Research in Developmental Disabilities 35 (2014) 2894–2905

Contents lists available at ScienceDirect

Research in Developmental Disabilities

An examination of writing pauses in the handwriting of children with Developmental Coordination Disorder

Mellissa M. Prunty [a,*], Anna L. Barnett [b], Kate Wilmut [b], Mandy S. Plumb [b]

[a] *Brunel University, Division of Occupational Therapy, Uxbridge, Middlesex UB8 3PH, UK*
[b] *Oxford Brookes University, Department of Psychology, Social Work & Public Health, Gipsy Lane, Oxford OX3 0BP, UK*

ARTICLE INFO

Article history:
Received 10 June 2014
Accepted 14 July 2014
Available online 7 August 2014

Keywords:
Developmental Coordination Disorder (DCD)
Handwriting
Pausing
Handwriting speed
Detailed Assessment of Speed of Handwriting (DASH)

ABSTRACT

Difficulties with handwriting are reported as one of the main reasons for the referral of children with Developmental Coordination Disorder (DCD) to healthcare professionals. In a recent study we found that children with DCD produced less text than their typically developing (TD) peers and paused for 60% of a free-writing task. However, little is known about the nature of the pausing; whether they are long pauses possibly due to higher level processes of text generation or fatigue, or shorter pauses related to the movements between letters. This gap in the knowledge-base creates barriers to understanding the handwriting difficulties in children with DCD. The aim of this study was to characterise the pauses observed in the handwriting of English children with and without DCD. Twenty-eight 8–14 year-old children with a diagnosis of DCD participated in the study, with 28 TD age and gender matched controls. Participants completed the 10 min free-writing task from the Detailed Assessment of Speed of Handwriting (DASH) on a digitising writing tablet. The total overall percentage of pausing during the task was categorised into four pause time-frames, each derived from the literature on writing (250 ms to 2 s; 2–4 s; 4–10 s and >10 s). In addition, the location of the pauses was coded (within word/between word) to examine where the breakdown in the writing process occurred. The results indicated that the main group difference was driven by more pauses above 10 s in the DCD group. In addition, the DCD group paused more within words compared to TD peers, indicating a lack of automaticity in their handwriting. These findings may support the provision of additional time for children with DCD in written examinations. More importantly, they emphasise the need for intervention in children with DCD to promote the acquisition of efficient handwriting skill.

1. Introduction

Developmental Coordination Disorder (DCD) is the term used to refer to children who present with motor coordination difficulties, unexplained by a general medical condition, intellectual disability, sensory or neurological impairment (American Psychiatric Association [APA], 2013). Handwriting difficulties are mentioned in the formal diagnostic criteria for DCD (APA, 2013), are frequently mentioned in parent and teacher reports and are the most common reason for referral to

* Corresponding author. Tel.: +44 01895268843.
E-mail address: mellissa.prunty@brunel.ac.uk (M.M. Prunty).

http://dx.doi.org/10.1016/j.ridd.2014.07.033

occupational therapy services for this population (Asher, 2006). While a knowledge base surrounding their handwriting deficits has emerged in recent years (Jolly & Gentaz, 2013; Prunty, Barnett, Wilmut, & Plumb, 2013; Rosenblum & Livneh-Zirinski, 2008), the underlying mechanisms of the handwriting deficits are still unclear. In particular, there is a limited understanding of the excessive pausing during handwriting reported in this population (Rosenblum & Livneh-Zirinski, 2008). This creates barriers for healthcare professionals in terms of prescribing intervention, as it is unclear what the pausing behaviour in the handwriting process actually represents. In a recent study we found that children with DCD produced less text than their typically developing (TD) peers in four handwriting tasks from the Detailed Assessment of Speed of Handwriting (DASH; Barnett, Henderson, Scheib. & Schulz, 2007; Prunty et al., 2013). However, closer inspection of the handwriting process through the use of a digital writing tablet revealed that the slowness in production was not due to slower movement of the pen, but due to a higher percentage of the task spent pausing (with the pen either in the air, or resting on the page) (Prunty et al., 2013). This 'pausing phenomenon' in the handwriting of children with DCD was initially revealed in a study in Israel by Rosenblum and Livneh-Zirinski (2008), where children with DCD were found to spend considerably more time than controls with the pen in the air. However, beyond the findings of these studies, little is known about the behaviour of pausing and the possible cognitive or physical explanations for why they occur in the handwriting of children with DCD. It is imperative to understand this pausing behaviour, as it has been shown to significantly impact on the production of text in children with DCD (Prunty et al., 2013).

The concept of 'pausing' during writing is complex in nature and cannot be considered without recognising handwriting as a component of the writing process. Handwriting is 'language by hand' (Berninger & Graham, 1998; Berninger, Abbott, Abbott, Graham, & Richards, 2002) and there are many cognitive processes which occur before, during and after the pen is placed on the page (Kandel, Soler, Valdois, & Gros, 2006; Van Galen, 1991). Van Galen's (1991) psychomotor model of handwriting which informs the current investigation illustrates this, by describing the process from the transformation of language into the sequencing of handwriting movements. At the highest level of the model is the activation of the intention to write followed by semantic retrieval, syntactical construction and spelling. The first step in the motor process is to select the appropriate allograph, which according to Van Galen (1991) is the activation of the motor programme (retrieval of an allograph action pattern from long-term motor memory). Following the activation of the motor programme the module of size control and speed is activated (Van Galen, 1991). The muscle synergies from both the agonist and the antagonistic muscles are then recruited during the muscular adjustment module, which results in the real time movement of the pen (Van Galen, 1991). Van Galen's model of handwriting, although the most complete in the literature, is not without limitations. According to Kandel and Spinelli (2010) it fails to account for parallel processing at different levels of the model, which results in an increased duration of the handwriting movements. In addition, research by Kandel, Soler, Valdopis and Gros (2006) in French writers has demonstrated that letters are not programmed individually, but rather in chunks, and the temporal profile is determined by the number of syllables in the word. This emphasises the relationship between the production of handwriting and the cognitive and linguistic aspects of writing and must be accounted for when examining pausing behaviour in more detail.

The definition of a pause in writing is inconsistent in the literature. Rosenblum and Livneh-Zirinski (2008) defined a pause as a pen lift from the writing tablet. However, it was not clear as to how long the pen needed to be raised from the surface in order to be classified as a pause. In the writing literature Alamargot, Chesnet, Dansac, and Ros (2006) and Alamargot, Plane, Lambert, and Chesnet (2010) defined a pause as a period of 15 ms or more with the pen not in contact with the tablet. The rationale for such a short pause threshold was to include all writing events that occurred; including raising the pen to think of an idea or briefly to dot an '*i*'. Other authors have omitted to define a pause and made reference only to the fact that pauses occurred during the writing task (Accardo, Genna, & Borean, 2013). In addition to the debate on how pauses are classified, it is also unclear even in the literature on writing what exactly a pause represents. Thus, the pause thresholds used in the current study are grounded in evidence where possible, while some aspects of the analysis are exploratory in nature.

