Developmental coordination disorder: a focus on handwriting

Mellissa Prunty (2013)

Developmental Coordination Disorder: A Focus on Handwriting

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Acknowledgements

As an Occupational Therapy graduate I chose the non-traditional route and undertook a PhD soon after qualification. My reason for doing so was driven by my final practice placement in paediatrics where I worked with children with DCD in Scotland. Having played sport competitively for many years I took a real interest in these children as many of them withdrew from sport and physical activity as a result of their 'silent' disability. During the placement I realised the significance of their handwriting difficulties and that many referrals received by the service stated handwriting as an issue. After being asked by my practice educator to plan an intervention, I realised quickly that the evidence base surrounding the nature of their difficulties and how best to support them was very limited. By the time the placement was over, I knew that research in this area was needed and I also knew that I was more than willing to do it!

None of this would have been possible without my Director of Studies, Prof. Anna Barnett. Anna I cannot thank you enough for providing me with such a wonderful opportunity to work with you. You have been an amazing teacher and mentor. You have challenged me and supported me and I have learned a tremendous amount from you. Thank you so much for your support and generosity with your knowledge. I am so very grateful for having hand the opportunity to learn from you and I look forward to continuing to learn from you in the future. To my second and third supervisors Mandy and Kate, thank you so much for your patience, time and expertise over the last three years. You have been so approachable and I believe your input from the fields of psychology, statistics and human movement science has been invaluable. You have given me the skills to approach the research questions in this thesis from a variety of angles. To the three of you, a sincere thank you for everything.

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Statement of Publication

The findings of the study reported in Chapter 4 were published in the following journals:

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.

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The findings of the study reported in Chapter 5 were published in the International Graphonomics Society Conference proceedings (reference below) and can be found in Appendix 1c:

Barnett, A., Rosenblum, S., & Prunty, M. (2013). Development of the Handwriting Legibility Scale (HLS): an examination of Reliability and Validity. *International Graphonomics Society 16th conference.* Nara, Japan.

Development of the Handwriting Legibility Scale was a collaborative project with Professor Anna Barnett (Oxford Brookes University) and Professor Sara Rosenblum (University of Haifa, Israel). I, Mellissa Prunty, made a significant contribution to the above paper. I assisted in the development of the items by reviewing the literature and drawing on my own clinical experience. I piloted the items and conducted initial tests of reliability. I collected and analysed data to examine the validity of the new tool and assisted in revision of the wording of items and formatting of the record form. This paper, with lead author Professor Anna Barnett, describes the development of the tool and its reliability and validity.

Abstract

Background. 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 or known neurological impairment. Difficulties with handwriting are often included in descriptions of DCD, including that provided in DSM-5 (APA, 2013). However, surprisingly few studies have examined handwriting in DCD in a systematic way. Those that are available, have been conducted outside of the UK, in alphabets other than the Latin based alphabet. In order to gain a better understanding of the nature of 'slowness' so commonly reported in children with DCD, this thesis aimed to examine the handwriting of children with DCD in detail by considering the handwriting product, the process, the child's perspective, the teacher's perspective and some popular clinical measures including strength, visual perception and force variability. Compositional quality was also evaluated to examine the impact of poor handwriting on the wider task of writing.

Method. Twenty-eight 8–14 year-old children with a diagnosis of DCD participated in the study, with 28 typically developing age and gender matched controls. Participants completed the four handwriting tasks from the Detailed Assessment of Speed of Handwriting (DASH) and wrote their own name; all on a digitising writing tablet. The number of words written, speed of pen movements and the time spent pausing during the tasks were calculated. Participants were also assessed in spelling, reading, receptive vocabulary, visual perception, visual motor integration, grip strength and the quality of their composition.

Results. The findings confirmed what many professionals report, that children with DCD produce less text than their peers. However, this was not due to slow movement execution, but rather a higher percentage of time spent pausing, in particular, pauses over 10 seconds. The location of the pauses within words indicated a lack of automaticity in the handwriting of children with DCD. The DCD group scored below their peers on legibility, grip strength, measures of visual perception and had poorer compositional quality. Individual data highlighted heterogeneous performance profiles in children with DCD and there was little agreement/no significant association between teacher and therapist's measures of handwriting.

Conclusions. A new model incorporating handwriting within the broader context of writing was proposed as a lens through which therapists can consider handwriting in children with DCD. The model incorporates the findings from this thesis and discusses avenues for future research in this area.

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Chapter 1

Developmental Coordination Disorder: An Outline of the Condition

1.0 Introduction

This chapter provides an introduction to Developmental Coordination Disorder (DCD) and outlines various aspects of the condition including how it is diagnosed, its developmental course and the affect it has on the person's life.

> Matthew is a 9 year old boy who does not have an intellectual disability or neurological impairment, but experiences many difficulties on a day to day basis. Matthew has difficulty tying his shoes, a skill many children his age accomplished three years ago. Matthew's mother has to frequently help him cut his food during mealtime and assist him with fastening the buttons of his school shirt, as he struggles to do this independently. He still cannot ride a bike therefore he is unable to cycle with his friends after school. Matthew has tried several team sports, but no one passes him the ball and he is frequently the last person picked for a team. He feels excluded and inferior to his teammates and no longer wants to participate in sports or physical education. Matthew's parents are worried that he is becoming socially isolated and withdrawn. At a school parents evening, Matthew's teacher commented that, while he is a clever and very capable student, his handwriting is slow and often illegible. Matthew does not complete many assignments or homework and as a result, his performance at school is deteriorating. Matthew's parents are increasingly concerned, as they do not know what is wrong with their son. (Zwicker, Missiuna, Harris & Boyd, 2012)

The term used to describe Matthew's presentation is Developmental Coordination Disorder (DCD), which refers to children who experience motor coordination difficulties, unexplained by a general-medical condition, intellectual disability or neurological impairment (American Psychiatric Association [APA], 2013). While competencies have usually emerged in most daily skills by the age of 4-5 years (Malina, Bouchard & Bar-or, 2004), some children like Alex commence school without the movement skills necessary to cope within the school, social or home environment (Chambers & Sugden, 2002). These children, who have no previously known medical condition, fail to develop age appropriate motor coordination skills and may demonstrate significant difficulties in manual dexterity, ball skills and/or balance (Zoia, Barnett, Wilson & Hill, 2006). As a result of coordination difficulties, the child's performance in everyday meaningful activities may be greatly impacted, affecting activities of daily living, including eating and self-care, along with other meaningful activities such as academic performance, leisure and play (APA, 2013; Polatajko & Mandich, 2004). The task of handwriting, which is the focus of this thesis, is significantly impacted (APA, 2013). In a study consisting of 88 children who met the diagnostic criteria for DCD, 86% were shown to have difficulties with handwriting (Missiuna, Gaines, Mclean, DeLaat, Egan & Soucie, 2008). Yet little is known about handwriting difficulties in children with DCD and at the time of writing, less than five studies have examined it in detail. Only one study has considered ecologically valid handwriting tasks (Rosenblum & Livneh-Zirinski, 2008) while the remainder focused on drawing (Smits-Engelsman, Niemeijer & Van Galen, 2001; Smits-Engelsman and Schoemaker, 2013) and isolated letters (Chang & Yu, 2010).

The aim of this chapter is to introduce DCD and the history of the condition, including some of the alternative terms that have been used to refer to it over the years. The complex issue of diagnosis will be outlined, followed by discussion of co-occurring disorders. The impact of DCD on daily life and psycho-social issues will be addressed, followed by an outline of the developmental course and importance of intervention. Poor handwriting is such a significant issue in this population that it is included in the formal diagnostic criteria for the disorder (APA, 2013). This chapter will provide the necessary background information on DCD in order to proceed to a thorough investigation of handwriting difficulties in this population.

1.1 Historical background

In the last 35 years, an increased awareness of children with motor coordination difficulties has emerged (Wilmut, 2010; Henderson & Henderson, 2003; Zoia et al, 2006). From a historical perspective, the DCD knowledge-base was derived from diverse professional input, including movement science, psychology, physiotherapy, occupational therapy, neurology and paediatric medicine. This multidisciplinary input has positively influenced the field in terms of providing a diverse knowledge-base, rich in a broad range of perspectives and approaches (Cermak, Gubbay & Larkin, 2002). However, combining such variety with a lack of cross-discipline communication, has led to differing terminology across the literature (Cermak et al, 2002), further influenced by geographical location and theoretical bias (Henderson & Henderson, 2003).
Early in the 20th Century motor impairment was described using terminology commonly associated with descriptions of intellectual ability, where motor performance was rated on a scale of *clever* to *very awkward* by Bagley (1900 cited in Cermak et al, 2002). The link between motor impairment and

handwriting was documented in 1937 by Orton (cited in Dewey, 1995) where 'abnormal' motor skills were described as not only impacting on general motor performance but handwriting and language development as well. In the 1960's and 70's specific descriptions of the motor issues related to DCD emerged in the field of neurology where terms such as *developmental apraxia* (deficits in motor planning) and *agnosia* (inability to recognise objects in space) emerged, which according to Walton et al (1962) were reasons for 'clumsiness'. In addition to Walton's (1962) line of thought, other authors in neurology described the disorder using terms such as *minimal brain dysfunction* (Clements, 1966). According to Clements (1966) *minimal brain dysfunction* was an unproven, presumptive diagnosis but given the relationship between neurological function and learning/behaviour, the nervous system was assumed to be involved. This was echoed in other neurological terms such as *minimal cerebral dysfunction syndrome* (Bax & MacKeith, 1963) and *minimal cerebral palsy* (Wigglesworth, 1963). However, *developmental dyspraxia* or *dyspraxia* evolved as the most common medical term used to refer to DCD and still remains popular in the United Kingdom and North America (Henderson & Henderson, 2003; Cermak et al, 2002). Dyspraxia refers to the breakdown of praxis (action), combined with a lack of ability to effectively use voluntary movement during structured tasks and play (Bowens & Smith, 1999). The term spread from neurology into alternative professions such as occupational therapy (Missiuna & Polatajko, 1995) and it now appears in the title of the United Kingdom's national support group for DCD; the Dyspraxia Foundation (Chambers, Sugden & Sinani, 2006). However, despite its popularity, the phrase has been heavily criticised by academics, due to the absence of an established systematic diagnostic criteria and whose popularity may be largely owed to its medical resonance (Henderson & Henderson, 2003).

In addition to neurology, physical education and psychology have also used alternative terms to describe children with performance issues indicative of DCD, such as *clumsy children* (Geuze & Kalverboer, 1994; Henderson, Barnett & Henderson, 1994), *clumsy child syndrome* (Gubbay, 1975), *coordination* and/or *movement difficulties* (Sugden & Keogh, 1990), *perceptuo-motor dysfunction* (Laszlo, Bairstow, Bartrip & Rolfe, 1988) and *physical awkwardness* (Miyahara & Register, 2000). The term *clumsy* became increasingly popular among many professions and was documented by Geuze, and colleagues (Geuze, Jongmans, Schoemaker & Smits-Engelsman, 2001), as the most commonly used term in the DCD literature in the 20th Century. In comparison to some of the neurological terms listed above, the terms used in physical education and psychology were more descriptive in nature and were an attempt to denote the behaviours and movement characteristics observed in the children. In recent years however, the term '*clumsy'* is no longer in widespread use, due to its perceived negative connotation (McGovern 1991 cited in Gibbs, Appleton & Appleton, 2007), and has subsequently been deemed unacceptable for use (Missiuna & Polatajko, 1995).

Since the 1980s at least two diagnostic classification systems have been developed, which have provided guidance on diagnostic criteria and terminology related to DCD (Geuze et al, 2001). The International Classification of Diseases 10 (ICD-10) published by the World Health Organisation (WHO, 1992) has contributed to documenting the condition, alongside the Diagnostic and Statistical Manual of Mental Disorders, 5th ed, (DSM-5) published by the American Psychiatric Association (APA, 2013). These publications have historically shown differences and similarities in terms of how the disorder is described (Chambers et al, 2006). However according to Baird (2013) work is underway to reduce the differences between both classification systems. While the ICD-10 currently makes reference to the term DCD, the formal term used is *Specific Developmental Disorder of Motor Function*.

In light of the range of terminology used to refer to the condition, the last 30 years has seen two international consensus meetings, which were held to address such issues. Both consensus statements endorsed use of the term Developmental Coordination Disorder (Missiuna & Polatajko, 1995; Sugden, 2006) and in 2011 the European Academy of Childhood Disability (EACD, 2011) issued guidelines for the term DCD, with the goal of improving the identification of children with this disorder. The guidelines stated that in countries which adhere to the DSM criteria, the term DCD should be used. In countries where the ICD-10 (WHO, 1992) has legal status, the term Specific Developmental Disorder of Motor Function (SDDMF) should be applied (EACD, 2011).

1.2 Prevalence

The most commonly reported prevalence rate for DCD and the one published by the EACD (2011) is 5-6% (Gaines et al., 2008). However, in the literature the prevalence rate for DCD varies from 1.8% of school-aged children in the UK (Lingham, Hunt, Golding, Jongmans & Emond, 2009) to 19 % in Greece (Tsiotra, Flouris, Koutedakis et al., 2006). This varying prevalence rate is attributed to the selection criteria used when assessing for DCD. For example, if the diagnostic criteria are not strictly adhered to or some criteria are met but others are not, this may result in higher prevalence rates (Lingham et al., 2009). According to Geuze et al (2001) the varying rates may also be attributed to a lack of awareness surrounding the condition, or due to different cut-offs being applied to identify motor difficulties (5^{th} versus 15^{th} percentile) (Sugden, 2006). In terms of gender ratios, DCD is more common in males than in females and similar to that of the findings on prevalence, varying gender ratios have been cited in the literature. In a study by Kadesjö and Gillberg (1999) the ratio was reported to be 7:1 (male to female), while other studies in the UK have reported 2:1 (Lingham et al., 2009).

1.3 The International Classification for Functioning, Disability and Health (ICF): A Template for Discussion

The International Classification for Functioning, Disability and Health (ICF) (World Health Organisation; WHO, 2001) (see Figure 1.1) was developed as a multi-disciplinary framework to provide a standard language for the description of health related states (WHO, 2002). It serves as a method of describing the health condition and the contextual factors (both environmental and personal) that an individual with a disability experiences. It provides an international framework for the characterisation of health and to supply a global language, in an attempt to measure health on a global scale (WHO, 2001). The ICF includes body, societal and individual levels (Haglund & Henriksson, 2003). The framework consists of two parts, each of which contains two elements. The first part is *functioning and disability* which contains the three elements, *body structures* (anatomy and physiology) *and functions* (psychology and physical performance),*participation* and *activities* (functional status) (WHO, 2001). The second part is *contextual factors* incorporating *environmental* (family, work, government agencies, laws and cultural beliefs) and *personal factors* (race, gender, age, educational level, coping styles) (WHO, 2001). By using the ICF as a template for discussing DCD in this chapter, the impact of the disorder on the person can be explored in greater detail using inter-disciplinary terminology. It will therefore be applied to describe the impact of the disorder in children with DCD.

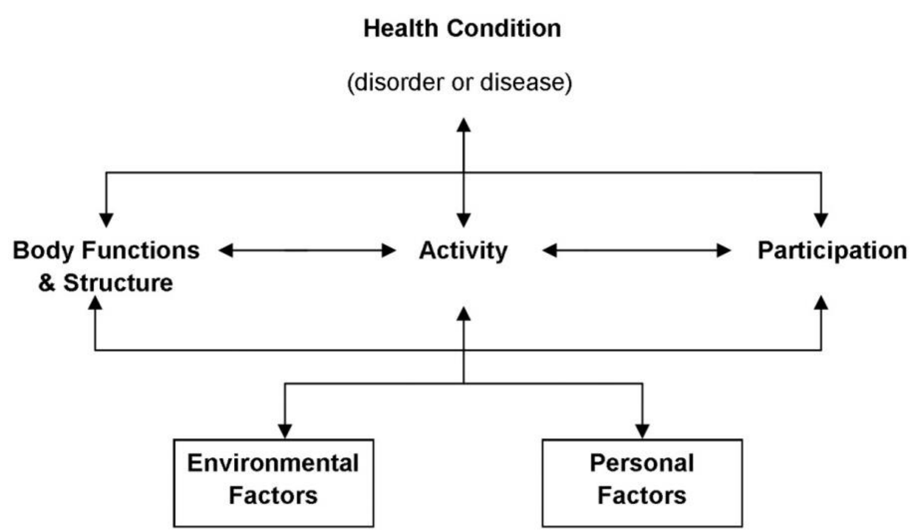


Figure 1.1. The International Classification for Functioning, Disability and Health (ICF) (WHO, 2001).

1.4 Underlying Factors of DCD

DCD is largely idiopathic in nature (EACD, 2011); however a range of studies have reported underlying deficits in specific areas which will be discussed using the ICF (WHO, 2001) level of *body functions*.

In relation to *psychological* factors of DCD, research has suggested that poor spatial processing (O'Brien, Spencer, Atkinson, Braddick, & Wattam-Bell, 2002) poor spatial judgement (Mon-Williams, Tresilian & Wann, 1999), poor motor imagery (Wilson, Maruff, Ives, & Currie, 2001) and difficulties with visual memory (Dwyer & McKenzie, 1994) are characteristic of the disorder. In addition, difficulties with coupling visual and proprioceptive information in order to perform a movement (Volman & Geuze, 1998) along with general abnormalities in processing efferent information have also been reported (Maruff, Wilson, Trebilcock, & Currie, 1999). These proposed psychological factors are thought to contribute to the motor deficits in children with DCD.

Some of the *physical* factors of DCD reported in the literature include difficulties with basic strength and fitness (Raynor, 2001), fine motor skills (Smits-Engelsman, Niemeijer, & Van Galen, 2001; Smits-Engelsman, Wilson, Westenberg, & Duysens, 2003), balance (Deconick, Savelsbergh, De Clercq, & Lenoir, 2010), ball skills (Lefebvre & Reid, 1998) and postural stability in action (Volman & Geuze, 1998). Given the range of factors reported in the literature a meta-analysis was conducted to prioritise and clarify findings from many studies to inform the European guidelines (EACD, 2011). In the meta-analysis the largest effect size was found for deficits related to the physical level of *body functions,* where difficulties with reaching, grasping, catching and target directed reaching were the best discriminators of DCD. Moderate effects were found for the *psychological* factors including motor imagery, visuospatial and verbal working memory (EACD, 2011).

Many of the above factors would arguably be involved in the skill of handwriting. For example, *psychological* factors such as spatial processing and coupling visual and proprioceptive information in order to perform a movement would both contribute to where the letters are placed in relation to each other and the base line. In addition, physical factors such as fine motor skills and strength and endurance could impact both speed and legibility. However in addition to the above factors, a meta-analysis by Wilson and McKenzie (1998) demonstrated that children with DCD have difficulties with visual-perceptual skills and have significant deficits in visual motor integration, particularly in tasks which require speed. With this in mind, it would seem viable that a task such as handwriting would likely be impacted, given the need to integrate vision with motor skill, under the constraint of speed while writing.

The range and complexity of underlying deficits reported in the literature highlights the complex nature of DCD and the many factors which could underlie the difficulties with handwriting. Many of the factors listed above, such as visual perception, visual motor integration, strength and fine motor skills are considered in the forthcoming chapters in this thesis to ascertain their role in handwriting difficulties in DCD.

1.5 Diagnosing DCD

During the period of writing this thesis, the DSM-5 criteria for DCD were released. As a result, the available literature on the diagnosis of DCD relates to the previous edition (DSM-IV).

According to the Leeds Consensus Statement (Sugden, 2006) and the EACD (2011), the DSM-IV-TR (APA, 2000) was advocated for use in diagnosing DCD, which has recently been replaced by the DSM-5 (APA, 2013). According to Sugden (2006) while the DSM-IV was not without its limitations, it was the most useful diagnostic classification tool published at the time. During the course of the current research programme the DSM-IV- criteria were applied in the selection of children with DCD, as the DSM-5 was published after the completion of data collection. However, the main difference in DSM-5 is the provision of a more thorough description of DCD, as the basic principles of diagnosis remain the same. Therefore both the DSM-5 and DSM-IV will be discussed simultaneously in this section.

1.5.1 *Diagnosing DCD using the DSM (2000;2013) Criteria*

In the UK a diagnosis of DCD is usually made by a general practitioner and an occupational therapist and/or physiotherapist (Kirby, Sugden, Beveridge, Edwards, & Edwards, 2008). However, it is not likely to be diagnosed before the age of 5 years (Zoia et al, 2006), nor is this advocated in the European guidelines (EACD, 2011). The diagnosis should be made by a professional who is qualified to examine the criteria for DCD and according to the EACD (2011) this should involve a multi-disciplinary approach.

The EACD (2011) provides guidelines and recommendations regarding best practice when applying the diagnostic criteria. While the EACD (2011) developed the guidelines in line with the DSM-IV criteria, they remain relevant to DSM-5. Table 1.1 illustrates the DSM-IV (APA, 2000) diagnostic criteria for DCD which was applied when recruiting participants for the current research programme.

It is recommended by the EACD (2011) that when applying the DSM diagnostic criteria that careful history taking is essential. This should include parent interviews, ascertaining information on family history, neurological disorders, social condition, issues surrounding birth, developmental milestones, academic achievements and the burden of DCD (EACD, 2011). In addition, where possible, the views of the teacher should be ascertained to examine school-based behaviour, co-morbidity for attention deficits, learning disorders and academic achievement. The views of the child should also be included.

Table 1.1

The DSM-IV-TR diagnostic criteria for DCD (APA, 2000, p.58)

A. Performance in daily activities that require motor coordination is substantially below that expected given the person's chronological age and measured intelligence. This may be manifested by marked delays in achieving motor milestones (e.g., walking, crawling and sitting), dropping things, "clumsiness", poor performance in sports, or poor handwriting.
B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living.
C. The disturbance is not due to a general medical condition (e.g. cerebral palsy, hemiplegia, or muscular dystrophy) and does not meet criteria for a Pervasive Developmental Disorder.
D. If Mental Retardation is present, the motor difficulties are in excess of those usually associated with it.

Table 1.2 illustrates the recently published DSM-5 (APA, 2013) criteria for DCD. Some of the main changes from the DSM-IV (APA, 2000) in criterion A include the opportunity for skill acquisition, where motor deficits are still present even though the child has been given ample opportunities to acquire skills. In addition, more description has been added to the presentation of motor deficits, such as slowness and inaccuracy of performance in specific activities of daily life. Handwriting is included

in the list of activities affected, which is formally recognised as a significantly impacted skill in children with DCD. However, despite the new edition, the same guidelines proposed by the EACD (2011) apply to the ways in which the disorder is assessed.

For criterion A, the EACD (2011) recommends to individually administer an appropriate, valid, reliable and standardised motor test (norm-referenced). The 15th percentile point (standard score of 7 or less) is recommended as the cut off point to denote difficulties when using a motor test. Specific tests are discussed in more detail in Chapter 3. For children below the age of 5 years, although an official diagnosis can not be given, a cut off score of below the 5th percentile on a motor competency test should be applied for treatment purposes (EACD, 2011).

Table 1.2

The DSM-5 diagnostic criteria for DCD (APA, 2013, p.74)

A. The acquisition and execution of coordinated motor skills is substantially below that expected given the individual's chronological age and opportunity for skill learning and use. Difficulties are manifested as clumsiness (e.g., dropping or bumping into objects) as well as slowness and inaccuracy of performance of motor skills (e.g., catching an object, using scissors or cutlery, handwriting, riding a bike, or participating in sports).
B. The motor skills deficit in Criterion A significantly and persistently interferes with activities of daily living appropriate to chronological age (e.g., self-care and self-maintenance) and impacts academic/school productivity, prevocational and vocational activities, leisure, and play.
C. Onset of symptoms is in the early developmental period.
D. The motor skills deficits are not better explained by intellectual disability (intellectual developmental disorder) or visual impairment and are not attributable to a neurological condition affecting movement (e.g., cerebral palsy, muscular dystrophy, degenerative disorder).

For criterion B, one of the changes made in the DSM-5 relates to the 'persistence' of motor skill deficits and their interference with activities of daily living across a range of meaningful activities. The DSM-5 also extended this to include adults with DCD, where vocational and pre-vocational activities were specifically mentioned. In applying criterion B, it is recommended to use validated questionnaires (discussed in Chapter 3) to collect information on the characteristics of DCD from the parent, teacher and child/adult (EACD, 2011).

Criterion C in the DSM-IV and both criteria C and D of the DSM-5 are used as a method of screening for alternative medical conditions such as neurological impairments, developmental delay, pervasive developmental disorder (PDD) or acquired injury, all of which may influence motor coordination (Geuze et al, 2001). Concerning the above, a clinical examination with respect to neurological and behavioural issues should be undertaken to verify that the motor difficulties are not a result of a general medical, neurological or behavioural condition (EACD, 2011). Initially, the DSM-IV had four criteria listed as A,B,C and D. However when the European guidelines were developed, there was intense discussion surrounding criterion D, where the consensus group felt that defining a specific IQ cut-off below which the diagnosis of DCD would not be possible seemed artificial (EACD, 2011). The complexities of defining cut-offs for level of IQ was deemed difficult (EACD, 2011) and it was therefore decided that a diagnosis of DCD can be given once an intellectual disability does not better explain the motor deficits. In order to ensure this is not the case, the EACD proposed careful consideration of clinical history to ensure cognitive status does not potentially explain poor motor performance. The EACD (2011) also stated that cognitive function does not need to be evaluated by objective measures (e.g., IQ testing) if there is a normal history of school and academic achievements. However, a test for intellectual ability is recommended if there is any doubt (EACD, 2011). In the UK, many children with disabilities are integrated into mainstream education therefore for research purposes screening for intellectual ability would be beneficial for research purposes.

1.6 The impact of DCD on Participation and Performance of Everyday Activities

When discussing the impact of DCD on daily life, it is important to emphasise the heterogeneity of the condition, as children may experience the disorder in many different ways. This has been reflected in the many activities listed in Criterion A of the DSM-5. In order to discuss the effect of DCD on daily life, the ICF (WHO, 2001) is used as a framework for discussion (see Figure 1.1).

At the level of *participation* in the ICF (WHO, 2001) children with DCD face many barriers in performing everyday activities both at home and at school (Missiuna, Moll, King, King, & Law, 2007; Mandich, Polatajko, & Rogers, 2003; Stephenson & Chesson, 2008). In the home, activities of daily living such as feeding, washing, dressing and self-care can be greatly impacted (APA, 2013). These challenges can manifest in different ways; for example, difficulties with dressing can be apparent in tasks such as buttoning shirts or dresses, manipulating zips or tying a school tie, all of which require fine motor manipulation and organisational skills (Roger, Ziviani, & Watter, 2003). Feeding and washing demands can expose additional issues, with deficits in manual dexterity effecting tasks such as applying toothpaste to a toothbrush or manipulating cutlery. Within the school environment, these difficulties transfer into a range of school activities (Wang, Tseng, Wilson, & Hu, 2009), such as eating lunch, dressing for physical education and manipulating objects such as, scissors, blocks and jigsaw puzzles (Cermak et al, 2002). However, one of the most significantly impacted activities and one of the main reasons for referral to health professionals is that of handwriting (Miller, Missiuna, Macnab, Malloy-Miller, & Polatajko, 2001). This is a notable issue for children with DCD, as handwriting ability contributes to success and participation in school, and can greatly hinder the child's self esteem and self-efficacy if affected (Piek, Baynam, & Barrett, 2006; Feder & Majnemer, 2007). Initial difficulty may arise when learning letter formation, followed by issues with legibility and the speed/accuracy trade-off (Cermak et al, 2002). As the child progresses through the education system, there is a higher demand for the production of fast and legible handwriting (Sugden, 2006). Therefore, if DCD presents a barrier to effective handwriting, the child may be at risk of academic underachievement (Sugden, 2006).

