexia (Cheng-Lai et al., 2013; Martlew, 1992). However, research focusing on graphomotor skills in this population is still scarce. It is widely accepted that children with dyslexia show slow handwriting and poor handwriting quality (Rose, 2009). The alphabet writing task, in which children have to reproduce the sequence of letters of the alphabet under time pressure, has been the most frequently used task to assess handwriting fluency in both typically developing children (Abbott & Berninger, 1993; Alamargot, Caporossi, Chesnet, & Ros, 2011; Alamargot & Morin, 2015; Pontart et al., 2013) and children with dyslexia (Berninger, Nielsen, Abbott, Wijsman & Raskind, 2008; Sumner et al., 2013). Berninger et al. (2008) observed that English-speaking children with dyslexia wrote fewer readable letters of the alphabet under time restrictions (15 seconds) than typically developing children. Sumner et al. (2013) also administered an alphabet writing task to children with dyslexia aged 9, but in this case, children were asked to write for one minute. Their results indicated that although children with dyslexia wrote a similar number of letters as age-matched controls, they spent more time pausing. Children matched by ability, and therefore younger, paused for a similar amount of time than dyslexics. According to Sumner et al. (2013), children with dyslexia have longer pauses, reducing the fluency of their writing, because they require more time to recall the alphabet sequence. However, they do not seem to have problems in forming the letters quickly. Both studies underline the difficulty that children with dyslexia have in writing fluency in the alphabet task, which is considered an automated task at this age (Pontart et al., 2013).

It is assumed that the development of handwriting skills is related to the acquisition of other more basic graphic skills (such as drawing or tracing), at least in early ages. Adi-Japha & Freeman (2001) reported similarities between writing and drawing fluency until the age of 6. Bonoti, Vlachos & Metallidou (2005) found that writing and drawing abilities were correlated in children attending 2nd-6th grade. Interestingly, Khalid, Yunus & Adnan (2010) reported that children with handwriting difficulties produced a higher number of velocity peaks and lower mean pen velocity when drawing than children without handwriting difficulties. These findings indicate that a relationship exists between handwriting ability and other graphic skills. This means that difficulties in producing fluent handwriting observed in children with dyslexia might be associated with difficulties in other graphic skills. Few studies have been conducted on this issue, but some evidence suggests that this might be the case. Cheng-Lai et al. (2013) carried out a study to investigate the relationships between word dictation, handwriting performance, lexical knowledge, orthographic awareness, rapid automatic naming (RAN), and other perceptual-motor skills (visual-perception, fine-motor, visual-motor integration, oculomotor control) among a group of 45 Chinese children with dyslexia (9.14 years). Fine motor skills that are relevant in school activities, such as writing and drawing, were assessed using the subtests on fine manual control and on manual coordination of the Bruininks–Oseretsky test of motor proficiency—2nd edition (BOT-2; Bruininks & Bruininks, 2005). Cheng-Lai et al. (2013) observed that children with dyslexia as a group performed worse than their peers without dyslexia in a test of fine manual control, even though none of the children in the dyslexic group met the criteria to be considered to have severe difficulties in this area. Thus, it seems that some problems with more general fine motor skills can be found in individuals with dyslexia, but the origin and extent of these are not clear yet.

Classical writing models have not sufficiently accounted for the relationship between spelling and handwriting, but recent investigations have begun to investigate this (Caravolas et al., 2020; Sumner et al., 2014). The studies that have attempted to explain the presence of handwriting difficulties in dyslexia have suggested that the difficulties with spelling may hinder handwriting production (Afonso et al., 2015; Berninger et al., 2008; Sumner et al., 2013, 2014; Suárez-Coalla et al., 2016; Tops, Callens, Bijn & Brysbaert, 2012). More specifically, their poor spelling skills cause individuals with dyslexia to produce longer pauses both within words and between words during writing (Kandel et al., 2017; Sumner et al, 2013, 2014). Other authors have claimed that handwriting difficulties are a product of poor motor abilities (Goldup, 2000; Rose, 2009). Additional investigations have suggested that a high level of comorbidity exists between motor problems (for example, Developmental Coordination Disorder (DCD) or dyspraxia) and dyslexia (Iversen, Berg, Ellertsen & Tonnessen, 2005; Rose, 2009). Iversen et al. (2005) reported a high incidence of motor coordination problems in groups of poor readers, although not all of them evidenced these problems. As can be inferred from the above, there is evidence of a relationship between spelling skills and handwriting performance, but it is necessary to continue investigating the nuance of this relationship in dyslexia.

New methodologies permit to characterise writing difficulties more accurately. In addition, children with dyslexia are often compared with age-matched controls; it may be that in such cases the control group is faster not because its members have better motor skills but because they are more experienced in writing, as children with dyslexia often avoid writing tasks. Thus, it is also necessary to compare children with dyslexia with younger controls matched on literacy ability in order to determine whether children with dyslexia are deviant or delayed in their writing performance.

In this context, our aim was to better understand the difficulties met by children with dyslexia when writing. In particular, this study explores the possible handwriting difficulties faced by Spanish children with dyslexia and how these difficulties might relate to spelling problems and to basic graphic skills. Regarding spelling, we sought to confirm a language-based difficulty among the dyslexics through the manipulation of lexicality (words vs. pseudowords) and word length (2 vs. 3 syllables). We also examine the impact of these variables in order to know the extent to which these children use lexical and sublexical spelling strategies. Regarding handwriting the aim was to determine whether handwriting difficulties are a result of spelling disabilities or they reflect the presence of additional problems affecting fine motor skills. Handwriting fluency was explored by means of an alphabet writing task, and graphic skills were assessed with two graphic tasks. Based on previous literature supporting the existence of a spelling deficit in dyslexia (Angelelli el al., 2010; Callens et al., 2012; Kemp et al., 2009) that is often reflected in longer written latencies and writing durations (Afonso et al., 2015; 2020), we hypothesized that children with dyslexia would show impaired spelling development when compared to their typically developing peers. This finding would be in line with the claim that the development of transcription skills can be hindered in different neurodevelopmental disorders including dyslexia (Caravolas et al., 2020). Similarly, in the context of handwriting and basic graphic skills, we expected children with dyslexia would perform more slowly and less fluently and would have reduced graphic skills than chronological age peers, as some studies have shown that spelling influences handwriting fluency, speed and legibility (Kandel & Perret, 2015; Rose, 2009). However, we predicted that the group with dyslexia would perform similarly to younger children with less writing experience. In addition, as the development of handwriting skills is related to the acquisition of other more basic graphic skills (Adi-Japha & Freeman, 2001; Bonoti, et al., 2005) and some studies have supported the idea that children with handwriting difficulties have several difficulties when drawing (Khalid et al., 2010) we hypothesized that children with dyslexia would perform worse than their peers in general fine motor skills.

Method

Participants

Twenty children with dyslexia (nine girls, M_{age} = 10 years 2 months, *SD* = .71) participated in the study. They were recruited from speech therapy centers in [name deleted to maintain the integrity of the review process]. All were native Spanish speakers and from families of middle-class socio-economic status. The performance of children with dyslexia (DYS) was compared with that of two other groups of children recruited from primary schools in [name deleted to maintain the integrity of the review process]: a group of chronological age-matched (CA) peers (eight girls, M_{age} = 10 years 1 months, *SD* = .71); and a group of reading level-matched (RL) peers (eight girls, M_{age} = 8 years 2 months, *SD* = 1). All participants had normal or corrected-to-normal vision, presented no cognitive impairment apart from dyslexia and were within normal IQ range. Children with a physical or sensory disability were not invited to take part in the study.

A Spanish reading assessment battery – PROLEC-R (Cuetos, Rodríguez, Ruano, & Arribas, 2007) were used to diagnose dyslexia. PROLEC-R provides scores for word and pseudoword reading and good reliability (α= .79). In addition, the Wechsler Intelligence Scale for Children Revised (WISC-R; Wechsler, 2001), was administered to children with dyslexia to confirm that their difficulties were not due to general cognitive problems. Participants with dyslexia (DYS) had an IQ Total of 85 or higher (*M*=107.5, *SD*= 9.91; IQ Verbal: *M*=103.7, *SD*= 9.98; IQ non-Verbal *M*=109.45, *SD*=10.56) according to the Wechsler Intelligence Scale for Children (WISC, Wechsler, 2001). According to the criteria of the International Association of Dyslexia, participants were included in the DYS group if they scored more than 1.5 standard deviations below the control group matched by age on the word and pseudoword reading tasks (accuracy and speed) of PROLEC-R; if they had persistent reading problems despite instruction and training; and if their reading problems were not due to a reduced intellectual capacity and socioeconomic status. Control children, who were assessed by the school psychologist, did not show any type of learning disability. We reconfirm that control participants did not display any dyslexic symptoms, as all scored adequately on the standardized reading test. For matching the RL to the DYS group, we used a measure of word and pseudo-word reading efficiency. To obtain this measure of "reading efficiency" the accuracy and reading time were combined by multiplying the accuracy (correct answers) by 100 and dividing the result by the total reading time. Once the diagnosis was verified, children performed the experimental tasks. Means and standard deviations for demographic characteristics and scores obtained in reading assessment tests are provided in Table 1.

[Insert Table 1]

In this study, instead of calculating the required sample size a priori, we selected the same sample size (20 participants per group) that we have observed to be effective in detecting a significant effect for an interaction between group and word frequency in a sample recruited from the same population (similar age range and same school area) in a previous study conducted within our research group [name of authors deleted to maintain the integrity of the review process].

Materials

The study included three experimental tasks. The first one consisted of a spelling-to-dictation task. Forty-eight stimuli were selected, 24 words and 24 pseudowords, half short and half long. The lexical frequency was $M = 131.96$, $SD = 72.54$ for the short words (two syllables, four letters), and $M = 134.37$, $SD = 88.95$ for the long ones (three syllables, six to seven letters). To determine the lexical frequency, we used the values provided by ONESC (Martínez & García, 2008); a database created according to the Dictionary of Frequencies for written language in children 6–12 years of age by Martínez & García (2004). The difference in word frequency between the short and long words was not significant. Each pseudoword was created from two experimental words, where the first syllable of the words was retained, and the remaining syllables exchanged (e.g. from the two experimental words '***sol**dado*' [soldier] and '***mer**cado*' [market] we obtained the two pseudowords '***sol**cado*' and '***mer**dado*'). Thus, words and pseudowords were matched on all syllables, syllable frequency, length (letters and syllables) and in syllable structure. In addition, four stimuli (two words and two pseudowords) were used as practice at the beginning of the task in order to familiarise children with the task. All items were regular with consistent mappings (i.e., with only one spelling option for each phoneme). In order to correctly write the stimuli, it is enough to have a good knowledge of the conversion rules of phonemes into graphemes (e.g., “pelota” [ball]). Experimental stimuli are given in Appendix A. Taking accuracy as a measure, the internal consistency was good, with a Cronbach’s alpha coefficient of .97.