In relation to pausing in children with DCD, Rosenblum and Livneh-Zirinski (2008) proposed anomalies in the lower level processes of handwriting, such as between stroke muscular adjustments, as reasons for excessive pausing. Alternative explanations for the excessive pausing include physiological factors such as fatigue (Rosenblum & Livneh-Zirinski, 2008). However, none of these theories have been tested and it remains unclear whether children with DCD pause excessively for short periods of time (i.e. <1 s), or whether they pause for longer periods possibly as an indication of fatigue or higher-level writing processes such as planning (i.e. >4 s). In a study by Alamargot et al. (2010) on French writers it was found that longer pauses possibly reflected processes such as planning. In their study, five participants with varying levels of writing expertise were asked to compose a text by extending a narrative provided to them. There were no time constraints and they were asked to write as much as they felt was necessary to finish the story. The participants included three school students, one in grade 7 (12 years old), one in grade 9 (14 years old) and the third in grade 12 (17 years old). The remaining two participants included a university graduate student (22 years old) and an established expert author. The writing task was completed on a writing tablet and eye-tracking was used to infer processes that occurred during pauses in the writing. Alamargot et al. (2010) analysed four types of pausing activity for each writer which they labelled as 'quartiles'. The quartiles consisted of pauses between 78 and 189 ms, 129 and 416 ms, 194 and 624 ms, 695 and 23,248 ms. The participant in grade 7 had the most pauses in quartile 4 (longer pauses) compared to the other four writers. In fact, the 7th grade writer had pauses as long as 13–18 s at times. According to Alamargot et al. (2010) the longer pauses were due to a strategy known as step-by-step production of text, where the child switches between planning and formulation of the text to cope with the cognitive demands of handwriting. Indeed as the level of writing expertise increased, the number of longer pauses decreased substantially. Using eye-tracking Alamargot et al. (2010) were able to investigate the longer pauses based on gaze fixations. These were classified based on whether the participant was looking back at text, looking at the handwriting area or looking away from the task. They found that the least experienced writers were inclined to look away from the task, which according to Alamargot et al. (2010) was an indication of planning. Despite the detailed analysis of pausing in typically developing children, the nature of pausing has not been investigated in the handwriting of children with DCD and knowing whether the pauses are driven by many pauses of small duration or a few of longer duration is needed to inform approaches to intervention.

Another issue alongside the duration of pauses is their location within text. Previous research by Kandel et al. (2006) on children found that words tend to be programmed prior to execution, followed by online processing during the execution phase. According to Alamargot et al. (2010) if the cognitive demands of handwriting exceed working memory capacity, the word cannot be processed online, therefore a pause occurs within the word. The pause would allow the information to be processed before completing the next word segment (Alamargot et al., 2010). Indeed issues with word level pausing have been found in other developmental disorders, where children with dyslexia paused for greater periods within words and particularly around misspellings (Sumner, Connelly, & Barnett, 2012; Sumner, 2013). According to Sumner (2013), this was indicative of difficulties at the word level due to the constraints that spelling difficulties had on word processing. Although spelling difficulties are distinctly different to motor difficulties, both spelling and handwriting form the basis of transcription skills in models of writing and handwriting (Berninger & Amtmann, 2003; Van Galen, 1991). According to Kandel et al. (2006) both spelling and motor planning for handwriting are processed prior to writing the word and online thereafter. It is therefore plausible that the motor difficulties associated with DCD would manifest in a within word pause, similar to that of dyslexia, as the child would be unable to plan words online given the strain of the handwriting on cognitive resources. Prunty et al. (2013) hypothesised that a lack of automaticity in the handwriting of children with DCD contributed to the lack of production of text. Indeed examining whether children with DCD pause within words would be a method of examining automaticity of handwriting and their ability to manage cognitive processes in parallel. Exploring this area in more detail would provide a better description of the handwriting process in children with DCD and in doing so inform an evidence base to support the provision of intervention in this group. Therefore the aim of this study was to investigate the pausing behaviour demonstrated by the same group of children with DCD in Prunty et al. (2013) compared to their TD peers. To do so, their pausing behaviour on a 10 min free-writing task was analysed and categorised using four time-frames chosen from the available literature on handwriting in DCD and writing.

Since children with DCD have motor difficulties, it was hypothesised that the DCD group would pause for a greater percentage of time within smaller time-frames due to possible difficulties manipulating the pen to form the letters. In addition, it was anticipated that the DCD group would also pause more within-words as a result of the lack of automaticity in their handwriting. Additional measures of pause frequency and mean pause duration were also examined separately to compare findings from previous studies on the handwriting process in children (Alamargot et al., 2010; Rosenblum & Livneh-Zirinski, 2008).

2. Methods

2.1. Participants

Twenty eight children with DCD (27 boys, 1 girl) and 28 age (within 4 months) and gender matched typically developing (TD) controls were included in the study.

2.1.1. DCD group

All children met the DSM-5 diagnostic criteria for DCD (APA, 2013) and a diagnostic assessment was in line with recent European guidelines (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012). The children had significant motor difficulties, with performance below the 10th percentile (24 below the 5th, 4 below the 10th) on the Movement Assessment Battery for Children 2nd edition Test (MABC-2; Henderson, Sugden, & Barnett, 2007) which examines three components of motor competency; manual dexterity, ball skills and balance. These motor difficulties had a significant impact on their activities of daily living, as reported by their parents and evident on the MABC-2 Checklist (Henderson et al., 2007). A developmental, educational and medical history was taken from the parents, which confirmed that there was no history of neurological or intellectual impairment and no medical condition that might explain the motor deficit. The British Picture Vocabulary Scale 2nd edition (BPVS-2, Dunn, Dunn, Whetton, & Burley, 1997) was used to give a measure of receptive vocabulary, which correlates highly with verbal IQ (Glenn & Cunningham, 2005). This was in at least the average range for all children, confirming the absence of a general intellectual impairment. The Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) was also used to note other behavioural difficulties reported by the parent, which commonly occur with DCD such as attention deficit hyperactivity disorder (ADHD) (Miller, Missiuna, Macnab, Malloy-Miller, & Polatajko, 2001). No child had a diagnosis of ADHD, but hyperactive behaviour was noted on the SDQ for seven children. The children were also assessed on the reading and spelling components of the British Ability Scales 2nd Edition (BAS-II; Elliott, 1996). These revealed that eight children with DCD had literacy difficulties (1 in reading, 7 in spelling), as defined by a standard score of less than 85 on the BAS-II components, although none had a formal diagnosis of dyslexia or other language impairment.