In addition to activities of daily living, and those associated with academic performance, other meaningful activities which impact at the ICF level of *participation* are likely to be effected, specifically the popular childhood occupations of leisure and play (Roger & Ziviani, 2006). Playground games such as ball skills, hopping, skipping, jumping, riding a bike and fine motor tasks such as writing, painting and crafts are all popular childhood activities, all of which promote inclusion and social interaction (Roger & Ziviani, 2006). A child who demonstrates difficulties with gross motor skills, such as that of DCD, may withdraw from participation in physical activity and play (Roger & Ziviani, 2006). In doing so, this may facilitate the development of secondary impairments due to the negative consequences of decreased activity and decreased conditioning (Cantell & Kooistra, 2002); therefore negatively influencing self-esteem and self-efficacy (Raynor, 2001).

1.7 Co-occurring Disorders

The issue of co-morbidities is complex in its own right, with well documented evidence supporting the co-existence of DCD with other disorders (Lingham, Golding, Jongmans, Hunt, Ellis, & Emond, 2010) such as, autistic spectrum disorder (ASD) (Mari, Castiello, Marks, Marraffa, & Prior, 2003), attention deficit hyperactivity disorder (ADHD) (Piek & Dyck, 2004), specific language impairment (SLI; Gaines & Missiuna, 2007) and dyslexia (Fox & Lent, 1996; Kaplan, Wilson, Dewey, & Crawford, 1998; Kirby, Sugden, Beveridge, Edwards, & Edwards, 2008). Co-occurring disorders are discussed through the ICF framework (WHO, 2001), as the issue of co-occurring disorders impacts on many different areas of the person's life.

At the ICF level of *body functions,* specifically psychological functioning, the most common co-occurring disorder with DCD is ADHD, with some studies reporting a 50% co-occurrence (Green Baird, & Sugden 2006; Kadesjo & Gillberg, 2001). Green et al (2006) used the Strengths and Difficulties Questionnaire (SDQ, Goodman 1997) which the parents of 47 children completed in relation to their child with DCD. The SDQ, which is discussed in greater detail in Chapter 3, incorporates questions on emotional and behavioural attributes of the child and provides an indication of difficulties surrounding emotional symptoms, conduct problems, hyperactivity, peer problems and pro-social behaviour (Goodman 1997). While over half of the children were reported to have difficulties with hyperactivity/inattention, only four of the children had a formal diagnosis of ADHD (Green et al, 2006). However, 31 out of the 74 children recruited did not participate in the study. According to Green et al (2006) the 47 parents that did return the forms may have been those that have children with behavioural difficulties, while the 31 who opted out may not have shown the same profile. Based on this premise, Green et al (2006) suggested that the rate of ADHD would perhaps be closer to 37-51% depending on the samples used in studies.

In children with SLI the prevalence of DCD as a co-occurring disorder was reported as 32.3% by Flapper and Schoemaker (2013), while Lingham et al (2009) reported ASD in 8% of children with severe DCD and in 4% of children with moderate DCD. With ASD in particular there have been many issues in terms of this being recognised as a co-occuring disorder, as earlier versions of the DSM (2000) depicted pervasive developmental disorders (PDD) as separate conditions, despite much evidence to dispute this (Geuze et al, 2001). While the DSM-IV (APA, 2000) agreed that ADHD and DCD could be diagnosed as co-occurring disorders, when it came to ASD, the DSM-IV cited conflicting reports (Geuze et al, 2001). To provide clarity on the matter, the 2006 Leeds consensus statement addressed the issue, concluding that both DCD and ASD could be diagnosed simultaneously and should be, when criteria for both are met (Sugden, 2006). The most recent diagnostic criteria (APA, 2013) have now reflected this and a dual diagnosis of ASD and DCD can be given. In terms of the co-occurrence of DCD with reading and spelling disorders such as dyslexia, a study by Iverson and colleagues (Iverson, Berg, Ellertsen & Tonnessen, 2005) reported that more than 50% of children with severe dyslexia had difficulties with motor coordination. However, this was not found to be the case by Sumner, Barnett and Connelly (2013) where children with dyslexia in general were not found to have difficulties on manual tasks.

At the level of *personal factors* in the ICF (WHO, 2001) where coping styles are accounted for, it is common for children with DCD to demonstrate emotional difficulties (Sugden, 2006) or low self-perception (Poulsen, Johnsons & Ziviani, 2011) in childhood through to adulthood. The nature and extent of such problems is variable but in some cases they may be severe enough to constitute co-occurring disorders. Indeed, in a large UK based study Lingham et al (2012) reported that children with DCD aged between 9 and 10 years were found to be two times more likely than typically developing peers to report depression. In the same study, their parents were four times more likely to report behavioural or mental health issues in their children (Lingham et al, 2012). This pattern appears to continue into the adolescent years as found by Missiuna et al (2007), where the parents of 13 children with DCD were interviewed in-depth. Missiuna et al (2007) found that parental concerns shifted away from motor deficits and play during the early years into areas such as self-care, academic progress and peer difficulties in middle childhood. By adolescence, significant challenges with emotional health and self-esteem became apparent (Missiuna et al, 2007). The issues with self-esteem have in part been linked to peer acceptance and feeling "part of the group" (Mandich et al, 2003). In a study by Mandich et al (2003) the parents of 12 children with DCD were interviewed. It was found that the incompetence experienced by the children in everyday activities had serious negative consequences. Crucially, the intervention with these 12 children was focused on enabling them to participate, and in doing so, it had a positive impact on their quality of life as reported by their parents (Mandich et al, 2003). When the children were successfully able to participate, the parents noted a boost in their child's self-confidence and a willingness to try new activities (Mandich et al, 2003). This finding is also in line with a study by Cairney et al (2005) where a relationship between self-esteem and the level of physical activity and participation was found.

In addition to internal issues with self-esteem, external influences such as peer opinion can contribute greatly to psychosocial outcomes in children with DCD. Such peer-related issues are at the level of *environmental factors* in the ICF (WHO, 2001) as these are issues outside the child's control. In studies which have looked at bullying, children with DCD were reportedly more affected by being victimised compared to typically developing children who were also bullied (Piek, Barrett, Allen, Jones, & Louise, 2005). Piek et al (2005) found that the concept of self-worth was particularly affected by bullying and lack of peer acceptance.

Another important issue at the level of *environmental factors* in the ICF (WHO, 2001) is societal systems such as the law, health care and education. In the ICF model, these societal systems play a significant role in a person's life. Poor psycho-social adjustment may mean that children with DCD experience these systems in a negative way, where the high rate of co-occurring difficulties may contribute to poor psychosocial outcomes. In a study by Rasmussen et al (2000) a group of children with both DCD and ADHD were examined for psychosocial outcomes. In the group with both DCD and ADHD, 58% had poorer outcomes than 13% of the group with just ADHD. Some of the difficulties which occurred in the group with both DCD and ADHD consisted of antisocial behaviour, substance misuse, criminal offending, reading disorders and a low level of education (Rasmussen & Gillberg, 2000). In these instances, it is likely that the system of law would become involved, while education which is an important resource for all children would be central to those underachieving at school.

In children with DCD the experience of failing in many activities has a detrimental effect on their self-esteem and self-efficacy (EACD, 2011). As a consequence, children with DCD may withdraw from participating and avoid particular activities through which their motor deficits are exposed (EACD, 2011). However, it is imperative to note that although many of these psycho-social issues co-occur with the motor deficits, a causal relationship has yet to be determined. It is therefore necessary to exhibit caution when discussing the relationship between such issues.

1.8 Developmental Course

Historically, it was thought that children with DCD would simply outgrow the condition (Losse et al, 1991). However, it is now widely accepted, that without appropriate intervention, the child is likely to continue to experience significant difficulties (Sugden & Chambers, 1998). In a longitudinal study by Cantell & Kooistra (2002) assessments of balance, ball skills, fine motor skills, visual motor tasks (copying geometric forms) and kinaesthetic tasks were administered to three groups of children. The first group comprised of children with DCD who when tested at 15 years of age were below their typically developing peers on a range of measures. The second group consisted of 23 children who had DCD when younger, but when tested at 15 years were found to be similar to TD peers (intermediate group). The third group of 20 children consisted of typically developing controls. In addition to the above measures, measures of vocabulary, educational status, self-perception and self-understanding were also administered. At age 17 the children with DCD were still distinguishable from the typically developing group and intermediate group on all of the perceptual motor tasks. Moreover, in terms of educational status and motivation, the group with DCD were below their typically developing peers on these measures. The results of Cantell & Kooistra (2002) illustrate that while some children with DCD may improve with age, many do not and the same difficulties experienced as a child, continue into adulthood.

In a study by Cousins and Smyth (2003), which focused specifically on adulthood, 19 adults aged between 18 and 65 with DCD and 19 controls were tested on manual dexterity, handwriting, construction, obstacle avoidance, dynamic balance, static balance, dual task performance, ball skills, reaction time, movement time and sequencing. The results indicated that the DCD group scored below their typically developing peers on all tasks. Cousins and Smyth (2003) was one of the only studies to examine handwriting in adulthood. To do so, handwriting was examined under a speeded and a non speeded condition. In both conditions, the group with DCD copied fewer words than their typically developing peers. The findings of Cousins and Smyth (2003) demonstrate that even in adulthood, difficulties are still apparent, including in the area of handwriting. Although handwriting was not considered in Cantell et al (2002), their results demonstrated that fewer children with DCD completed high school compared to typically developing controls and were more likely to engage in vocational opportunities. It may be that difficulties with handwriting impacted on academic productivity and may have influenced this pattern. Indeed many studies have shown that DCD continues well into adulthood. As a result, studies have started to investigate the effect of DCD on adult activities such as driving (Oliveria & Wann, 2012), while also examining the quality of their lives as adults (Hill, Brown & Sorgardt, 2011).

1.9 Intervention

A valuable catalyst for change in the level of participation in children with DCD lies in the importance of intervention (Polatajko & Cantin, 2007). According to Polatajko and Cantin (2007) children with DCD can benefit significantly from the right intervention. Intervention strategies can target different aspects of performance in the person’s life. In order to discuss approaches to intervention, the ICF (WHO, 2001) is used as a structure to explain the types of interventions for children with DCD.

At the level of *body functions*, the section on underlying factors in DCD outlined many areas in which children with DCD perform below their typically developing peers. Some interventions target these areas by focusing on underlying factors of DCD and addressing them through what is known as a 'bottom up' or process orientated approach (Missiuna, Rivard, & Bartlett, 2006). These 'bottom up' approaches aim to develop foundational skills such as visual perception and strength and balance which are thought to underlie task performance (Mandich, Polatajko, Macnab, & Miller, 2001). Cermak et al (2002) reported that many occupational therapists use a sensory integration frame of reference which is a process orientated or ‘bottom-up’ approach. This has been used in the context of many skills; for example in handwriting where the child engages in activities such as manipulating Play-Doh or Theraputty, or completing wall push ups to increase hand and shoulder strength. The rationale for this, according to Schneck and Amundson (2010) is that some children present with poor proximal stability and strength. In order to promote co-contraction of the muscles in the neck, shoulders, elbows and wrists Schneck and Amundson (2010) proposed that some children may benefit from strengthening exercises. These are examples of activities used to address handwriting difficulties in children with DCD, despite limited evidence to support this practice (Hoy, Egan, & Feder, 2011).

More recently, alternative 'top- down' approaches which are more focused on the ICF (WHO, 2001) level of *activity* have become increasingly promising (Lipson, Edwards, & Logan, 2009). The 'top-down' approach to intervention employs a more task focused approach, by concentrating on the child's roles and meaningful activities (Polatajko & Mandich, 2004). A problem-solving strategy utilising skills at the ICF *activity or performance* level is often applied and used to promote enablement in the context of the child's chosen task and environment (Polatajko & Mandich, 2004). The EACD (2011) supports the use of 'top down' interventions and recommends interventions which focus on the level of the task. There are three interventions in particular which are advocated for use in children with DCD by the EACD (2011) including Neuromotor Task Training (NTT) (Schoemaker & Smits-Engelsman, 2005) the Cognitive Orientation to daily Occupational Performance (CO-OP) (Polatajko & Mandich, 2004) and the Ecological Intervention (EI) (Sugden & Henderson, 2007) all of which are embedded in motor learning theories. The evidence for these task-specific interventions is growing (Wilson, 2005; Sugden, 2007).

In addition to intervening at the levels of *body functions* and *activity,* adaptations at the ICF (WHO, 2001) level of *environment* can also be made. This can take many different forms ranging from the inclusion of key individuals in the child's life such as parents and teachers in the intervention process to adapting the physical environment. According to Polatajko (2012) schools have a significant role to play in terms of intervention at the environmental level, as educational materials and methods of classroom and school design can enable goals to be met by children who differ widely in their abilities and their level of participation in the curriculum. The philosophy proposed by Polatajko (2012) is that environmental design is necessary for some children, but beneficial for all. This has also been advocated by Sugden and Henderson (2007).

The significance of intervention in DCD is substantial; if a child with DCD receives the right intervention, the functional implications of the disorder can begin to be reversed (Mandich et al, 2003). Although there are many issues and questions with regards to interventions, the rationale for intervention is clear; children do not grow out of the condition naturally (Sugden, 2006), the presence of associated daily challenges are apparent (Sugden & Chambers, 2005) and more significantly, the rationale for alleviating any emotional anxiety is considerable (Sugden & Chambers, 2003). However, the task of handwriting is unlike other motor skills, in that, it is closely intertwined with language and cognitive components, which adds to the complexity of intervention. In children with DCD we know very little about the nature of their handwriting difficulties. The evidence suggests that decreased strength (Raynor, 2001), fitness (O'Beirne, Larkin & Cable, 1994; Scheng, Hsiao-Hui, Yao-Chuen, & Cairney, 2010), fine motor skills (Smits-Engelsman et al, 2001), balance (Deconinck et al, 2010) and/or visuomotor skills (Przysucha & Taylor, 2004) are all underlying factors of DCD. However it is not known whether any of these factors significantly impact on handwriting ability. In interventions such as CO-OP (Polatajko & Mandich, 2004), which have shown promise in remediating handwriting difficulties (Taylor, Fayed, & Mandich, 2007; Banks, Rodger, & Polatajko, 2008), a motor learning deficit has been proposed (Polatajko, 2013). This motor learning deficit implies that children with DCD have the ability to learn motor skills but must be taught the skill to gain an understanding of what the process of the task involves (Polatajko, 2013). To date there has been little investigation of any of these deficits in relation to the skill of handwriting. Previous research tells us little about whether children with DCD have difficulties with legibility or speed or difficulties with both. It also has yet to be seen whether all children with DCD present in a similar manner, or whether their handwriting ability is heterogeneous in nature where some children write quickly but illegibly, while others write legibly but are unable to meet speed demands. Chapter 2 will introduce a theoretical framework for the investigation of handwriting and writing in children with DCD in this thesis. It will review the literature on handwriting in children with DCD to examine the gaps in the current evidence base which will be addressed in this thesis.

Chapter 2

Handwriting as Part of the Writing Process

2.0 Introduction & Background

The skill of handwriting is an important gateway to academic success (Graham, Berninger, Weintraub & Schafer, 1998), with deficits in the skill often having significant implications for academic achievement. Handwriting not only serves as a facilitator for academic progression, but also represents a core occupation in school age children, by promoting participation in school activities and providing a valuable source of self-esteem (Cunningham, 1992; Engel-Yeger, Nagauker-Yanuv & Rosenblum, 2009). However, handwriting is not an isolated, motor skill; in fact it is an important part of the wider writing process. It is a complex skill that cannot be understood independent of its connection with linguistic aspects and higher-level processes of writing (Graham & Weintraub, 1996). Since handwriting is ‘language by hand’ (Berninger, Abbott, Abbott, Graham, & Richards, 2002), there are many complex, linguistic processes that occur before the pen is placed on the page. In order to investigate handwriting in detail it is imperative to understand the writing processes, so a greater understanding of handwriting difficulties can be achieved (Smits-Engelsman, Schoemaker, Van Galen, & Michels, 1996).

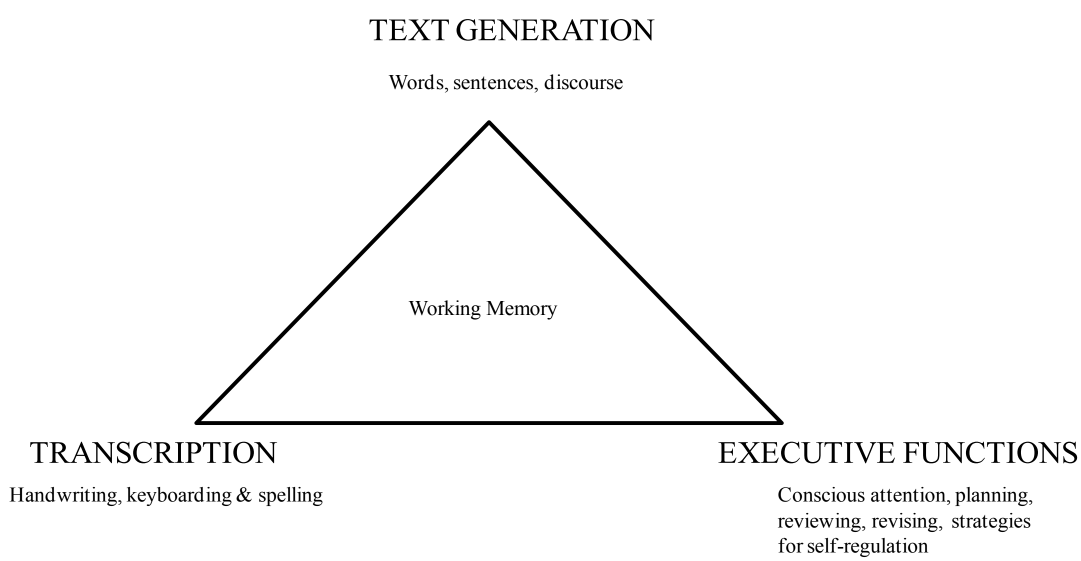
In this chapter the processes of writing are introduced and serve as a framework for the investigation of handwriting in children with DCD in this thesis. Models of typical writing performance and handwriting provide a lens through which atypical handwriting is viewed and interpreted in the studies which follow. Children with DCD are specifically at risk for handwriting difficulties, given the deficits in motor coordination and fine motor skills commonly associated with the condition (APA, 2013). This chapter provides a theoretical framework for use as a backdrop for the investigation of handwriting and includes a review of the literature on handwriting in children with DCD.

2.1 Models of Writing Performance: The thinking behind the handwriting

According to Olive (2004), writing is one of the most cognitively complex tasks that humans engage in during their lifetime. It involves the complex interaction of a wide range of different processes all competing for limited working memory resources (Kellogg, 1996: McCutchen, 1996). In this section, a developmental model of writing is introduced in order to emphasise the many cognitive processes that occur during handwriting performance.

2.1.1 Berninger & Swanson (1994) developmental model of writing

In 1980 the Hayes and Flower model of writing was developed and based on typically developing adult writers. It included three major elements of writing: the task environment (the writing problem/question/topic), long term memory (knowledge of the writing topic, the audience and writing plans) and the writing processes (planning, translating and reviewing). However, Hayes and Flowers' model (1980) did not include transcription skills (spelling and handwriting), nor did it cater for a developmental perspective on novice writers. Therefore in 1994, Berninger and Swanson combined research on writing development from the fields of psychology, cognition, education and linguistics and produced the 'simple view' developmental model of writing. The model was based on extensive research in the USA focusing on children from the ages of 6-15 years using compositional tasks. The model aimed to reflect the development of writing processes in children and beginner writers (Alamargot & Chanquoy, 2001). The Berninger and Amtmann (2003) simplification of Berninger and Swanson's (1994) model is illustrated below in Figure 2.1 and forms the theoretical framework for the examination of writing in this thesis. At the centre of the model is working memory, which is thought to oversee the synthesis of the writing processes. Working memory is a resource of limited capacity and is thought to influence the task of writing (Berninger & Swanson, 1994). Tasks that use working memory require the retention of information in the mind while simultaneously processing other demands in parallel (Kellogg, 1996).



Note: Working memory activates long-term memory during composing; short-term memory during reviewing

Figure 2.1. The Simple View of the Berninger & Swanson (1994) model (taken from Berninger & Amtmann, 2003).

2.1.1.1 Transcription

Berninger and Swanson (1994) emphasised that transcription skills are the first skills to be learned in young writers and in the process, act as a constraint on the higher level processes of writing. In their model, transcription is considered to be a lower level skill and consists of two components; spelling (word production) and handwriting/typing (letter production) (Berninger & Swanson, 1994). In children aged 6-9 years of age Berninger et al (1992) found that the level of motor skill (determined by a finger succession task, which requires the child to touch the thumb to each finger in sequence while the hands are out of sight) combined with remembering letter clusters in a word, was the best predictor of the amount of text produced, and the quality of the written composition. Based on these findings, Berninger and Swanson (1994) combined both spelling and handwriting under the heading of 'transcription'.

When beginning to write, the initial stages of learning to spell involves developing an awareness of the sounds in language (phonology), the relationships between sounds and words (orthography) and the grammatical units of language (morphology) (Siegel, 2008). At the same time, when learning handwriting, young writers need to be able to plan the correct movements and control the movement of the pen to form the letters (Van Galen, 1991). However, in young writers handwriting can be so laboursome that it consumes substantial working memory resources. The notion of handwriting consuming working memory in young writers was supported in a study by Bourdin and Fayol (1994), where children aged 7-9 recalled fewer words in a written recall condition, compared to a verbal recall condition. In contrast, the adult writers in the same study showed no difference between conditions (Bourdin & Fayol, 1994). According to Bourdin and Fayol (1994) this was due to the strain handwriting imposed on working memory resources in young writers, as the adults had 'automatic' handwriting where the capacity to allow working memory resources to focus on a recall task was possible.

In young children spelling and handwriting constrain their ability to focus on other processes of writing (Berninger & Swanson, 1994). This has been demonstrated in many studies on handwriting speed, measured by the number of letters produced in a timed alphabet task, which was found to correlate highly with text length and quality of the composition produced (Berninger et al., 1992; Berninger & Swanson, 1994; Graham, Berninger, Abbott, Abbott & Whitaker, 1997). In addition, other studies have considered both handwriting speed and spelling ability and found that the faster the handwriting and better the spelling, the higher the scores were for compositional quality (Puranik & Alotaiba, 2011). It is not until these 'transcription' processes become more automatic (less working memory is required), that higher level processes which affect writing quality can be attended to. The term 'automaticity' in relation to handwriting will be discussed in greater detail in Chapter 4. It should also be noted that although the emphasis in the writing literature is on speed of production, it is also important to state that if the text is not readable it defeats the communicative purpose of the task. Therefore handwriting as a communication skill relies on both speed and legibility.

2.1.1.2 Text Generation

As children progress through school and have gained experience with transcription skills, 'text generation' becomes the new constraint on writing (Berninger & Swanson, 1994). Text generation refers to the transformation of ideas into language. It occurs at different levels of language and involves the selection and integration of content, lexical (word) retrieval and syntactic processes (sentence construction) (Berninger & Swanson, 1994). According to a study by Berninger et al (1994), compositional quality of writing in children aged 9-12 years was determined by vocabulary and ability to generate sentences from picture prompts. The transcription skills of handwriting and spelling were no longer the biggest predictors of writing quality, as these were more developed than in younger children (Berninger et al., 1994). However, it is important to note that text generation and transcription may develop at different rates. For example in Berninger et al (1992) some children produced very little when asked to write in a compositional task, yet their handwriting was legible. In these children, Berninger et al (1992) suggested that text generation was the constraint, rather than transcription skills. However, in Berninger et al (1992) it was unclear whether handwriting speed posed an issue. Of particular relevance to children with DCD, Berninger et al (1992) also observed children who could verbally provide many ideas, but the words on the page were illegible. In these children, text generation had developed more rapidly than transcription (Berninger et al., 1992). This may be the case in many children with DCD, where difficulties with handwriting constrain the expression of ideas. However, this has never been empirically tested in children with DCD.

2.1.1.3 Executive Function

The final component of the Berninger & Swanson model (1994) is 'executive function'. Executive function includes the higher-level processes such as planning (goal setting, generating and organising the text) and reviewing (reading, error detection and correction). These higher level processes develop once the lower level transcription skills are established. The working memory resources, which were once consumed by laboured handwriting and spelling, can now be used to self-regulate and modify text while writing. These processes usually occur in parallel, but sequential processing of information can occur if transcription is not yet automatic, as working memory has a very small capacity (McCutchen, 1996). According to Berninger and Swanson (1994), the quality of written compositions in adolescents aged 12-15 years is related to their ability to plan and revise text, rather than skills in transcription or text generation.

2.1.2 Cognitive Cost of Transcription on the Writing Processes

Transcription skills require considerable effort in novice writers and because of this, it impacts on text generation and the higher writing processes (Berninger et al, 1992: Berninger et al, 1994; Berninger, Fuller & Whitaker, 1996). In a study by Olive et al (2009) as children got older, there were signs of decreased cognitive effort in handwriting. This was shown through the use of diversified connectives in their writing (words to link other phrases). Olive et al (2009) argued that the ability to use diverse connectives was an indicator of planning, which was possible when the cognitive cost of handwriting was reduced. The cognitive cost associated with writing is related to working memory resources, which is at the centre of Berninger and Amtmann's (2003) model (see Figure 2.1). When a child is learning to produce handwriting, it consumes most of the working memory resources. As a result, a strategy of switching attention from handwriting to planning is often adopted. In fact, the impact of reduced working memory resources is so significant in young writers that they compensate through using a style of writing known as 'knowledge telling' (Almargot & Fayol, 2009; Kellogg, 2008). Here the child presents their knowledge about a particular topic through producing a series of statements from memory. Whatever comes to mind is what is written down (Berninger et al, 1996). Through this style of writing, the focus is not on the reader's needs, but rather on coping with the working memory demands absorbed by transcription (Almargot & Fayol, 2009; Kellogg, 2008). It is not until transcription skills become more automatic, that working memory resources can be redirected to focus on higher-level processes such as planning and revising (Bourdin & Fayol, 1994).

2.1.3 Spelling

In a study by Sumner et al (2013) children with dyslexia performed significantly below their typically developing (TD) peers on a number of writing related measures. However, through the use of a digitising writing tablet, it was demonstrated that handwriting execution speed (the actual movement of the pen) was similar to TD peers and a verbal compositional task showed that vocabulary was not impaired. However, the nature of dyslexia meant that the dyslexic group had difficulties with spelling which was shown to impact on vocabulary and handwriting through excessive pausing within misspelled words and avoidance of words that were difficult to spell. As a result, the dyslexic group wrote less text and demonstrated limitations in the diversity of vocabulary used in their writing. Sumner et al (2013) raised important issues, in that handwriting skill and writing quality can be constrained by spelling ability. These findings suggest a more complex link between spelling and handwriting than previously thought but also emphasise the relationship between spelling ability and the higher-level processes of writing.