The second experimental task consisted of writing the alphabet. This task, that has a linguistic component and is an intermediate task between the spelling task and the graphic tasks, allows us to determine the ability to generate the movement sequences of each letter of the alphabet. Children were instructed to write each letter of the alphabet on a blank sheet of paper. This is a version of the task used in several recent studies (Barnett, Henderson, Scheib, & Schulz, 2009; Berninger, 2001; Berninger et al., 1997Connelly, Campbell, MacLean, & Barnes, 2006). Variants of this task have been widely used in previous research with a demonstrable reliability (r = ,97; Berninger et al., 1997).

Finally, the last task consisted of two drawing tasks that assessed basic graphic skills. In the first one (henceforth graphic task 1) the child had to follow three paths with different forms (zigzag, wave and loop) avoiding touching the edges. This task was created specifically for this study and the material used was just a sheet of paper with the paths printed on it (Appendix B). Taking accuracy as a measure, Cronbach’s alpha coefficient was .83. The second one (henceforth graphic task 2) was based in the graphic speed task used in the Detailed Assessment of Speed of Handwriting of Barnett and colleagues (2009). Participants had to make a series of crossed lines whose intersection passed through the central part of concentric circles. These two tasks tried to assess children’s ability to produce basic movements in an accurate and consistent way. This task also gives information about the ability to control the pen when writing. The material included a sheet of paper with the circles (Appendix C). Taking accuracy as a measure, the crossed circles task showed a low level of reliability, as Cronbach's alpha coefficient was .70.

Procedure

Children were tested individually in a quiet room. Those with dyslexia were tested in the language psychology laboratory while the age- and literacy ability-matched controls were tested in their schools. All the participants performed both tasks in the same order: the spelling-to-dictation task; the alphabet writing task and finally the graphic tasks. In the spelling task, children were asked to write down the stimuli they heard, in lowercase and as quickly and accurately as possible. Each child received the following verbal instructions from the experimenter: 'This is a writing task. You will hear words or invented words through these headphones. You must write fast but avoid making mistakes. When you tell me that you are ready, I will press the button to start. When you have heard the word, you can write it on the first line with this pen'. Each trial started with the presentation of an auditory signal and a fixation point that remained on the screen for 500 milliseconds. The first auditory stimulus was then presented. Children had to write, using an inking pen, on a lined sheet of paper stuck to a digital tablet (Wacom, Intuos 5) and which was connected to a laptop. Once the participants had finished giving their response, they were instructed to move the pen to the following line just below their previous response, avoiding contact with the paper. Then, the experimenter clicked the left button of the mouse to continue onto the next stimulus. In order to randomise the presentation of the stimuli, eight lists were created (four for the words and four for the pseudowords).

In the alphabet writing task, children were asked to write in lowercase all the letters of the alphabet, in sequence and as quickly and accurately as possible. Each child received the following verbal instructions from the experimenter: 'In this task you must write all the letters of the alphabet in the correct order, fast but avoiding making mistakes. When you hear the signal through the headphones, you can start. Please remember to use lowercase letters'.

In the graphic task 1, children were asked to complete a drawing task. A sheet on which the paths had been printed was placed over the digitising tablet. Each child received the following verbal instructions: 'This task consists of following three paths. You must complete it fast, but without touching the outside lines. When you tell me that you are ready, I will press the button to start. Then you will hear a sound and you can get started. You must complete all the paths to the end without stopping'.

In the graphic task 2 participants had to make a cross whose intersection passed through the central part of the concentric circles. A sheet of paper on which a set of concentric circles had been printed was placed on the digitizing tablet. Each child received the following verbal instructions: 'This task consists in making crosses in all the following circles. You must touch the outside lines but avoiding getting out of them. The crossing of the lines must occur in the central area of both circles. When you tell me that you are ready, I will press the button to start. Then you will hear a sound and you can get started. You must complete all circles to the end without stopping'.

The Ductus programme (Guinet & Kandel, 2010) was used to present the stimuli and record responses. The auditory stimuli presented in the spelling-to-dictation task were recorded beforehand using an H4n voice recorder with a microphone Ht2-P Audix and edited with Praat software. The whole experiment lasted around 30 minutes, although this varied considerably particularly with the children with dyslexia. Nevertheless, in no case did the time taken exceed 40 minutes.

The study design and procedure were approved by the Ethics Committee for Research of the Principality of Asturias, Spain. It was developed in accordance with the Declaration of Helsinki and the Spanish Law of Personal Data Protection (15/1999 and 3/2018) principles, and data collection was authorised by written informed parental consent obtained for all participants.

Statistical Analysis

For the statistical analyses of the spelling task, in addition to accuracy we examined a series of kinematic measures of the written response. These measures included writing latency (WL, time between the onset of the stimulus and the first contact of the pencil with the digitiser), total writing duration (TD, time between the first contact of the pencil with the digitiser and completion of the stimulus being written), writing speed (measured as the distance advanced with the pen divided by the time spent, expressed in cm/sec), and peaks of speed (the number of absolute velocity peaks in the velocity profile for each item). For the kinematic measures only data from correct responses were included in the analyses, so responses with misspellings, self-corrections or missing data were excluded from analyses.

For WL, TD, writing speed and peaks of speed, separate ANOVAs were performed with mixed-effects analyses (Baayen, 2008) using R-software (RStudio Team, 2015); participants and items were the random-effect variables, while group (DYS, CA, RL), lexicality (words, pseudowords) and length (short, long) were the fixed factors. Stepwise model comparisons were conducted from the most complex to the simplest, and the model with the most complex adjustment but the lowest AIC (Akaike's Information Criterion) and significant $\chi 2$ test for the log-likelihood was retained (Schwarz, 1978). F values for type III ANOVAs, with Satterthwaite approximation for degrees of freedom, were reported for fixed effects. If 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 generalized mixed-effect model with binomial distribution, using the lme4 package in R (R Core Team, 2012). A p-value $< .05$ was adopted as a level of significance.

For the statistical analyses of the alphabet writing task, we considered TD, writing speed, and peaks of speed. Errors were not analyzed because in Spain there is no emphasis during handwriting instruction on the correct routing of strokes when writing letters. Omissions and letters produced in the wrong order reflect problems with alphabet learning or memory and not handwriting problems, and therefore they were not considered relevant to this research. ANOVAs were performed with mixed-effects analyses, with participant and letter as random-effect variables and group as fixed factor.

For the statistical analyses of the graphic tasks, the following measures were considered: TD, graphic speed, peaks of speed and number of errors. In the graphic task 1, errors were counted as the number of times the pen touched the outside line. In the graphic task 2, it was considered an error when the strokes of the crosses did not touch the outlines or when the junction of the crosses did not occur in the center of the concentric circles. In graphic task 1, the three measures were taken for each path. ANOVAs were performed with mixed-effects analyses; participants and type of path were the random-effect variables, while group were the fixed factor. In graphic task 2 the same analysis was performed, however, in this case participant was the only random-effect variable.

We also conducted Pearson's correlations to test the relationship between the spelling measures and the graphic and alphabetic ones in each group.

Results

Spelling Task

Excluding the practice trials, a total of 2,880 responses were obtained, 960 for each group (48 for each participant). Errors (misspellings and self-corrections) were removed from the analysis. Means and standard deviations for scores (written latencies, total durations, and errors) are provided in Table 2.

[Insert Table 2]

Writing latencies. Using the linear mixed-effects model fit by REML, we found that the best model (or lowest AIC) was: WL ~ Group + Lexicality + (1|Item) + (1|Subject), ($\chi^2(1) = 10.222$, p < .01). The model is illustrated in Figure 1. The main effect of group was significant ($F(2, 57) = 5.25$, $p < 0.01$), with significant differences between CA and RL ($t(57) = 2.800$, $p <. 05$; *Estimate* = 280, *SE* = 100), and between CA and DYS ($t(57)= 2.810$, $p < .05$; *Estimate* = 281, *SE* = 100). No differences were found between RL and DYS ($t(57) = -.011$, $p=. 99$; *Estimate* = -1.14, *SE* = 100). The effect of lexicality was also significant ($F(1, 44.86) = 11.12$; $p < 0.01$, *Estimate* = 91.4, *SE* = 27.4), as WL were longer for pseudowords.

[Insert Figure 1]

Total writing duration. For TD, the best model (or lowest AIC) was: TD ~ Group * Lexicality * Length + (1|Item) + (1|Subject), ($\chi^2(6) = 17.3$, p < .01). The model is illustrated in Figure 2. The main effects of group ($F(2, 56.9) = 11.8$; $p < .001$) and length ($F(1, 44.4) = 340.3$; $p < .001$) were significant. Pairwise comparisons showed significant differences between CA and RL ($t(57) = 4.814$, $p < .001$; *Estimate* = 1,139, *SE* = 237), and between CA and DYS ($t(57) = 2.921$, $p < .05$; *Estimate* = 691, *SE* = 237). No differences were found between RL and DYS ($t(57) = 1.891$, $p = .15$; *Estimate* = 448, *SE*= 237). As expected, TDs were higher for long items (*M* = 3,271, *SE* = 123) compared to short ones (*M* = 1,938, *SE* = 123).

The interaction Group x Lexicality was significant ($F(2, 2616.9) = 5.83$, $p < .01$). Pairwise comparisons showed differences between the CA and RL groups for words ($t(58.4) = 4.839$, $p < .001$; *Estimate* = 1152, *SE* = 238) and pseudowords ($t(58.6) = 4.721$, $p < .001$; *Estimate* = 1,125, *SE* = 238); however, a significant difference between CA and DYS was found only for words ($t(58.5) = 3.255$, $p < .05$; *Estimate* = 775, *SE* = 238). The interaction Group x Length was also significant ($F(2, 2617) = 59.4$, $p < .001$). Pairwise comparisons revealed significant differences between the CA and RL groups on both short ($t(58.4) = 3.560$, $p < .01$; *Estimate* = 848, *SE* = 238) and long ($t(58.5) = 6.012$, $p < .001$; *Estimate* = 1432, *SE* = 238) stimuli, but between CA and DYS only in long ones ($t(58.6) = 3.692$, $p < .01$; *Estimate* = 880, *SE* = 238).

Finally, the three-way interaction Group x Lexicality x Length approached significance ($F(2, 2616.9) = 2.75$, $p = .06$), suggesting that the lexicality by length interaction was different in the three groups. For short stimuli there were no differences between groups for pseudowords; however, there were differences between CA and RL ($t(61.4) = 3.701$, $p < .05$; *Estimate* = 893, *SE* = 241). For long stimuli, pairwise comparisons revealed a significant difference between CA and DYS for words ($t(61.5) = 4.103$, $p < .01$; *Estimate* = 990, *SE* = 241) and a marginally significant difference for pseudowords ($t(62) = 3.137$, $p = .09$; *Estimate* = 758, *SE* = 242). Finally, we found differences between the two control groups in long stimuli for both words ($t(61.4) = 5837$, p < .001; *Estimate* = 1408, *SE* = 241) and pseudowords ($t(61.8) = 6.041$, $p < .001$; *Estimate* = 1460, *SE* = 242).