Table 1
Mean (SD) age and performance scores for DCD and TD groups on selection measures.

Selection measures	DCD $n = 28$	Control $n = 28$	p
Age in years	10.61 (2.23)	10.95 (2.12)	.441
MABC-2 test percentile	3.45 (2.96)	43.37 (25.4)	<.001*
- Manual dexterity	6.41 (8.12)	51.07 (26.82)	<.001*
- Aiming and catching	21.55 (23.64)	64.67 (20.41)	<.001*
- Balance	5.98 (4.67)	30.42 (19.85)	<.001*
BPVS standard score	108.9 (14.4)	110 (12.2)	.655
BAS-spelling standard score	95.8 (13.7)	111 (12.7)	<.001*
BAS-reading standard score	109.5 (13.8)	122 (12.6)	.001*

MABC-2: Movement Assessment Battery for Children test component. BPVS: British Picture Vocabulary Scale, BAS: British Ability Scale.
* $p \leq .050$.

2.1.2. Typically developing (TD) control group

The control group was recruited through local primary and secondary schools in Oxfordshire, England. Teachers were asked to use their professional judgement to identify children without any motor, intellectual or reading/spelling difficulties. To ensure the children identified were free of these difficulties, they were individually tested on the MABC-2 Test (Henderson et al., 2007), BPVS-2 (Dunn et al., 1997) and the reading and spelling components of the BAS-II (Elliott, 1996). Children were included in the control group if they scored at least at the level expected for their age on all measures.

Children from both groups with a diagnosis of dyslexia, and/or those who had English as a second language were excluded from the study. Children in both groups who had a reported physical, sensory or neurological impairment were also excluded. This was to ensure that handwriting difficulties could not be attributed to other disorders. See Table 1 for performance profiles of both groups.

The study was approved by the University Research Ethics Committee at Oxford Brookes University. Parents were required to sign a consent form and children were asked to either assent (below 11 years), or counter sign the parent consent form (over 11 years). The handwriting component of this study took place over one 60-min session.

2.2. Measures

2.2.1. The handwriting task

2.2.1.1. The detailed assessment of speed of handwriting (DASH; Barnett et al., 2007). The free-writing task from the DASH (Barnett et al., 2007) was chosen for an extended analysis of pausing data presented in Prunty et al. (2013). This is an ecologically valid task in terms of its similarity and relevance to handwriting demands in the classroom. Free-writing involves the integration of all aspects of the writing process including idea generation, production of language, spelling and handwriting. Examining the pauses in the context of a free-writing task provides an overall view of the child's ability to cope with the demands of the writing system at work. It also provides an opportunity to examine whether the writing process is forced to succumb to high cognitive loading by imposing pauses where text would have otherwise been processed online.

The DASH free-writing task requires the child to write about the topic of 'my life' for 10 min using their everyday handwriting. They are presented with a spider diagram prior to the beginning of the task which provides topics that they could write about. They are then given 1 min to plan their writing and are asked to write continuously once the task starts (Barnett et al., 2007). The handwriting product scores for the DCD and TD groups on this measure have been previously reported by Prunty et al. (2013). The DASH has UK norms for children aged 9–16 years. The internal reliability of the total score is between $\alpha = .83–.89$ and the inter-rater reliability for all four tasks is .99, as reported in the test manual.

2.2.2. The pausing analysis

2.2.2.1. Procedure. When completing the DASH free-writing task the participants wrote with an inking pen on paper placed on a Wacom Intuos 4 digitising writing tablet (325.1 mm × 203.2 mm) to record the movement of the pen during handwriting. The writing tablet transmits information about the spatial and temporal data of the pen as it moves across the surface. The data was sampled at 100 Hz via a Celeron Dual Core CPUT3500@2.10GHz laptop computer. Eye & Pen version1 (EP1) software (Alamargot et al., 2006) was used to analyse the pauses.

The pauses were examined in three separate analyses in order to address independent questions. The rationale for the three analyses is provided below and included the following:

1. The categorisation of pauses into time-frames and taken as a percentage of the overall pause time.
2. An analysis of the location of pauses to ascertain where in the writing process the pauses occurred.
3. An examination of the frequency and duration of pauses.

1. Categorising the pauses

The first analyses included the categorisation of pauses into time-frames to examine the pauses which attributed to the overall percentage of pause time. The analyses included an examination of the following.

Pausing at the letter level

The first analysis in categorising the pauses examined short pauses of between 30 and 250 milliseconds (ms). This time-frame was chosen from the literature, as it is thought to represent the graphomotor component of handwriting. Alamargot et al.'s (2010) study mentioned above established a link between short pauses and graphomotor execution, particularly in pauses between 78 and 189 ms. However, it is not clear from the literature exactly what is meant by 'graphomotor' activity. It could include for example, the transition between individual letters, or a split second pause between letter strokes. Nevertheless, short pauses are thought to represent the pauses that occur specifically at the letter level. Since the study by Alamargot et al. (2010) included a small sample size of five participants ranging from a novice, grade 6 writer to an expert published author, the time-frame for letter level pauses was adjusted to 30–250 ms for the current analysis to capture variation in the writing process of children.

The second time-frame used to examine between letter pauses was 250 ms to 2 seconds (s). This was chosen based on previous research by Rosenblum and Livneh-Zirinski (2008), where children with DCD were found to pause for longer between letter strokes. Rosenblum and Livneh-Zirinski (2008) reported in-air time (pause time) ranging from .37 s to 1.27 s on the alphabet task, suggesting that this was the pause time which occurred between letters. Given the difference in the production of Hebrew and Latin based letters a 250 ms to 2 s time-frame was used to capture any variation due to kinematic differences in the production of Latin based letters. The pauses between 250 and 2 s were analysed and calculated as a percentage of the overall pause time.

Pausing at the word-level

To examine word level pauses, the time frame for analysis was between 2 and 4 seconds (s). This was chosen from the literature on writing, where a 2 s pause in typically developing (Alamargot et al., 2010; Alves et al., 2007; Wengelin, 2007) and atypically developing (Sumner, 2013) writers is considered to represent a pause from formulating the text in order to access a higher-level writing process such as planning It was important to capture pauses at or above 2 s to examine pauses at the word level. However, it was also important to restrict the pause time-frame to below 4 s, so lengthy pauses possibly due to fatigue could be measured separately.