2.1.4 Handwriting

Based on the above factors, it is apparent that handwriting plays an intricate role in the overall task of writing. It is preceded by and intertwined with many higher and lower-level writing processes. However, one of the limitations of models of writing is a tendency to focus on the components of planning, translation and reviewing, rather than the processes of graphic transcription (Alamargot & Chanquoy, 2001). Graphic transcription is responsible for producing the message on the page and according to Almargot and Chanquaoy (2001) it has been neglected in the writing models. Almargot and Chanquaoy (2001) proposed reasons as to why the processes of handwriting have not been integrated into writing models. One reason is that historically, models of writing primarily focused on adult writers, where transcription skills were assumed to be automatic (Hayes & Flower, 1980). As a result, the examination of alternative processes such as planning was prioritised in the literature over lower level components such as handwriting (Almargot and Chanquaoy, 2001). Although the models of writing go some way in contextualising handwriting within the writing process (Hayes & Flowers, 1980; Berninger and Swanson, 1994), a limitation exists in the lack of information regarding the production of handwriting movements. Therefore, Van Galen's (1991) psychomotor model of handwriting is applied in partnership with Berninger and Amtmann (2003) in this thesis to create a more comprehensive theoretical framework for the investigation of handwriting. Van Galen's (1991) model of handwriting is presented in the following section.

2.2 **Van Galen's (1991) Psychomotor Model of Handwriting: The mechanics behind the** handwriting

Since the models of writing do not expand on the underlying processes in the production of handwriting movements, consideration of an additional model specifically related to handwriting is necessary. According to Van Galen (1991) handwriting is a multi-component task, which not only involves cognitive elements, but also requires the integration of psychomotor and biophysical processes. Based on an extensive review of the literature on handwriting, Van Galen (1991) developed a psychomotor model of handwriting, which according to Connelly, Dockrell and Barnett (2012), provides the most complete model of handwriting to date.

Van Galen's model (1991) is a multi-stage, hierarchical model which describes the process from the transformation of language into the sequencing of movements. The model includes processing units (also known as modules) at each level; from the selection of a word, through to the execution of the pen strokes (Van Galen, 1991). Each module is processed one after the other at different points in time; for example, generating language will occur before the muscular adjustments for the pen stroke. From the top of the model through to the bottom, the processing units (illustrated in figure 2.2) decrease in size. All modules are concurrently engaged in processing activities, but higher level processes such as semantic retrieval are further ahead than lower level, real time movements. Figure 2.2 provides a visual description of Van Galen's model (1991). The vertical nature of the columns corresponds to the hierarchical structure of the model.

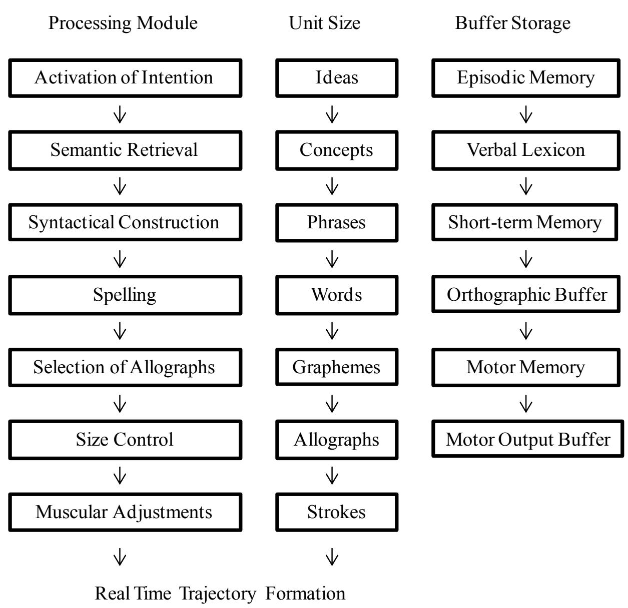


Figure 2.2. The process modules from Van Galen's (1991) Psychomotor Model of Handwriting.

At the very top of the model is the activation of the intention to write, semantic retrieval and syntactical construction. According to Van Galen (1991) these three modules were taken from the literature both on writing and speech. However, at the point of spelling, handwriting begins to differ from speech, as the sounds of the letters have to be transformed into graphemic codes (Van Galen, 1991). This process can occur in two ways; through the mapping of phoneme-to-grapheme (sound to letter) rules or through knowledge of spelling a particular word (Van Galen, 1991). Either way, the motor process comes into effect directly after the spelling component.

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 program (retrieval of an allograph action pattern from long-term motor memory). This is also where the type of script is activated (joined, un-joined, capital letters, small letters). Following the activation of the motor program 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 model in the literature, is not without its criticisms. According to Kandel and Spinelli (2010), when various levels of the handwriting process are active in parallel, processing capacities become limited. As a result, the duration of the handwriting movements increase. Research by Kandel and colleagues (Kandell, Soler, Valdopis & Gros, 2006) on 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. For example, Kandel et al (2006) demonstrated that if a writer is approaching the beginning of a syllable, the motor system anticipates the forthcoming syllable and increases its processing demands by planning it in parallel with real time movements. Therefore during the production of the planned syllable, no further processing is needed. This fluctuation in processing was found to influence the movement times of handwriting, where handwriting would speed up or slow down depending on the linguistic makeup of a word (Kandel et al, 2006). However, in Van Galen's model (1991), the higher-level, linguistic units as modulators for handwriting movements were not accounted for (Connelly et al., 2012). This has subsequently been proposed as a modification to Van Galen's model by Kandel, Peereman, Grosjaques and Fayol (2011). The work of Kandel and colleagues is re-visited in Chapter 4, where a variety of influences on handwriting speed are discussed in greater detail.

2.3 Handwriting in DCD

Despite the inclusion of handwriting difficulties in DSM-5 (APA, 2013) and reports from parents and teachers regarding poor handwriting performance (Dunford, Missiuna, Street & Sibert, 2005), there have been very few empirical studies on handwriting in children with DCD. Parents and teachers report poor letter formation, reduced word legibility and slow handwriting (Dunford et al, 2005) but little has been done to formally investigate and measure this. The studies which have investigated handwriting in children with DCD have been conducted in alphabets outside the Latin base and in languages other than English (Rosenblum & Livneh-Zirinski, 2008; Chang & Yu, 2010). Given the limited literature on handwriting in DCD, it is appropriate to also examine studies that have focused more on other graphic tasks such as drawing. The studies which have addressed handwriting in children with DCD are reviewed in this section. However, specific aspects of handwriting such as handwriting speed and legibility are explored in greater detail in later chapters.

Since there are a limited number of studies that have specifically addressed handwriting in children with DCD, it is important to consider the few studies in detail in order to gain an understanding of the evidence base. To do so, this review focuses on each individual study initially, ranging from the most comprehensive and ecologically valid study of handwriting, through to studies which have examined drawing. Issues are explored study by study and then integrated into a general discussion. It is worth highlighting that the studies focus on performance at a group level and as a result, little is known about the performance of children as individuals. This is an area which will be addressed later in this thesis.

2.3.1 Studies using Handwriting Tasks

The most comprehensive examination of handwriting in children with DCD to date is that by Rosenblum and Livneh-Zirinski (2008), where the product (the text produced on the page) and process (the process of production) measures of handwriting performance were examined in detail. An important feature of Rosenblum and Livneh-Zirinski's (2008) study was the investigation of classroom based tasks, which were ecologically valid. In their study, the handwriting product was examined in detail using clinical measures, while the handwriting process was analysed through digitising writing tablet technology. The study included 40 children (4 girls, 36 boys) aged between 7 and 10 years. Twenty children met the DSM-IV (APA, 2000) criteria for DCD and 20 typically developing children were assigned to the age-matched peer group. Three handwriting tasks were used and were all written in the Hebrew language. The tasks involved writing ones name, generating the alphabet sequence from memory and copying a paragraph of written text (Rosenblum & Livneh-Zirinski, 2008). The copying task was taken from the Hebrew Handwriting Evaluation (HHE) (Erez & Parush 1999 cited in Rosenblum & Livneh-Zirinski, 2008) which includes 30 words (107 letters). In Rosenblum and Livneh-Zirinski (2008) the children were only asked to copy two sentences (60 letters). One of the limitations in relation to the selection of tasks in their study was the absence of a 'free-writing' task, which is common in the classroom and certainly during examinations. Free-writing tasks involve integrating the writing processes and would have provided insight into the level of difficulty in children with DCD when having to generate content and manage a number of processes together.

Rosenblum and Livneh-Zirinski (2008) evaluated the handwriting product using the HHE, which examines legibility using global and analytical measures. The HHE has been found to be reliable and valid for use in Israel (Rosenblum, Weiss & Parush, 2003) and includes a 4-point scale for the evaluation of legibility. In relation to handwriting speed, Rosenblum and Livneh-Zirinski (2008) recorded the letters produced during the first minute. The results of the handwriting product scores revealed that throughout the three tasks, there were no significant differences between the groups in pen-tilt, stoke-width or stroke-height. However, the DCD group performed significantly below the level of their age-matched peers in global legibility, had a greater number of letters rectified (erased or overwritten) and spatial arrangement of their writing was poor.

In terms of handwriting speed, the children with DCD demonstrated slowness in handwriting through the production of fewer letters per minute (Rosenblum & Livneh-Zirinski, 2008). In addition, the writing tablet data shed considerable light on the slowness observed in the product of children with DCD. Writing tablet technology is a relatively new method of recording handwriting movements, through which more objective measures of the movement of the pen can be obtained. For example, the speed of the pen can be examined (execution speed) along with the duration of pauses when the pen is no longer moving. In the case of Rosenblum and Livneh-Zirinski (2008) the movement pathways of the pen when it was in the air were also analysed. A closer look at the grey line trajectories (movement of the pen off the page), combined with examining the 'on paper' and 'off paper' time, indicated that the DCD group spent considerable extra time with the pen 'in-air', and demonstrated a more complex transition between individual letters and words. According to Rosenblum and Livneh-Zirinski (2008) the differences in the handwriting process such as extra time in-air was responsible for the slowness of text production.

One issue that arose from the analysis of the handwriting process data in Rosenblum and Livneh-Zirinski (2008) was the definition of 'in air' time or 'pauses' and what the 'slowness' in handwriting is thought to represent. Studies in the writing literature tend to define a pause by applying specific criteria, such as any halt above 30 milliseconds (Sumner et al., 2013). However, this information was not specified in Rosenblum and Livneh-Zirinski (2008), which creates barriers to interpreting the findings and ease of replication. It was also unclear in Rosenblum and Livneh-Zirinski (2008) whether the children with DCD spent more time 'in-air' due to the transition between letters/strokes, or whether they were pausing for longer periods due to a higher level process of writing, such as planning. While Rosenblum and Livneh-Zirinski's (2008) study represented an important step towards investigating the handwriting process in children with DCD, further research is needed in order to explore the underlying mechanisms of the pauses ('in-air' time) in greater detail. One method of doing so would be to explore handwriting through the lens of Van Galen's model (1991), where very specific pause durations would be thought to represent specific processes of writing. This type of analysis is emerging in the literature on writing (Sumner et al., 2013; Alves et al., 2007). However, this is a relatively new area and is exploratory in nature. Nevertheless it would promote a more focused method of investigation and is investigated in detail in Chapter 4 of this thesis.

Another finding of Rosenblum and Livneh-Zirinski (2008) was in relation to pen pressure. In their study, children in the DCD group exerted less pressure on the work surface than those in the typically developing group. This outcome was surprising, as clinical reports on children with DCD cite excessive pressure on the writing surface during handwriting tasks (Missiuna & Pollock, 1995). Rosenblum and Livneh-Zirinski (2008) attributed this finding to a possible decrease in strength and endurance in children with DCD based on Raynor (2001), where differences were reported in strength and endurance between children with DCD and their typically developing peers.

One of the limitations in generalising the findings from Rosenblum and Livneh-Zirinski (2008) is the difference between the Latin based and Hebrew writing systems. For example, in the Hebrew language text is produced from right to left and requires different strokes to the Latin based alphabet. For right-handed individuals it would require pushing movements rather than pulling, which would be common in right-handed English writers. It is not known whether children with DCD in the UK demonstrate a similar handwriting profile to children in Israel, or whether the demands of the Hebrew alphabet result in different product and process profiles.

Another limitation in terms of generalising the findings from Rosenblum and Livneh Zirinski (2008) is in relation to spelling difficulties that may have been present, as the children in the study were not screened for dyslexia. This is an important issue to consider when examining DCD and handwriting, as handwriting has been shown to be closely linked with spelling within the level of transcription (Sumner et al., 2013). Since there is over 50% co-occurring rate with dyslexia (Iverson et al, 2005), it is important when investigating their handwriting that the spelling ability is controlled for. If spelling ability is poor, then this in itself will constrain handwriting, which has been found to be the case in children with dyslexia (Sumner et al., 2013). Therefore in order to gain a true representation of the impact of motor difficulties on handwriting it is important that spelling is controlled for and in instances where difficulties are present, separate sub analyses need to be done before including them in large group analyses. The literature on handwriting in children with DCD has never controlled for this possible confounding factor. In the case of Rosenblum and Liveneh-Zirinski (2008) since their sample may have included children with dyslexia, the pausing phenomenon may have been linked to spelling difficulties in addition to motor deficits.

2.3.2 Studies using Individual Letters/Characters

An alternative approach to investigating handwriting difficulties in children with DCD has involved the examination of individual letter forms rather than specific classroom writing tasks. One such study by Chang and Yu (2010) aimed to identify handwriting dysfunction in children with DCD through movement analyses within single characters. Chang and Yu (2010) used two different control groups including typically developing children and children with handwriting difficulties without motor deficits (referred to as 'dysgraphia') in order to investigate the DCD group. The study consisted of 72 participants (40 females, 32 males) aged between 6-8 years and was based in Taiwan. Of the participants, 33 met the authors' criteria for DCD, which did not appear to explicitly fulfil the DSM-IV criteria for DCD, as neurological examinations were not reported. It was therefore unclear whether children with medical conditions or mild neurological deficits were included. A further 39 children demonstrated handwriting difficulties without DCD and 22 typically developing age-matched peers were selected to participate (Chang & Yu, 2010). The children were asked to write three simple pseudo characters each requiring three strokes, followed by three complex pseudo characters with over eight strokes on a digitising writing tablet. Each character was practiced three times followed by its production three times during the formal trials. The number of vertical or horizontal velocity peaks were analysed for every stroke based on research by Mergle et al (1999), which suggested that the number of directional changes of velocity per stroke was an indication of handwriting automaticity. The results revealed a significant difference between the typically developing children and both groups with handwriting difficulties (DCD and dysgraphia). Between the two groups with handwriting difficulties, the children with DCD demonstrated higher velocity than that of the dysgraphia group during the simple task, but lower velocity during the more complex task. According to Chang and Yu (2010), the children with DCD had multi-peaked velocity profiles indicative of dis-automated handwriting. However, they did not hypothesise as to why the task dependent velocity occurred. According to the authors, the pressure exerted on the writing surface may have been a contributor to this, as the children exerted less pressure during the complex task. This may have been a result of a weaker hold, in turn reducing the amount of stiffness necessary to move the pen at speed (Chang and Yu, 2010).

One of the issues with using isolated characters for analysing handwriting deficits is its dissociation from the linguistic factors which are present during functional handwriting tasks. Research by Kandel and Spinelli (2010) emphasised the link between the linguistic makeup of a word and the speed at which letters are produced. Therefore, although Chang and Yu (2010) provided insight into multi peaked velocity profiles when learning individual characters, this could have presented differently had the characters been integrated into a language based task. In addition, Chang and Yu (2010) examined characters from the Taiwanese language, with different movement requirements to English and it is not known whether the same results would have been found within Latin based handwriting.

2.3.3 Studies using Drawing

An examination of other grapho-motor skills, such as drawing might help gain an understanding of handwriting performance in children with DCD. In 2001 Smits-Engelsman et al conducted kinematic analyses to explore underlying deficits of motor control using a drawing trail task. They investigated 125 children aged 6-9 years of age in the Netherlands to ascertain the prevalence of handwriting difficulties in Dutch schools. In doing so, 12 children were identified as having handwriting difficulties through poor performance on the concise assessment method for children's handwriting (BHK, Hamstra-Bletz et al., 1987) and through teacher evaluations. The 12 children with handwriting difficulties were examined for motor function using the Movement Assessment Battery for Children (MABC) test (Henderson & Sugden, 1992). Only three of the children scored below the MABC 15th percentile, the remaining children were within the range expected for their age. While the aim of the study was to investigate underlying deficits in DCD, there were only three children with general motor difficulties consistent with DCD in their sample.

To assess their handwriting difficulties in more detail, the 12 children completed the MABC drawing trail task on a digitising writing tablet (Smits-Engelsman et al., 2001). The children were instructed to draw a line between two solid black lines as accurately as possible under no time constraints. The results indicated that the children with handwriting difficulties made more errors through crossing over the boundary lines more frequently than the control group. The poor writers finished the task in a shorter period of time than the control children and had fewer velocity peaks. The authors interpreted this as a preference in children with handwriting difficulties to use a more ballistic movement strategy, less dependent upon visual correction (Smits-Engelsman et al., 2001).

The contrast in the tasks used in both Smits-Engelsman et al (2001) and Chang and Yu (2010) means that the velocity profiles cannot be applied to the handwriting of children with DCD in the UK, as the tasks were very different. For example, the MABC drawing trail task is different to tasks that involve the production of letters and words. During the MABC drawing trail task the emphasis is on continuous line drawing, lifting the pen as few times as possible, whereas handwriting involves the integration of many, varied letter strokes (Van Galen, 1991). The fact that the children with handwriting difficulties finished the task more quickly than their typically developing peers is also in contrast to Rosenblum and Livneh-Zirinski (2008), where the children with DCD were found to be slower in tasks specific to handwriting. This raises issues with the idea of comparing drawing movements to ecologically valid handwriting tasks, as the nature of the tasks are entirely different.

Another factor which may have contributed to the contrast between Smits-Engelsman et al (2001) and Chang and Yu (2010) was the severity of motor impairment in the DCD groups. Not all children with handwriting difficulties in the Smits-Engelsman et al (2001) study had general coordination difficulties consistent with DCD. In contrast, all children in the DCD group in Chang & Yu (2010) had general motor difficulties confirmed by performance below the 15th percentile on the MABC (Henderson & Sugden, 1992).

Other inconsistencies also emerged between Smits-Engelsman et al (2001) and Rosenblum and Livneh-Zirinski (2008) in terms of handwriting speed. While Rosenblum and Livneh-Zirinski (2008) noted differences between the DCD group and control group in words produced per minute, this was not found to be the case in Smits-Engelsman et al (2001). There was no difference between the group with handwriting difficulties and the typically developing group in words per minute on a handwriting test, the BHK (Smits-Engelsman et al, 2001). This may have been due to the differences in the level of motor skill in the DCD groups, as the children with DCD in Rosenblum and Livneh-Zirinski (2008) met the DSM-IV (APA, 2000) criteria for DCD.

In a more recent study by Smits-Engelsman and Schoemaker (2013), two groups with handwriting difficulties and one without were examined using drawing tasks, to identify whether the underlying deficits in motor control processes in children with poor handwriting were different to those with DCD. The two experimental groups with handwriting difficulties were referred to as a ‘dysgraphia’ group and a ‘DCD+’ group (Smits-Engelsman & Schoemaker, 2013). The term ‘dysgraphia’ was used in their study to refer to a disability that manifests as a difficulty with the motor execution of handwriting in the absence of wider motor difficulties. The DCD+ group included children with DCD who also had difficulties with handwriting.

In their study 32 children aged between 6-12 years with handwriting difficulties participated; 19 with handwriting difficulties only (dysgraphia) and 13 with handwriting difficulties and DCD (DCD+) (Smits-Engelsman & Schoemaker, 2013). The 13 children in the DCD group all scored below the 10th percentile on the MABC (Henderson & Sugden, 1992), were recruited only from main stream schools (indicating the absence of learning disability) and had difficulties with handwriting according to the BHK assessment (Hamstra-Bletz et al., 1987) and teacher questionnaires. In addition to the two experimental groups, there was a typically developing control group (without handwriting or motor difficulties) which consisted of 15 children in the same age range as the experimental groups.

Smits-Engelsman and Schoemaker (2013) used the Van Galen (1991) model of handwriting to try and isolate underlying motor deficits. The experimental procedure required the child to copy a series of patterns from a computer screen as quickly and as accurately as possible. Eight blocks with 8 patterns were completed (Smits-Engelsman & Schoemaker, 2013). When executing the tasks, the children were encouraged to draw the pattern from memory if possible. The drawing task was designed to increase in complexity to impact at the motor program module, where the number of strokes, shapes and spatial relations are stored in memory. In order to increase the complexity, the patterns were manipulated through varying the number and combination of movements (one up stroke followed by a downward stroke). Four levels of complexity were used in the study. Through increasing the complexity of the patterns Smits-Engelsman and Schoemaker (2013) hypothesised that it would increase the motor planning. This would be reflected in pauses between strokes and/or increased movement time. The authors also considered the module of paramaterisation from Van Galen's model (1991). If the children had difficulty paramaterising the size of patterns, this would be indicative of weaknesses in this area. This was measured through examining trajectory length, with the hypothesis that it would be less consistent if there were problems in paramaterisation. According to the authors, the height of patterns would also be inconsistent. The results indicated that both experimental groups used a slower movement velocity, had a smaller trajectory length and were less accurate than the typically developing group, but were not different from each other on these measures. There were no differences between any of the groups for movement time or duration of pauses between strokes.

Although the study was designed to focus on motor planning, it appeared to be based around a learning task, where the child had to memorise an unfamiliar pattern and then produce it on the page. This would have involved beginning at the cognitive stage of motor learning, where an understanding of the nature of the task would have had to be developed along with generating strategies to produce the pattern (Fitts & Posner, 1967). In handwriting, the letters are familiar representations of language (Van Galen, 1991), which children are used to seeing, rather than symbols that are unfamiliar. Thus the reported group differences may have related to learning an unfamiliar pattern, rather than motor planning and parameterisation within handwriting. It is therefore difficult to apply the findings of this study to the handwriting of children with DCD.

2.3.4 Literature on 'Dysgraphia'

The few studies which have specifically focused on handwriting in children with DCD were discussed in detail in the previous section. However, many studies have examined handwriting difficulties in children who do not have motor impairments, but do have difficulties with handwriting. These children are often referred to in the literature as children with ‘dysgraphia’ (Smits-Engelsman & Schoemaker., 2013; Di Brina, Niels, Overvelde, Levi & hulstijin, 2008; Rosenblum, Parush & Weiss, 2003). The term ‘dysgraphia’ is problematic as it lacks a formal definition and has no clear or formal diagnostic criteria. However, according to Smits-Engelsman and Schoemaker (2013) there were no differences between the performance of children with DCD and those with ‘dysgraphia’ on the pattern copying task described above. It was therefore assumed that there were no differences in the severity of handwriting problems, or in the underlying deficits, between children with dysgraphia and those with DCD. Based on the findings of Smits-Engelsman and Schoemaker (2013) it was suggested by Connelly et al (2012) that the literature on ‘dysgraphia’ could perhaps be considered in unison with the literature on DCD. As discussed in the previous section, there are possible limitations to Smits-Engelsman and Schoemaker’s (2013) study in terms of the type of task that was used. Nevertheless, based on the lack of available evidence on handwriting in DCD it is important to consider the wider literature on handwriting to gain a greater understanding of underlying mechanisms of handwriting dysfunction. Therefore, some studies which considered handwriting difficulties in children with no movement difficulties will be discussed in this section.

In a study by Di Brina et al (2008) dynamic time warping techniques were used to obtain an objective measure of the spatial characteristics of poor handwriting. They recruited 40 children in Dutch primary schools aged 7-10 years, 20 of whom were assigned to a ‘dysgraphia’ group based on poor performance on the BHK handwriting assessment (Hamstra-Bletz et al., 1987) and 20 to the typically developing group. However it does not appear as though the children were screened for a general movement difficulty by the examiners. Instead, the authors state that the children had not been referred to occupational or physiotherapy for their difficulties with handwriting.

In Di Brina et al’s (2008) study the children were required to write the letter ‘a’ several times in three different conditions. The first condition was the normal condition, which involved writing the letter in an ordinary, spontaneous writing assignment, keeping within the boundaries of a wide frame. The second condition was the fast condition, which involved writing the letter as fast as possible while retaining legibility. Finally there was an accurate condition, where the children wrote the letters between two horizontal lines, similar to that of school writing requirements. During these tasks, a number of variables were measured, including writing time, trajectory length, velocity, pause time and pressure of the pen on the paper/tablet.

The results indicated that both groups demonstrated similar writing times throughout the three separate conditions. The ‘dysgraphia’ group produced larger letters and demonstrated a greater variability in their movement. However, in the accurate condition, the ‘dysgraphia’ group were capable of writing a similar size to that of the typically developing group. In the fast condition the typically developing group deviated from consistent letter-forms, while the ‘dysgraphia’ group were less variable.

Additional measures showed that both groups demonstrated similar pausing profiles and appeared to pause for 25% of the writing time, although this was significantly reduced during the fast condition for both groups. In terms of applying these findings to children with DCD, Di Brina et al (2008) examined handwriting through the use of Latin based letters, which has not been done in the DCD population. Although Smits-Engelsman and Schoemaker (2013) reported no differences between children with ‘dysgraphia’ and DCD in the underlying processes of handwriting, this would need to be examined in language based tasks similar to that in Di Brina et al (2008).

In Di Brina et al (2008) the ‘dysgraphia’ group were found to exert in excess of twice the pressure on the tablet compared to the typically developing group. This is in contrast to Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010) where the opposite was found for children with DCD. This again raises issues in terms of integrating the literature on DCD with that of ‘dysgraphia’, as although there are some similarities in the handwriting profiles, there are also many differences.

In a more ecologically valid study by Rosenblum et al (2003), the temporal characteristics of handwriting were examined in order to identify the difference between proficient and non-proficient writers. The participants consisted of two groups of 50 children aged between 8-9 years of age; one with ‘dysgraphia’ and one without. The ‘dysgraphia’ group consisted of children who scored poorly on the Teacher’s Questionnaire for Handwriting Proficiency (Rosenblum, Jessel, Adi-Japha, Parush & Weiss, 1997) and also on the HHE handwriting assessment (Erez & Parush 1999 cited in Rosenblum et al, 2003) but who did not have a neurological or intellectual disability. In their study, Rosenblum et al (2003) used a digitising writing tablet to investigate total writing time, "on-paper" time, "in-air" time, and the writing speed during four copying tasks in Hebrew. The tasks consisted of copying seven letters from a computer screen, four different words, two 22 character long sentences (one familiar, one unfamiliar) and a 100 character long paragraph.

Overall, the children in the dysgraphia group exhibited slowness in generating individual characters in all tasks compared to the age-matched controls (Rosenblum et al., 2003). The results also demonstrated a significantly longer period of "in-air" time in the children with dysgraphia, which appeared to increase as the tasks progressed in length. For example, the ‘dysgraphic’ writers spent seven times as much time "in-air" during the 100-character paragraph, compared to the 22-character sentence. Interestingly, the behaviour exhibited during the "in-air" phase differed between both groups, as the non-proficient writers did not tend to hold the pen in a stationary position. Instead, they demonstrated a wandering and twisting movement above the writing surface. Rosenblum et al (2003) labelled this movement above the writing surface as 'motion tours' and this was also found in children with DCD in Rosenblum and Livneh-Zirinski (2008). However, it is not known whether these 'motion tours' which seem to present as complex transitions between letters/words actually impact on the temporal aspects of the task. For example, it would be important to examine whether the 'motion tours' occur during very short pauses (between letters), or during longer pauses and indeed whether they cause a slower transition between letters impacting on handwriting speed.