[Insert Figure 2]

For speed and peaks of speed no significant effects or interactions were found.

Accuracy analysis. Participants committed a total of 151 spelling errors, which represented 5.24% of the responses. The DYS group made the highest percentage of errors (3.02%), followed by the RL group (1.39%) and then the CA group (0.83%). In terms of lexicality, errors were distributed as follows: 1.18% were made in words, 4.06% in pseudowords. Finally, in terms of the length of stimuli, 2.05% of the errors occurred with short stimuli and 3.19% with long ones. Table 3 shows the distribution of spelling errors.

Analyses showed a group effect, with significant differences between the CA and DYS groups ($p < .001$; *Estimate* = 1.53, *SE* = 0.30; *OR* = 0.21, CI = 2.56-8.33). RL group did not differ from either of the other groups. There was also a significant lexicality effect ($p < .001$, *Estimate* = 1.26, *SE* = 0.35; *OR* = 3.55, CI = 1.79-7.04), with a higher probability of making mistakes in pseudowords than in words.

[Insert Table 3]

Alphabet writing task

In this task we should have a total of 1,620 responses: 540 for each group (27 letters for participant). However, some participants did not remember some letters of the alphabet and some data were missing. A total of 136 (out of 1,620) letters were missing (8.39%): 44 in the DYS group (2.72%; *M* = 2.2, *SD* = 2.14); 28 in the CA group (1.72%; 1.4, *SD* = 1.39); and 64 in the RL group (3.95%; *M* =3.2, *SD* = 3.95).

In the alphabet writing task, we analyzed TD, writing speed and peaks of speed (means and standard deviations for each group are provided in Table 4). These measures were obtained by calculating the average of all the letters written by each participant. For all measures, we identified a significant group effect. For TD ($F(2, 54.88) = 8.78$, $p < .001$), we found significant differences between CA and DYS ($t(54) = -3.04$, $p < .05$; *Estimate* = -172.2, *SE* = 56.5) and between CA and RL ($t(54.9) = -4.04$, $p<.001$; *Estimate* = -229.8, *SE* = 56.8), as CA and DYS had longer TD than RL. No differences were found between RL and DYS ($t(55.5)= 1.038$, $p=.91$; *Estimate*= 57.6, *SE*= 55.5). For writing speed ($F(2, 55.05) = 5.07$, $p < .05$), we found significant differences between CA and DYS ($t(53.6) = -2.72$, $p < .05$; *Estimate* = -25.84, *SE* = 9.5) and between RL and DYS ($t(55.8) = -2.76$, $p < .05$; *Estimate* = -25.85, *SE* = 9.35), as CA and RL were faster than DYS. No differences were found between CA and RL ($t(54.9)= .001$, $p= 1$; *Estimate*= .011, *SE*= 9.57). For peaks of speed ($F(2, 53.99) = 7.18$, $p < .05$), we found significant differences between CA and RL ($t(54) = -3.73$, $p=.001$; *Estimate* = -1.433, *SE* = .384) and between CA and DYS ($t(53.8) = -2.501$, $p< .05$; *Estimate* = -.947, *SE* = .379), as RL and DYS had more peaks of speed than CA. No differences were found between RL and DYS ($t(54.2)= 1.296$, $p= .60$; *Estimate*= .0485, *SE*= .374).

[Insert Table 4]

Graphic Task 1

In the first graphic task, 180 responses were collected: 60 for each group (three per participant). We considered total duration, graphic speed and peaks of speed, as indicators of basic graphic skills. Means and standard deviations for each group are provided in Table 5.

[Insert Table 5]

For all measures, we found a significant group effect. For TD ($F(2, 57.001) = 4.03$, $p < .05$), only the difference between CA and DYS was significant ($t(57) = -2.703$, $p < .05$; *Estimate* = -2.329, *SE* = .862). The difference between CA and RL being just marginally significant (*t*(57) = -2.108, *p* = .09; *Estimate* = -1.816, *SE* = .862); and no differences were found between RL and DYS (*t*(57) = -.595, *p* = .82; *Estimate* = .513, *SE* = .862) (see Figure 3). For graphic speed (*F*(2, 54.96) = 4.59, *p* < .05), we found significant differences between CA and DYS (*t*(55) = 2.621, *p* < .05; *Estimate* = 1119, *SE* = 427) and between CA and RL (*t*(55) = 2.640, *p* < .05; *Estimate* = 1113, *SE* = 422). No differences were found between RL and DYS (*t*(55) = .014, *p* = .99; *Estimate* = 6.05, *SE* = 422). For peaks of speed (*F*(2, 56.146) = 4.05, *p* < .05), we found significant differences between CA and DYS (*t*(56.2) = -2.446, *p* < .05; *Estimate* = -13.74, *SE* = 5.62) and between CA and RL (*t*(56) = -2.507, *p* <.05; *Estimate* = -14.07, *SE* = 5.61). No differences were found between RL and DYS (*t*(56.2) = .059, *p* = .99; *Estimate* = 0.33, *SE* = 5.55).

Participants committed a total of 79 errors. The DYS group made the highest percentage of errors (51.9%), followed by the CA group (31.6%) and then the RL group (16.5%). In accuracy, we did not find a group effect (*F*(2, 56.99) = 2.34, *p*= 0.105).

Graphic Task 2

In the second graphic task, 2,400 responses were collected: 800 for each group (forty per participant). However, to perform the analyses we obtained an average of responses for each subject; therefore, we used 60 scores, one score for each subject. As in graphic task 1, we considered TD, graphic speed, peaks of speed and number of errors (means and standard deviations for each group are provided in Table 6.

[Insert Table 6]

For all measures, we found a significant group effect. For TD (*F*(2, 7.6819) = 4.97, *p* < .05) only the difference between CA and DYS was significant (*t*(45.9) = -3.456, *p* < .01; *Estimate* = -18.49, *SE* = 5.35); the difference between CA and RL was just marginally significant ($t(4.74) = -2.737$, $p = .09$; *Estimate* = -12.34, *SE* = 4.51), and no differences were found between RL and DYS ($t(45.9) = -1.148$, $p = .49$; *Estimate* = -6.14, *SE* = 5.35) (see Figure 3). For graphic speed ($F(2, 52.306) = 3.59$, $p < .05$), we found significant differences only between CA and DYS ($t(53) = 2.661$, $p < .05$; *Estimate* = 1.75, *SE* = .659). No difference was found between CA and RL ($t(50) = 1.653$, $p = .23$; *Estimate* = -1.11, *SE* = .673), and between RL and DYS ($t(53) = -.972$, $p = .59$; *Estimate* = .64, *SE* = .659). For peaks of speed ($F(2, 12.94) = 4.72$, $p < .05$), we found significant differences between CA and DYS ($t(48.65) = -2.511$, $p < .05$; *Estimate*= -62.01, *SE*= 24.7); the difference between CA and RL being just marginally significant ($t(7.72)= -2.665$, $p=.06$; *Estimate*= -55.53, *SE*= 20.8). No differences were found between RL and DYS ($t(48.65)= -.262$, $p=.96$; *Estimate*= -6.48, *SE*= 24.7).

Participants committed a total of 211 errors. The CA group made the highest percentage of errors (48.8%), followed by the DYS group (26.1%) and then the RL group (25.1%). In accuracy, we found a group effect ($F(2, 54.01) = 3.33$, $p < .05$), as CA group had a large error rate. However, pairwise comparison did not show differences between groups (CA - RL, $p=.11$; CA-DYS, $p=.20$; RL - DYS, $p=.1$).

[Insert Figure 3]

Correlations

The relationship between spelling performance and the performance in the graphic and alphabet tasks was examined using the Pearson correlation coefficient. These analyses were performed using the SPSS.22 program. Because when the groups are heterogeneous, each group should be considered independently (Rosen, 2003), separate analyses were performed for each one.

As showed in Table 7, for DYS children TD of the spelling task had a high correlation with graphic task 1 (speed), graphic task 2 (TD, speed, and peaks of speed) and alphabet task (TD, graphic speed and peaks of speed). Also, the number of errors in the spelling task has a high correlation with the graphic task 1 (speed), graphic task 2 (TD and speed) and with the alphabet task (TD and peaks of speed). Writing speed only correlated with speed in the alphabet task, while WL did not correlate with any other measure.

For the CA group, the TD of the spelling task only correlated with the TD of the alphabet task; writing speed correlated with the speed in alphabet task; and peaks of speed correlated with the TD of the alphabetic task. WL and errors did not correlate with any other measures.

For RL group, TD of the spelling task had a high correlation with the graphic task 2 (errors) and alphabet task (TD and peaks of speed). Also, the peaks of speed in the spelling task correlated with both TD and peaks of speed in the alphabet task. WL only correlated with TD in the alphabet task; while speed and number of errors in the spelling task did not correlate with any other measures.

[Insert Table 7]

Discussion

Besides the commonly reported presence of a spelling deficit (Bernstein, 2009; Snowling, 2000), previous studies have indicated that handwriting difficulties can also be detected in children with dyslexia (Cheng-Lai et al., 2013; Martlew, 1992; Søvik & Arntzen, 1986; Søvik et al., 1987). However, this possibility has not been sufficiently investigated. In this context, the aim of the present study was to explore the potential handwriting difficulties met by children with dyslexia and how they might relate to spelling difficulties and to basic graphic skills. To better characterize the spelling difficulties of children with dyslexia (DYS), their performance in a spelling-to-dictation task was compared to that of two control groups: a chronological-age matched control group (CA), and a reading level-matched control group (RL). The target items varied in lexicality and in length in order to assess both the lexical and the sublexical spelling routes. Participants' handwriting fluency was further explored by means of an alphabet writing task, and graphic skills were assessed with two graphic tasks (following a trail and crossing concentric circles). For all the tasks, the total duration of the response, writing/graphic speed, number of velocity peaks and accuracy (except in the alphabet task) were analysed. In the spelling task, writing latencies were also measured.

The results obtained in the spelling task showed that children with dyslexia were less accurate and slower in preparing (latency) and executing the written response than children without difficulties of the same age. The DYS group was less accurate than both the RL and the CA group, however only the differences between the DYS and CA groups were significant, as DYS group showed a pattern of results generally similar to that observed for the RL-matched controls. Both groups made a similar number of errors, wrote equally fast and needed approximately the same amount of time to initiate writing. Hence, we found that the writing performance of children with dyslexia was below the level expected given their age, general cognitive ability and the writing instruction received. This pattern of results is in agreement with previous findings that suggest that children with dyslexia show an impairment in their spelling development when compared to their typically developing peers (Suárez-Coalla et al., 2016; Wimmer & Mayringer, 2002) and confirm that even in transparent orthographic systems children with dyslexia experience difficulty with spelling (Wimmer & Mayringer, 2002).