Long pauses

Two time-frames were analysed for the longest pauses in writing. A pause that was between 4 and 10 s was considered to represent a higher level writing process (generating ideas) or resting due to fatigue. A pause above 10 s was considered to be a significant halt in the writing activity, possibly due to fatigue or a lack of writing ideas. Alamargot et al. (2010) found that the younger, 6th grade writer paused at times for over 10 s which they hypothesised as representative of planning during writing.

2. Location of pauses

The second set of analyses examined the location of pauses in order to evaluate the breakdown in the writing process in greater detail. The analyses included an examination of the following.

Word level pauses

All pauses above 2 s were analysed to examine pauses at the word level. This is the threshold previously used to explore the issue of word level pausing in relation to spelling difficulties in children with dyslexia (Sumner, 2013).

Between word pauses

For the calculation of between-word pauses, the total number of opportunities to pause between words was always one less than the total words produced. For example, if a child produced 60 words, there were 59 opportunities to pause between words. Since the children with DCD produced fewer words (M = 119.60 SD = 59.59) than the TD group words (M = 156.53 SD = 43.65) (see Prunty et al., 2013), the between-word pauses and within-word pauses were analysed as a percentage of each participants' word count. When coding a between word pause, if a child paused twice between two words, only one of them was coded as a between-word pause '1′, the other was labelled as miscellaneous '−1'. This was to differentiate between pauses due to programming the following word versus those used to revise or edit previously written text.

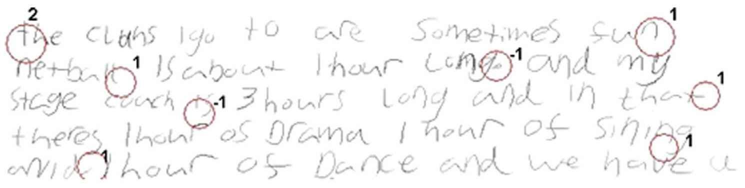
Within word pauses

Paueses that occurred at or above 2 s were examined and coded as within word pauses where appropriate. Not every pause was coded. For example, if a child paused more than once in a word then only one pause was coded, the rest were coded as miscellaneous, '−1'. Similar to between word pausing, this was to differentiate between pauses due to programming the remainder of the word versus those used to edit previously written text. Equally if a child finished writing a word and paused to go back and dot an '*i*' this was also coded as '−1' as it was not considered to be a between word or within word pause (i.e. it was not considered to be planning the execution of the next word). Also, if a child paused within a word to go back and edit a previous word and then paused within the previous word during the edit, only one pause was coded, the rest were coded as '−1'.

The pauses within words were also coded based on the accuracy of spelling and legibility. Pauses within correctly spelled words were coded as '2', pauses within misspelled words were coded as '3' and pauses within illegible words (identified by DASH scoring instructions) were coded as '4'. The amount of time spent over 2 s within these locations were calculated as a percentage of overall pause time (Fig. 1).

Longer 10 s pauses

The longer pauses were divided into two categories to distinguish between those related to fatigue and those related to a lack of ideas for writing. To do so, the pauses over 10 s that occurred within a sentence or writing topic/idea were identified and were coded as '1', suggesting that the child had already generated ideas to write about. In this instance, having to stop



Note. -1= miscellaneous: pausing within a full stop, or pausing to go back and dot an 'i', 1= Between word pause, 2= Within a correctly spelled word

Fig. 1. The Eye and Pen coding used to extract within word and between word pauses (10 year old boy with DCD).

within a sentence may indicate fatigue. The code '2' was assigned to a pause over 10 s that occurred between the end of a writing topic and the beginning of a new one. A pause before a new topic of writing would perhaps suggest that the pre-writing pause was due to planning. Fig. 2 illustrates an example of code '1' and '2'.

3. Frequency and duration of pauses

The third and final set of analyses included an examination of behaviours reported in the literature on writing and to report their presentation in children with DCD. The analyses included an examination of the following.

<u>Frequency of pausing</u>

The frequency of pausing was also considered here as Alamargot et al. (2010) found no difference in the frequency of pausing between a novice writer and an expert author. However, it is not known whether children with DCD demonstrate similar frequencies of pausing compared to TD children. It remains unknown whether their pausing behaviour is driven by the length of their pauses rather than the frequency. Therefore, the frequency of pauses was calculated for three time-frames, those over 250 ms (letter level based on Rosenblum & Livneh-Zirinski, 2008 and above), between 4 and 10 s (longer pauses possibly due to planning) and those over 10 s (longer pauses possibly due to planning or fatigue).

<u>Mean pause duration</u>

The mean pause duration over 2 s was examined in order to ascertain whether children with DCD paused for longer on average *during a word level pause* compared to their TD peers. This analysis was based on Rosenblum and Livneh-Zirinski (2008) where children with DCD demonstrated a longer mean pause duration than TD peers. However, it is not known whether this is the case within English children with DCD.

2.3. Statistical analysis

For comparisons between the DCD group and TD group, tests of normality were conducted initially and descriptive statistics for the dependent variables examined. *T*-tests were used to examine the differences in the mean values between the groups for all normally distributed measures. Those measures which did not meet the normal distribution assumptions were compared using the nonparametric Mann–Whitney-*U* test. Since age was often a significant co-variate for the handwriting product measures in our previous work (Prunty et al., 2013) and many variables in the pausing analysis violated normal distribution, Spearmans bivariate correlations were used to examine the relationship between age and the pausing measures. Both groups were analysed together and separately with a significance level set at $p < .05$. Regression analyses were undertaken for children with DCD to ascertain what factors best predict pausing behaviour.

In order to ensure that any difficulties with reading and/or spelling did not influence the results, a sub analysis of the DCD group was undertaken prior to the main analyses. Results for the 20 children from the DCD group with at least average reading and spelling scores were compared to the eight children with poor reading and/or spelling (standard scores below 85). There was no significant difference between these two groups in any of the pausing analyses; therefore the two groups were combined to form one DCD group for all subsequent analyses. A similar sub-analysis was completed for those children who demonstrated slightly raised profiles on the SDQ for attention. However there was no significant effect of group for any of the pause analysis therefore the children were combined into one DCD group ($n = 28$).