2.4 Possible explanations for poor handwriting performance

There are a variety of theories surrounding the possible explanations of handwriting difficulties in DCD. So much so, that the ICF (WHO, 2001) would serve as a useful framework in discussing the theories proposed. At the ICF level of *body functions* a meta-analysis by Wilson and McKenzie (1998) highlighted numerous studies which found that children with DCD have difficulties with visual-perceptual skills and have significant deficits in visual motor integration, particularly in tasks which require speed. In a task such as handwriting, which involves the integration of all three of these areas, it would perhaps seem viable to consider visual perceptual deficits in the context of handwriting difficulties. This has already been proposed by Rosenblum and Livneh-Zirinski (2008) who in their discussion suggested possible explanations for the pausing phenomenon, ranging from the inability of children with DCD to retrieve the correct letter form from memory or visualise the letters prior to forming them. However, neither of these theories was examined by Rosenblum and Livneh-Zirinski (2008), therefore it remains unclear whether deficits in visual perception or visual motor integration impact on the handwriting process. Despite the lack of clarity surrounding the role of visual perceptual deficits in contributing to handwriting difficulties, visual perception is an area commonly assessed in paediatric occupational therapy practice worldwide (Feder, Majnemer & Synnes, 2000; Butner, McMain & Crowe, 2002; Rodger, Brown & Brown, 2005). This practice is often embedded in a 'bottom-up', or information processing approach to assessment, where it is hypothesised that the improvement of *body functions* such as visual-motor perception or muscle strength will lead to improvements in functional skills (EACD, 2011). However, it is a controversial topic within the occupational therapy profession at present, as the role of visual perceptual measures in screening for or explaining underlying mechanisms of handwriting difficulties remains unclear (Klein, Guiltner, Sollereder & Cui, 2011).

Other areas commonly considered using bottom up approaches at the level of *body functions* are physical strength and the amount of pressure the child exerts on the paper while writing. In relation to the literature, Chang and Yu (2010) proposed a lack of strength and endurance for the decrease in work surface pressure observed in the DCD group. However, although strength has been examined in the lower body by Raynor (2001), it has not been measured in detail in the upper extremities in DCD. It therefore remains unclear to what extent physical strength relates to underlying mechanisms of handwriting performance. From a practical perspective, many occupational therapists use hand strengthening exercises with children who have difficulties with handwriting. Whether this is a worthwhile practice in children with DCD in the UK has yet to be established.

2.5 Overall Summary

The 'simple view of writing' model (Berninger & Swanson, 1994) has been used to investigate writing in children with dyslexia (Sumner, Connolly & Barnett, 2012) and SLI (Connelly, Dockrell, Walter & Critten, 2012). However, no study has applied a writing framework when investigating handwriting in DCD. It is useful to do this as it serves as a framework for investigation and provides a theoretical foundation for understanding difficulties with the writing processes in DCD. However, despite the usefulness of the 'simple view of writing' model, the handwriting component is not well specified. It is unclear in the model whether handwriting specifically refers to speed or legibility. Therefore in order to ensure handwriting and the linguistic factors that influence it are considered in relation to writing, more detail is achieved through the application of Van Galen's (1991) handwriting model in addition to the 'simple view of writing'.

Although parents, teachers and therapists report that children with DCD have difficulties with handwriting, this review has demonstrated that, at present, there is little research evidence to support this, particularly within the English language. The majority of studies that do confirm difficulties with handwriting in children with DCD are based on studies in the Hebrew and Taiwanese languages. In addition, other studies which have attempted to examine underlying mechanisms of handwriting difficulties have used non language based tasks such as drawing, which is difficult to apply to classroom handwriting tasks. Despite a larger evidence base in existence for children with handwriting difficulties without DCD, it is unclear to what extent these findings can be generalised across groups. In addition, no studies have considered the impact of handwriting on quality of written composition, despite being the method through which children are assessed in the school system. It is therefore necessary that further research is done to investigate handwriting in children specifically with DCD.

A common criticism of the majority of the studies reviewed in this chapter was the lack of attention to literacy difficulties such as reading or spelling. It is clear from models of writing and handwriting that language skills and spelling are an intricate part of handwriting production and can indirectly constrain it (Sumner et al, 2013). However, no study in the literature on DCD has accounted for dyslexia, which has been found to impact on handwriting irrespective of motor difficulties. Likewise, children with ADHD also pause during handwriting (Rosenblum, Epsztein & Josman, 2008), but this has not been controlled for in the literature on DCD. In future work it is important to consider language and attention difficulties when investigating handwriting in children with DCD.

2.6 General Research Questions

Research supporting the models of typical writing and handwriting provide a theoretical framework to examine the handwriting and writing produced by children with DCD. Within this, the overarching aim of the current research project was to explore in detail the performance of children with DCD on a range of measures of handwriting performance.

The background literature on DCD exposed a number of gaps in the literature in relation to handwriting. To bridge the gap between the empirical evidence base and clinical/parent reports, five main questions are addressed in this thesis. Each question is examined in an empirical study and presented in individual chapters (4-8). More specific research questions and predictions are given in the individual chapters following a more detailed literature review.

1. Handwriting speed in children with DCD

In Israel, Rosenblum and Livneh-Zirinski (2008) demonstrated that children with DCD produced fewer words per minute and spent considerable extra time with the pen 'in-air' during handwriting. However, it is not known whether this is the case in children with DCD in the UK. Therefore, the following question was addressed in this thesis:

Do children with DCD produce **less text** than typically developing peers and if so, is this explained by **slower execution speed** or **excessive pausing** during handwriting? (Chapter 4)

2. Handwriting legibility in children with DCD

Although many parent and teachers report poor legibility in the handwriting of children with DCD, legibility has only ever been investigated in Rosenblum and Livneh-Zirinski (2008) within the Hebrew language. Although poor legibility has been used as an inclusion measure in some studies, the specific results related to legibility were not reported in great detail (Smits Engelsman et al, 2001; Smits-Engelsman & Schoemaker, 2013). Therefore in order to examine legibility in greater detail the following question was addressed in this thesis:

Do children with DCD produce a higher percentage of illegible words in their writing compared to typically developing peers? (Chapter 5)

3. Compositional Quality in children with DCD

The relationship between handwriting speed and compositional quality has been consistently demonstrated in research in TD children and those with other developmental disorders (Connelly, Campbell, MacLean & Barnes, 2006; Graham et al., 1997; Gregg et al., 2007; Wagner et al., 2011). Therefore children with DCD are predicted to write more slowly due to their motor difficulties which will be associated with poorer compositional quality. The following question was investigated in this thesis:

Do Children with DCD produce written text that is poorer in compositional quality compared to their typically developing peers? (Chapter 6)

4. Individual handwriting performance profiles in children with DCD

Clinical case studies have shown that while some children with DCD may present with difficulties forming letters (Polatajko & Mandich, 2004) others may present with slow and laboured handwriting (Chambers et al, 2006). However, little is known about the overall profile of handwriting difficulties in children with DCD and whether all children with DCD have some level of handwriting impairment. Although group data is important for understanding atypical development in different populations, this neglects the performance of individual children and can suggest that all children have performed in a similar manner. In order to profile handwriting performance in children with DCD in a more individualized manner the following question was addressed in this thesis:

Do all children with DCD have difficulties with handwriting and according to which measures? (Chapter 7)

5 Underlying components of handwriting performance

Possible explanations for the differences in the handwriting process between children with DCD and typically developing peers have been suggested by authors in the field of DCD, although none have been empirically tested. Two aspects are considered here. First, Rosenblum and Livneh-Zirinski (2008) suggested that children with DCD have difficulties visualising the letters prior to forming them. This notion is supported by many occupational therapists who use tests of visual perception to detect underlying mechanisms of handwriting dysfunction (Feder et al, 2000; Butner et al, 2002; Rodger et al, 2005). Second, both Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010) suggested that children with DCD exert less pressure on the writing surface due to a decrease in strength and endurance. Both of these suggestions were examined in this thesis:

Can measures of strength and visual perception predict performance on handwriting product and process measures in children with DCD? (Chapter 8)

The following chapter will present the methods used to address the research questions presented in this chapter.

Chapter 3

Methods: Recruitment and selection

3.0. Introduction

This chapter provides background information on the children who participated in this research programme. It focuses on the recruitment strategy and the selection measures. Since the number of participants varied across the different studies, the characteristics of the participants and measures used to address specific research questions are discussed in detail in the relevant chapters.

3.1. Recruitment of participants

Participants in this research programme were aged 8 to 15 years, recruited from the final three years of primary/elementary school (years 4, 5 and 6 in Key Stage 2) and in the first three years of secondary/high school (years 7, 8 and 9 in Key Stage 3). This age range was selected for a number of reasons. Firstly, the focus of the research programme was on handwriting performance in children with DCD across a number of educational stages, both primary and secondary. According to the English national curriculum for Writing in children aged 5-8 years, children should be taught how to start and finish letters correctly, form letters of regular shape and size, adhere to good spacing between letters and words and to present their work neatly in order to communicate their work effectively (DfE, 2011). By the age of 8 years, handwriting should have been practiced and learned in line with the curriculum and be moving towards a level of automaticity (DfE, 2011). In Key Stage 3 by age 14-15 years, handwriting speed should be approaching that of adults (Graham et al, 1998). From a practical perspective this age range was deemed appropriate to cope with completing a range of assessment tasks, to allow for a profile of abilities to be obtained.

Nonrandom based sampling was used to recruit the participants with DCD. This approach was used to select children who were representative of a clinical sample and had known motor difficulties. However, 11 children were initially referred to the study as typically developing children by their teachers. When tested, they met the criteria for DCD. The final sample was therefore a mixture of those who had been to clinics in the past versus children who had motor difficulties when assessed in this programme. Although it is acknowledged that non-random sampling would have limited the chance of bias (Banerjee & Suprakash, 2011), given the short timeframe of this research programme, random sampling would not have been feasible. Details regarding how the participants were recruited are provided in the following section.

3.1.1 Recruiting the DCD group

Children for the DCD group were recruited through advertising at parent support groups, schools and through the research group website. To be included in the research programme, each child met the DSM-IV diagnostic criteria for DCD (APA, 2000) (see Table 3.1), following a full assessment. Most of the children had previously been seen by an occupational therapist (OT) and had received a diagnosis of DCD/'dyspraxia' but some had not previously been formally assessed. Children with an additional diagnosis of Specific Language Impairment (SLI) or dyslexia were excluded, as the spelling and language difficulties associated with these disorders could have confounded the results. Following the initial assessment, an information sheet (see Appendix 2) and consent form (see Appendix 3) was then sent to the parents inviting them to participate in the rest of the research programme. Additional children were recruited directly through schools, having originally been put forward by teachers to be part of the typically developing group. However, on initial assessment it was suspected that they met the DSM-IV criteria for DCD. This reflects the general lack of awareness of DCD in education and in the general public, as highlighted in the literature (Kirby, Davies & Bryant, 2005). In these cases a letter was sent to parents indicating that their child exhibited some difficulties on the initial assessments and invited them to contact the research team to discuss this (see appendix 4). If they did so, then further information was gathered to establish whether all diagnostic criteria were met. Table 3.2 shows the procedures and assessments used to establish each of the DSM-IV diagnostic criteria. For most children this included a telephone interview with the parent to obtain a developmental and medical history, completion of parent questionnaires and testing of the child's motor skills. For 9 of the children recruited directly from schools, a slightly different protocol was used as it was not possible to conduct a telephone interview.

3.1.2 Typically developing-aged and gender matched group

A chronological-age matched group is often used in the DCD literature to examine whether children with DCD are different to their typically developing peers on selected tasks/measures. Indeed, children with DCD are frequently compared to age matched peers through the use of age appropriate norms. Furthermore, the European guidelines encourage the use of norm-referenced assessments where possible (EACD, 2011; Sugden, 2006). In addition, within the context of a school environment, age comparisons provide teachers with an opportunity to identify children that may require additional support or a referral to health professionals.

Another important element of the research design was to match the children with DCD for gender. This was particularly important in relation to handwriting performance, as a study by Graham et al (1998) reported that girls had faster handwriting speed than boys at ages 11-13 years and had more legible handwriting than boys between 6-15 years. The same gender difference has also been found in other studies (Barnett, Henderson, Scheib & Schulz, 2007). Given the higher ratio of boys with DCD compared to girls, it was also important to control for this by matching on gender.

Previous research by Graham et al (1998) reported that left-handed writers had slower handwriting speed than right-handed writers in a study of 900, 6-15 year old students. However, a more recent study by O'Mahony, Dempsey and Killeen (2008) reported that handedness did not have an effect on handwriting speed. Indeed, the literature pertaining to whether handedness is a confounding factor in handwriting speed is generally inconclusive. Nevertheless, to make a more direct comparison between the groups, the participants were also matched on handedness. There is evidence to suggest that children with DCD present with a higher frequency of left handed dominance compared to the general population (Goez & Zelnik, 2008), therefore matching for handedness was important in order to facilitate direct comparison.

3.1.2.1 Recruiting the Typically Developing Group

The typically developing children were recruited from local schools in Oxfordshire. Ideally, the school would have been matched to those attended by the children with DCD, however this was not practical given the large range of schools attended by those with DCD and also that many of them were preparing for an external audit/regulatory visit from the Office for Standards in Education, Children's Services and Skills (Ofsted). Therefore at the time of recruitment, some schools were not in a position to accommodate research. However, there was a mixture of schools in both rural and urban areas and with varying demographics in line with the DCD group.

Initially, an information sheet about the study was forwarded to the head teacher in local schools. For schools who were interested in taking part, a meeting with a school representative (head teacher or Special Educational Needs Co-ordinator: SENCo) was arranged. Before progressing to the recruitment stage, the inclusion and exclusion criteria were discussed with the school representative. The school representative was requested to ask teachers of the appropriate year groups to identify children who were performing within the average range academically, and who exhibited no signs of motor coordination difficulties. Handwriting performance was not specified as part of the selection criteria. Once the teachers identified appropriate participants, the parent information sheets (see Appendix 5) and consent forms (see Appendix 3) were forwarded to the parents/guardians.

3.1.3 Inclusion criteria

The children with DCD were selected on the basis of the Diagnostic and Statistical Manual of Mental Disorders, 4th Edition (DSM-IV-TR) criteria (APA, 2000), and in line with the European Academy of Childhood Disability guidelines (EACD, 2011) and the Leeds International Consensus Statement (2006). At the time of writing the DSM-IV was used but since then the DSM-5 (APA, 2013) has been published. The DSM-IV criteria are listed in Table 3.1 however the protocol used here would apply equally to the new DSM-5 criteria.

Table 3.1

The DSM-IV-TR diagnostic criteria for DCD (APA, 2000, p.58)

A. Performance in daily activities that require motor coordination is substantially below that expected given the person's chronological age and measured intelligence. This may be manifested by marked delays in achieving motor milestones (e.g., walking, crawling and sitting), dropping things, "clumsiness", poor performance in sports, or poor handwriting.
B. The disturbance in Criterion A significantly interferes with academic achievement or activities of daily living.
C. The disturbance is not due to a general medical condition (e.g. cerebral palsy, hemiplegia, or muscular dystrophy) and does not meet criteria for a Pervasive Developmental Disorder.
D. If Mental Retardation is present, the motor difficulties are in excess of those usually associated with it.

Since the DCD group was recruited in two separate ways, Table 3.2 illustrates how the inclusion criteria for the DCD group were met including those recruited through the community (parent groups and research website) and those recruited from schools.

Table 3.2

How the inclusion criteria from the DSM-IV-TR (APA, 2000) were met for children recruited from schools and from the community in other ways

	DCD Community	DCD Local Schools
A	Performance substantially below the expected range for age on a UK norm referenced test of motor competency.	
B	The motor deficits had to have a significant impact on academic performance and/or activities of daily living, evident though a parent questionnaire.	In cases where a parent questionnaire was not available (s), both the teacher's and the child's perspectives on performance confirmed criterion B *(see note)
C	No history of neurological impairment confirmed through a parent phone interview.	In cases where a parent interview was not possible the child's teacher either stated that a diagnosis of DCD had been given by a local health professional, or alternatively, no known neurological impairment was noted on the student's file.
D	The absence of an intellectual disability evident through performance within the expected range on a UK norm referenced test of receptive vocabulary and attendance in a mainstream school.	

Note. * The tools used to gather information from the teacher and the child were part of the study in Chapter 7. See Chapter 7 for detail on the teacher and child data.

3.1.3.1 Exclusion criteria

It has been established that children with DCD often have co-occurring developmental disorders such as dyslexia, specific language impairment (SLI), attention deficit hyperactivity disorder (ADHD) and autistic spectrum disorder (ASD) (EACD, 2011). In this research programme children who had a formal diagnosis of dyslexia or SLI were not included on the basis of additional deficits having an impact on handwriting performance. For example, Sumner et al (2012) reported that children with dyslexia paused for longer periods of time than typically developing peers, but specifically around misspelled words. Similarly, Connelly et al (2012) found that children with SLI also paused for a greater percentage of the time on a handwriting task.

Children with a diagnosis of ADHD or ASD were included in the study, but those who were unable to attend to the handwriting tasks due to difficulties with attention were excluded. Two children were excluded on this basis, as they failed to attend to the task demonstrating a preference to draw on the page instead of write. Children with ADHD who were on medication were excluded, since research suggests that they exhibit slower handwriting speed compared to typically developing peers (Rosenblum et al, 2008). In addition, those who scored below the average range in receptive vocabulary or had English as a second language were excluded from the study. This was due to difficulties with vocabulary and issues such as grammar impacting on the writing process. Children who had a reported physical, sensory or neurological impairment were excluded. This was to ensure that handwriting difficulties were not attributed to other disorders. The above exclusion criteria were applied across both groups.

3.2 Measures

Descriptions of the selection measures used in this research programme are presented below. Additional measures specific to individual research questions will be presented in the appropriate chapters.

3.2.1 Selection Measures for all children

Motor Skill Assessment. The Test component of the Movement Assessment Battery for Children, 2nd edition (MABC-2 Test) (Henderson, Sugden & Barnett, 2007) was used to assess general motor competence. All children completed the MABC-2 test, which is a standardised test with UK norms for children aged 3-16 years. It is recommended for use by the EACD guidelines (2011) and the Leeds International Consensus Statement for assessing motor skills in children with DCD (Sugden, 2006). The MABC-2 assesses motor competence in three different components, manual dexterity, ball skills and balance. There are three age bands for children aged 3-6, 7-10 and 11-16 years. Only the second and third age bands were required in this research programme. The tasks are similar across the age bands but increase in difficulty depending on the child's age.

The manual dexterity component includes tasks such as unilateral dexterity, which examines speed and accuracy of both the preferred and non-preferred hand. This is measured through placing pegs in a pegboard with one hand as quickly as possible. The second manual dexterity item examines bimanual coordination at speed. It requires the use of both hands to complete either a threading task, or manipulating nuts and bolts to form a triangle. Both of these tasks are measured by time in seconds. The third manual dexterity task is a motor control task, which emphasises accuracy. This involves controlling a pen to draw a trail between two boundary lines (with a narrower track for older children). Any divergence outside the boundary lines or gaps in the trail are counted and scored as errors. Raw scores from each of the three manual dexterity tasks are converted to standard scores, which are summed to provide a component score for manual dexterity (mean of 10, standard deviation of 3). Test re-test reliability for the manual dexterity component of the MABC-2 is acceptable (r=.77, Henderson et al., 2007).

The aiming and catching component of the MABC-2 consists of two items. The first involves a catching task, which is graded in levels of complexity depending on age. For example, 7-10 year olds throw a tennis ball against the wall and catch it in two hands. At age 7 and 8 years they are allowed to let the ball bounce once before catching. At 11-16 years, the children must catch the ball in one hand with no bounce permitted. Both the left hand and the right hand are tested in the older children. The ball skills component also includes an aiming task, which examines accuracy in throwing to a target. For age band 2 this involves throwing a beanbag to a red target circle on a floor mat. In age band 3 children are required to throw a tennis ball to a target placed at head height on a wall. The number of successful attempts out of 10 are recorded. Raw scores from the two ball skills tasks are converted to standard scores, which are summed to provide a component score for aiming and catching (mean of 10, standard deviation of 3). Test re-test reliability for the aiming and catching component of the MABC-2 is acceptable (r=.84, Henderson et al., 2007).

The balance component of the MABC-2 has three items; one static balancing task and two that examine dynamic balance. The static balance task involves balancing on a balance board, which is adapted to add complexity depending on the child's age. The task records the number of seconds that the child can balance on the balance board for up to 30 seconds. The two dynamic balance tasks include walking accurately along a line, either facing forwards or backwards depending on age. The child is required to take one step at a time, ensuring the heel touches the toe before the foot is placed straight on the line. The child is not allowed to adjust their foot once it is positioned on the line. The number of correct consecutive steps is recorded. The final dynamic balance task requires the child to start from a stationary position and hop continuously from one mat to the next. The mats are either in a straight line or placed in a zig-zag manner, depending on the child's age. The number of correct consecutive jumps is recorded up to a maximum of 5. Raw scores from the three balance tasks are converted to standard scores, which are added together to provide a component score for balance (mean of 10, standard deviation of 3). Test re-test reliability for the balance component of the MABC-2 is acceptable (r=.73, Henderson et al., 2007). The standard scores for each of the eight test items are then summed to give a total test score. The total test score is then used to obtain a standard score and percentile rank for the overall test. In terms of validity, the MABC-2 has been shown to correlate (.53) with the composite score of the Bruininks-Oseretzky Test of Motor Proficiency – 2nd Edition (BOTMP) (Bruininks & Bruininks, 2005) which is a norm-referenced test mainly used in the USA and Canada (Croce, Horvat & McCarthy, 2001). According to studies by Tan et al (Tan, Parker and Larkin, 2001) and Van Waelvelde and colleagues (Van Waelvelde, Peersman, Lenoir & smits-Engelsman, 2007) the MABC-2 has also been shown to correlate with the McCarron Assessment of Neuromotor Development (MAND) (McCarron, 1982) and the Peabody Developmental Motor Scales (PDMS-1) (Folio & Fewell, 2000).Although the MABC first and second edition have been the most frequently used motor competency tests to assess DCD in the literature and the best examined (EACD, 2011), alternatives s such as the BOTMPhave norms based on a USA sample and according to the EACD (2011) a test which uses culturally relevant developmental norms is preferred. Given that the MABC-2 was standardised using a UK based sample, this was selected for the current research programme.

<u>Receptive Vocabulary.</u> All children completed the British Picture Vocabulary Scale-second edition (BPVS-2) (Dunn, Dunn, Whetton & Burley, 1997) to measure receptive vocabulary. Since this measure correlates highly with verbal IQ (.61) (Glenn & Cunningham, 2005) it was used to ensure that none of the participants had an intellectual impairment. This test has been used by other authors in the field of DCD to acquire an indication of verbal IQ, as it does not require a motor response which would impact on performance in this group (Dunford, Street, O'Connell, Kelly & Sibert, 2004). As a measure of receptive vocabulary it was also important in terms of the impact it may have on the quality of written composition which is addressed in Chapter 6. The BPVS-2 is a standardized test with UK norms and it is commonly used to examine the level of receptive vocabulary in children. The child is presented with four pictures on a page and a word is spoken out loud to them. The child is required to

either say the picture number, or point to the picture that best represents the word. The procedure for administering and scoring the assessment was carried out in line with the test manual. The raw scores were converted to standard scores (mean 100, SD 15). Reliability of the BPVS-2 has been reported as good, with median corrected split half reliability at .86 (Dunn et al, 1997).

Spelling. All children completed the single-word dictated spelling task from the British Ability Scales (BAS-II) (Elliott, 1997), which has UK norms for children aged 5-18 years. The age of the child dictates the starting point of the test. The child is provided with a lined piece of paper and they complete the spellings in pencil. The list of words was dictated to the child in blocks of ten words. They continued until they reached their ceiling point making 8 or more misspellings in a block of 10. The raw score was calculated and converted to a standard score (mean 100, SD 15). The spelling task has a high internal reliability (α= .84 to .93) and has been shown to correlate with the spelling subtest of the Wechsler Objective Reading Dimensions (WORD; Wechsler, 1993) r= .63, indicating a high level of validity (Field, 2013).

Reading. To assess reading ability, all children completed the single word reading test from the BAS-II (Elliot, 1997), which has UK norms for children aged 5-18 years. It requires the child to read single words out loud from an A4 page. The starting point was determined by the child's age. The words gradually increased in complexity until the child made eight errors out of a set of 10 words. The raw score was calculated and converted to a standard score (mean 100, SD 15). The reading task has a high internal reliability (α= .88 to .95) and a good level of validity as demonstrated by a correlation with single word reading in the WORD (Wechsler, 1993; r= .71).

3.2.2 Additional Selection Measures for children with DCD

Activities of Daily Living. The Movement Assessment Battery for Children (MABC-2) Checklist (Henderson et al, 2007) was used to collect additional information from parents to inform Criterion B (APA, 2000). The checklist was initially standardised for use by teachers in order to identify children likely to have a movement difficulty. However, although not validated for parental use, it is frequently used by parents as they are in a unique position to observe performance in skills such as dressing and ball skills (Henderson et al, 2007). The checklist contains three sections including movement in a static/predictable environment, movement in an unpredictable environment and non-motor factors that may affect movement. It contains 15 statements which the parent rates their child using one of four responses (very well, just ok, almost, not close). The ratings are then summed to provide a total score, which is then mapped to a traffic light system showing whether a child falls into the normal range for their age (green), shows some delay in motor skills (amber) or is likely to have movement difficulties (red). The checklist is designed for children aged 5-12 years. The EACD guidelines (2011) state that checklists should not be used as a general screening tool for motor difficulties as the sensitivity of the available tools has not been shown to be strong enough for population screening. In this research programme the MABC-2 checklist (Henderson et al, 2007) was used to gain qualitative information in order to inform criterion B and was not used for screening purposes.

Attention. The Strengths and Difficulties Questionnaire (SDQ) (Goodman, 1997), completed by the parent was used to report any other behavioural difficulties which commonly occur with DCD such as attention deficits. The SDQ was designed for assessing the psychological adjustment of children aged 3-16 years. It consists of 25 attributes and uses a 3-point Likert scale to indicate how much an attribute applies to the child. The 25 items are divided between five areas including emotional symptoms, conduct problems, hyperactivity-inattention, peer problems, and pro-social behaviour (Goodman, 1997). A total score is obtained by summing the scores on the first four areas. Reliability and validity of the SDQ is satisfactory and this tool has been advocated as a useful measure in identifying emotional and behavioural difficulties (Goodman, 2001). It has been used in studies which examined the co-occurrence of DCD with ADHD (Green at al, 2006) and has been used in this research programme to ascertain whether any of the children with DCD had difficulties with attention.

3.3. Details of Participants with DCD

Thirty children with DCD were recruited, but two were excluded (1 male, 1 female) due to attentional difficulties and non-compliance, therefore the final DCD group comprised of 28 children (27 boys, 1 girl).

Twenty one children (20 boys, 1 girl) were recruited from the community through advertising research on DCD (e.g. at local parent support groups and on the university website) and an additional 9 (all boys) were recruited directly through the local authority primary and secondary schools where the research was being undertaken. As noted above, these 9 children with DCD were initially referred to the study as typically developing children. These 9 children were compared to the community sample of children with DCD on the inclusion measures and no group differences were found for the MABC total percentile (U= 261.0, Z = -.731, p=.498), spelling ($t(26) = -1.67$, $p = .105$) reading ($t(26) = -.620$, $p = .541$) or receptive vocabulary ($t(26) = 1.07$, $p = .291$). This is illustrated in Table 3.3.

3.3.1. Performance on Motor Competency: Establishing DSM-IV Criteria A

The children with DCD were required to score at or below the 15th percentile on the Movement Assessment Battery for Children, 2nd edition (MABC-2) (Henderson et al, 2007). This cut off is in line with international guidelines for the assessment of DCD both in Europe and worldwide (EACD, 2011;

Sugden, 2008). Twenty four were below the 5^{th} percentile and 4 were below the 10^{th}.