The absence of differences in accuracy between the RL and the DYS groups indicates again that the performance of DYS children was similar to that of younger children with less writing experience (RL). These results strongly support the idea that spelling abilities are delayed in dyslexia as a consequence of reduced reading experience, rather than affected by a deficit independent and comorbid with the reading difficulties (Afonso et al., 2020).

The analyses conducted on the writing durations provided further information about the effect that spelling processes have on the handwriting of children with and without dyslexia. In our study, the extent to which the effects of lexicality and length influenced writing durations was different across groups. Writing durations produced by children with dyslexia were more affected by linguistic variables than the writing durations of their peers without dyslexia. It seems that the exceptional demands exerted by the spelling process associated to dyslexia continue to disrupt also the fluency of handwriting movements. The DYS group displayed a larger lexicality effect than the CA group only when spelling long stimuli, while the length effect was larger for children with dyslexia only when spelling long words. Thus, Spanish children with dyslexia seem to spell short pseudowords similarly to their typically developing peers. As previously suggested, this may reflect the fact that the spelling delay affects the number of words stored in the lexicon (Afonso et al., 2020; Angelelli et al., 2010; Di Betta & Romani, 2006), as well as the ability to hold long orthographic representations in orthographic working memory (Afonso et al., 2020). The application of the sublexical route, provided that strong demands are not imposed on working memory, does not seem to be affected in these children. These findings are also consistent with those reported for other transparent orthographic systems different from Spanish, such as Italian, Czech or German (Angelelli et al., 2004; Caravolas & Volín, 2001; Wimmer, 1996). It is widely accepted that children learning to spell in languages with transparent orthographies rely mainly on sublexical processes to write (Coltheart, 1978; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Seymour, Aro, & Erskine, 2003). Further research should clarify if this claim can be generalized to less transparent orthographies, in which phonology-to-orthography correspondences are more difficult to learn.

The second question we sought to answer was whether the slower handwriting reported in children with dyslexia (Angelelli et al., 2010; Callens et al., 2012; Kemp et al., 2009; Swanson & Hsieh, 2009; Wimmer & Mayringer, 2002) is related to a deficit affecting motor abilities (Goldup, 2000; Rose, 2009) or it is better characterized as a by-product of the literacy difficulties (Berninger et al., 2008; Caravolas et al., 2020; Sumner et al., 2013). Results revealed longer production times and greater dysfluency in children with dyslexia than in the CA children in the alphabet writing task and in both graphic tasks, none of which draw upon spelling knowledge. Still, children with dyslexia produced the letters more slowly (whether total letter production or speed of on-paper tracing was considered) and less fluently (i.e., they produced more velocity peaks per letter). The alphabet task does entail some level of linguistic processing, as it requires the ability to quickly access the letters of the alphabet from long-term memory. It had been previously reported that children with dyslexia require more time to perform this task than children without literacy difficulties (Berninger et al., 2008; Sumner et al., 2013). The present study extends these findings to Spanish children. Differently from previous research, kinematic measures of handwriting were collected here for each individual letter to minimize the influence of the level of knowledge of the alphabet on these analyses. With this methodology, we intended to obtain a valid measure of the automatization of letter writing. Even with this strict focus on handwriting dynamics, children with dyslexia performed more slowly and less fluently than the CA group.

Moreover, children with dyslexia were also outperformed by the CA group in the graphic tasks. These tasks are more similar to drawing than to writing as they do not have a linguistic component. However, we still found that the DYS group needed more time to complete them, showed reduced graphic speed and produced a greater number of velocity peaks than the CA group. Thus, children with dyslexia seem to have reduced graphic skills in comparison to their typically developing peers. Crucially, in the present study differences in writing times and number of velocity peaks were only significant between the DYS and the CA groups. As observed with the spelling task, children with dyslexia performed the alphabet and the graphic tasks very similarly to the RL-matched controls (with the sole exception of writing speed in the alphabet writing task). Thus, the reduced speed and fluency of children with dyslexia in the graphic tasks seem to be associated to their literacy level, rather than reflecting a primary deficit affecting fine motor skills. This pattern is consistent with previous findings obtained by Cheng-Lai and colleagues (2013), who reported that although children with dyslexia scored as a group lower than children without dyslexia in a test of fine manual control, none of the dyslexic children met the criteria to be considered as having severe difficulties in fine manual control. Altogether, the results obtained here and those reported in this previous study could be better accounted by the existence of a delay in the development of handwriting and graphic fluency related to the level of reading and spelling skills rather than by the presence of a core deficit affecting fine motor skills in dyslexia.

Reduced handwriting and graphic fluency and speed might be related to differences in the amount of time that children in the different groups spend writing. As they need more time to complete writing tasks, children with dyslexia may in fact accomplish less amount of handwriting practice than CA children in the same period of time. It is also conceivable that children with dyslexia are exposed to fewer activities involving spelling and writing, either at school or at home. For example, curricular adaptations may be in place that limit the amount of writing that this group of children is demanded to produce in the classroom (e.g., they may be exempt of copying question headings or allowed to use a computer for certain activities). At home, children with low spelling or writing skills are likely to write for pleasure less often, just as reading ability has been shown to be positively related with reading for pleasure (Twist, Schagan, & Hogson, 2007). If, as suggested by some authors (Lust & Donica, 2011), handwriting practice not only increases handwriting fluency but also contributes to enhance other fine motor abilities, then reduced graphic abilities can be expected in children that engage substantially less with writing. An interpretation of the poor performance of the DYS group in the graphic tasks as a consequence of underdeveloped literacy skills is further supported by our finding that only the group with dyslexia showed positive correlations between speed in the graphic tasks and spelling accuracy and total duration in the linguistic tasks (spelling and alphabet). This seems to suggest that the control groups had the typical level of basic graphic skills for their age, while the performance of the DYS group was somewhat linked to reading/spelling proficiency. Previous research has indicated that reading skills mediate the association between handwriting and motor abilities (Berninger, 2009; Julius, Meir, Shechter-Nissim, & Adi-Japha, 2016), and our findings also suggest that a stronger relationship might exist between more general hand skills and handwriting ability in children with literacy difficulties such as dyslexia than in typically developing children aged 8-12.

In summary, difficulties affecting the fluent production of handwriting can be identified in dyslexic children. Spelling problems manifest themselves in longer writing latencies and poorer accuracy in spelling tasks, and they cascade to affect writing durations. Children with dyslexia also produce slower and less fluent handwriting, both in word and letter production tasks, as well as slower and less fluent responses in other non-linguistic graphic tasks. In general, their performance in these tasks is similar to that of younger children with the same level of literacy skills. Thus, our results provide evidence consistent with the idea that reduced literacy skills may affect the development of other abilities usually enhanced with handwriting practice, such as fine motor skills.

References

Abbott, R. D., & Berninger, V. W. (1993). Structural equation modeling of relationships among developmental skills and writing skills in primary- and intermediate-grade writers. *Journal of Educational Psychology, 85*(3), 478–508. DOI:10.1037/0022-0663.85.3.478.

Abbott, R. D., Berninger, V. W., & Fayol, M. (2010). Longitudinal relationships of levels of language in writing and between writing and reading in grades 1 to 7. *Journal of Educational Psychology, 102*, 281. DOI:10.1037/a0019318.

Accardo, A. P., Genna, M., & Borean, M. (2013). Development, maturation and learning influence on handwriting kinematics. *Human Movement Science*, *32*(1), 136–146. DOI:10.1016/j.humov.2012.10.004.

Adi-Japha, E., & Freeman, N. (2001). Development of differentiation between writing and drawing systems. *Developmental Psychology, 37,* 101-14. DOI: 10.1037/0012-1649.37.1.101.

Afonso, O., Suárez-Coalla, P., & Cuetos, F. (2015). Spelling impairments in Spanish dyslexic adults. *Frontiers in Psychology, 6*, 466. DOI:10.3389/fpsyg.2015.00466.

Afonso, O., Suárez-Coalla, P., & Cuetos, F. (2020). Writing impairments in Spanish children with developmental dyslexia. *Journal of Learning Disabilities, 53*(2), 109-119. DOI:10.1177/0022219419876255.

Alamargot, D., Caporossi, G., Chesnet, D., & Ros, C. (2011). What makes a skilled writer? Working memory and audience awareness during text composition. *Learning and Individual Differences*, *21*(5), 505–516. DOI:10.1016/j.lindif.2011.06.001.

Alamargot, D., & Morin, M. F. (2015). Does handwriting on a tablet screen affect students'graphomotor execution? A comparison between grades two and nine. *Human Movement Science*, *44*(1), 32–41. DOI: 10.1016/j.humov.2015.08.011.

Angelelli, P., Judica, A., Spinelli, D., Zoccolotti, P. & Luzzatti C. (2004). Characteristics of writing disorders in Italian dyslexic children. *Cognitive Behavioral Neurology, 17*(1), 18-31. DOI:10.1097/00146965-200403000-00003.

Angelelli, P., Notarnicola, A., Judica, A., Zoccolotti, P., & Luzzatti, C. (2010). Spelling impairments in Italian dyslexic children: phenomenological changes in primary school. *Cortex, 46*, 1299–1311. DOI:10.1016/j.cortex.2010.06.015.

Baayen, R. H. (2008). *Analyzing linguistic data: A practical introduction to statistics.* Cambridge: Cambridge University Press.

Barnett, A., Henderson, S. E., Scheib, B., & Schulz, J. (2007). The detailed assessment of speed of handwriting (DASH) [Assessment instrument]. London, UK: Pearson.

Barnett, A., Henderson, S. E., Scheib, B., & Schulz, J. (2009). Development and standardisation of a new handwriting speed test: the DASH. *British Journal of Educational Psychology*, 6, 137–157. DOI:10.1348/000709909X421937.

Berninger, V. W. (2001). *Process assessment of the learning (PAL)*. Test Battery for Reading and writing. San Antonio, TX: The Psychological Corporation.

Berninger, V. W., & Amtmann, D. (2003). Preventing written expression disabilities through early and continuing assessment and intervention for handwriting and/or spelling problems: Research into practice. In H. L. Swanson, K. Harris, S. Graham (Eds.) *The handbook of learning disabilities* (pp.345-363).

Berninger, V. W., Mizokawa, D. T., & Bragg, R. (1991). Theory-based diagnosis and remediation of writing disabilities. *Journal of School Psychology, 29*, 57-79. DOI:10.1016/0022-4405(91)90016-K.

Berninger, V. W., Nielsen, K. H., Abbott, R. D., Wijsman, E., & Raskind, W. (2008). Writing problems in developmental dyslexia: Under-recognized and under-treated. *Journal of School Psychology*, *46*(1), 1–21. DOI:10.1016/j.jsp.2006.11.008.