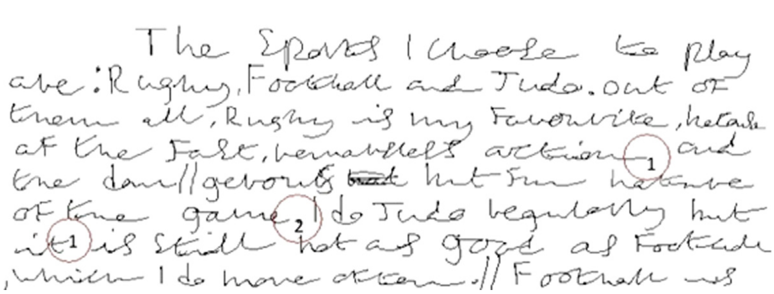


Fig. 2. The Eye and Pen coding used to extract within idea pauses over 10 s (1) and before a new idea pause over 10 s (2). (13 year old boy with DCD).

Table 2
Mean (SD) and percentage pause times for the DCD and TD groups within each time frame.

	DCD $n = 28$	TD $n = 28$	p
Total overall pause time (min)	5.96 (1.30)	5.36 (0.87)	.023*
Pause time between 30 and 250 ms (min)	1.20 (0.94)	1.06 (0.51)	.935
Percentage of pause time between 30 and 250 ms	21%	20%	.721
Pause time between 250 ms and 2 s (min)	2.19	2.38	.380
Percentage of pause time between 250 ms and 2 s	37%	46%	.032*
Pause time between 2 and 4 (s) (min)	.86 (0.38)	.80 (0.30)	.844
Percentage of pause time between 2 and 4 s	14%	15%	.272
Pause time between 4 and 10 (s) (min)	.85 (1.30)	.80 (0.86)	.676
Percentage of pause time between 4 and 10 s	14%	14%	.874
Pause time above 10 (s) (min)	0.86	0.32	.029*
Percentage of pause time above 10 s	14%	5%	.032*

* $p \leq .050$.

3. Results

1. Categorising the pauses

Table 2 illustrates the total overall pause time for each group during the 10-min free-writing task along with the breakdown of each pause time-frame for both groups. The total pause time and breakdown of pauses within specific time-frames are reported in minutes. There was a significant group difference for the overall total pause time ($t(54) = 2.34$, $p < .023$), as previously reported by Prunty et al. (2013).

Pausing at the letter level

There was no effect of group for the amount of time ($U = 387.0$, $Z = -.082$, $p = .935$) or percentage of pause time spent pausing within the 30–250 ms range ($t(54) = .359$, $p = .721$).

For the 250 ms to 2 s time-frame there was no effect of group for the amount of time spent pausing within this time-frame ($t(54) = -.887$, $p = .380$). However, there was a significant effect of group for the percentage of overall pause time, with a greater percentage of pausing for the TD group ($t(54) = -2.21$, $p = .032$).

Pausing at the word-level

There was no significant group difference for the time spent pausing at the word level ($U = 380.0$, $Z = -.197$, $p = .844$) or the percentage of overall pause time attributed to pauses between 2 and 4 s ($U = 325.0$, $Z = -1.09$, $p = .272$).

Long pauses

There was no significant group difference for the amount of time spent pausing between 4 and 10 s, ($t(54) = .420$, $p = 676$) or for the percentage of pausing within this time frame ($t(54) = -.160$, $p = 874$).

The DCD group paused for significantly longer over 10 s ($U = 323.5$, $Z = -2.19$, $p = .029$) and a greater percentage of their pausing occurred above 10 s compared to the TD group ($U = 265.5$, $Z = -2.14$, $p = .032$).

Fig. 3 highlights all pauses above 250 ms in the writing of a 13 year old male participant with DCD. Fig. 4 highlights the same pauses but in a typically developing male participant. The figures illustrate that both participants have a high frequency of pauses. The difference is in the size of the circles, as larger circles indicate longer pauses. Fig. 3 illustrates a higher percentage of longer pauses.

2. Location of pauses

Word level pauses

Between word pauses

There was no significant group difference in the time spent pausing between words ($U = 303.5$, $Z = -1.45$, $p = .147$) or the percentage of between word pauses ($U = 326.0$, $Z = -1.08$, $p = .279$).

Within word pauses

The DCD group paused within 22% of the words produced during the free-writing task, compared to 16% for the TD group. However, this difference was not statistically significant ($U = 299.0$, $Z = -1.52$, $p = .127$). In terms of the duration of time spent pausing, there was a significant group difference in within word pausing when all three categories were combined (within

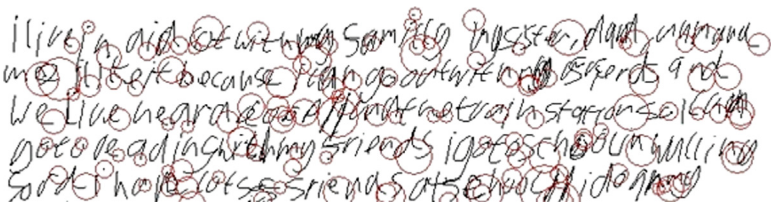


Fig. 3. A view of all pauses over 250 ms for a boy with DCD aged 13.02 years in the first 4 min of the DASH free-writing task. Pauses are shown as circles on the text.

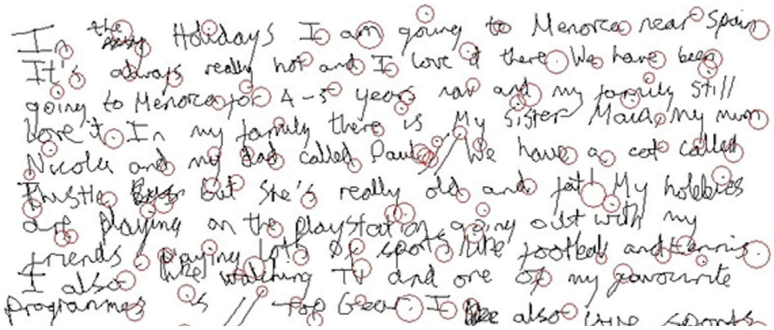


Fig. 4. A view of all pauses over 250 ms for a typically developing boy aged 13.02 years in the first 4 min of the DASH free-writing task.

correctly spelled words, misspelled words and illegible words) ($t(54) = 2.28$, $p = .026$). Individually, there was no significant effect of group for the duration of time spent pausing within correctly spelled words ($U = 363.5$, $Z = -.468$, $p = .640$) or misspelled words ($U = 322.0$, $Z = -1.55$, $p = .121$), but there was a significant effect of group for within illegible word pauses ($U = 270.0$, $Z = -2.08$, $p = .037$). Table 3 illustrates the duration of pauses within words and also shows the percentage of overall pause time spent within words and the locations of word level pausing.