3.3.2. The Impact on Motor Competency on Activities of Daily Living and/or Academic Performance: Establishing DSM-IV Criteria B

The European guidelines for DCD (EACD, 2011) recommend the use of a validated parent questionnaire in support of criteria B from the DSM-5 criteria (APA, 2013). A questionnaire that is culturally relevant and has national norms is recommended (EACD, 2011). The Movement Assessment Battery for Children-Checklist (MABC-2-Checklist) (Henderson et al, 2007) has UK norms and, where possible, was used to gather information from parents. Although the checklist was initially developed for teachers, it was used here to ascertain the parent's perspectives on their child's motor performance and was the preferred method of establishing criteria B in this research programme. In the cases where the checklist was not returned, both the teacher's and the child's perspectives on performance confirmed criterion B as these measures were taken during specific studies surrounding teacher and child perspectives in this thesis.

3.3.3 The Disturbance is not due to a general medical condition or intellectual disability: Establishing DSM-IV Criteria C & D

For 20 children it was possible to conduct a telephone interview with their parent to obtain a medical and developmental history. Specific questions were asked in line with the EACD guidelines (2011), relating to birth and early development, sensory and neurological problems, accidents and diseases and performance at school. Information was also requested regarding any formal diagnoses and motor and non-motor difficulties. All children were born full term and none had reported sensory, physical or neurological conditions that might explain their motor difficulties.

In addition to the parent interview, although the EACD (2011) guidelines do not require the use of an objective measure for examining IQ in children with DCD, it is recommended in cases of doubt. Therefore, to ensure all children were at least in the average range of intellectual ability, all children had to achieve a standard score of 85 or above on the British Picture Vocabulary Scale 2^{nd} edition (BPVS-2) (Dunn et al, 1997). This was used to give a measure of receptive vocabulary, which correlates highly with verbal IQ (Glenn & Cunningham, 2005). Table 3.3 provides a summary of group performance on the BPVS-2.

Additional Screening Measures

3.3.4. Performance on Reading and Spelling-DCD Group

All children with DCD completed the reading and spelling tasks from the British Ability Scales 2nd edition (BAS-II) (Elliott, 1997). Due to the high incidence of DCD with reading and spelling difficulties, children with DCD were initially classified into two groups. The first group contained those who achieved a standard score at or above 85 on reading and spelling. This group was referred to as the DCD group. The second group was named the DCD+ group and it contained those who scored below the average range (below standard score of 85) on reading, spelling or both. Crucially, none of the participants had a diagnosis of SLI or dyslexia.

During each specific research question that required reading and spelling skills, scores from the DCD and DCD+ group were compared. If no significant differences emerged between the DCD and DCD+ groups in each specific study, the two groups were combined. Chapter 4 describes the DCD and DCD+ groups in more detail in relation to their handwriting performance and justifies the inclusion of both groups as one. Table 3.4 provides details on the performance of the DCD group on the selection measures.

Table 3.3

Mean Performance scores of the community DCD and school DCD groups on selection measures

Selection Measures	DCDC n=19 *m(SD)*	DCDS n=9 *m(SD)*	*p*
MABC-2 Test percentile	2.82 (2.55)	3.77 (3.41)	.414
BPVS Standard Score	110.9 (15.81)	104.6 (10.59)	.291
BAS-Spelling Standard Score	92.5 (13.99)	108.3 (11.72)	.105
BAS-Reading Standard Score	108.3 (15.23)	111.8 (10.84)	.541

MABC-2: Movement Assessment Battery for Children. BPVS: British Picture Vocabulary Scale, BAS: British Ability Scale

3.3.5 Attention Difficulties

The Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) was used to note any other behavioural difficulties reported by the parent, which commonly occur with DCD such as attention deficits (Miller et al., 2001). The parent interviews revealed that no child had received a formal diagnosis of ADHD, but a raised score in inattention/ hyperactivity was revealed by the SDQ for seven children (see Table 3.4). Although the seven children attended adequately to the tasks, the data from the handwriting measures for these seven children were compared against the rest of the DCD group and no differences were seen, therefore all children were included in the final DCD group.

3.3.6. The Selection of Typically Developing (TD) Participants

Thirty typically developing children (29 boys, 1 girl) aged between 8:0 years and 14:11 years were recruited to individually match those in the DCD group in terms of age (+/- 7 months), gender and handedness. The children in the TD group scored above the 16th percentile on the MABC-2 (Henderson et al, 2007) to ensure the absence of motor deficits. Receptive vocabulary was 85 or above for all the TD children. Reading and spelling ability as measured on the BAS-II was also age appropriate, with all standard scores above 85 (Elliott, 1997).

Table 3.4

Description of the performance of the DCD group on the selection measures.

Selection Measures	DCD n	DCD m(SD)
Age in years	28	10.61 (2.23)
DSM-IV Criteria A		
MABC-2 Test Percentile	28	3.45 (2.96)
- Below 5th percentile	26	
- Below 15th percentile	2	
DSM-IV Criteria B		
MABC-2-Checklist (amber or red zone)[a]	20	
DSM-IV Criteria C & D		
BPVS Standard Score	28	108.9 (14.4)
Additional Measures		
Attention		
SDQ		
- No behavioural difficulties	21	
- Inattention/Hyperactivity	7	
Literacy		
BAS-Spelling Standard Score	28	
- SS above 85	21	102.5 (9.68)
- SS below 85	7	79.25 (5.99)
BAS-Reading Standard Score		
- SS above 85	27	114.8 (11.5)
- SS below 85	1	82

MABC-2: Movement Assessment Battery for Children. BPVS: British Picture Vocabulary Scale, SDQ: Strengths & Difficulties Questionnaire. BAS: British Ability Scale

[a] Eight children who were recruited from schools did not return the checklist.

3.3.7. Group comparisons

The results in Table 3.5 illustrate the mean performance scores for the selection measures for both groups. There was no significant group difference in age (U= 345.0, Z = -.771, p=.441) or receptive vocabulary ($t(54) = -.449$, $p = .655$). Both groups performed within the average range for reading and spelling, but the TD group had significantly higher scores than the DCD group on both reading ($t(54) = -3.66$, $p = .001$) and spelling ($t(54) = -.438$, $p < .001$).

Table 3.5

Mean Age and Performance scores of DCD and TD groups on selection measures

Selection Measures	DCD n=28 *m(SD)*	TD n=28 *m(SD)*	*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*
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. BPVS: British Picture Vocabulary Scale, BAS: British Ability Scale

3.4 Test Procedures

This research programme was approved by the University Research Ethics Committee at Oxford Brookes University (see Appendix 6 for confirmation letter). Following recruitment all parents were required to sign a consent form (see Appendix 3) and children were asked to either assent (below 11 years), or countersign the parent consent form (over 11 years).

All participants were tested individually by the first author, therefore the test administrator was not blinded. However the raw data was anonymised for data analysis in order to address specific research questions therefore reducing the possibility of bias based on performance.

The children were tested either at Oxford Brookes University, in the child's home or in their school. The MABC-2 and BPVS were initially administered to confirm the inclusion criteria. Thereafter, the assessments used to address the specific research questions were implemented (see Table 3.6).

On receipt of the information sheet, the parents could document on the consent form whether they preferred their child to be seen at school, in their home or at Oxford Brookes University. For testing in schools, both in the TD group and the DCD group, children were seen over four separate sessions lasting approximately 30 minutes each. Given the nature of the school day, time constraints of 30 minutes were often imposed in schools. The sessions were a week apart where possible.

The sessions at the University or in the child's home took part over two separate sessions, lasting approximately 1 hour each. These sessions were out of school time, usually school holidays or in the evenings and were a week apart where possible. One-hour sessions were possible in these environments due to fewer time constraints.

During the sessions the children were given breaks in between tasks, usually as the upcoming task was being prepared. All children were made aware that they could stop at any point and they did not have to give a reason. Where children appeared bashful or anxious, they were encouraged to relax and do their best and were given reassurance. One child was excluded on the basis of non-compliance, as handwriting evoked anxiety in the child and he therefore did not complete the handwriting tasks appropriately. Otherwise, none of the children refused to commence or complete any of the assessment tasks used in this research programme.

3.4.1 Outline of experimental design

Table 3.6 provides a list of all of the assessment tools used in this research programme, how they were matched to research questions and at what stage they were implemented. The measures that have not already been discussed in this chapter are included in the table in their abbreviated form and are clarified below the table.

The selection measures were implemented in the first session followed by the additional measures specific to research questions. This also allowed for the scoring of selection measures and allocating groups or excluding children from further participation if necessary. The assessments were presented in an order that would provide the participant with a different challenge rather than spending too much time on one type of task. The order of the assessments also depended on the environment, for example in schools a number of short tests would need to be administered during one session, followed by a longer test during the next session. This was due to time constraints imposed by schools.

Table 3.6

Testing session protocols and the measures implemented

Session	Objective	Measure
1	Chapter 3: Selection and background measures	• MABC-2
2	Chapter 3: Selection and background measures	• BAS - Spelling • BAS - Reading • BPVS
3	Chapter 4 & 5: Handwriting Speed & Legibility Chapter 8: Physical Factors	• DASH tasks - Copy best task - Alphabet task - Copy fast task - Graphic Speed task - Free-writing task - Name writing task • Grip Strength
4	Chapter 8: Occupational Therapy Clinical Assessments Chapter 7: Teacher and Child Perspectives	• TVPS • Beery VMI • COPM

Note: MABC-2=Movement Assessment Battery for Children-2; BAS= British Ability Scales. BPVS=British Picture Vocabulary scale; DASH=Detailed Assessment of Speed of Handwriting; TVPS=Test of Visual Perceptual Skills; Beery VMI=Beery-Buktenica Developmental Test of Visual Motor Integration; COPM=Canadian Occupational Performance Measure.

3.5 Data analysis

In depth descriptions of scoring and analysis for tasks that did not use standardised scores are provided in the relevant chapters. Most of the assessments used in this research programme standardised, norm-referenced measures.

3.5.1 Standardised scores and standard deviations

To correctly adhere to the standardised procedures of most assessments used in this research programme, careful attention was paid to the test manuals in terms of administration and scoring. The raw scores were calculated and then converted into standardised scores where possible. All standardised assessments in this research programme had a mean standard score of 100 and a standard deviation of 15. One standard deviation from the mean therefore gives a score between 85 and 115. Standard scores allow for comparisons between participants based on age and most of the assessments had the benefit of norms specific to children within the UK.

For children with motor coordination difficulties, standard scores have a significant role in the assessment and diagnosis of DCD (EACD, 2011). Indeed the European Guidelines (EACD, 2011) and the Leeds Consensus Statement (Sugden, 2006) make specific recommendations in terms of standardised scores and indicate preferred ‘cut offs’ at which a diagnosis may be given. The ‘cut off’ would normally occur when a child performs more than one standard deviation below the mean standard score on a test, indicating performance below the average range expected. The EACD (2011) recommend a cut-off below the 15th percentile on a motor skills test to fulfil criterion A of the DSM criteria, a level which is approximately equivalent to one standard deviation below the mean.

3.5.2 Statistical analysis

The data collected for this research programme was analysed using the statistical software IBM-SPSS version 19. The data in this chapter and the relevant analyses chapters were initially tested for normality. Normal distribution was assessed using the Kolmogorov-Smirnov test, which calculated a level of significance. If the significance value was above .05, the data were considered to be normally distributed and appropriate for parametric tests to be conducted (Field, 2013). If the significance value was less than .05 the data deviated from normality (Field, 2013) and non-parametric tests were conducted on the data.

Homogeneity of variance was also initially examined using Levene’s test for equality of variance. If the significance value was greater than .05, the variances were assumed to be equal (Field, 2013). This allowed for parametric tests to be conducted on the data. Otherwise, if the value was below .05, non-parametric tests were conducted as an alternative.

Descriptive statistics are provided in each of the results tables throughout this thesis. The tables include means and standard deviations. To compare the mean scores across the two groups, t-tests or the non-parametric equivalent Mann Whitney-U tests are the most common tests used in this thesis. They allow for straightforward comparisons between the two groups (Field, 2013).

Some of the specific research questions required an analysis that could consider group differences across a range of different tasks, for example across the handwriting tasks. In this instance two-way mixed analysis of co-variance were used to examine group effects, task effects and group-by-task interactions. Age was used as the covariate in these analyses due to the wide age range of children in this research programme. Pairwise post hoc comparisons using Bonferroni corrections were used to compare performance between the DCD and the TD groups. Significance was set at $p<.05$ in all cases.

Bi-variate correlational analyses were conducted in order to ascertain whether a significant relationship existed between two or more variables of particular importance to the research questions. If significant relationships existed, the variables were entered into a regression analyses. Separate regression analyses were computed for each group so that clear distinctions could be made with regards to the effect of group membership and to examine whether the same relationships existed for both groups separately. Multiple regression analysis was used when more than one variable was considered to be a predictor. However, this was specifically limited to 3 predictor variables entered the regression, as each participant group had 28 children and 10 participants allow one predictor (Field, 2009).

3.6. Contextualising the sample

The selection measures discussed in this chapter were carefully chosen in order to ensure both groups met the relevant inclusion criteria. Importantly, the measures confirmed that the participants in the DCD group were children who met the DSM-5 criteria for the diagnosis of DCD (APA, 2013). Careful attention was paid to the Leeds International Consensus Statement (Sugden, 2006) and the EACD (2011) guidelines during the recruitment and initial testing process. The results from Table 3.4 indicated that as expected, the children with DCD not only scored substantially below the TD group in motor competency skills, but also below the 5th percentile on the MABC-2 as a group. Only two of the children in the DCD group had a MABC-2 score between the 10th and 5th percentile. The children in the DCD group did not present as 'borderline' cases and had clear and significant motor deficits below the 5th percentile. In terms of the sub-components of the MABC-2 test, 26 children with DCD scored below the 15th percentile on manual dexterity, while 15 were below on aiming and catching and 26 below on balance. Manual dexterity and balance were poor in the vast majority of cases, while ball skills were only an issue in half of the sample.

In terms of the avenue of recruitment for children with DCD, the children who were recruited from schools did not perform differently to the children with DCD recruited from the community. Table 3.3 illustrates the performance of both groups (community and school based) on the selection measures and provides support for integrating the children into one DCD group.

Of particular importance was the performance of the DCD group on the reading and spelling measures. Table 3.4 illustrates that seven children with DCD had difficulties with spelling. However, key to this research programme was the absence of a diagnosis of dyslexia. Despite this, it was important to ensure that the spelling difficulties experienced by the seven children in the DCD group did not have an impact on the handwriting results. Separate analyses are conducted in Chapter 4 to control for this factor.

Another co-occurring issue was in the area of attention. Seven children in the DCD group had 'slightly raised' scores for inattention/hyperactivity, as noted by their parent on the SDQ (Goodman, 1997). However, none of the children had significantly raised scores or a diagnosis of ADHD. Separate analyses were conducted in the relevant chapters to ascertain whether this had an impact on the results.

3.7. Summary

This chapter provided the relevant background information on the pool of participants that were used in this research programme. It defined and clarified the characteristics and background information on the DCD group and TD group. The measures provided in this chapter provide an overview of all children that participated in this research programme and numbers will vary throughout the forthcoming chapters depending on the specific research question. The following chapter gives a detailed examination of handwriting speed in the TD and DCD groups.

Chapter 4

Handwriting Speed in Children with DCD: Are They Really Slower?

4.1 Introduction to the Chapter

In the UK handwriting is still the preferred method of producing text in examinations (DfE 2013). The student needs to be able to write quickly and transfer their ideas to the page while trying to keep up with their thoughts (Graham & Weintraub, 1996). In Chapter two the ‘simple view of writing’ (Berninger & Amtrann, 2003) combined with Van Galen’s (1991) model of handwriting illustrated that in order to ensure ideas are expressed, the higher-level processes such as idea generation and translation, need to work effectively. In order to do so, the child’s handwriting must be automatic. Issues begin to emerge when handwriting is effortful and laboured, as the attentional resources available to focus on higher-level processes become limited. This can lead to underachievement, as examinations in particular require the ability to express ideas and demonstrate knowledge under set time constraints. Handwriting skill is vital within education, as it is the main medium through which learning is expressed (DfE, 2013).

For children with DCD, having to write quickly can be problematic, as the notion of quick movement poses a particular challenge. Many studies have found that children with DCD demonstrate longer movement times than their typically developing peers on a range of fine motor tasks including reaching and grasping (Plumb et al, 2008; Wilmut, Barnett & Byrne, 2013). In relation to handwriting, there is anecdotal evidence to suggest that many children with DCD exhibit ‘slowness’ in writing. However in terms of empirical evidence, only a few studies have investigated this. As discussed in Chapter 2, children with DCD highlighted a distinct slowness by producing less text and taking longer to produce letter strokes across a range of handwriting tasks (Rosenblum et al, 2003; Rosenblum & Livneh-Zirinski, 2008; Chang & Yu, 2010). However, it is not known to what extent these findings can be applied to Latin based alphabets. Furthermore, to date no study has examined speed of performance in the task of free writing, which is perhaps the most common in the classroom and the most demanding in terms of cognitive load. Crucially, the nature of reported slow performance has not yet been examined, so it may relate to slow movement time in the actual movement of the pen to form letters on the page, and/or it may reflect longer pauses between the formation of letters and words. A close examination of speed of performance and where pauses occur in the text could shed light on the nature of handwriting difficulties in children with DCD.

To investigate handwriting speed in detail, this chapter comprises two parts. The first part examines handwriting speed in children with DCD, using a range of writing tasks including free-writing. In order to understand the nature of any slowness in handwriting production, measures of the handwriting product were supplemented with a more detailed analysis of the temporal aspects (process measures) of performance.

The second part examines the handwriting process in further detail by quantifying the frequency, duration and location of pauses that occur in the production of handwriting, in both the DCD and TD groups. A detailed analysis using four different pause thresholds was undertaken, to build on the findings from Part 1 and to understand the nature of pausing observed in the children with DCD.

The overall hypothesis was:

Handwriting speed will be slower in the DCD group notable by the production of fewer letters and words per minute.

The following literature review outlines the development of handwriting speed, linguistic constraints on handwriting speed, how it is assessed and issues surrounding terminology. It concludes with a review of the findings on handwriting speed related to DCD.

4.2 Literature Review

4.2.1 The Development of Handwriting Speed/Fluency

Handwriting speed and fluency takes time to develop (Barnett et al, 2007). As highlighted in Chapter 2, there are different expectations for handwriting achievement depending on the child's educational stage. In the early years of handwriting, correct letter formation, shape and size are emphasized (DfE, 2013) and as the child progresses to Key Stage 2 and above (8+ years of age, final three years of primary school), an increase in handwriting speed and fluency is expected (DfE, 2013). The child is required to adapt their handwriting production to meet task demands and this requires an ability to write quickly. Graham et al (1998) highlighted a nine-year process of development from novice to adult speed. In their study, the handwriting speed of 900 children between grades 1-9 (aged 6-15 years) in the USA was examined (Graham et al, 1998). The task involved copying a paragraph as quickly as possible without making any mistakes. The children were given a maximum of 1.5 minutes to complete the paragraph and the number of letters produced was calculated. They found that handwriting speed typically increased from one year to the next, but not necessarily in a linear fashion. From the ages of 6-10 years there was a steady increase in the number of letters produced per minute, but the rate of development tapered off at age 11 years. According to Graham et al (1998), the children reached a similar handwriting speed to adults in grade 9 (age 14 years).

In the UK, similar findings were reported during the development of the Detailed Assessment of Speed of Handwriting (DASH) (Barnett et al, 2007; Barnett, Henderson, Scheib & Schulz, 2010), where a year on year gain in handwriting speed was reported. This increase was observed on a range of handwriting tasks including two copying tasks (copy best and copy fast), writing the alphabet from memory and a free-writing task. The age range examined extended from 9 to 25 years, in order to capture the development of handwriting speed in both school-aged and university students. Contrary to the nine year developmental process of handwriting speed presented by Graham et al (1998), Tait (2007) found that handwriting speed continues to develop well into adulthood. This was noted through significant differences on the DASH free-writing task between 16 and 25 year old students. However, the contrast between the findings from the two studies may well have been related to task differences. While Graham et al (1998) used the alphabet task, Tait (2007) quantified speed through free-writing. The findings of Tait (2007) may have related to writing experience, where the more experienced, older writers may have been able to compose and produce more text compared to younger writers.

Research suggests that the development of handwriting speed is also related to gender, as both Barnett et al (2007) and Graham et al (1998) reported faster handwriting speed in girls than in boys. However, Graham et al’s (1998) measure of speed was through only one type of task; a 90 second copying task, while Barnett et al (2009) found gender differences in favour of girls on four different handwriting tasks. In addition to gender, the debate on whether handedness contributes to handwriting speed is still under dispute, as although Graham et al (1998) reported faster handwriting speed in right-handed writers, this was not found to be the case by other authors (O’Mahony et al, 2008). However, the issue of task may again have been a contributing factor to the contrast in findings, as although both Graham et al (1998) and O’Mahony et al (2008) used copying tasks, they were of different durations; 90 seconds in Graham et al (1998) versus 9 minutes in O’Mahony et al (2008) and involved producing different sentences.

4.2.2 Linguistic Constraints on Handwriting Speed

Handwriting is a complex skill that cannot be understood independent of its connection with linguistic aspects and higher-level processes of writing (Graham & Weintraub, 1996). However, although handwriting speed can constrain the quality of writing through demands on working memory (Bourdin & Fayol, 1994), it too can be influenced by other factors.

One linguistic constraint on handwriting speed is that of spelling. Like handwriting, spelling is also a transcription skill and is included as a lower level process in models of writing (Berninger & Amtrann, date) and handwriting (Van Galen, 1991). When a child learns how to write, they need to be aware that letters represent the sounds of speech – graphemes (Kandel et al, 2006). The child must learn to associate a particular movement with producing a specific letter. Research by Kandel and colleagues in France has examined how spelling and word-structure mediate the kinematics of handwriting production. An example was provided in Kandel et al (2006) to illustrate this. The example demonstrated that when writing the word *milk* (/milk/), the child must be aware that each sound has its own individual letter counterpart /m/=M, /i/=I, /l/=L and /k/=K. However, to write the word *look* (/luk/), the child needs to know that there are three phonemes (sounds), but four letters, /l/=L, /u/=OO and /k/=K. Therefore to spell 'look' correctly, the child needs to map the sound to the appropriate letters (Kandel et al, 2006). This irregularity in spelling tends to occur in languages that have deep orthographies such as English and French (Seymour et al, 2003), where the correspondences between spelling and pronunciation are inconsistent. Based on this premise, Kandel et al (2006) investigated whether the graphemic structure of a word influenced the timing of handwriting production. It was predicted, based on Van Galen et al (1989) that since spelling in French did not directly map sounds to letters, a higher-order linguistic unit (graphemes) would have to be retrieved before any individual letter could be produced. Using a digitising writing tablet to examine movement time and dysfluency (variations in velocity) Kandel et al (2006) found that 1st grade students (aged 6-7 years) prepared the movement to produce the first syllable before writing it. This was determined based on variations in velocity during two syllable words which contained seven letters. Kandel et al (2006) found that the first few letters were performed at a similar velocity, followed by a peak in velocity at the syllable boundary. This, according to Kandel et al (2006), was an indication that the proceeding syllable was programmed as a whole unit on-line, while parameterising and executing the first syllable. The progressive decrease in dysfluency towards the end of the word suggested that the last syllable had been processed as a whole prior to execution midway through the word.

The linguistic makeup of words has also been shown to influence handwriting speed through examining latencies or pauses during the writing process. Lambert, Kandel, Fayol and Esperet (2008) used writing tablet technology to investigate whether the number of syllables in a word affected the timing of handwriting production. In their study French students copied words or pseudo words from a computer screen. They found that the number of syllables modulated the speed of handwriting production, as the students were more likely to pause before producing a word containing low-frequency syllables. However, an element of caution is necessary here as this line of enquiry has not been undertaken in the English language, therefore, it is unclear to what extent the number of syllables modulates the speed of handwriting in English speaking writers.

Given the high co-occurring rate of DCD with dyslexia (Chaix et al, 2007), it is important to acknowledge the constraints that linguistic aspects can have on handwriting production. Indeed Sumner et al (2012) found that children with dyslexia produced fewer words per minute than typically developing peers on a range of writing tasks and had a tendency to pause around misspelled words (Sumner, 2013). In addition, regression analyses indicated that spelling ability and phonological skills were the largest predictors of the number of words produced per minute on copying tasks. This suggests that the handwriting of children with dyslexia was constrained by factors related to spelling. Given this evidence to support the contribution of linguistic aspects to handwriting production, it is important to account for this when examining handwriting in children with DCD. It may be that reading and spelling difficulties play a part in constraining handwriting speed in children with DCD in addition to the existing motor deficits. In the current study, therefore, these factors are taken into account.

4.2.3 Assessing Handwriting Speed

Before reviewing how handwriting speed has been assessed, the different terminologies used in this field are first discussed below. In particular, the terms *automaticity*, *fluency* and *speed,* which are sometimes used interchangeably are examined below.

Automaticity

The term 'automaticity' in the writing literature tends to be used in the context of the alphabet writing task, which was developed by Berninger, Mizokawa & Bragg (1991). This requires the participant to write the alphabet from memory as quickly as possible in lower case and the number of correct letters written is recorded (taking into account legibility and correct order) (Berninger, Mizokawa & Bragg, 1991). Studies by Berninger and colleagues have used the term 'automatisation' in the context of a 15 second alphabet task (Berninger et al, 1992; Berninger, Nielson, Abbott, Wijsman & Raskind, 2008). Berninger & Rutberg (1992) hypothesised that the more automatised the retrieval of letter forms and reproduction of them, the more letters would be produced in this time. Berninger (2012) argued that the 15 second task provides the best representation of how quickly the child can retrieve the initial letter forms from long term memory, hence measuring how automatic the retrieval process is. Anything after 15 seconds according to Berninger (2012) is self-regulation, where the child produces the next letter based on reflecting on what had come before.

Other variations of the alphabet task have been used in the literature with regards to automatisation. Berninger et al (1997) used a 60 second alphabet task to screen for handwriting difficulties in a study of 700 children in the US. The 60 second task requires the child to write as many letters as possible using lower case letters. In terms of scoring, the number of legible letters written in the correct order over a 60 second period are counted. Both the 15 second and 60 second alphabet tasks have been shown to predict the number of words written in a compositional task and the quality of the written text (Berninger et al, 1997; Connelly et al, 2006). However, the debate on whether a 60 second or 15 second task is superior in measuring automaticity is ongoing as no study has examined both tasks simultaneously. However, while both have been shown to predict writing quality, the 15 second task does not allow for the production of the entire alphabet. Therefore, it could be argued that when working with children who have handwriting difficulties the 60 second task would be more beneficial, as a qualitative analysis could be applied to examine the quality of letter formation.

In the motor learning literature, the term ‘automaticity’ was defined by Fitts and Posner (1967) as the stage at which a motor skill has been learned and thus the cognitive effort associated with the task is reduced. The skill can then be performed while the person is engaged in another (secondary) task (Fitts & Posner, 1967). This is fitting in terms of applying this concept to the models of writing and handwriting. Indeed when handwriting has become automatic, the attentional resources can be directed to the higher-level cognitive processes responsible for planning (Berninger & Amtmann, 2003; Van Galen, 1991). In the interest of clarifying the use of handwriting terminology, the use of the term ‘automatisation’ in this chapter, is in line with the Fitts and Posner (1967) definition, where handwriting is automatic if it can be produced legibly at a speed necessary to meet task demands.