Berninger, V. W, Vaughn, K., Abbott, R., Abbott, S., Rogan, L., Brooks, A., et al. (1997). Treatment of handwriting problems in beginning writers: Transfer from handwriting to composition. *Journal of Educational Psychology, 89*, 652–666. DOI: 10.1037/0022-0663.89.4.652.

Bernstein, S. E. (2009). Phonology, decoding, and lexical compensation in vowel spelling errors made by children with dyslexia. *Reading and Writing, 22*(3), 307–331. DOI:10.1007/s11145-008-9116-z.

Bonoti, F., Vlachos, F., & Metallidou, P. (2005). Writing and Drawing Performance of School Age Children Is There Any Relationship? *School Psychology International*, *26*(2), 243-255. DOI: 10.1177/0143034305052916.

Bourdin, B., Cogis, D., & Foulin, J. N. (2010). Influence des composantes graphomotrice et orthographique sur la production de textes écrits: perspective pluridisciplinaire. *Langages 177,* 57–82. DOI:10.3917/lang.177. 0057,

Bourdin, B., & Fayol, M. (1994). Is written language production more difficult than oral language production? A working memory approach. *International Journal of Psychology*, *29*(5), 561620. DOI: 10.1080/00207599408248175.

Bruck, M., & Treiman, R. (1990). Phonological awareness and spelling in normal children and dyslexics: The case of initial consonant clusters. Journal of *Experimental Child Psychology, 50*(1), 156–178. DOI:10.1016/0022-0965(90)90037-9.

Bruininks, R. H., & Bruininks, B. D. (2005). *Bruininks–Oseretsky test of motor proficiency* (2nd ed.). Minneapolis, MN: Pearson Assessment.

Callens, M., Tops, W., & Brysbaert, M. (2012). Cognitive profile of students who enter higher education with an indication of dyslexia. *PLOS ONE, 7*(6), e38081. DOI:10.1371/journal.pone.0038081.

Caravolas, M., Downing, C., Hadden, C.L., & Wynne, C. (2020). Handwriting Legibility and Its Relationship to Spelling Ability and Age: Evidence from Monolingual and Bilingual Children. *Frontiers in Psychology*, *11,* 1097. DOI:10.3389/fpsyg.2020.01097.

Caravolas, M., & Volín, J. (2001). Phonological spelling errors among dyslexic children learning a transparent orthography: The case of Czech. *Dyslexia. 7*, 229-245. DOI:10.1002/dys.206.

Cheng-Lai, A., Li-Tsang, C. W. P., Chan, A. H. L., & Lo, A. G. W. (2013). Writing to dictation and handwriting performance among Chinese children with dyslexia: Relationships with orthographic knowledge and perceptual-motor skills. *Research in Developmental Disabilities, 34*, 3372–3383. DOI: 10.1016/j.ridd.2013.06.039.

Coltheart, M. (1978). Lexical access in simple reading tasks. In G. Underwood (Ed.), Strategies of information processing (pp. 151–216). San Diego, CA: Academic Press.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108*(1), 204–256. DOI: 10.1037 /0033-295X.108.1.204.

Connelly, V., Campbell, S., MacLean, M., & Barnes, J. (2006). Contribution of lower-order letter and word fluency skills to written composition of college students with and without dyslexia. *Developmental Neuropsychology, 291*, 175–196. DOI:10.1207/s15326942dn2901_9.

Cuetos, F., Rodríguez B., Ruano E., & Arribas D. (2007). PROLEC-R. Batería de evaluación de los procesos lectores, Revisada. [Battery of reading processes assessment—Revised]. Madrid, Spain: TEA Ediciones.

Di Betta, A. M., & Romani, C. (2006). Lexical learning and dysgraphia in a group of adults with developmental dyslexia. *Cognitive Neuropsychology, 23*, 376-400. DOI:10.1080/02643290442000545.

Fayol, M., & Miret, A. (2005). Ecrire, orthographier et rédiger des textes. *Psychologie Française* 50, 391–402. DOI:10.1016/j.psfr.2005.05.008.

Friend, A., & Olson, R.K. (2010). Phonological Spelling and Reading Deficits in Children with Spelling Disabilities. *Scientific Studies of Reading, 12*(1), 90-105. DOI:10.1080/10888430701773876.

Goldup, W. (2000). Developing Writing Skills. In J. Townend & M. Turner (Eds.), *Dyslexia in Practice: A Guide for Teachers* (131–153). London, United Kingdom: Springer. DOI:10.1007/978-1-4615-4169-1_6.

Graham, S., Berninger, V. W., Abbott, R. D., Abbott, S. P., & Whitaker, D. (1997). Role of mechanics in composing of elementary school students: a new methodological approach. *Journal of Educational Psychology, 89,* 170–182. DOI:10.1037/0022-0663.89.1.170.

Graham, S., Berninger, V. W., Weintraub, N., & Schafer, W. (1998). Development of handwriting speed and legibility in grades 1–9. *The Journal of Educational Research*, *92*(June), 42–52. DOI: 10.1080/00220679809597574.

Graham, S., & Harris, K. R. (2005). Improving the writing performance of young struggling writers: Theoretical and programmatic research from the center on accelerating student learning. *The Journal of Special Education*, *39*(1), 19–33. DOI:10.1177/00224669050390010301.

Graham, S., Harris, K. R., & Fink, B. (2000). Is handwriting causally related to learning to write? Treatment of handwriting problems in beginning writers. *Journal of Educational Psychology, 92*, 620. DOI:10.1037/0022-0663.92.4.620.

Graham, S., Harris, K. R., Mason, L., Fink-Chorzempa, B., Moran, S., & Saddler, B. (2008). How do primary grade teachers teach handwriting? A national survey. *Reading and Writing*, *21*(1–2), 49–69. DOI: 10.1007/s11145-007-9064-z.

Guinet, E., and Kandel, S. (2010). Ductus: a software package for the study of handwriting production. *Behavioral Research Methods 42*, 326–332. DOI:10.3758/BRM.42.1.326.

Hayes, J. R., & Flower, L. S. (1980). Identifying the organization of writing processes. In Gregg, L. W. & Steinberg, E. R. (Eds.), *Cognitive processes in writing* (pp. 3-30).

Hayes, J. R., & Flower, L.S. (1986). Writing Research and the Writer. *American Psychologist, 41* (10), 1106-1113.

Hayes, J. R (1996). A New Framework for Understanding Cognition and Affect in Writing. In C. M. Levy y Sarah Ransdell (Eds), *The Science of Writing. Theories, Methods, Individual Differences and Applications* (pp. 1-27). New Jersey: Mahwah.

Iversen, S., Berg, K., Ellertsen, B., & Tonnessen, F. E. (2005). Motor coordination difficulties in a municipality group and in a clinical sample of poor readers. *Dyslexia, 11*, 217–231. DOI:10.1002/dys.297.

Juel, C., Griffith, P. L., & Gough, P. B. (1986). Acquisition of literacy: A longitudinal study of children in first and second grade. *Journal of Educational Psychology*, *78*(4), 243–255.

Julius, M. S., Meir, R., Shechter-Nissim, Z., & Adi-Japha, E. (2016). Children's ability to learn a motor skill is related to handwriting and reading proficiency. *Learning and Individual Differences*, *51*, 265-272. DOI:10.1016/j.lindif.2016.08.034.

Kandel, S., Lassus-sangosse, D., Grosjacques, G., & Perret, C. (2017). The impact of developmental dyslexia and dysgraphia on movement production during word writing. *Cognitive Neuropsychology*, *34*(3–4), 219–251. doi: 10.1080/02643294.2017.1389706.

Kandel, S., & Perret, C. (2015). How does the interaction between spelling and motor processes build up during writing acquisition? *Cognition, 136*, 325–336. DOI:10.1016/j.cognition.2014.11.014.

Kemp, N., Parrila, R. K., & Kirby, J. R. (2009). Phonological and orthographic spelling in high-functioning adult dyslexics. *Dyslexia*, *15*(2), 105–128. DOI:10.1002/dys.364.

Khalid, P. I., Yunus, J., & Adnan R. (2010). Extraction of dynamic features from hand drawn data for the identification of children with handwriting difficulty. *Research in Developmental Disabilities, 31,* 256–262. DOI: 10.1016/j.ridd.2009.09.009.

Lust, C. A., & Donica, D. K. (2011). Effectiveness of a handwriting readiness program in Head Start: A two-group controlled trial. *American Journal of Occupational Therapy*, *65*(5), 560-568. DOI: 10.5014/ajot.2011.000612.

Martínez, J. A., & García, M. E. (2004). *Diccionario de frecuencias del castellano escrito en niños de 6 a 12 años*. Salamanca: Universidad Pontificia de Salamanca, Servicio de Publicaciones.

Martínez, J. A., & García, M. E. (2008). ONESC: A database of orthographic neighbors for Spanish read by children. *Behavior Research Methods, 40,* 191–197. DOI:10.3758/BRM.40.1.191.

Martlew, M. (1992). Handwriting and spelling: Dyslexic children's abilities compared with children of the same chronological age and younger children of the same spelling level. *British Journal of Educational Psychology, 62*, 375–390. DOI:10.1111/j.2044-8279.1992.tb01030.x.

McCutchen, D. (2011). From novice to expert: Implications of language skills and writing relevant knowledge for memory during the development of writing skill. *Journal of Writing Research*, *3*(1), 51–68.

Medwell, J., Strand, S., & Wray, D. (2007). The role of handwriting in composing for Y2children. *Journal of Reading, Writing and Literacy, 2*, 11–21.

Menghini, D., Finzi, A., Carlesimo G., A., & Vicari, F. (2011). Working memory impairment in children with developmental dyslexia: Is it just a phonological deficity? *Developmental Neuropsychology, 36*, 199-213. DOI:10.1080/87565641.2010.549868.

Overvelde, A., & Hulstijn, W. (2011). Handwriting development in grade 2 and grade 3 primary school children with normal, at risk, or dysgraphic characteristics. *Research in Developmental Disabilities*, 32, 540–548. DOI:10.1016/j.ridd.2010.12.027.

Palmis, S., Danna, J., Velay, J., & Longcamp, M. (2017). Motor control of handwriting in the developing brain: A review. *Cognitive Neuropsychology*, *34*(3–4), 187–204. DOI:10.1080/02643294.2017.1367654.

Pontart, V., Bidet-Ildei, C., Lambert, E., Morisset, P., Flouret, L., & Alamargot, D. (2013). Influence of handwriting skills during spelling in primary and lower secondary grades. *Frontiers in Psychology*, *4*, 1–9. DOI:10.3389/fpsyg.2013.00818.