Longer 10 s pauses

Sixty-eight percent of children with DCD had pauses of over 10 s compared to 50% of the TD group. There was a significant effect of group for the location of pauses, as the DCD group paused more frequently within an idea compared to the TD group ($U = 230.5$, $Z = -2.885$, $p = .004$). In terms of pausing to think of new ideas, there was no significant effect of group for 10 s pauses before a new topic of writing ($U = 342.0$, $Z = -.948$, $p = .343$). A Wilcoxon signed-rank test revealed that the DCD group produced more of their 10-s pauses within an idea ($Z = 2.78$, $p = .006$), whereas there was no distinction between pause locations within the TD group ($Z = -.162$, $p = .871$).

3. Frequency and duration of pauses

Frequency of pausing

There was no effect of group for frequency of pausing above 250 ms ($U = 363.5$, $Z = -.467$, $p = .640$) or above 4 s ($U = 265.0$, $Z = -1.12$, $p = .260$) but there was a significant group difference for frequency of pausing over 10 s ($U = 258.0$, $Z = -2.27$, $p = .023$).

Mean pause duration

For mean pause duration, there was a significant group difference, as children with DCD paused for longer with a mean pause duration of 5.33 s ($SD = 1.90$) ($Mdn = 5$) compared to 4.15 s ($SD = 1.16$) ($Mdn = 4$) ($U = 265.0$, $Z = -2.081$, $p = .037$).

3.1. Correlations between age and pausing measures

Table 4 shows the Spearmans bivariate correlations that examined the relationship between pausing and age (years and months). As can be seen, for children with DCD and their TD peers, pause time over 4 s, mean pause duration and frequency of pausing over 10 s were all significantly negatively related to age. In addition, for children with DCD a significant negative correlation was found between age and the time spent pausing within misspelled words. A significant positive relationship was found between age and time pausing between 250 ms and 2 s for the TD group only indicating that as TD children

Table 3
Mean (SD) and percentage of between and within-word pauses for the DCD and TD groups.

	DCD $n = 28$	TD $n = 28$	p
Between word pauses			
Total duration of BWP (min)	2.00 (1.17)	1.49 (.80)	.147
Percentage of pausing due to BWP	32%	27%	.279
Within word pauses			
Total duration of WWP (min)	.29 (.26)	.16 (.12)	.026*
Percentage of time pausing due to WWP	5%	3%	.070
Breakdown of within word pausing			
Percentage of WWP in correctly spelled words	2%	2%	.640
Percentage of WWP in misspelled words	1%	.5%	.121
Percentage of WWP in illegible words (%)	2%	.5%	.037*

Note. BWP = between word pauses, WWP = within word pauses.
* $p \leq .050$.

Table 4
Correlations between age and pausing measures for the DCD and TD groups.

	DCD ($n = 28$)	TD ($n = 28$)
Time pausing between 250 ms and 2 s	.41	.41*
Time pausing over 4 s	−.50**	−.44*
Time pausing within misspelled words (ms)	−.49**	−.12
Mean pause duration (s)	−.49**	−.43*
Frequency of pauses over 250 ms	.36	−.24
Frequency of pauses over 10 s	−.45**	−.39*

Note.
* $p < 05$.
** $p < 001$ (two-tailed).

Table 5
Regression analysis: predictors of frequency of pauses over 10 s.

	Standardised coefficients		Unstandardised coefficients	p
	Beta	Standard error		
Age	−.37	.190	−.42	.034*
Manual dexterity	−.38	.242	−.56	.028*

Note.
* $p < 05$.

increase in age, the amount of time pausing within 250 ms to 2 s increases. The measure of frequency of pauses over 250 ms revealed no significant correlations for either of the two groups.

3.2. Regressions

Regression analyses were undertaken for children with DCD to ascertain what factors best predict the frequency of pausing over 10 s. Spelling ability was included due to the close relationship between spelling and handwriting in models of writing (transcription skills). Although the participants were closely matched for age, age was entered into this regression due to the wide age range of participants and the correlation shown between age and frequency of 10 s pauses. In addition, manual dexterity as measured by the manual dexterity component of the M-ABC-2 test was included to see if this explained any of the variance. The regression model was a predictor of frequency of pauses above 10 s in the DCD group, $R^2 = .32$, adjusted $R^2 = .27$, $F(2, 25) = 5.98$, $p = .008$. It was found that age significantly predicted frequency of 10 s pauses ($\beta = -.372$, $p = .034$), as did manual dexterity ($\beta = -.387$, $p = .028$) indicating that better manual dexterity was associated with a decrease in the frequency of pauses. Coefficients can be found in Table 5.

4. Discussion

Until now, the most detailed studies on handwriting in children with DCD were those of Rosenblum and Livneh-Zirinski (2008) and Prunty et al. (2013), where children with DCD were found to spend considerable extra time pausing, compared to their typically developing peers. However, information was lacking on the exact nature of the pausing in children with DCD. The aim of this study was to pinpoint and characterise the pausing behaviour by locating the exact time-frames and locations of pauses in the handwriting of children with DCD. This type of analysis was the first of its kind in the field of DCD and was developed in an attempt to form a greater understanding of the pausing behaviour and its impact on the writing process. While debates continue to surround the categorisation and interpretation of pauses, where possible the different pause categories in this study were selected in line with the available literature on writing.

The first two research questions investigated pausing at the grapho-motor level of the handwriting process to examine whether children with DCD spent a greater amount of time than their TD peers pausing at the letter level. The justification for this analysis lay in previous research in the field of DCD where Rosenblum and Livneh-Zirinski (2008) proposed three possible reasons for pausing, including difficulties with the perceptual aspect of the movement, difficulties with motor memory for letter formation and/or difficulties in visualising the letters prior to forming them. While there may well be difficulties in these areas in children with DCD, they did not appear to contribute to the excessive pausing in this study, as there were no group differences in the amount of time spent pausing between 30 and 250 ms and they were not shown to pause more than the TD group in the time frame of 250 ms to 2 s. This finding was also supported in our previous study (of which this is a more detailed analysis) through the lack of group differences that emerged on the alphabet writing task (involving writing the alphabet from memory as quickly as possible for 60 s) (Prunty et al., 2013). In-fact the alphabet task in the previous study was the only handwriting task that did not reveal group differences in pausing. However, it is important to note that there may be separate issues that occur at the letter level, as the DCD group spent more time pausing within illegible words. This calls into question the quality of the movement and the possibility that although the children with DCD were able to transition between letters as quickly as their TD peers, they produced poorer quality letters. Legibility is a crucial element of handwriting performance that needs to be examined in more detail empirically in the future. Meanwhile, it may be necessary for clinicians to examine both speed and legibility in children with DCD given their behaviour of pausing within illegible words. In terms of the behaviour of pausing, the group difference did not appear to be represented at the letter level.