Fluency

Another term used in the writing literature in the context of handwriting speed is that of ‘fluency’. The term ‘fluency’ is commonly used to denote the amount of letters or words produced in a given time. Authors such as Connelly et al (2006) and Olive et al (2009) have used the 60-second alphabet task to measure ‘fluency’, the amount of letters produced in one minute. However, the word ‘fluency’ also refers to a free, uninterrupted flow and is applied in different ways in the writing and handwriting literature. In line with this definition, studies by Alamargot and colleagues have investigated interruptions or pauses in writing using writing tablets (Alamargot, Plane, Lambert & Chesnet, 2010). They found that all writers pause during writing, but for different reasons and lengths of time (Alamargot, Dansac, Chesnet, & Fayol, 2007). Under the free flowing definition of 'fluency', excessive interruptions would insinuate less fluent writing. Therefore excessive pauses in the writing process (revising or planning content) would present as a non-fluent handwriting profile due to the halt in production. To clarify use of the word 'fluency' in this chapter, it will be used in line with the free-flowing definition and specifically in the context of pausing, where a pause is considered to represent an interruption in the flow of handwriting.

Speed

In the UK, occupational therapy is the primary route for assessment and intervention for children with handwriting difficulties (Dunford, Street, O'Connell, Kelly & Sibert, 2004). In other countries, such as the Netherlands, children with handwriting difficulties are often assessed by physiotherapists (Nijhuis-van der Sanden & Overvelde, 2010). In the context of occupational therapy and physiotherapy clinical settings, handwriting 'speed' is the term used to refer to the amount of text a child can produce. This is usually measured on a timed task, where the number of letters or words produced per minute is recorded. However, within clinical settings the emphasis appears to be simply on the quantity of text that can be produced in a given time, without assumptions about what this means in relation to writing. Indeed, it is less common for the term 'speed' to be used in the writing literature, although it has been used in some studies by Graham and colleagues (Graham et al, 1998; Graham, Berninger & Weintraub, 2001). In the writing literature it is more usual to refer to the amount of text written as 'fluency'. However, given that many children are referred to health professionals for handwriting remediation, the term 'speed' will be used in this chapter in line with the health care definition. However, there is also another factor to consider when applying the clinical context, as speed can also refer to how quickly the pen moves across the page. Therefore this chapter will also use the term 'execution speed' which refers to how quickly the pen moves across the page (see methods section below for how it is measured).

To summarise the use of terminology in this chapter Table 4.1 provides an illustration of how each term will be applied.

Table 4.1

Terms to Refer to Handwriting in this Thesis

Term	Application
Automaticity	Text is produced legibly at a speed necessary to meet task demands
Fluency	Excessive pausing which represents an interruption in the flow of handwriting
Speed	How many letters/words are produced during a task and the 'execution speed' of the pen

4.2.4 Measuring Handwriting Speed

When measuring handwriting speed it is important to note that handwriting is a complex skill that integrates cognitive, perceptual and motor skills to meet task demands. Therefore the extent to which these skills are utilised often depends on the type of task requirements. In health care and educational settings, handwriting speed is measured in a variety of different ways through the use of different writing tasks. Several tests of handwriting speed are available. Some, including The Handwriting Speed Test (Wallen, Bonney & Lennox, 2006), use only one task. Wallen et al (2006) used a copying task, where the child copies the sentence '*the quick brown fox jumps over the lazy dog'* as quickly as they can for 3 minutes. However, Levene (1993) and Berninger et al (1997) point out that copying tasks do not require the child to retrieve letter-forms from long term memory, therefore the motor planning element is not being assessed. According to Levene (1993) when using a copying task, the children can imitate what they see, rather than having to plan the text themselves. However, other handwriting tasks may receive other criticisms. For example a 'free writing' task involves text generation and linguistic planning in addition to the actual production of handwriting. Given these criticisms, it has been argued that a mixture of different tasks is the best method of gaining insight into a student's performance. The Detailed Assessment of Speed of Handwriting (DASH) (Barnett et al, 2007) is one assessment that adopts this approach, by including a variety of different handwriting tasks to investigate handwriting speed. It is the only standardised test of handwriting speed with normative data in the UK. In the DASH (Barnett et al, 2007) the alphabet task (60 seconds) used in previous writing literature (Berninger et al, 1997: Olive et al, 2009, Connelly et al, 2006) is implemented. In addition, the sentence '*the quick brown fox jumps over the lazy dog'* is examined under two conditions; best and fast. The two copying conditions were developed to address anecdotal evidence from teachers suggesting that some children had difficulties speeding up their handwriting to meet task demands. The DASH aimed to provide a more accurate measure of this by including two copying tasks to calculate the difference in production between the two tasks. This measure provides information on whether the child has the ability to increase their handwriting speed (Barnett et al, 2007). In addition, the DASH also assesses handwriting speed within the context of the ecologically valid task of free-writing. Free-writing (composition) not only involves integrating the higher level processes of writing with handwriting execution, but it is also common in the classroom and closest to what a student is expected to do in an examination (Barnett et al, 2007).

4.2.5 Handwriting speed in children with DCD

Chapter 2 provided an in-depth review of the literature related to handwriting in children with DCD. On the specific topic of handwriting 'speed' in DCD, the on-line handwriting performance has been investigated using writing tablets, which measure the temporal characteristics of handwriting. It has been reported in the literature that children with DCD demonstrate a distinct slowness (produce less text and take longer to produce letter strokes) across a range of handwriting tasks, including copying (Rosenblum et al, 2003; Rosenblum & Livneh-Zirinski, 2008; Chang & Yu, 2010), writing from memory (Rosenblum et al, 2003, Chang & Yu, 2010) and the habitual task of writing one's name (Rosenblum & Livneh-Zirinski, 2008). However, since these studies examined Hebrew and Taiwanese writing, it is not known to what extent these findings can be applied to Latin based alphabets. Furthermore, no study to date has examined speed of performance in the task of free writing, which is perhaps the most common in the classroom and the most demanding in terms of cognitive load. It is also not known whether the slow performance relates to slower movement time in the actual movement of the pen to form letters on the page or whether it actually reflects longer pauses between the formation of letters and words. In addition, literacy skills such as reading, spelling and vocabulary have not previously been examined in studies of handwriting in children with DCD, even though these may have an impact on performance (Kandel et al, 2006).

4.3 Predictions based on the literature

Part 1

Children with DCD have significant motor deficits, which are known to cause difficulty in all sorts of activities including that of handwriting (APA, 2013). In many studies involving children with DCD, slow movement time was observed in a variety of reaching, grasping and fine motor manipulation tasks (Plumb et al, 2008; Wilmut et al, 2013). It is therefore hypothesised that the children with DCD will be unable to move the pen as quickly as their TD peers and will therefore have a slower execution speed than their age matched, typically developing peers.

The children with DCD are predicted to pause for a greater percentage of the tasks than their typically developing peers. It is predicted that the slower execution speed, excessive pausing or both, will contribute to the group differences in handwriting productivity.

The free-writing task is predicted to encompass the greatest amount of pausing due to the high cognitive demands of having to generate ideas and content alongside the motor execution. The copying tasks and the alphabet task will not be as greatly affected as the free-writing task due to the provision of letter-forms (copying) and the familiarity of the alphabet task. These predictions will all be addressed in Part 1.

4.4 Part 1

The main aim of Part 1 of this study was to assess the speed of handwriting performance in children with DCD in English using a range of writing tasks including free-writing. Measures of the handwriting product were supplemented with more detailed temporal aspects (process measures) of performance to understand the nature of any slowness in production. Finally, reading and spelling skill were also assessed, as these may have an impact on performance as well as the motor difficulties associated with DCD. Table 4.2 presents the specific research questions in Part 1 of this chapter.

Table 4.2

Specific research questions in Part 1

	Compared to their TD peers, do children with DCD:
1	Write fewer words per minute on the Detailed Assessment of Speed of Handwriting tasks (copying, alphabet writing & free-writing)?
2	Have slower execution speed?
3	Pause for a higher percentage of the writing tasks?
	The following questions were examined across both groups:
1	Are the handwriting measures (handwriting speed, execution speed and pauses) consistent across the DASH tasks?
2	Does reading, spelling or vocabulary skill relate to any of the handwriting measures?

4.4. Method

4.4.1 Participants

Twenty eight children with DCD (27 boys, 1 girl) and 28 age (within 7 months) and gender matched typically developing (TD) controls were included in the study. Details about participant selection and group comparisons on the selection measures can be found in Chapter 3. Table 4.3 summarises the inclusion measures for this study (also reported in Chapter 3), showing the results for the group of 20 children with DCD who had spelling and reading in at least the average range (DCD group) and alongside the 8 children with DCD who had poor spelling and/or reading scores (DCD+ group).

Table 4.3

Mean Age and Performance scores (SD) of DCD sub-groups on selection measures.

Selection Measures	DCD n=20	DCD+ n=8	p
Age in years	10.09 (1.90)	11.91 (2.58)	.060
MABC-2 Test Percentile	3.67 (2.94)	2.88 (3.15)	.348
BPVS Standard Score	108.9 (14.1)	108.8 (16.3)	.877
BAS-Spelling Standard Score	102.5 (9.68)	79.25 (5.99)	<.001*
BAS-Reading Standard Score	114.8 (11.5)	96.3 (10.1)	<.001*

4.4.2 Measures

The Handwriting Product:

The Detailed Assessment of Speed of Handwriting (DASH; Barnett et al, 2007)

This was used to examine the handwriting product, assessing speed of performance on a range of writing tasks, which are often required in the classroom or written examinations. The DASH was chosen as it is the only standardised handwriting speed test with UK norms for 9 to 16 year olds. It also includes tasks that are ecologically valid (free-writing) and provides an opportunity to examine a range of different types of handwriting tasks (copying and writing from memory).

The four main DASH tasks were used in this study and are described below. The tasks were administered and scored using the instructions in the manual:

Copy Best: The child copied the sentence “The quick brown fox jumps over the lazy dog”, in their best handwriting for two minutes. This sentence includes all the letters of the alphabet therefore providing an opportunity to examine each individual letter-form. The average number of words per minute was recorded. Totally illegible words, the final word (if incomplete) and punctuation marks were excluded from the score.

Copy Fast: As copy best, but with instructions to write as fast as possible, ensuring every word was readable. The average number of words per minute was recorded in the same way as copy best.

Alphabet: The child wrote the alphabet repeatedly from memory as fast as possible for 60 seconds. They were instructed to write it in the correct order using lower case letters, making sure that every letter was readable. A letter was not counted if it was out of sequence, reversed, capitalised (if it was a different form in uppercase) or could not be recognised out of the context of the task. The number of letters per minute was recorded.

Free-writing: A spider diagram on the topic of *my-life* was presented to the child prior to writing. It offered different writing topics in order to elicit ideas from the child. The content of their writing was not assessed, but they were instructed to try and write continuously over a 10-minute period using their everyday handwriting. They were given one minute prior to beginning the task in order to think of some ideas. The number of words per minute averaged over the 10-minute period was recorded. Only those words that were legible were included in the word count.

The raw scores for each of these four writing tasks were then converted to standard scores, which have a mean of 10 and standard deviation of 3, using tables from the test manual. A total test score was also computed and a total standard score obtained (with a mean of 100 and standard deviation of 15). The standard scores were reported for the 9-14 year olds in this study. As there are no norms available for eight year olds, the raw scores were also used to incorporate all participants.

The internal reliability of the total score for the DASH is between α=.83 to .89 and the inter-rater reliability for all four tasks is .99, as reported in the test manual. The DASH has demonstrated discriminant validity for age and clinical group differences. In addition it has been shown to correlate with another free-writing task described by Allcock (2001).*Name writing:* While the DASH does not evaluate the child's performance on writing their name, it does suggest they write their name at the top of the sheet before commencing. Rosenblum and Livneh-Zirinski (2008) found that children with DCD were slower in all tasks, including writing their own name, which should be a highly practised skill. To investigate whether there was a level of automaticity in writing their name, the name was recorded before the free-writing task.

The Handwriting Process: temporal features

When completing the DASH participants wrote with an inking pen on paper placed on a Wacom Intuos 4 digitising writing tablet (325.1mm x 203.2mm) to record the movement of the pen during

handwriting. The writing tablet transmits information about the degree of pen pressure on the tablet surface, as well as spatial (XY coordinates) and temporal data about the pen as it moves across the surface. Eye & Pen version 1 (EP1) software (Alamargot et al, 2006) was used to analyze the data. In this study a wireless inking pen (model KP-130-10) was used with an A4 page lined sheet of paper, which was trimmed to 18cm in length to accommodate the landscape orientation of the tablet. The paper was then secured to the writing tablet. The data was sampled at 100Hz via a Celeron Dual Core CPU T3500 @ 2.10GHz laptop computer.
The following variables obtained from EP1 were evaluated for each handwriting task:

Duration of the task (secs): To ensure that both groups had engaged in the tasks for an equal amount of time, the duration of the tasks were calculated. This was taken as the time between the first pen-contact with the paper after the 'go' prompt, to the last pen lift at the end of the task.

Execution speed (cm/sec): The speed of the pen when it is in contact and moving on the page. This does not include when the pen is pausing on or off the page.

Execution speed is calculated by EP1 as the distance covered by the pen (cm) divided by the writing time (time between first time the pen touches the tablet to the last pen lift of the task).

Pause duration (% of writing time): The percentage of time during the task where the pen was either off the page (in-air pause), or halted on the page (on paper pause). A pause was defined as three successive digital samples without movement (a halt >30 ms) (Alamargot, chesnet, Dansac & Ros, 2006). This threshold has been used by other researchers in the case of handwriting in dyslexia, in children with Specific Language Impairment and in typically developing populations (Sumner et al, 2012; Connelly et al, 2012; Alamargot et al, 2006). It is the minimum threshold available with the EP1 software and is thought to capture all writing events.

4.4.3 Procedure

The handwriting component of this study took place over either one 60-minute or two 30 minute sessions (depending on school time constraints). Each child met with the researcher and completed the reading, spelling and handwriting tasks, in the order suggested in the DASH manual. The sessions were completed either at the child's home, school or at Oxford Brookes University. During the handwriting tasks the children were seated at a height adjustable table and chair, with knees positioned at approximately 90 degrees and elbows approximately 2-4 cms above the table. The participants were encouraged to position their paper as they would normally do in the context of their natural environment; therefore, they were invited to manoeuvre the tablet to a position that was comfortable for them.

4.5 Data Analysis

In order to consider the effects of literacy skill on handwriting speed the DCD group was initially divided into two sub-groups, one including those with at least average literacy skills (DCD, n=20) and the other including those with literacy difficulties (standard score below 85 on BAS-II reading, spelling or both) (DCD+, n=8). Scores for the handwriting measures and the MABC-2 were compared across these two groups using t-tests. No significant difference between the DCD and the DCD+ groups were found suggesting that literacy skill, as measured here, did not influence handwriting product or process or general motor ability. Therefore, the two groups were combined to form one DCD group for all subsequent analyses.

Data from the handwriting tasks was analysed to consider duration of writing, the writing product and the writing process. The first analysis examined the duration of each task across the two groups. This showed whether the instructions had been followed correctly and whether the two groups had spent the same amount of time on each of the tasks. Handwriting product was measured in the second and third analysis. The second analysis, examined the standard scores on the DASH (this allows a more direct comparison across DCD and TD groups in a format that would be employed in clinical settings). For both analyses differences across groups were examined using t-tests where data were normally distributed and using Mann-Whitney-U tests where data were not normally distributed. For both tests the significance level was set at $p<.05$. The third analysis examined the DASH raw scores (words/letters per minute). To do so two-way mixed ANCOVAs were used to examine group differences across the tasks. Age was used as a co-variate due to the wide age-range of participants. Significant main effects and significant interactions were broken down using post-hoc tests and simple main effects respectively. For both, Bonferroni correction with significance levels set at .05 were used to control for the elevated type I error. Finally the fourth and fifth analysis considered handwriting process again using ANCOVA as described above but this time considering execution speed and pause duration (as a percentage of writing time).

Bivariate correlations were also conducted to examine the relationship between reading/spelling/vocabulary skills with the handwriting process measures (execution speed and pausing).

4.6 Results

4.6.1 Duration of handwriting tasks:

There was no significant effect of group for the copy best task (U=344.5, z= -.778, ns), copy fast task (U=385.5,z= -.107, ns), alphabet (U=385, z= -.115, ns) or the 10-minute free-writing task (U=302.5,z= -1.47, ns) for the duration of the tasks. Therefore, the DCD group did not finish or terminate tasks any sooner than their TD peers.

4.6.2 Speed of the Handwriting Product:

For the measures of handwriting speed using the standard scores for the four DASH tasks, there were significant group differences on all four tasks. The DCD group had significantly lower standard scores than their TD peers on all tasks (see Table 4.4) and on the overall total test standard score. Eleven of the twenty 9+ year old children in the DCD group scored below 84 on the total test standard score. In contrast, the TD group performed exactly as expected, with their mean standard score at 100. The standard scores exclude the eight 8 year old children, as norms are only available for 9-16 year olds.

Table 4.4

A comparison of the mean DASH Standard Scores (±SD) for the DCD and TD groups.

Measures	DCD n=20[a]	TD n=23[a]	t(41)	p
DASH Standard Scores				
Total Standard Score[b]	84.3 (14.3)	100.3 (12.31)	3.93	<.001*
Copy Best[c]	8.15 (2.79)	10.6 (2.42)	3.14	.003*
Copy Fast	6.30 (2.63)	10.0 (2.82)	4.41	<.001*
Alphabet Task	7.70 (2.27)	10.13 (2.13)	3.62	.001*
Free-Writing	7.70 (2.57)	9.30 (2.11)	2.24	.031*

*$p \leq .050$, [a]excludes 8 year olds, [b]Mean score 100±15, [c]Mean score 10±3

The DASH raw scores were calculated for all participants including the 8 year olds (see Table 4.5). The alphabet task was analysed separately, as the units were recorded in letters per minute rather than words. A one-way ANCOVA (Group x Writing Task with age as covariate) indicated a significant effect of group for the alphabet task, as the DCD group produced fewer letters than their TD peers during the one minute task ($F[1,53] = 14.54$, $p<.001$, $\eta^2=.215$). The covariate, age, was significantly related to the number of letters produced in the alphabet task ($F[1,53] = 26.82$, $p<.001$, $\eta^2=.336$).

For the number of words written during the copy best, copy fast and free-writing task, a two-way mixed ANCOVA (Group x Writing Task with age as covariate) was used to examine group differences across the three tasks. The free-writing raw scores for the first two minutes of the free-writing task were included in the ANCOVA in order to make the three tasks more comparable. The covariate, age, was significantly related to the raw scores on the DASH ($F[1,53] = 73.11$, $p<.001$, $\eta^2=.580$). There was a significant effect of group ($F[1,53] = 20.46$, $p<.001$, $\eta^2=.279$), as the children with DCD wrote fewer words than their TD peers. There was no significant effect of task ($F[2,106] = .679$, $p=.494$, $\eta^2=0.13$) but there was a significant group-by-task interaction ($F[2,106]=54.07$, $p<.001$, $\eta^2=.141$) (df corrected for violation of sphericity with a Greenhouse-Geisser correction). Simple main effects indicated that the children with DCD were slower on all three of the writing tasks compared to TD children. However, this does not explain the interaction. Looking at the data, it seems that the interaction may be driven by a larger difference between the copy best and copy fast task in the TD children compared to the DCD group. In order to investigate this, the difference between the number of words written on these two tasks was calculated and analysed using a one-way ANCOVA (group, with age as covariate). A main effect of group was found ($F[1,53] = 14.60$, $p<.001$, $\eta^2=.216$) indicating that the TD group showed a larger change in the number of words between the copy best and copy fast task (mean increase of 5 wpm) as compared to the DCD group (mean increase of 2 wpm). The covariate age was significant ($F[1,53] = 12.44$, $p=.001$, $\eta^2=.190$).

Table 4.5

A comparison of the mean DASH Raw Scores (SD) for the DCD and TD groups

Measures	DCD n=28	TD n=28
Dash Raw Scores		
Alphabet Task (lpm)	37.64 (17.31)	53.57 (17.05)*
Copy Best (wpm)	12.64 (5.76)	17.14 (5.52)*
Copy Fast (wpm)	14.93 (6.28)	22.39 (7.09)*
Free-Writing (wpm) (first 2 minutes)	13.25 (6.14)	17.01 (5.09)*
Free-Writing (wpm) (10 minute task)	11.99 (6.07)	15.67 (4.41)*

**p*≤ .050, wpm= words per minute, lpm= letters per minute

4.6.3 The Handwriting Process: temporal features

For the analyses of process measures, only the first two minutes of the 10 minute free-writing task were included. This was to control for differences that may have occurred due to the length of the task.

Execution Speed:

The execution speed (the speed of the pen when it is in contact and moving on the page) for both groups averaged between 2-3 cm/s across all four DASH tasks and name writing. Figure 4.1 illustrates the execution speed of both groups during the five tasks. A two-way mixed ANCOVA (Group x Writing Task with age as covariate) was used to examine group differences across the five tasks. The co-variate age was significantly related to the execution speed $F[1,53]=10.03$, p=.003, $\eta^2=.159$. There was no effect of group ($F[1,53]=.008$, p=.927, $\eta^2<.001$), indicating that the children with DCD had a similar execution speed to their TD peers. There was also no effect of task $F(3.28,174.2)=.1.04$, p=.377, $\eta^2=0.19$ (df corrected for violation of sphericity with a Greenhouse-Geisser correction).

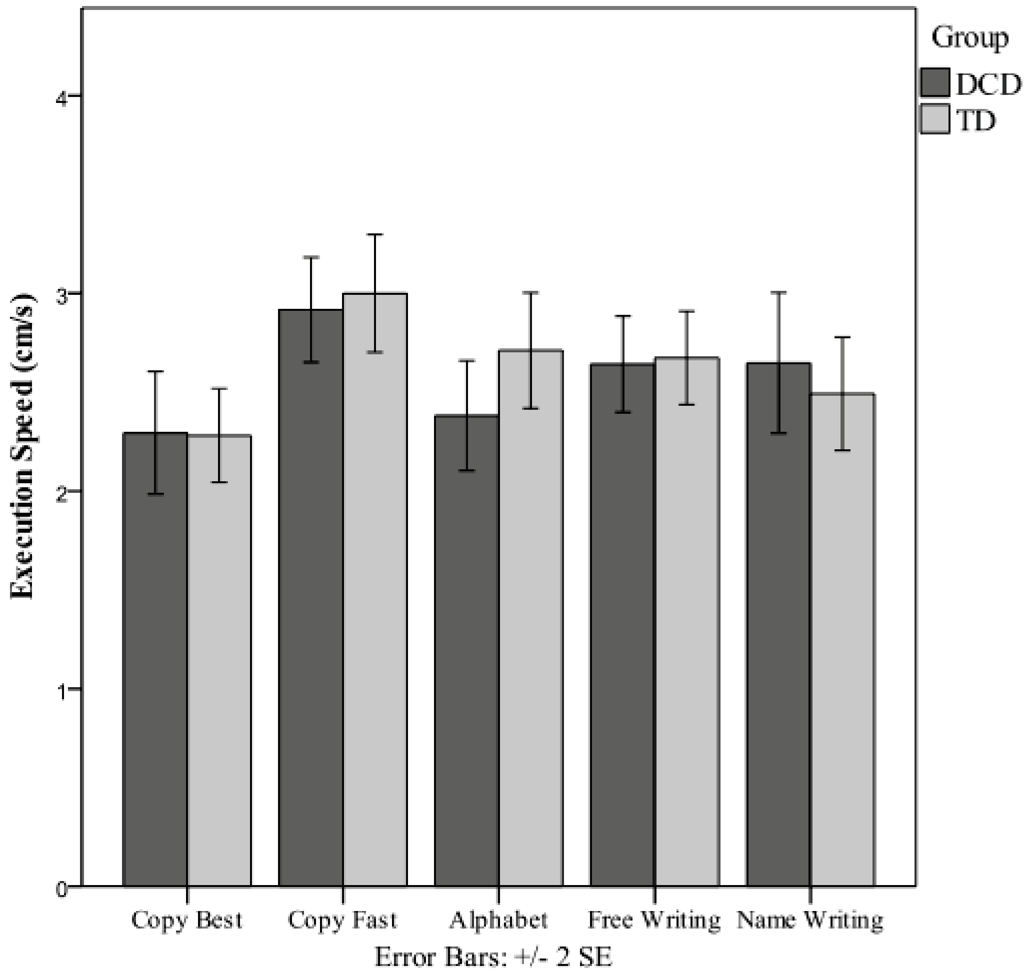
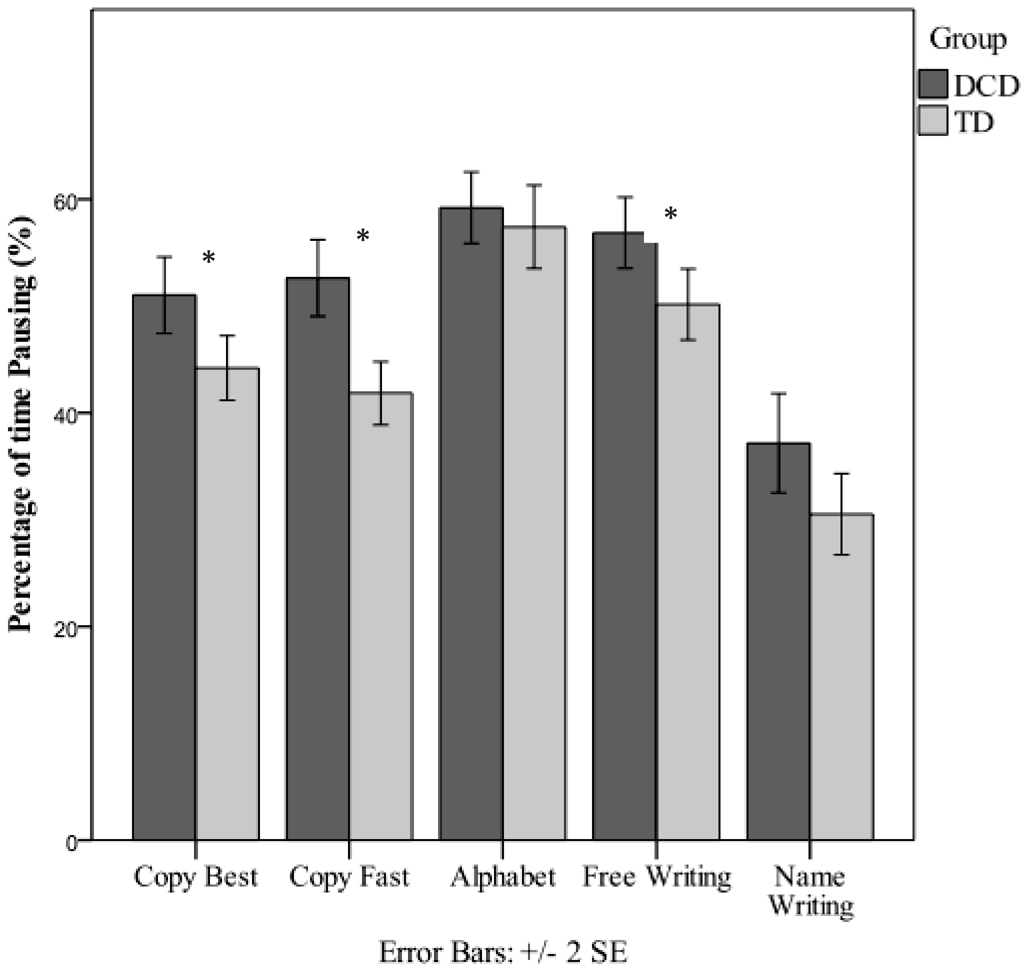


Figure 4.1. Execution speed (cm/s) for both groups across the handwriting tasks

Pausing Percentage:

Figure 4.2 illustrates the percentage of time spent pausing by both groups during the four DASH tasks and name writing. A two-way mixed ANCOVA (age as covariate) was used to examine group differences across the five tasks. The co-variate age was significantly related to the pausing percentage $F[1,53]=10.51$, $p=.002$, $\eta^2=.166$. There was a significant group effect ($F[1,53]= 9.52$, $p=.003$, $\eta^2=.152$), as children with DCD spent a significantly longer percentage of time pausing than their TD peers. There was also a significant effect of task ($F[3.04,161.1]=2.75$, $p=.044$, $\eta^2=.049$). Pairwise post hoc comparisons indicated that both groups spent a greater percentage of time pausing during the alphabet task, followed by the free-writing task ($p<.001$). The copying tasks were not different from each other ($p=1.00$) but showed significantly less percentage of pause time compared to the free-writing task ($p<.001$) and the name writing task ($p<.001$). Both groups spent the least amount of time pausing on the name writing task (summary: alphabet> free-writing> copy-best>=copy fast>name writing). Finally a significant group-by-task interaction was also found ($F[3.04,161.1]= 4.10$, p=.008, $\eta^2=.072$) (df corrected for violation of sphericity with a Greenhouse-Geisser correction). Simple main effect tests were used to examine this interaction by considering whether a group effect was present for each writing task. A main effect of group was found for copy best (p=.006), copy fast (p<.001) and free writing (p=.008). There was no group difference in the alphabet task (p=.573). Following Bonferroni adjustment the name writing task did not meet the critical value (p<.01), therefore it showed only weak significance (p=.038).