Prunty, M., Barnett, A. L., Wilmut, K., & Plumb, M. S. (2013). Handwriting speed in children with Developmental Coordination Disorder: Are they really slower? *Research in Developmental Disabilities, 34*(9), 2927–2936. DOI:10.1016/j.ridd.2013.06.005.

R Core Team (2017). R: A language and environment for statistical computing (version 3.3.3). R Foundation for Statistical Computing, Vienna, Austria. [Computer software]. Retrieved from https://www.R-project.org/.

Romani, C., Olson, A., & Di Betta, A.M. (2005). Spelling Disorders. In: Snowling MJ, Hulme C, editors. *The science of reading: A handbook* (431–448). Malden, MA: Blackwell publishing Ltd.

Rose, J. (2009). *Identifying and teaching children and young people with dyslexia and literacy difficulties.* London, United Kingdom: Department for Children Schools and Families.

Rosen, S. (2003). Auditory processing in dyslexia and specific language impairment: Is there a deficit? What is its nature? Does it explain anything? *Journal of Phonetics, 31*, 509–527. DOI:10.1016/S0095-4470(03)00046-9.

Rosenblum, S., Weiss, P. L., & Parush, S. (2003). Product and process evaluation of handwriting difficulties: A review. *Educational Psychology Review*, *15*(1), 41–81. DOI: 10.1023/A:1021371425220.

RStudio Team (2015). *RStudio: Integrated Development for R. RStudio, Inc., Boston, MA.* http://www.rstudio.com/

Schwarz, G. E. (1978). Estimating the dimension of a model. *Annals of Statistics,* 6, 461–464. DOI:10.1214/aos/117634413.

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. *British Journal of Psychology, 94*(2), 143–174. DOI: 10.1348/000712603321661859.

Snowling, M. J. (2000). *Dyslexia* (Second ed.). Oxford: Blackwell Publishing.

Sovik, N., & Arntzen, O. (1986). A comparative study of the writing/spelling performances of ‘normal’, dyslexic, and dysgraphic children. *European Journal of Special Needs Education, 1*, 85–101. DOI:10.1080/0885625860010201.

Søvik, N., Arntzen, O., & Thygesen, R. (1987). Relation of spelling and writing in learning disabilities. *Perceptual and Motor Skills, 64*, 219–236. DOI:/10. 2466/pms.1987.64.1.219.

Suárez-Coalla, P., Villanueva, N., González-Pumariega, S., & González-Nosti, M. (2016). Spelling difficulties in Spanish-speaking children with dyslexia. *Infancia y Aprendizaje, 39* (2), 275–311. DOI: 10.1080/02103702.2015.1132979.

Sumner, E., Connelly, V., & Barnett, A. L. (2013). Children with dyslexia are slow writers because they pause more often and not because they are slow at handwriting execution. *Reading and Writing, 26,* 991-1008. DOI:10.1007/s11145-012-9403-6.

Sumner, E., Connelly, V., & Barnett, A. L. (2014). The influence of spelling ability on handwriting production: children with and without dyslexia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 40* (5), 1441-1447. DOI:10.1037/a0035785.

Swanson, H. L., & Hsieh, C. J. (2009). Reading Disabilities in Adults: A Selective Meta-Analysis of the Literature. *Review of educational Research, 79,* 1362-1390. DOI:10.3102/0034654309350931.

Szmalec, A., Loncke, M., Page, M. P. A., & Duyck, W. (2011). Order or dis-order? Impaired Hebb learning in dyslexia. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*, 1270-1279. DOI:10.1037/a0023820.

Thibon, L. S., Gerber, S., & Kandel, S. (2018). The elaboration of motor programs for the automation of letter production. *Acta Psychologica*, *182*, 200–211. DOI: 10.1016/j.actpsy.2017.12.001.

Tops, W., Callens, M., Bijn, E., & Brysbaert, M. (2012). Spelling in Adolescents With Dyslexia: Errors and Modes of Assessment. *Journal of Learning Disabilities, 47*(4), 295–306. DOI:10.1177/0022219412468159.

Treiman, R., & Kessler, B. (2014). *How children learn to write words*. UK: Oxford University Press.

Twist, L., Schagan, I. & Hogson, C. (2007). Progress in International Reading Literacy Study (PIRLS): Reader and Reading National Report for England 2006. NFER and DCSF.

Vander Hart, N., Fitzpatrick, P., & Cortesa, C. (2010). In-depth analysis of handwriting curriculum and instruction in four kindergarten classrooms. *Reading and Writing*, *23*(6), 673–699. DOI: 10.1007/s11145-009-9178-6.

Van Galen, G. P. (1995). Handwriting: Issues for a psychomotor theory. *Human Movement Science, 10*, 165–191. DOI: 10.1016/0167-9457(91)90003-G.

Wechsler D. (2001). WISC-R: Wechsler Intelligence Scale for Children—Revised. [Escala de inteligencia de Wechsler para niños—Revisada]. Madrid, Spain: TEA Ediciones.

Wicki, W., Lichtsteiner, S. H., Geiger, A. S., & Müller, M. (2015). Handwriting fluency in children. *Swiss Journal of Psychology, 73*, 87–96. DOI:10.1024/1421-0185/a000127.

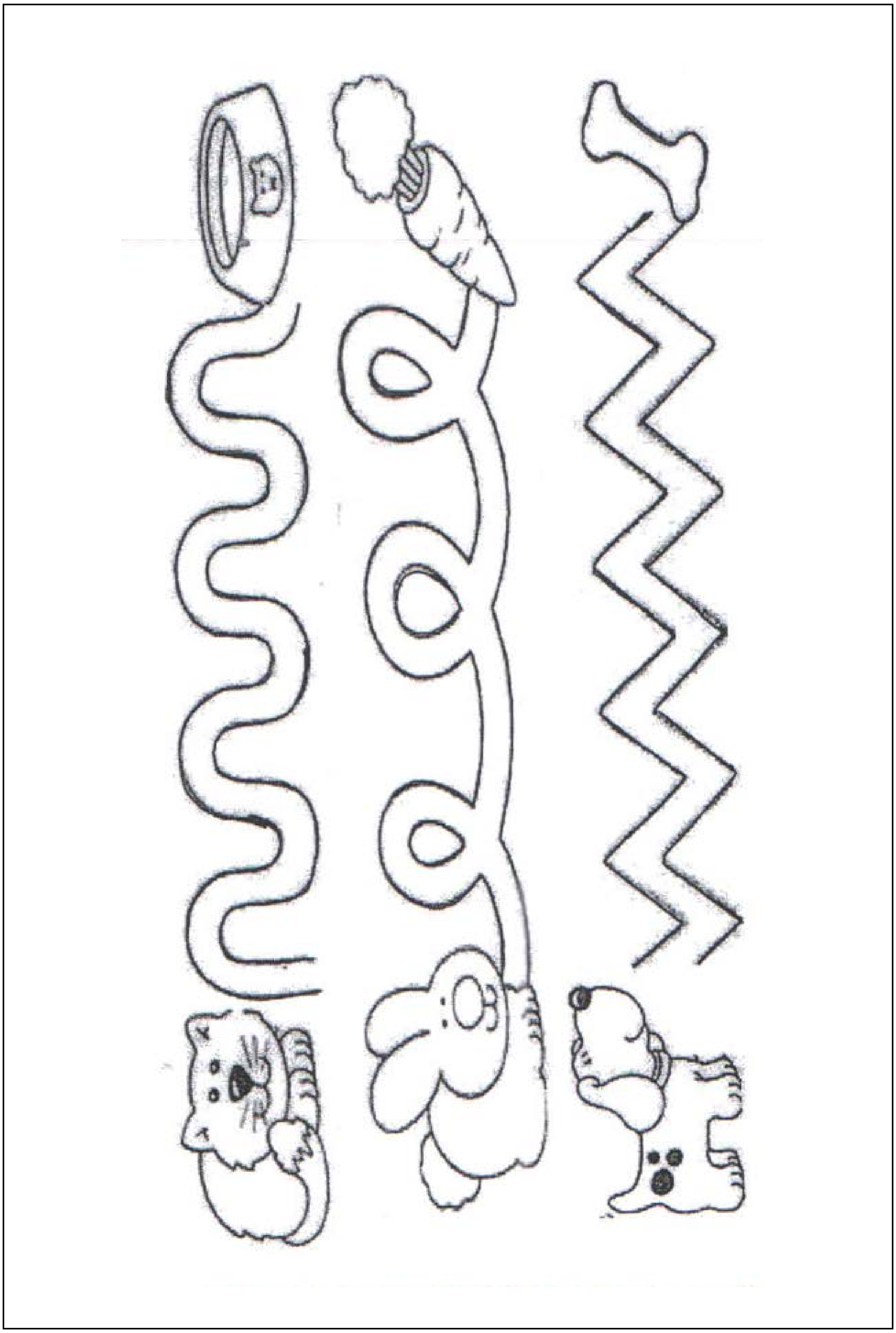
Wimmer, H., & Mayringer, H. (2002). Dysfluent reading in the absence of spelling difficulties: A specific disability in regular orthographies. *Journal of Educational Psychology*, *94*(2), 272–277. DOI:10.1037/0022-0663.94.2.272.

Wimmer, H. (1996). The early manifestation of developmental dyslexia: Evidence from German children. *Reading and Writing, 8*(2), 171–188. DOI:10.1007/BF00555368.