The second time-frame that was analysed focused on word level pauses and whether the excessive pausing in children with DCD lay within a 2–4 s time-frame. The 2-s threshold has been previously used in the writing literature, where a boundary of 2 s is thought to represent higher units of processing rather than letter production (Alamargot et al., 2010; Alves et al., 2007; Wengelin, 2007). Word level pausing was also of interest here, as previous research by Kandel et al. (2006) has shown that spelling and motor programming of words occur prior to the execution phase and online thereafter. This suggests that children with DCD might be forced to pause within a word to cope with the excessive cognitive load imposed by handwriting. However, the findings revealed no group differences in the amount of time or percentage of time pausing within a 2–4 s time-frame. With regards to the location of word level pausing, there was also no group difference for between-word pausing, which may suggest that the DCD group did not take longer than their TD peers to programme words prior to executing them. However, a lack of fluency in the writing process did emerge in the DCD group through within word pausing, as they spent a greater amount of time pausing within words compared to their TD peers. Therefore, although there were no differences prior to executing the words, there were halts within words indicating difficulties with processing information on-line (Kandel et al., 2006). Figs. 3 and 4 provide a visual representation of this behaviour, as the sample of writing from the child with DCD clearly exhibits pauses within-words compared to the behaviour of the TD child in Fig. 4. This finding is in contrast to studies on other developmental disorders, where it was found that children with dyslexia paused more both between and within-words compared to TD peers (Sumner, 2013; Wengelin, 2007). In dyslexia, within-word pausing occurred in correctly spelled and misspelled words (Sumner, Connelly, & Barnett, 2014). However, this was not found to be the case here, as the DCD group did not pause more within correctly or incorrectly spelled words, but did pause more within illegible words. Although difficulties with spelling are distinctly different from difficulties with motor skill, it may be that within word pausing occurs in dyslexia and DCD as a means of coping with difficulties in transcription. In the case of DCD, this study found that the within word pausing occurred within illegible words, a concept which should be considered in more detail in the future.

The analysis of longer pauses between 4 and 10 s was addressed in order to distinguish between shorter, letter-level pauses and those of longer duration attributed to higher-level writing processes. In Alamargot et al.'s (2010) study it was found that the grade 7 (12 year old) writer had the longest pause times of the five writers and paused for as long as 13–18 s at times. According to Alamargot et al. (2010) the longer pauses were due to a strategy known as step-by-step production of text, where the child switches between planning and formulation of the text to cope with the cognitive demands of handwriting. Indeed as the level of writing expertise increased (22+ years), the number of longer pauses decreased substantially. In the current study, this was also found to be the case, as a relationship was found between age and duration of pauses above 10 s. However using eye-tracking Alamargot et al. (2010) were able to investigate the longer pauses based on gaze fixations. These were classified based on whether the participant was looking back at text, looking at the handwriting area or looking away from the task. They found that the least experienced writers were inclined to look away from the task, which according to Alamargot et al. (2010) was an indication of planning. In the current study, there was a significant group difference in longer pauses above 10 s, as children with DCD not only had more pauses above 10 s, but also paused for longer than the TD group when doing so. This could suggest that the difference in the groups lay in the fact that the handwriting skill in the children with DCD was not automatic enough to concurrently process higher-level writing components. Instead, the DCD group may have been forced to take longer pauses to plan the next phase of text. However, Chang and Yu (2010) suggested that a decrease in strength and endurance was a possible contributor to poorer handwriting control in children with DCD. This is possibly supported by our finding that the children with DCD paused more above 10 s within ideas, particularly a sentence, rather than before starting a new topic. If they were planning the content in a similar way to that of the 7th grader in Alamargot et al.'s (2010) study, they perhaps would have been more inclined to pause before a new topic rather than within a sentence or current idea. Further research needs to be done to investigate this in more detail in an effort to rule out physiological factors such as fatigue.

However, practical implications follow from this particular finding as it provides some empirical evidence to support additional time for students with DCD to complete examinations. This type of support is termed 'access arrangements' in the UK, where schools are allowed to offer the child extra time to complete exams, if they satisfy specific criteria, usually in relation to handwriting (Department for Education (DfE), 2013).

Another interesting finding was that the TD group spent 46% of their pause time within a time-frame of 250 ms to 2 s compared to 37% in the DCD group. In the TD group a positive relationship between age and pausing within this time-frame was found, possibly indicating that as TD children become more experienced at writing, they are able to manage most of the lexical and spelling processes within this time. However, this relationship was not found in the DCD group. This suggests that the DCD group may need longer to process this information given that 14% of their pause time was above 10 s compared to 5% in the TD group. This difference in the distribution of pauses suggests that while the TD group had the ability to process the lexical and spelling components within a range of 250 ms to 2 s, the DCD group were unable to do so and were forced to take longer pauses as a result. From a practical perspective this highlights the need for handwriting intervention in children with DCD, where they are given an opportunity to acquire competency in the skill of handwriting so they can process information on-line, in a similar way to that of their TD peers.

Another area addressed in this study was the overall frequency of pausing. According to Alamargot et al. (2010) the frequency of pauses was not an indication of a less experienced writer. In fact, in their study the expert author exhibited the greatest number of pauses, but the key factor lay in their duration. The excessively frequent pausing in the expert author did not have a costly effect on the writing, as they were short pauses allowing for on-line processing to occur quickly. In the current study there were no group differences in the frequency of pauses above 250 ms indicating that the costly effect of the pausing was not attributed to pausing frequency, but due to their duration. The only exception for this was in pauses over 10 s, where the DCD group did pause more frequently in this time-frame. Regression analyses indicated that the frequency of pauses over 10 s was predicted by both the age of the child and the manual dexterity score. Given the role of manual dexterity in the frequency of pauses over 10 s, the role of fatigue should be investigated in future research.

The final area for consideration was the overall mean-pause-duration. Rosenblum and Livneh-Zirinski (2008) found that children with DCD had a longer mean-pause-duration than TD peers. However, without knowing how a pause was defined it is difficult to interpret their findings. In a more specific instance, Alamargot et al. (2010) found that less experienced writers exhibited a longer mean-pause-duration than the more experienced authors. In the current study, the DCD group had a longer mean-pause-duration than their TD peers. However, it seems that this may have been driven by the pauses over 10 s. Similarly to Alamargot et al. (2010) a negative relationship with age was found for mean-pause-duration for both groups, indicating that as children get older and possibly more experienced at handwriting, the duration of the pauses decrease.