Note. $^*p \leq .050$

Figure 4.2. Percentage of Pausing for both groups across the handwriting tasks.

Correlations with Vocabulary, Reading & Spelling Measures:

Partial correlations controlling for age were conducted with both groups separately and combined to examine whether a relationship existed between any of the literacy measures (vocabulary, reading, spelling) and the handwriting process measures on the DASH (execution speed and pausing percentage). No significant correlations were found between any of these variables.

4.7 Discussion

The previous studies that have investigated temporal characteristics of handwriting in children with DCD were conducted in alphabets outside the Latin-base and in languages other than English (Rosenblum & Livneh-Zirinski, 2008; Chang & Yu, 2010). The purpose of the present study was to compare the speed of handwriting performance between children with DCD and typically developing children, in English. The DCD sample in this study met the DSM-IV (APA, 2013) criteria and the children were also examined in reading, spelling and receptive vocabulary. Following a detailed examination of handwriting speed considering both the product and the process measures, the current study has found very different performance profiles between the TD and DCD groups.

The children with DCD performed below their peers on the DASH scores. However, this was not attributed to a slower execution speed, but rather to a higher percentage of time pausing while writing. It is important to note that throughout the four DASH handwriting tasks, both groups were writing for the same overall duration, as computed and verified through the writing tablet data. This suggests that the performance of the DCD group cannot be attributed to early termination of tasks. The DASH is widely used by education and health professionals in the UK (mainly occupational therapists) and decisions in relation to intervention and provision of support in schools are commonly made on the basis of the DASH standard scores. If the DASH scores are considered in isolation, it is apparent that the DCD group produced significantly less text than their TD peers. By taking the raw scores and the standard scores of the DASH at face value, it would appear that the DCD group were ‘slower’ than the TD group at producing text. This was apparent in all DASH handwriting tasks, each with different demands. The DCD group produced fewer legible words per minute on the copy best task and free-writing task and the group difference was even more pronounced when asked to speed up on the copy fast task. Similarly, on the alphabet task, they were slower than their TD peers, notable by the production of fewer letters per minute. Many teachers and therapists may be familiar with this outcome, as there is anecdotal evidence to suggest that many children with DCD exhibit ‘slowness’ in writing. However, in terms of empirical evidence, few studies have quantified or documented the amount of text produced by children with DCD compared to their TD peers. Barnett et al (2011) reported fewer words produced per minute by a teenager with DCD in a case study related to the development of the DASH 17+ (an extension of the test for older students, (Barnett et al, 2010)). Elsewhere, Rosenblum and Livneh-Zirinski (2008) characterised handwriting performance in children with DCD in Hebrew and reported that children with DCD produced significantly fewer letters per minute than their TD peers during a two-sentence copying task. It was unclear however, whether the children were instructed to copy in their everyday handwriting or to meet different demands. Nevertheless, the findings were similar to the current study, despite the differences in task protocols and between the Hebrew and English languages (e.g. direction of text, continuity of writing).

A closer examination of the handwriting process through the use of the writing tablet revealed that the DCD group did not actually execute text at a slower speed than their TD peers on any of the handwriting tasks. In-fact, while the pen was moving on the page, it was moving at a similar speed in both groups. This finding of similar execution speed suggests that the children with DCD did not have difficulty moving the pen at speed. Moreover, they were observed to increase their speed during the copy-fast task, indicating an ability to alter their speed with task demands. This was unexpected given that in previous studies, children with DCD are reported to demonstrate slower movement time during the performance of many manual tasks (Henderson et al, 1992; Missiuna, 1994; Plumb et al., 2008; Wilmut et al., 2013). However, whether or not they were proficient at controlling the pen at this speed is another question, as the relationship between handwriting speed and legibility is a complex, trade-off relationship (Weintraub & Graham, 1998). Although the focus of this study was handwriting speed, the DASH scoring protocol involves identifying illegible words and excluding these from the word count. It was apparent through this process that there were issues with legibility in the DCD group. This is an area that warrants further investigation and will be addressed in detail in the following chapter on legibility. Thus, although the execution speed in the DCD group was just as fast as the TD group, one possible explanation for their lower score on the DASH could be attributed to difficulties with legibility.

A further look at the handwriting process, particularly the pausing profiles, helps shed more light on the reduced performance on the DASH by the DCD group. Indeed, the analysis indicated that the children with DCD paused for a significantly longer percentage of time on the tasks, with the exception of the alphabet task. The extent of the pausing also seemed to depend on the type of task demands, as compared to the two copying tasks, both groups paused for a greater percentage of time in the alphabet and free-writing task. This could be attributed to the increase in cognitive load associated with particular tasks such as free-writing and writing from memory, where cognitive and linguistic processes (planning, semantic retrieval, spelling etc.) are competing for limited working memory resources (Van Galen, 1991; Berninger & Amtmann, 2003). In contrast, copying tasks provide visual feedback for the writer, which reduces the demands for spelling and letter retrieval. Copying tasks also provide an opportunity for the child to 'imitate' (Levine, 1993) what they see. When handwriting is automatic and fluent it allows for attentional resources to be made available for higher order aspects of writing such as planning and revision (Berninger & Amtmann, 2003). However, if the writer needs to focus their attention on the process of producing the letters and words on the page, then this inhibits the ability to concentrate on the important aspects of writing such as content and ideas. Although the percentage of time spent pausing increased in both groups during the free-writing task, the DCD group paused for over half the time. This suggests that when asked to write independently, as would be the case in an academic environment such as an examination, the DCD group demonstrated difficulty with handwriting fluency evident through the pausing. This impacted on the amount of text they produced on the DASH. Importantly, this did not relate to any difficulties with other aspects of literacy (spelling and reading).

This finding of longer pauses in writing for the DCD group is consistent with that of Rosenblum and Livneh-Zirinski (2008), where children with DCD were found to spend more time than controls with the pen in the air. It seems to be that in some of the tasks where the DCD group executed at a similar rate to their peers, such as in the copy best, free-writing and copy fast tasks, their 'slowness' on the DASH scores was related to their longer percentage of time pausing. The amount of time spent pausing appears to be significantly limiting the handwriting performance of children with DCD, but little is known about this pausing phenomenon. Interestingly, it is not limited to children with DCD. Indeed, this issue of longer pausing has also been found in other developmental disorders such as SLI (Connelly et al., 2012), dyslexia (Sumner et al., 2012) and ADHD (Rosenblum et al., 2008). Sumner et al. (2012) found that children with dyslexia execute handwriting at a similar speed to TD peers, but have a tendency to pause for a greater percentage of the task. In dyslexia, the pausing was found to be related to spelling, based on the location of pauses and the difficulties demonstrated in the spelling measures (Sumner et al., 2013). However in the current study, both groups were within the average range for reading and spelling and there were no significant correlations between reading or spelling and any of the handwriting measures. This therefore reduces the possibility of spelling being a contributing factor.

The limited research available on handwriting in children with DCD has proposed a variety of possible explanations for the pausing phenomenon, which is seen both in the current study using a Latin based alphabet and in previous studies using a non-Latin based alphabet (Rosenblum & Livneh-Zirinski, 2008; Chang & Yu, 2010). There are essentially two lines of enquiry in the literature. The first comprises physiological theories proposed by Chang and Yu (2010), which suggest that reduced strength and endurance among children with DCD and/or a possible lack of tonic stiffness in the hand while writing are contributors to slower performance. While there is evidence to suggest that children with DCD demonstrate reduced strength and endurance compared to typically developing peers (Raynor, 2001), in the current study the children with DCD were able to execute as quickly as their TD peers for the duration of the 10-min free-writing task. This would suggest that they do have some endurance for this type of handwriting task. However, the excessive pausing noted in the DCD group could be due to small periods of rest related to fatigue, which is an area addressed in Chapter 8 through an analysis of grip-strength.

The second line of enquiry proposes a lack of automaticity in the lower-level, motor components of the handwriting process (Van Galen, 1991), including possible slow movement time, 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, all of which were proposed by Rosenblum and Livneh-Zirinski (2008). In terms of movement time, the current study found no group differences regardless of task. However, a lack of automaticity was indeed apparent, not only in the longer pausing and possible issues with legibility, but also in name writing, which showed a trend towards a group difference. This may indicate that some of the children in the DCD group did not achieve a level of automaticity even with a task as highly practiced as writing one's name.

Outside the literature on handwriting there are other possible avenues to explore in the search for an understanding of the pausing phenomenon in children with DCD. One such avenue is that of deficits in motor learning. A study by Smits-Engelsman et al (2008) found that children with DCD demonstrated difficulties with fine-tuning forces in manual tasks, while other studies have reported difficulties in sequence learning (Gheyse et al, 2011). However, these theories have yet to be examined in ecologically valid tasks such as that of handwriting and are areas that warrant further investigation.

Another area that could be considered is the cognitive abilities of children with DCD and particularly difficulties with executive function that have been reported (Piek et al., 2004). Aspects of this might be useful to explore in future handwriting research in DCD. It is apparent through the results of this study and that of Rosenblum and Livneh-Zirinski (2008) that a lack of automatization exists in the handwriting of children with DCD regardless of language and cross-cultural differences. Part 2 of this chapter will investigate the pauses in greater detail.

This first part has served to provide a greater understanding of the handwriting speed of children with DCD in English. The results advance our knowledge of handwriting speed in children with DCD, demonstrating that the 'slowness' so commonly reported in this group was not due to slow movement execution, but due to excessive pausing. Further research needs to examine this in more detail to aid in the provision of evidence for planning future interventions. Part 2 of this chapter investigates the pausing phenomenon in further detail.

Part 2: Investigating the Pausing Phenomenon

4.8 Introduction

The purpose of Part 2 of this study was to examine the pausing characteristics demonstrated by the children with DCD in Part 1 in greater detail. This type of analysis has never been reported in the DCD literature and is an emerging method of analysis in the broader writing literature.

To investigate the pausing behaviour identified in Part 1, the pausing observed on the DASH free-writing task was categorised and analysed in detail. This particular task was chosen for a number of reasons. Firstly, it is an ecologically valid task in terms of its similarity and relevance to handwriting demands in the classroom. Secondly, alternative tasks such as copying provide the child with the writing ideas, language and spelling, therefore exerting fewer demands on the writing system (Levene, 1993; Berninger et al, 1997). It is widely accepted in the writing literature that the cognitive load in copying and alphabet tasks is less than that of free-writing. In addition, the pausing exhibited during copying tasks may have been influenced by having to look at the stimuli (sentence), adding another dimension to an already complex analysis. The third and most important reason for analysing free-writing is that it involves the integration of all aspects of the writing process including idea generation, production of language, spelling and handwriting. By examining the pauses in the context of a free-writing task, it 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.

4.8.1 Defining a 'pause'

The definition of pauses in writing are inconsistent in the literature, and hence a barrier to examining pausing in children with DCD. 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 off the surface in order to be classified as a pause. In the writing literature Alamargot et al (2006; 2010) defined a pause as three successive samples where the pen was not in contact with the tablet. This meant that anything over 15 milliseconds was classified as a pause. 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. In recent years there have been developments in our understanding of pausing in the typically developing population, as research by Alamargot and colleagues in France (2006; 2010) has advanced methods through integrating eye tracking technology with writing tablets. By doing so, eye movements during pauses can be examined. Theories such as parallel processing in writing have been supported as a result of this advancement in technology (Alamargot et al, 2010). For example, Alamargot et al (2006) found that adult writers had the ability to continue executing handwriting while looking back at previously written text. However despite the advancements in technology, it is still an under researched area, which as a consequence, offers little guidance in terms of selecting pause thresholds for analysis. Based on this premise, the pause thresholds used in the current study are grounded in evidence where possible, however, in light of the lack of literature in this particular area, some aspects of the analysis are exploratory in nature. Both Rosenblum and Livneh-Zirinski (2008) and Part 1 of this chapter found that children with DCD pause for a greater percentage of the task than their TD peers during handwriting. However, beyond this finding, little is known about the location and duration of the pauses and what exactly they represent. This type of information is key to understanding exactly where the handwriting process in children with DCD breaks down and to what extent the overall writing process is affected. Therefore despite a lack of clarity in the literature surrounding the selection of pause thresholds, this type of analysis is important in order to begin to understand the behaviour in greater detail.

4.8.1.1 Temporal Analysis of Pauses

Despite limited literature on pausing in general, the framework for this analysis was established through combining the available literature on DCD with theories on pausing from the writing evidence base. Part of this analysis focused on the theories proposed within the field of DCD, where anomalies in the lower level processes of handwriting such as between stroke muscular adjustments were suggested as reasons for excessive pausing (Rosenblum & Livneh-Zirinski, 2008). Other theories in the DCD literature have proposed alternative explanations including physiological factors such as fatigue (Rosenblum & Livneh-Zirinski, 2008). However, none of these theories have been tested to date. It therefore remains unclear whether children with DCD pause excessively for short periods of time (i.e. < 1 second), or whether they pause for longer periods possibly as an indication of fatigue or higher-level writing processes such as planning (i.e. > 4 seconds). 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 of varying writing expertise were asked to compose a text by extending a narrative provided to them. There were no time constraints imposed on them 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), another 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 technology 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 78-189ms, 129-416ms, 194-624ms and 695-23,248ms. 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 seconds 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. However using eye-tracking technology 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. This level of investigation has never been implemented on 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 would go some way in understanding their handwriting process in greater detail.

4.8.1.2 Location of Pauses

Another line of enquiry in the current study was to investigate the impact of pausing on the writing process and to ascertain whether this was interrupted more frequently in children with DCD. Research by Alamargot et al (2006) considered factors thought to affect pausing during writing, in particular, pausing at the word level. Work 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 et al, 2012; Sumner et al, 2013). According to Sumner et al (2013), this was indicative of difficulties at the word level due to the constraints the 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. The only difference being; it would be attributed to difficulties with the handwriting component of transcription rather than spelling. By investigating the location of pauses within the text, a greater understanding of the underlying processes can be examined. Table 4.6 summarises the research questions for this analysis.

4.8.1.3 Frequency of Pauses

According to Alamargot et al (2010) the frequency of pausing did not distinguish between the expertise of writers. In fact, in their study the expert author executed the greatest number of pauses, however, the key factor lay in their duration. The excessive 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 terms of frequency of pausing in children with DCD, it is not known whether their excessive pausing is driven by a greater number of pauses than the TD group, or whether they just pause for longer periods at a time.

The findings of this analysis will also be linked to the chapter on legibility (Chapter 5) and compositional quality (Chapter 6).

4.8.2 Part 2 Predictions based on the literature

It was hypothesised in line with the simple view of writing (Berninger & Amtrann, 2003) and the handwriting model by Van Galen (1991) that the handwriting skills of children with DCD would be so effortful, that a breakdown in the writing process would occur through pauses. Kandel et al (2006) demonstrated that children were able to plan the second syllable of a word without having to stop. If handwriting is not yet automatic, within-word pauses would occur in order to compensate for the lack of cognitive resources available to plan the word online. The frequency, duration and location of any pauses found in Part 1 will be explored in Part 2.

4.9 Temporal Analysis of Pauses in the current study:

The temporal analysis of pauses examines how much as a percentage of overall pause time is spent pausing at the letter level, word level and during longer pauses (possibly due to planning/rest). In addition, an analysis of the frequency of pausing was conducted in order to ascertain whether the children with DCD paused more often. However, not all time-frames were analysed using the same variables. For example, it was deemed excessive to analyse the frequency of all pauses above 30ms, therefore for the analyses surrounding frequency other time-frames were used. Likewise for mean pause duration, specific time frames were used to consider this. An explanation of how the temporal characteristics of the pauses were analysed follows. Table 4.6 provides a summary of the analyses undertaken in Part 2.

Table 4.6

Summary of the analyses undertaken for each pause category

	Pause Time Frames				
	30-250ms	250ms-2s	2-4s	4-10s	>10s
Percentage of overall pausing spent in	✓	✓	✓	✓	✓
Total length of time spent pausing in	✓	✓	✓	✓	✓
Frequency of pausing	X	✓	✓	✓	✓
Mean pause duration	X	X	✓	X	X
	Location of Pauses				
	2-4s			>10s	
Length of time spent pausing	Between words	Within words		✓	
Percentage of overall pausing spent	In correctly spelled words	In misspelled words	In illegible words	In same idea	Before new idea

Note. ms-milliseconds, s=seconds

4.9.1 Pausing at the letter level.

This analysis considered two separate time-frames.

The first analysis examined whether the children with DCD paused for a higher percentage within a small time-frame of between 30-250 milliseconds (ms). This time-frame was chosen from the literature, as it is thought to represent the graphomotor component of handwriting (Alamargot et al, 2010). Research on pauses in writing by Alamargot et al (2010) using an eye tracker and writing tablet established a link between short pauses and graphomotor execution, particularly pauses between 78-189ms. 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. 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. Therefore, the time-frame for capturing letter level pauses in their study was adjusted for the current analysis given the focus on children in this study. For this reason the time-frame of 30-250ms was selected for analysis. Since children with DCD have motor difficulties, it was hypothesised that they would pause for a greater percentage of time within this time-frame due to possible difficulties manipulating the pen to form the letters.

Initially, the threshold on the Eye and Pen 1 (EP1) software was set at 30ms. All the pauses above 30ms were extracted first. Once this was completed, the threshold on EP1 was set at 250ms and all pauses above this threshold were extracted. The total time pausing above 250ms was subtracted from the total time pausing over 30ms. This provided the time spent pausing between 30-250ms. This process is summarised in Table 4.7. The time spent pausing within this time frame was then calculated as a percentage of the overall pausing time on the free-writing task, which was presented in Part 1.

Table 4.7

The formula used for calculating the total time pausing within each time-frame

	Total time pausing above threshold	-	Total time pausing above threshold	=	Total time pausing within time-frame
1	30ms	-	250ms	=	30-250ms
2	250ms	-	2000ms	=	250ms-2s
3	2000ms	-	4000ms	=	2-4 s
4	4000ms	-	10000ms	=	4-10 s
5	10000ms			=	10000ms

ms= milliseconds, s=seconds

The second time frame used to examine between letter pauses was 250ms-2 seconds (s). This was chosen based on previous research by Rosenbum 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 .37s to 1.27s on the alphabet task suggesting that this was the pause time which occurred between letters. Therefore, the time spent pausing within a 250ms-2s time-frame was analysed and calculated as a percentage of the overall pause time. See Table 4.7 for the analysis protocol.

4.9.2 Pausing at the Word-level

To examine word level pauses, the time frame for analysis was between 2-4 seconds (s). This was chosen from the literature on writing, where a 2 second pause in typically developing writers is considered to represent a pause from formulating the text in order to access a higher-level writing process such as planning (Alamargot et al, 2010; Alves et al., 2007; Wengelin, 2007). It was important to capture pauses at or above 2 seconds to examine pauses at the word level. However, it was also important to restrict the pause time-frame to below 4 seconds, so lengthy pauses possibly due to fatigue could be measured separately. See Table 4.7 for the analysis protocol.

Two dependent measures were calculated for this time-frame. The first was the percentage of pause time spent pausing in this time-frame. The second was mean pause duration in order to ascertain whether children with DCD paused for longer on average than their TD peers.

4.9.3 Long Pauses.

This analysis consisted of two separate time-frames.

The first time-frame analysed was between 4-10 seconds. A pause that was greater than four seconds was considered to represent a higher level writing process (generating ideas) or resting due to fatigue. See Table 4.7 for the analysis protocol.

The second time-frame to examine long pauses included pauses at or above 10 seconds. A pause above 10 seconds was considered to be a significant halt in the writing activity, possibly due to fatigue or a lack of writing ideas. Research by Alamargot et al (2010) found that the younger, 6^{th} grade writer paused at times for over 10 seconds.

For the above analysis the dependant variables included the total time pausing in each time-frame and the percentage of overall pause time that occurred within each time-frame. Mean pause duration was not considered for pauses over 10 seconds as the purpose of the analysis was to identify whether long pauses occurred or not.

4.9.4 Frequency of Pauses

The frequency of pausing was also of interest in this study. 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. To consider this, the frequency of pauses was only considered above 250 milliseconds and over 10 seconds. The dependent variables for frequency included the number of pauses that occurred over 250ms and 10 seconds.

4.10 Location of Pauses:

By considering the location of pauses, the breakdown in the writing process can be evaluated in greater detail. For example, research by Alamargot et al (2010) and Kandel et al (2010) on adult writers has shown that excessive cognitive load during handwriting can be recognised through word level pausing. If a writer pauses within a word, this raises an issue, as according to Kandel et al (2010) words are programmed prior to commencement and simultaneously thereafter. Although the above studies focused on adults, by comparing children with DCD to a TD group, it would shed light on whether their handwriting process was dissimilar to peers. To investigate whether there was a breakdown within words in the children with DCD, the following analysis was completed.

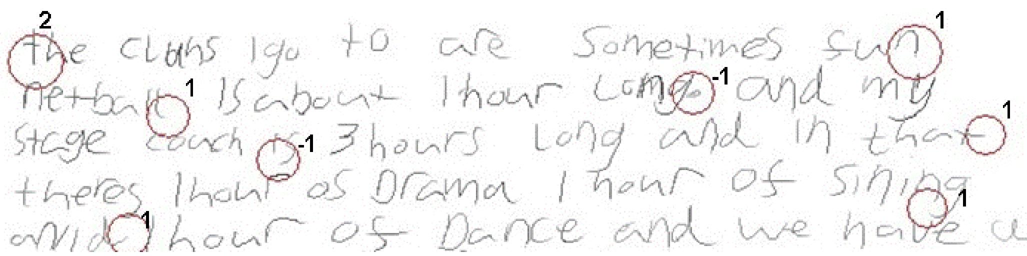
4.10.1 Word Level Pauses. For this analysis the data needed to be coded. To do this, the threshold was set at 2000ms on the EP1 software. The 2000ms threshold has previously been used by other authors to explore the issue of word level pausing in relation to spelling difficulties in children with dyslexia (Sumner et al, 2013). Table 4.8 provides an overview of how the data was coded.

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 children with DCD produced fewer words than the TD group in Part 1, 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, the other was assigned '-1' for miscellaneous.

Within Word Pauses

On EP1 software it is possible to manually scroll through each individual pause and locate the pause within the context of the text. For this analysis the writing product was presented on the screen (see Figure 4.3) and each pause that occurred at or above a 2 second threshold appeared on the text. It was possible to scroll through each pause and code it as necessary. 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 -1 (miscellaneous). 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. 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.



Note. -1= miscellaneous: pausing within a full stop, or pausing to go back and dot an ‘i’

Figure 4.3. The Eye and Pen coding used to extract within word and between word pauses (10 year old boy with DCD)

Table 4.8.

The Eye and Pen coding used to extract within word and between word pauses

Code	Code Representation
1	Between word pause
2	Within a correctly spelled word
3	Within a misspelled word
4	Within an illegible word
-1	Miscellaneous (more than one pause in a word, moving back to a different word to make an adjustment, anything that was not within a word or progressing to the next word)

4.10.2 Longer 10 second pauses.

To distinguish whether the longer 10-second pauses were due to fatigue or lack of ideas for writing, the location of the pauses needed to be coded. To do so, the threshold was set at 10000ms on the EP1 software. A similar process of visually locating the pauses within the writing text was used. In this analysis only two codes were used on the pauses.

Since one of the possible explanations for pausing in the DCD literature relates to lack of strength and endurance (Chang & Yu, 2010), it was important to examine whether the long pauses were due to writing processes such as planning or physiological factors such as fatigue. In the current study the pauses were coded to distinguish between planning and resting. To do so, the number 1 was assigned to pauses over 10s that occurred within a sentence or writing topic/idea, suggesting that the child had already generated ideas to write about. In this instance, having to stop within a sentence may indicate fatigue. Figure 4.4 illustrates this type of pause. The second code was assigned to a pause over 10s 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. Figure 4.4 illustrates this type of code '2' pause.

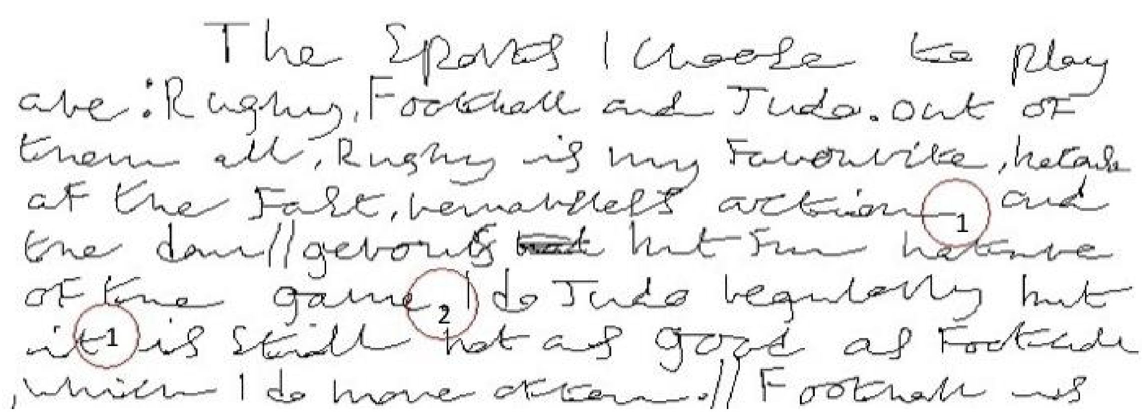


Figure 4.4. The Eye and Pen coding used to extract within idea pauses over 10 seconds (1) and before a new idea pause over 10 seconds (2). (13 year old boy with DCD)

4.11 Data Analysis

For comparisons between the DCD group and TD group, tests of normality were conducted initially and descriptive statistics for the dependent variables were 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 in the first analysis and many variables in the second 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 $p<.05$.

4.12 Results

4.12.1 Pausing at the letter level.

Initially, the DCD group was divided into two sub-groups similar to that in Part 1, one including those with at least average literacy skills (DCD, n=20) and the other including those with literacy difficulties (standard score below 85 on BAS-II reading, spelling or both) (DCD+, n=8). There was no significant difference between the DCD and the DCD+ groups in any of the pausing analyses; therefore the two groups were combined again to form one DCD group for all subsequent analyses.

Table 4.9 illustrates the total overall pause time for each group during the 10-minute free-writing task (as reported in Part 1) 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. As reported in Part 1, there was a significant group difference for the overall total pause time ($t(54) = 2.34$, $p < .023$).