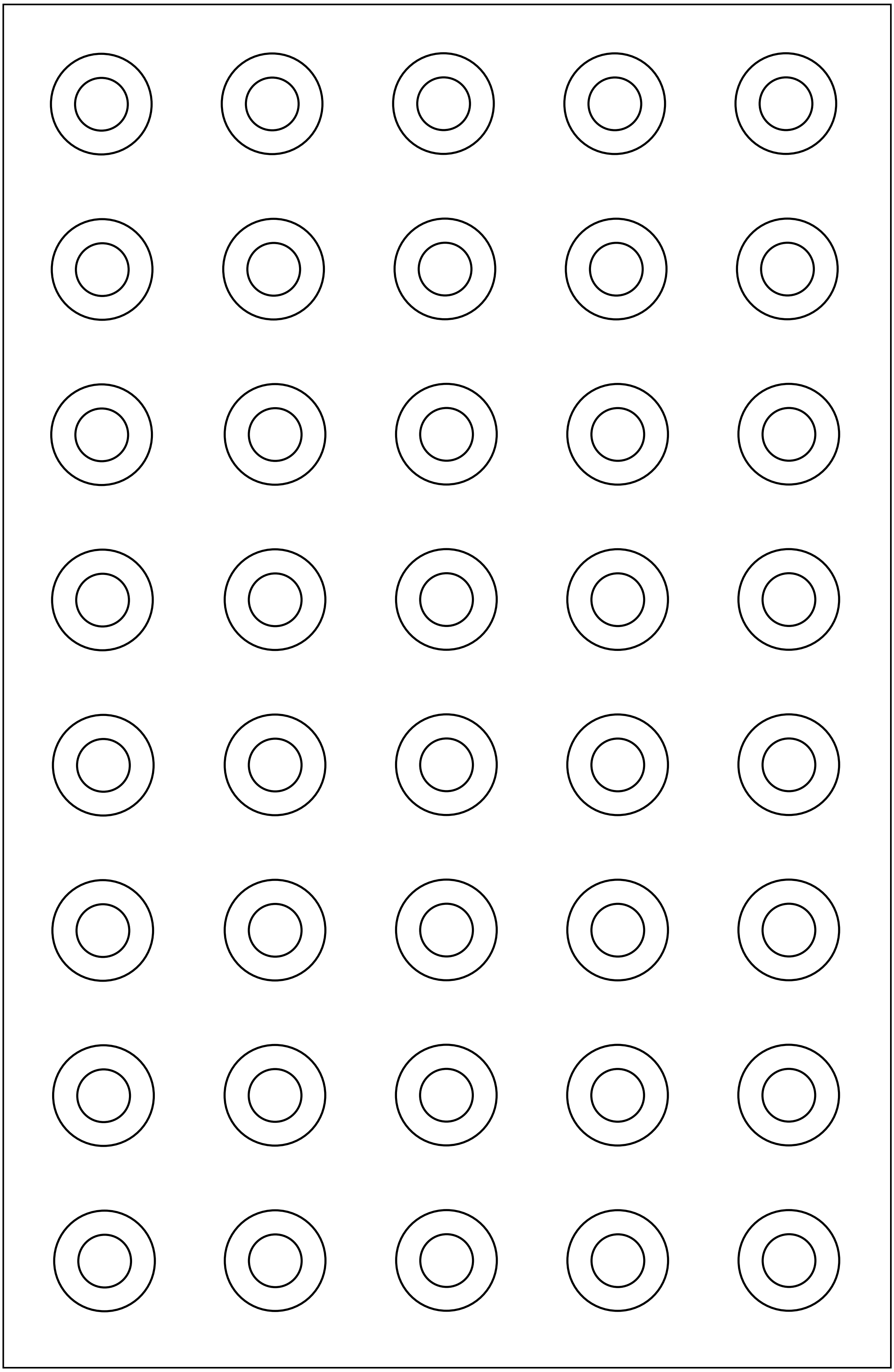
Appendix A

	Words	Pseudowords		Words	Pseudowords
	Daño	Dazo		Defensa	Delanca
	Dedo	Deña		Destino	Destaña
	Gota	Goro		Manzana	Mantema
	Lana	Laza		Mercado	Merdado
Short	Leña	Ledo	Long	Montaña	Montino
	Loro	Lota		Naranja	Naquete
	Nudo	Nuna		Palanca	Pafensa
	Pila	Pina		Paquete	Paranja
	Pozo	Poño		Pelota	Pemate
	Rana	Rado		Sistema	Siszana
	Taza	Tana		Soldado	Solcado
	Zona	Zola		Tomate	Tolota
Fillers	Tigre	Desmefo			
	Trompeta	Polemio			

Appendix B



Appendix C



Figures

Fig. 1

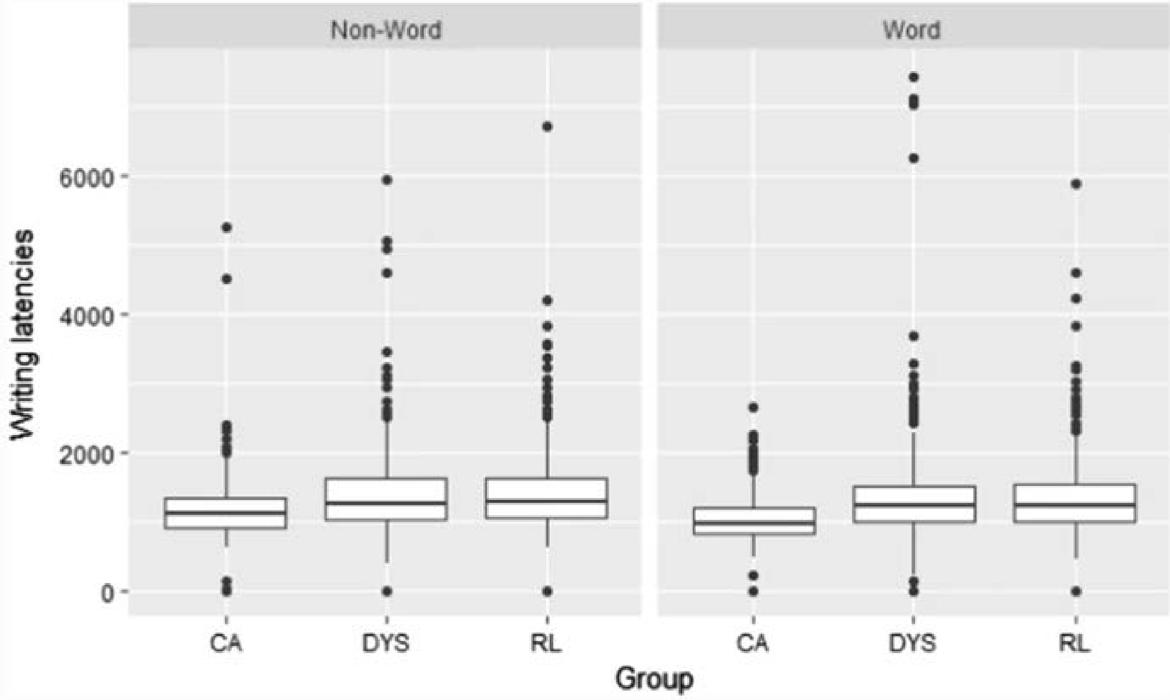


Illustration of mixed effects for writing latencies

Fig. 2

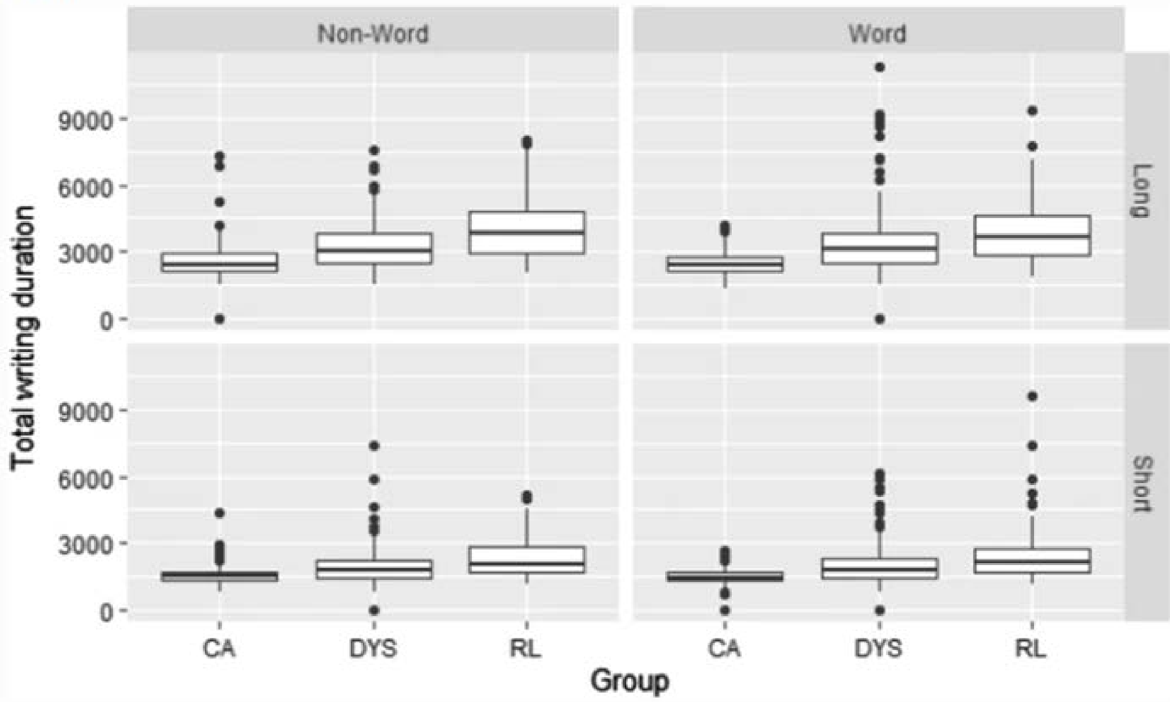
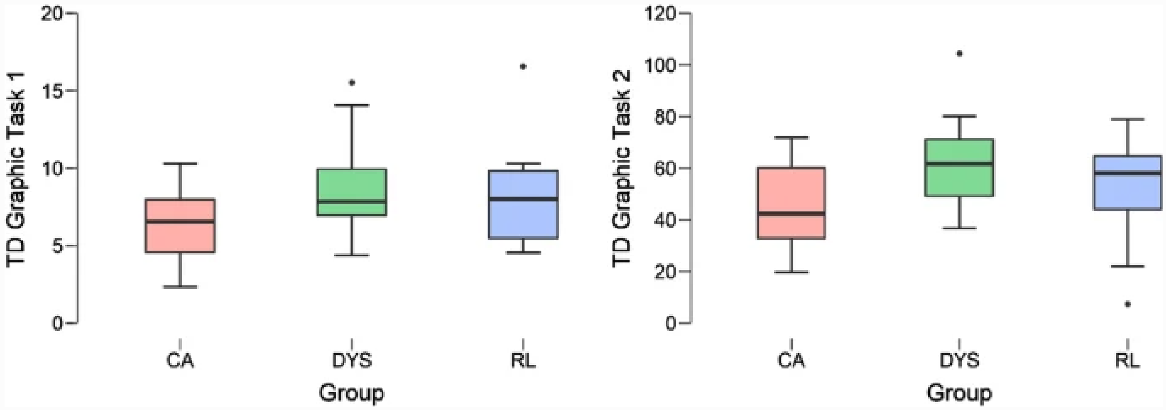


Illustration of mixed effects for Total Writing Duration

Fig. 3



Total Writing Duration in Graphic Tasks

Tables

		DYS[a] *M(SD)*	CA[b] *M(SD)*	RL[c] *M(SD)*
Age		10.17 (.71)	10.08 (.71)	8.08 (1)
Gender	Male	11	12	12
	Female	9	8	8
PROLEC-R	Reading speed (sec)	60.24 (29.62)	32.25 (6.1)	53.85 (15.56)
Words Reading	Reading accuracy (out of 40)	36.62 (2.52)	39.65 (.58)	37.8 (1.32)
PROLEC-R	Reading speed (sec)	81.81 (24.02)	49.9 (8.34)	68.45 (14.73)
Pseudowords Reading	Reading accuracy (out of 40)	31.76 (3.27)	38.35 (1.13)	35.85 (1.49)