The possible limitations of the current analysis lay in the lack of clarity in the writing literature to justify using particular time-frames to examine pauses. Although this study went some way in categorising the pauses into timeframes, it is still unclear given the novel nature of pausing analysis what the pauses actually represent. Further research needs to be conducted in the field of writing to support this type of analysis.

Within the available research on pauses in writing, it is generally accepted that longer pauses are capturing higher-level writing processes (Alamargot et al., 2010; Olive et al., 2009), while shorter pauses reflect transcription (Alamargot et al., 2010). In the present study a range of time-frames were used to capture the pausing patterns of children with DCD in an attempt to characterise them in a way that has not been done before. Further research is needed on handwriting in DCD to provide insight into the longer 10 s pauses in children with DCD, which seems to be the more influential time-frame emerging from this study.

Acknowledgements

This study was funded by the Doctoral Training Programme for Children and Young People at Oxford Brookes University. We would like to thank all of the participants, their families and the schools who took part in this study.

References

Accardo, A., Genna, M., & Borean, M. (2013). Development, maturation and learning influence on handwriting kinematics. *Human Movement Science, 32*, 136–146.

Alamargot, D., Chesnet, D., Dansac, C., & Ros, C. (2006). Eye and Pen: A new device to study reading during writing. *Behaviour Research Methods, Instruments and Computers, 38*(2), 287–299.

Alamargot, D., Plane, S., Lambert, E., & Chesnet, D. (2010). Using eye and pen movements to trace the development of writing expertise: case studies of a 7th, 9th and 12th grader, graduate student, and professional writer. *Reading and Writing, 23*, 853–888.

Alves, R., Castro, S., & De Sousa, L. (2007). Influence of typing skill on pause execution cycles in written composition. In G. Rijlaarsdam, M. Torrance, L. van Waes, & D. Galbraith (Eds.), *Writing and cognition: Research and applications* (pp. 55–65). Amsterdam: Elsevier.

American Psychiatric Association (2000). *DSM-IV-TR. Diagnostic and statistical manual of mental disorders* (4th ed.). Washington: American Psychiatric Association.

Asher, A. V. (2006). Handwriting instruction in elementary schools. *American Journal of Occupational Therapy, 60*, 461–471.

Barnett, A., Henderson, S., Scheib, B., & Schulz, J. (2007). *The detailed assessment of speed of handwriting*. London: Harcourt Assessment.

Blank, R., Smits-Engelsman, B., Polatajko, H., & Wilson, P. (2012). European Academy for Childhood Disability (EACD): recommendations on the definition, diagnosis and intervention of developmental coordination disorder (long version). *Developmental Medicine and Child Neurology, 54*(1), 54–93.

Berninger, V., & 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. Swanson, K. Harris, & S. Graham (Eds.), *Handbook of learning disabilities* (pp. 323–344). New York: Guilford Press.

Berninger, V., & Graham, S. (1998). Language by hand: A synthesis of a decade of research on handwriting. *Handwriting Review, 12*, 11–25.

Berninger, V., Abbott, R., Abbott, S., Graham, S., & Richards, T. (2002). Writing and reading: connections between language by hand and language by eye. *Journal of Learning Disabilities, 35*, 39–56.

Chang, S., & Yu, N. (2010). Characterization of motor control in handwriting difficulties in children with or without developmental coordination disorder. *Developmental Medicine and Child Neurology, 52*(3), 244–250.

Department for Education (DfE) (2013). *English tests mark scheme: Writing and spelling*. Retrieved April 2013, from, http://www.satspapers.co.uk/sats-papers/ks2/english/2012/ks2-english-2012-marking-scheme-writing-and-spelling-external.pdf.

Dunn, L., Dunn, L., Whetton, C., & Burley, J. (1997). *The British Picture Vocabulary Scale* (2nd ed.). London: nferNelson Publishing Company Ltd.

Elliott, C. (1996). *British Ability Scales (II); Administration and Scoring Manual*. London: nferNelson Publishing Company Ltd.

Glenn, S., & Cunningham, C. (2005). Performance of young people with Down syndrome on the Leiter-R and British picture vocabulary scales. *Journal of Intellectual Disability Research, 49*, 239–244.

Goodman, R. (1997). The strengths and difficulties questionnaire: A research note. *Journal of Child Psychology and Psychiatry, 38*, 581–586.

Henderson, S., Sugden, D., & Barnett, A. (2007). *Movement Assessment Battery for Children-2* (2nd ed.). London: The Psychological Corporation.

Jolly, C., & Gentaz, E. (2013). Analysis of cursive letters, syllables, and words handwriting in a French second-grade child with Developmental Coordination Disorder and comparison with typically developing children. *Frontiers in psychology, 4*, 1022.

Kandel, S., & Spinelli, E. (2010). Processing complex graphemes in handwriting production. *Memory and Cognition, 38*(6), 762–770.

Kandel, S., Soler, O., Valdois, S., & Gros, C. (2006). Graphemes as motor units in the acquisition of writing skills. *Reading and Writing, 18*, 313–337.

Miller, L., Missiuna, C., Macnab, J., Malloy-Miller, T., & Polatajko, H. (2001). Clinical description of children with developmental coordination disorder. *Canadian Journal of Occupational Therapy, 68*, 5–15.

Olive, T., Favart, M., & Beauvais, L. (2009). Children's cognitive effort and fluency in writing: Effects of genre and of handwriting automatisation. *Learning and Instruction, 19*(4), 299–308.
Prunty, M., Barnett, A. L., Wilmut, K., & Plumb, M. (2013). Handwriting speed in children with Developmental Coordination Disorder: Are they really slower? *Research in Developmental Disabilities, 34*, 2927–2936.
Rosenblum, S., & Livneh-Zirinski, M. (2008). Handwriting process and product characteristics of children diagnosed with developmental coordination disorder. *Human Movement Science, 27*(2), 200–214.
Sumner, E. (2013). *Children with Dyslexia: Spelling as a Constraint on Writing Development* (Unpublished doctoral dissertation) Oxford, UK: Oxford Brookes University.
Sumner, E., Connelly, V., & Barnett, A. (2012). Children with dyslexia are slow writers because they pause more often and not because they are slow at handwriting execution. *Reading & Writing*. http://dx.doi.org/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*. http://dx.doi.org/10.1037/a0035785
Van Galen, G. (1991). Handwriting: Issues for a psychomotor theory. *Human Movement Science, 10*, 165–191.
Wengelin, A. (2007). The Word-Level Focus in Text Production by Adults with Reading and Writing Difficulties. In M. Torrance & L. Galbraith (Eds.), *Writing and Cognition: Research and Applications* (pp. 67–82). Oxford: Elsevier.