IQ Intelligence quotient, *M* mean, *SD* standard deviation

[a]n = 20; [b]n = 20; [c]n = 20

Table 1. Demographic characteristics of controls and dyslexic children

	DYS[a] *M(SD)*	CA[b] *M(SD)*	RL[c] *M(SD)*
Spelling task			
Written latencies	1377.2 (670)	1103.8 (369.38)	1384.2 (590.94)
Total writing durations	2635.3 (1282.56)	1995.5 (723.82)	3109.09 (1392.05)
Writing speed	2862.5 (783.3)	3008.7 (843.8)	2843.9 (851.1)
Peaks of speed	17.01 (7.3)	14.7 (5.07)	18.87 (8.48)
Errors	.92 (.290)	.025 (.156)	.041 (.20)

[a]n = 20; [b]n = 20; [c]n = 20

Table 2. Scores (means and standard deviations) of the three groups of participants in spelling task

	DYS[a]	CA[b]	RL[c]
Words			
Short	0.24% (7)	0.17% (5)	0.07% (2)
Long	0.55% (16)	0% (0)	0.14% (4)
Non-Words			
Short	0.90% (26)	0.28% (8)	0.38% (11)
Long	1.32% (38)	0.38% (11)	0.80% (23)

[a]n = 20; [b]n = 20; [c]n = 20

Table 3. Distribution of writing errors

	DYS[a] *M(SD)*	CA[b] *M(SD)*	RL[c] *M(SD)*
Alphabet task			
Total durations	643.31 (834.01)	332.45 (134.44)	678.72 (619.8)
Speed	2662.7 (991.3)	3158.5 (1058.5)	3127.7 (1325.5)
Peaks of speed	3.68 (2.37)	2.71 (1.11)	4.16 (2.48)

[a]n = 20; [b]n = 20; [c]n = 20

Table 4. Scores (means and standard deviations) of the three groups of participants in alphabet task

	DYS[a] *M(SD)*	CA[b] *M(SD)*	RL[c] *M(SD)*
Graphic task 1			
Total graphic durations	8633.5 (3958.8)	6304.6 (2667.04)	8120.9 (3358.57)
Graphic speed	3226.7 (1210.8)	4345.7 (1985.8)	3232.8 (1067.2)
Peaks of speed	53.88 (27.9)	39.9 (19.9)	53.9 (22.04)
Errors	.63 (1.04)	.41 (.84)	.22 (.61)

[a] n = 20; [b] n = 20; [c] n = 20

Table 5. Scores (means and standard deviations) of the three groups of participants in graphic task 1

	DYS[a] *M(SD)*	CA[b] *M(SD)*	RL[c] *M(SD)*
Graphic task 2			
Total graphic durations	62,331 (16,302)	45,035 (16,379)	53,508 (18,788)
Graphic Speed	3267 (1023)	5023 (2825)	3931 (1913)
Peaks of speed	190 (88.6)	127 (62.5)	179 (83.4)
Errors	2.8 (2.63)	5.15 (5.25)	2.65 (3.41)

[a]n = 20; [b]n = 20; [c]n = 20

Table 6. Scores (means and standard deviations) of the three groups of participants in graphic task 2

	TD WORDS	RT WORDS	SPEED WORDS	PEAKS WORDS	ERROR TOTAL	TD_T1	SPEED T1	PEAKS T1	ERROR T1	TD_T2	SPEED T2	PEAKS T2	ERROR T2	TD_ABC	PEAKS ABC	SPEED ABC
TD WORDS		.168	− .448*	.344	.556*	.262	− .510*	.295	− .015	.565**	− .559*	.505*	− .322	.684**	.715**	− .447*
		.479	.048	.137	.011	.264	.026	.221	.950	.009	.010	.023	.166	.001	.000	.048
RT WORDS	.490*		− .201	− .186	.326	.367	− .313	.132	− .108	.277	− .268	.180	.327	.375	.207	− .006
	.028		.395	.432	.161	.111	.192	.590	.649	.237	.254	.448	.160	.103	.382	.981
SPEED WORDS	− .220	− .273		.001	.164	.053	− .015	.019	− .183	− .154	.202	− .319	.222	.038	.059	.592**
	.352	.244		.997	.489	.824	.951	.939	.440	.516	.393	.170	.347	.875	.806	.006
PEAKS WORDS	.611**	− .002	.002		.122	− .133	.138	− .137	− .028	− .132	.180	− .146	− .179	.384	.295	− .177
	.004	.994	.994		.608	.577	.572	.575	.908	.580	.448	.540	.450	.095	.207	.455
ERROR TOTAL	.107	.132	− .039	− .082		.417	− .619**	.413	− .121	.557*	− .461*	.377	.066	.734**	.763**	− .149
	.654	.578	.869	.730		.067	.005	.079	.611	.011	.041	.101	.782	.000	.000	.529
TD_T1	− .052	.013	.028	− .222	.150		− .878**	.971**	.193	.656**	− .574**	.425	− .196	.341	.257	− .070
	.827	.957	.905	.347	.529		.000	.000	.414	.002	.008	.062	.406	.142	.275	.768
SPEED T1	− .050	− .218	.109	.250	− .284	− .803**		− .865**	− .060	− .688**	.738**	− .518*	.274	− .551*	− .543*	.142
	.840	.369	.657	.301	.238	.000		.000	.806	.001	.000	.023	.257	.014	.016	.563
PEAKS T1	.062	.176	− .161	− .196	.117	.777**	− .907**		.326	.592**	− .526*	.422	− .296	.371	.321	− .124
	.801	.472	.511	.421	.633	.000	.000		.173	.008	.021	.072	.219	.118	.180	.613
ERROR T1	.056	− .218	.010	.290	− .338	− .586**	.627**	− .498*		− .158	.208	− .199	− .036	− .050	− .094	− .369
	.815	.356	.966	.214	.144	.007	.004	.030		.506	.378	.400	.881	.836	.692	.110
TD_T2	.040	.283	− .386	− .370	.139	.640**	− .703**	.686**	− .453		− .889**	.843**	− .010	.391	.439	− .259
	.874	.255	.114	.131	.582	.004	.002	.002	.059		.000	.000	.968	.088	.053	.270
SPEED T2	− .397	− .324	.293	.064	− .255	− .538*	.671**	− .645**	.498*	− .876**		− .876**	.179	− .354	− .413	.324
	.103	.190	.238	.801	.307	.021	.003	.005	.035	.000		.000	.451	.125	.070	.163
PEAKS T2	.009	.247	− .320	− .427	.076	.617**	− .635**	.613**	− .434	.971**	− .821**		− .175	.258	.337	− .364
	.971	.322	.196	.077	.763	.006	.006	.009	.072	.000	.000		.462	.272	.147	.114
ERROR T2	− .311	− .317	.082	.124	.013	− .147	.366	− .248	.398	− .537*	.718**	− .529*		− .099	− .130	.142
	.182	.173	.732	.602	.958	.538	.124	.306	.082	.022	.001	.024		.678	.585	.552
TD_ABC	.526*	.062	.174	.567*	.171	.491*	− .578*	.519*	− .276	− .048	− .153	− .124	− .019		.929**	− .231
	.025	.807	.490	.014	.497	.039	.015	.033	.268	.856	.558	.635	.941		.000	.326
PEAKS ABC	.433	− .034	.170	.448	.366	.208	− .223	.239	− .069	− .357	.125	− .391	.378	.707**		− .332
	.073	.893	.501	.062	.136	.406	.389	.357	.785	.159	.633	.121	.122	.001		.152
SPEED ABC	− .049	− .254	.850**	.122	− .149	− .067	.269	− .294	.096	− .228	.066	− .117	− .171	− .042	− .058	
	.846	.308	.000	.630	.555	.791	.297	.251	.706	.379	.801	.654	.497	.868	.819	

	TD WORDS	RT WORDS	SPEED WORDS	PEAKS WORDS	ERROR TOTAL	TD_T1	SPEED T1	PEAKS T1	ERROR T1	TD_T2	SPEED T2	PEAKS T2	ERROR T2	TD_ABC	PEAKS ABC	SPEED ABC
TD WORDS		.428	− .057	.528*	.333	.032	− .080	.079	.251	− .453	.442	− .424	.713**	.667**	.746**	− .141
		.060	.811	.017	.151	.893	.736	.740	.286	.059	.066	.080	.000	.001	.000	.552
RT WORDS			.202	.060	− .025	.198	− .230	.189	.360	− .152	.167	− .358	.372	.593**	.428	− .028
			.393	.802	.918	.403	.329	.424	.119	.548	.507	.144	.106	.006	.060	.906
SPEED WORDS				− .028	− .200	− .026	− .079	− .015	.333	.026	.176	− .019	.051	.305	.127	.072
				.906	.399	.912	.740	.948	.151	.920	.485	.940	.830	.192	.592	.762
PEAKS WORDS					.311	.058	− .150	.188	.012	− .161	.125	− .095	.291	.517*	.745**	− .132
					.182	.809	.528	.428	.961	.523	.622	.707	.213	.020	.000	.579
ERROR TOTAL						.171	− .191	.224	− .075	− .003	− .133	.012	.061	.233	.334	− .402
						.470	.420	.343	.753	.991	.599	.963	.799	.322	.150	.079
TD_T1							− .826**	.927**	− .183	.465	− .458	.437	− .179	.088	.060	.088
							.000	.000	.440	.052	.056	.070	.451	.711	.803	.712
SPEED T1								− .908**	.362	− .552*	.608**	− .519*	.212	− .329	− .282	.270
								.000	.117	.018	.007	.027	.368	.156	.229	.249
PEAKS T1									− .354	.437	− .507*	.467	− .158	.205	.209	− .111
									.126	.070	.032	.051	.506	.385	.378	.641
ERROR T1										− .430	.624**	− .547*	.321	.073	.063	.350
										.075	.006	.019	.168	.760	.791	.130
TD_T2											− .811**	.933**	− .616**	− .158	− .202	− .204
											.000	.000	.007	.532	.422	.418
SPEED T2												− .832**	.715**	.119	.121	.368
												.000	.001	.639	.633	.133
PEAKS T2													− .605**	− .203	− .184	− .186
													.008	.420	.466	.460
ERROR T2														.546*	.511*	.144
														.013	.021	.545
TD_ABC															.922**	− .356
															.000	.123
PEAKS ABC																− .390
																.089
SPEED ABC																

Above diagonal for children with dyslexia and under diagonal for chronological age controls. *TD* total duration; *RT* reaction time; *T1* graphic task 1; *T2* graphic task 2; *ABC* alphabet task

Above diagonal for reading level controls. *TD* total duration; *RT* reaction time; *T1* graphic task 1; *T2* graphic task 2; *ABC* alphabet task

*$p < .05$. **$p < .001$

Table 7. Correlation matrix among all the tasks [2 preceding images]