Time Frame 1: Pausing between letters

A 30-250ms time-frame was selected to analyse pausing at the letter level, it was also thought to measure short pauses due to muscular adjustments. 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 this range ($t(54) = .359$, $p=.721$). This suggests that the children with DCD did not pause for any longer than their TD peers within this time-frame.

Time Frame 2: Pausing between letters

For the 250ms-2s time-frame there was no effect of group for the 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 spent within the 250ms-2s threshold, as a greater percentage of pausing occurred in this time-frame for the TD group ($t(54) = -2.21$, $p = .032$). There was no effect of group for frequency of pausing over 250ms (U= 363.5, Z = -.467, p=.640). Figures 4.5 and 4.6 highlight all pauses above 250ms on the text of two 13 year old male participants, one with DCD, one without.

Table 4.9

A breakdown of pause times and comparisons (SD) for the DCD and TD

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

*$p \leq .050$

4.12.2 Pausing at the Word-level

A 2-4 second time-frame was selected to analyse pausing at the word level, it was also thought to measure pauses imposed by excessive cognitive load during the writing process. In terms of the amount of time spent pausing within this time-frame, the analysis did not reveal a group difference (U= 380.0, Z = -.197, p=.844). There was also no group difference in the percentage of overall pause time attributed to pauses between 2-4 seconds (U= 325.0, Z = -1.09, p=.272).

For mean pause duration, there was a significant group difference, as children with DCD paused for longer on pauses over 2 seconds with a mean pause duration of 5.33 seconds (*SD* = 1.90) (*Mdn* = 5) compared to 4.15 seconds (*SD* = 1.16) (*Mdn* = 4) (U= 265.0, Z = -2.081, p=.037).

4.12.3 Long Pauses.

For the amount of time spent pausing between 4-10 seconds, there was no significant difference between the groups $t(54) = .420$, $p = .676$. An analysis of the frequency of pauses above 4 seconds revealed no significant group difference in the number of pauses above 4 seconds (U= 265.0, Z = -1.12, p=.260).

The DCD group did pause for longer over 10 seconds, as a significant group difference was found for this analysis (U= 323.5, Z = -2.19, p=.029). There was a significant group difference for frequency of pausing over 10 seconds (U= 258.0, Z = -2.27, p=.023).

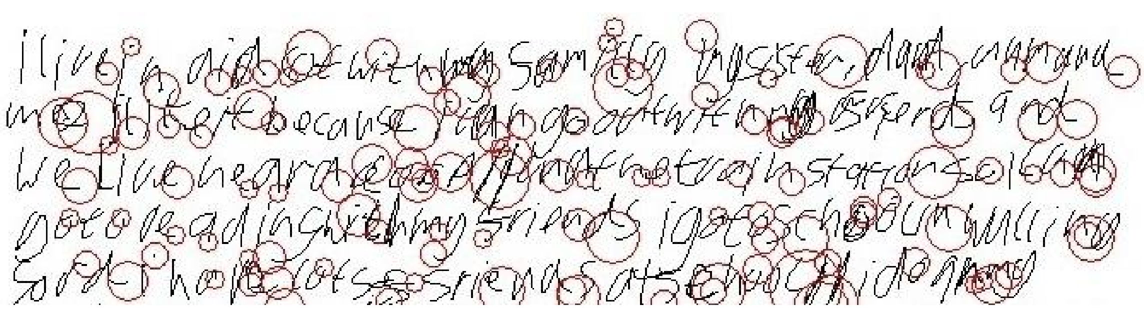


Figure 4.5. A view of all pauses over 250ms for a boy with DCD aged 13.02 years in the first 4 minutes of the DASH free-writing task

Figure 4.5 highlights all pauses above 250ms in red circles in the writing of a 13 year old male participant with DCD. Figure 4.6 below 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 red circles, as larger circles indicate longer pauses. Figure 4.5 illustrates a higher percentage of longer pauses.

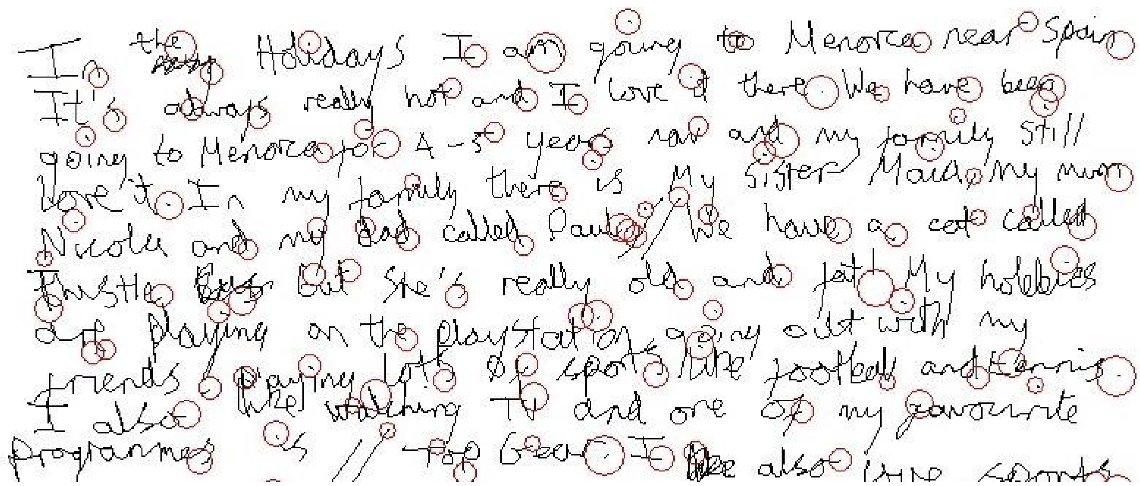


Figure 4.6. A view of all pauses over 250ms for a typically developing boy aged 13.02 years in the first 4 minutes of the DASH free-writing task

4.13. Pause Locations

4.13.1 Word Level Pauses.

Between Word Pauses

The DCD group did not spend any more time pausing between words compared to the TD group (U= 303.5, Z = -1.45, p=.147). There was no group difference in 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 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 4.10 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.

Table 4.10

A breakdown of word level pauses and comparisons (SD) for the DCD and TD

	DCD n=28	TD n=28	p
Between word pauses			
Total duration of BWP (minutes)	2.00 (1.17)	1.49 (.80)	.147
Percentage of pausing due to BWP	32%	27%	.279
Within word pauses			
Total duration of WWP (minutes)	.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*

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

4.13.2 Longer 10 second pauses.

Sixty-eight percent of children with DCD had pauses of over 10 seconds 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 second 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-second 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).

4.13.3 Correlations between age and pausing measures

Table 4.11 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 seconds, mean pause duration and frequency of pausing over 10 seconds 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 250ms-2s for the TD group only indicating that as TD children increase in age, the amount of time pausing within 250ms-2s increases. The measure of frequency of pauses over 250ms revealed no significant correlations for either of the two groups.

Table 4.11

Correlations between age and pausing measures

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

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

4.13.4 Regressions

Regression analyses were computed for children with DCD to ascertain what factors best predict the frequency of pausing over 10 seconds. 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 second pauses. In addition, manual dexterity was included to see if this explained any of the variance. The regression model was a predictor of frequency of pauses above 10 seconds 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 second pauses (β = -.372, p=.034), as did manual dexterity (β = -.387, p=.028) indicating that as manual dexterity score increased (i.e. a poorer score) the frequency of pauses decreased. Coefficients can be found in Table 4.12.

Table 4.12

Regression analysis: predictors of frequency of pauses over 10 seconds

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

*Note. * p < 0.05 level.*

4.14 Discussion

Until now, the most detailed study on handwriting in children with DCD was that of Rosenblum and Livneh-Zirinski (2008), where children with DCD were found to spend considerable extra time with the pen in the air, compared to their typically developing peers. However that research was conducted in the Hebrew language and it was unknown whether the excessive pausing would be observed in other language systems such as English. The first part of this chapter revealed a similar finding to that of Rosenblum and Livneh-Zirinski (2008), where children with DCD were found to pause for longer than their TD peers. However, the previous knowledge base did not extend beyond this finding, resulting in a lack of understanding about the exact nature of the pausing phenomenon in children with DCD. The aim of the second part of this chapter was to pinpoint and characterise the pausing phenomenon in detail by locating the exact time-frames and locations of pauses in the handwriting of children with DCD. This 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 phenomenon and its impact on the writing process.

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 the pausing phenomenon, 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 30-250ms and they were not shown to pause more than the TD group in the time frame of 250ms-2s. This suggests that any difficulties with the perceptual aspects of movement or motor memory did not appear to influence the amount of pausing in the DCD group. This finding was also supported in Part 1 of this chapter through the lack of group differences that emerged on the alphabet task. In-fact the alphabet task was the only 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 and will be addressed in Chapter 5. However in terms 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 second time-frame. The 2-second threshold has been previously used in the writing literature, where a boundary of 2 seconds 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. Based on this premise, it was queried whether children with DCD would be forced to pause within a word to cope with the excessive cognitive load imposed by handwriting. This study found no group differences in the amount of time or percentage of time pausing within a 2-4 second 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). Figure 4.5 and 4.6 provide a visual representation of this behaviour, as the sample of writing from the children with DCD clearly exhibits pauses within-words compared to the behaviour of the TD child in Figure 4.6. This finding is in contrast to studies on other developmental disorders, where it was found that children with dyslexia paused more both in-between and within-words compared to TD peers (Sumner et al, 2013; Wengelin, 2007). In dyslexia, within-word pausing occurred in correctly spelled and misspelled words (Sumner et al, 2013). 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 plausible to suggest 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 will be considered in more detail in the chapter on legibility.

The analysis of longer pauses between 4-10 seconds 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 seconds 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 seconds. However using eye-tracking technology Alamargot et al (2010) was 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 seconds, as children with DCD not only had more pauses above 10 seconds, 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, within the DCD evidence base Chang and Yu (2010) suggested in their discussion that a decrease in strength and endurance was a possible factor to explain poorer handwriting control in children with DCD. This may be plausible given that in the current study the children with DCD paused more above 10 seconds 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. Chapter 8 examines grip strength and pressure on the work surface in order to examine physiological factors which may contribute to fatigue.

Another interesting finding was that the TD group spent 46% of their pause time within a time-frame of 250ms-2 seconds 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 seconds compared to 5% in the TD group. Given this difference in the distribution of pauses, it may be plausible to suggest that while the TD group had the ability to process the lexical and spelling components within a range of 250ms-2seconds, the DCD group were unable to do so and were forced to take longer pauses as a result.

Another area addressed was the mean-pause-duration. Rosenblum & 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 in Rosenblum & Livneh-Zirinski's (2008) study, 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, judging by the amount of time they spent pausing over 10 seconds, the mean-pause-duration may have been driven by the longer pauses. 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 final area for consideration was the 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 milliseconds 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 seconds, where the DCD group did pause more frequently in this time-frame. Regression analyses indicated that the frequency of pauses over 10 seconds was predicted by both the age of the child and the manual dexterity score.

It should be noted that Alamargot et al's (2010) sample was very small and writing was produced on a writing tablet placed at an upright angle in order to accommodate the eye tracker. This is problematic in terms of ecological validity, as the angled writing position may have influenced the younger writer which may have affected the pausing profile.

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 are thought to represent. Further research needs to be conducted in the field of writing to support this type of analysis. However given 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. Future research on handwriting in DCD would be strengthened by the use of eye-tracking measures, as it would provide insight into the longer 10 second pauses in children with DCD, which seems to be the more influential time-frame emerging from this study.

4.15 Practical implications from this chapter

Part 1 of this chapter examined the handwriting product and process using the DASH, which is commonly used among occupational therapists and teachers in the UK. The process measures indicated that the lack of words produced during the tasks was a result of excessive pausing. Part 2 of this chapter unpicked this further and led to the following implications for practice:

1. Children with DCD do not pause more frequently than their TD peers except on pauses over 10 seconds. When children with DCD pause, they have a tendency to pause for longer. This emphasises the need to assist children with DCD in developing automaticity in their handwriting to reduce the length of their pauses.

2. Pauses over 10 seconds highlight a significant breakdown in the writing process. Practitioners must be aware of the consequences of this in terms of supporting additional time for children with DCD

during examinations. If they pause for long periods of time to cope with the demands of writing, this would support applications for extended time during examinations in the UK.

3. The pausing within words suggests a break down in the writing process. However, pausing within illegible words was the main issue. Therefore legibility must be considered an important factor and investigated in detail separately to speed.

Chapter 5

Handwriting legibility in children with DCD

5.1 Introduction to the Chapter

The demands on handwriting skill are not just limited to handwriting speed. Indeed a child may be able to write quickly, but if the content is not readable it defeats the communicative purpose of handwriting. The readability of a text is vital, especially within an academic environment. For children with DCD, issues with legibility are frequently reported, but are difficult to quantify given the complexities surrounding measurement.

In the previous chapter it was established that the children with DCD spent more time pausing within illegible words than their TD peers. Surprisingly however, they did not spend any more time than the TD group pausing at the letter level (30-250ms), nor did they move the pen any slower. However, an informal examination of the handwriting scripts suggested that legibility warranted closer inspection, as many of the scripts were difficult to read.

The purpose of this chapter is to examine handwriting legibility in children with DCD in detail by using clinical assessment tools as a means of investigation. The literature review considers issues relating to handwriting style, measurement of legibility and the development of handwriting in the typical population. The chapter is then divided into two parts.

In part one, the style of handwriting (i.e. the degree of joining) and legibility scores from the DASH (Barnett el al, 2007) are examined in the DCD and TD groups. The relationship between style, legibility and speed in the DASH free-writing task is then examined.

In part two the development of a new assessment tool is described. During the course of this research programme, it was apparent through a review of the literature that there was no available tool in the UK robust enough to measure legibility in a reliable and valid way. Therefore in collaboration with Professors Anna Barnett and Sara Rosenblum the Handwriting Legibility Scale (HLS) (Barnett et al, 2013) was developed for use within the UK context and to address legibility issues in this research programme. The HLS was then used to examine legibility in the two groups in the DASH free-writing task.

5.2 Literature Review

5.2.1 The Importance of Legibility

Legible handwriting is imperative, particularly in an academic environment. If the text is not readable, it makes it very difficult for a teacher or examiner to grade the piece of writing. In-fact ‘legibility bias’, which refers to a teacher/examiner penalising those who write less legibly has been reported in the literature for some time (Briggs, 1970; Markham, 1976; Greifeneder, Bottenberg, Seele, Zelt & Wagener, 2010; Greifeneder, Zelt, Seele, Bottenberg & Alt, 2012). Greifeneder et al (2010) examined the underlying cognitive processes associated with ‘legibility bias’ and reported that legible writing can be processed more fluently, examiners associate less legible writing with negativity and that both of these factors combined influence the examiner when evaluating written material. In addition to potential bias influencing academic achievement, the legibility of one’s handwriting can also influence self-esteem (Engel-Yeger et al, 2009). In a study which examined self-esteem in children with handwriting difficulties, Engel-Yeger et al (2009) found that those who had poor handwriting exhibited lower self-efficacy regarding their handwriting ability compared to typically developing peers. According to Berninger and Graham (1998) children who struggle with handwriting may simply decide to ‘give up’ and develop a mind-set that they cannot write (Berninger & Graham, 1998). Thus legibility is important for children, not only as an avenue to academic achievement but also from the perspective of developing self-esteem and self-efficacy.

5.2.2 The Teaching of Handwriting in the UK

The only official guidance on handwriting policy in the UK is the achievement milestones outlined in the national curriculum. In Key Stage 1 (5-7 years) the national curriculum for Writing in England emphasises the formation of regularly shaped and correctly sized letters. Regular spacing between letters and words is also emphasised along with the use of capital and lower case letterforms. However, exactly what constitutes regularly shaped letters, correctly sized letters and letter spacing is not provided. Children should also be taught to join their letters at this stage DfE, (2011). The guidance states that it is important to emphasise clear and neat presentation in order to effectively communicate through writing (DfE, 2011), but no information is provided on how these should be measured. By the time a student reaches Key Stage 2 (8-11 years) they should be able to produce legible handwriting in joined and un-joined styles and should have advanced in fluency and speed. The children should be able to use different forms of handwriting by age 11 years, for example a clear neat hand for finished presented work, or a faster script for note taking (DfE, 2011).

5.2.3 Does Handwriting Style Matter?

As there is no national handwriting style in the UK, these vary widely from school to school. Individual schools will choose to use a particular handwriting style, often in the context of a commercial handwriting scheme, which sets out how handwriting should be taught. There are a variety of handwriting schemes on the market for schools to invest in and the handwriting styles they use vary from circular letter shapes which are completely un-joined to oval, sloping letter shapes which are fully joined (including loops from descenders). In 2006, Barnett, Stainthorp, Henderson and Scheib conducted a survey on handwriting practice and policies in 39 English primary schools and found eight different handwriting schemes in use. The Nelson Handwriting Font (Watson & Cassidy, 2004), which includes both joined and un-joined styles, was the most popular handwriting font (18%), followed by Hand for Spelling (Cripps, 1998) which includes only joined writing (15.5%). The remaining six schemes were used between 2-5% of the time. However, one figure which stood out in Barnett et al (2006) was that 26% of schools did not specify the use of any particular writing scheme. This raises questions regarding how handwriting is taught in those schools and possibly adds to the range and diversity of the handwriting styles already in existence. Another issue is that students, particularly teenagers, are inclined to add individual style to their handwriting, which if excessive, can make the writing difficult to read (Scheib, Tiburtius & Hartnell, 2003). Even small, personalised styles such as a slant to the left or right can contribute to non-uniform handwriting across students in the UK. This therefore adds to the complexity of examining legibility, as there is no uniform exemplar through which handwriting can be measured. In addition, there are different methods for assessing legibility, which will be discussed in the following section.

5.2.4 Measuring Legibility:

The assessment of legibility is important for several reasons including the identification of difficulties, monitoring progress, informing intervention planning and measuring the effectiveness of interventions in practice. However, legibility is a complex issue to address, which is evident through the array of methods that have been used to evaluate it (see Table 5.1 and 5.2). There any many different approaches to evaluating legibility ranging from informal assessments to those that are formally scored. For example a teacher in a classroom may observe their students' handwriting using an informal approach. This might involve using strategies available through the National Handwriting Association (NHA) which provide information on areas to focus on. In particular, the 'S' rules serve as a guideline for teaching particular aspects of handwriting such as size, shape, speed, slant, spacing, sitting on the line and stringing letters together using joins (NHA, 2010). Teachers, parents and children alike can use these to focus on aspects of handwriting as an informal method of improving legibility (NHA, 2010).

A formal approach to the assessment of handwriting is an important aspect of occupational therapy practice. However, the lack of a robust assessment tool for examining legibility in the UK means that approaches to assessing legibility can vary from clinic to clinic. While some clinics may design their own assessment based on clinical experience, others may use alternative task analysis strategies such as the Dynamic Performance Analysis (DPA) as part of the Cognitive Orientation to Occupational Performance intervention (CO-OP; Polatajko & Mandich, 2004). The DPA involves identifying where exactly the handwriting performance breaks down and from there, it assists the therapist and child in testing out possible solutions to the problem (Polatajko & Mandich, 2004). However the DPA is not specific to handwriting difficulties, as it can be applied to all tasks, but it serves as a framework for the therapist to assess legibility if necessary. However, therapists using the DPA would still require an understanding of the task (Polatajko & Mandich, 2004), which means knowing about legibility and those factors which influence readability is important.

With regards to formal assessments of legibility available for clinicians in the UK, there are none that have been specifically designed for the UK context and this is an area which requires development. Legibility in itself is a very complex issue to address, as there are a number of tools available to assess it, but they vary widely in what exactly they measure. This not only stems from the wide variety of handwriting styles, but also a lack of clarity in the literature identifying specific and reliable components of legibility. Additionally, in the assessments available, the writing tasks and scoring systems are often poorly supported by the research literature.

5.2.4.1 Global versus Analytical methods

There are two strategies that appear in the literature with regards to examining legibility. One involves a global-holistic evaluation of the overall ‘readability’ of the handwriting sample, which involves making a judgment on how readable a sample is (Rosenblum et al, 2003). This approach usually involves rating the sample on a scale ranging from ‘readable’ to ‘unreadable’. The second strategy involves a more analytical examination, which considers particular aspects considered to relate to overall legibility (Rosenblum et al, 2003). An example of the latter strategy would involve rating various aspects of a handwriting sample, including letter formation, alignment to the baseline and slant. These two strategies are beneficial in some instances but can be problematic in others. A global-holistic evaluation of legibility was common in the early 20th Century, but was heavily criticised due to its subjectivity and lack of reliability (Starch, 1919 cited in Rosenblum et al, 2003). However it is apparent through legibility bias that judgments are often made on the overall readability of a sample (Greifeneder et al, 2010; Greifeneder et al, 2012). Therefore in some ways overall readability is still an important aspect to consider. Despite this, in recent years assessment tools have deviated from the global-holistic evaluations and have become almost exclusively based on analytical assessments. This approach is problematic in itself, as there are a wide variety of components that have been measured in handwriting assessments. Table 5.1 illustrates the range of components that have been measured in the assessment tools discussed later in this chapter and highlights the diversity in terminology used even within one component i.e. letter formation. Some scales have been developed to assess in great detail different components of handwriting legibility (for example, the extent to which individual letters match a standard, the consistency of letter size or spacing between letters). Such assessments require scrutiny and measurement of single letters can be time consuming to undertake and are therefore not practical for teachers to use in the classroom setting.

Table 5.1

The range of components measured in legibility assessments and the variety of terms used to refer to them

Letter Formation	Letter Height	Alignment	Spacing	Other
		Components		
Abrupt directional changes	Regularity of letter height	Straightness of sentence	Space between words	Unsteady writing trace
Fluency of letters	Letters too large	Alignment with margin	Insufficient word spacing	Spatial organisation
Letter reversals	Inconsistent letter size	Poor letter or word alignment	Collision of letters	Slant
Letter distortion/ poor letter closure	Incorrect letter height relative to other letters	Line straightness	Improper letter spacing	Tilt of letters and tilt of words
Overwriting			Too wide or overlapping	Vertical alignment of letters
Readability/ unrecognisable letters				

Note. Variables taken from the following assessments: ETCH=Evaluation Tool of Children's Handwriting, DASH=Detailed Assessment of Speed of Handwriting, S.O.S= Systematic Screening of Handwriting Difficulties, BHK= Concise Assessment Methods of Children's Handwriting, HHE=Hebrew Handwriting Evaluation, MMT=Minnesota Handwriting Test, TOHL=Test of Legible Handwriting, DRHP=Diagnosis and Remediation of Handwriting Problems, CHES=Children's Handwriting Evaluation Scale

5.2.4.2 Does the Task Matter?

One particular barrier to consider when measuring legibility is deciding what type of handwriting task to use. Table 5.2 provides descriptive details on each of the assessments reviewed for this chapter. In the eight tools that were identified for this review, seven included a copying task. The issues with copying tasks have already been discussed in the previous chapter, but in addition to requiring a lower cognitive load to free-writing, the way in which tasks are presented may also influence performance. For example, in The Minnesota Handwriting Test (Reisman, 1993), the sentence '*the quick brown fox jumps over the lazy dog'* is presented to the child, but in jumbled order. According to Graham and Weintraub (1996) handwriting is a complex skill that cannot be understood independent of its connection with linguistic aspects of writing. By jumbling up a sentence, it is presented in a way that is unfamiliar, perhaps grammatically incorrect and conflicts with the syntactical construction component of the handwriting process (Van Galen, 1991). Moreover, during the translation process of writing, the writer must apply the rules of the language system to their writing, including grammar and spelling. By presenting a jumbled sentence for copying, the linguistic make-up and cohesion has been manipulated. This may influence the legibility of the text, as it is plausible that more cognitive resources are assigned to deciphering the sentence, rather than focusing on the quality of the handwriting.

Other assessments such as the Concise Assessment Methods of Children's Handwriting BHK (Hamstra-Bletz, DeBie & Den Brinker, 1987) and the Systematic Screening of Handwriting Difficulties (SOS; Van Waelvelde, Hellinckx, Peersman & Smits-Engelsman, 2012) also use copying tasks. These assessments require the child to produce the handwriting on an unlined sheet of paper. In terms of ecological validity, particularly in the UK, children are mostly required to write on lined paper, unless developing a poster presentation. Most of their coursework is completed on lined paper. The issue of visual feedback in handwriting has been identified as a key factor for performance, as research has shown that the absence of visual feedback (being able to see what is being written) increases the cognitive demands on handwriting (Olive et al, 2002). Although visual feedback is not suppressed when using unlined paper, the point of reference or cue is withdrawn for those who use the line as a cue. Many children are taught to use the line as a start or end point for forming letters. Figure 5.1 provides an example of an activity book used to teach children in Key stage 1 and 2. The author refers to the line as a cue for the production of letters (Bell, 1997). For example, to produce the letter 'c' Bell (1997, p. 5) states to "Start half way between the dotted line and the baseline. Curve up over the top and stop, making sure you touch the dotted line on the way. Go back the way you came, curve down, touch the baseline and then up again". In the absence of a line, the child may have to resort to other, unfamiliar strategies to maintain the same horizontal alignment as the other letters. Daniel and

Froude (1999) stated that writing on un-lined paper is bound to impact on performance, while a study by Burnhill, Hartly and Lindsay (1983) found that handwriting quality was reduced when the children were writing on un-lined compared to lined paper.

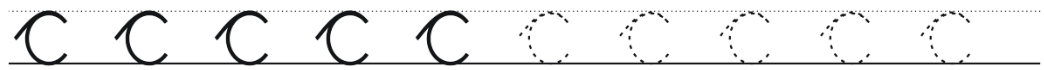


Figure 5.1. An example of an activity book by Bell (1997) used to teach children in Key stage 1 and 2. Here a baseline is used as a guide for writing.

Another task that has been used in legibility assessment is writing out the alphabet. However, despite the frequency of its use in the writing literature, the alphabet task is relatively uncommon in terms of assessing legibility. In the eight assessments included in this review, four included the alphabet task, one of which was the Hebrew Handwriting Evaluation (HHE) developed in the Hebrew language (Erez & Parush 1999 cited in Rosenblum et al, 2003). The HHE was included here as a means of comparing the results of this study to previous findings in DCD. Outside of the HHE, only the DASH (Barnett et al, 2007), Evaluation Tool of Children's Handwriting (ETCH: Amundson, 1995) and the Children's Handwriting Evaluation Scale (CHES: Phelps & Stempel, 1987, 1988) examined legibility in the Latin based alphabet. The ETCH (Amundson, 1995) was developed using a sample from grades 1-2 in the USA for the manuscript (un-joined) version, and grades 3-6 for the cursive (joined) version. The CHES (Phelps & Stempel, 1988) has two versions, one each for joined and un-joined writing. Similar to the ETCH, the un-joined is just for grades 1-2 in the USA and the joined is for grades 3-8. Although the CHES includes producing letters of the alphabet, the entire alphabet is not assessed as the letters i, q, v, x and z are all omitted from assessment. One advantage of using the alphabet task is that the assessor can evaluate letter formation for each letter of the alphabet and identify potential difficulties at a letter level.

Only two assessments included dictation as a means of assessing legibility, the ETCH (Amundson, 1995) and the HHE (Erez & Parush 1999 cited in Rosenblum et al, 2003). Dictation tasks pose difficulties when considering standardisation. For example the speed, volume and frequency at which the text is dictated can impact on the processing speed and reconstruction into written form. There is also the issue of auditory processing and hearing ability of the children, although this is likely to have a greater effect on handwriting speed more than legibility.

Another task that is used for examining legibility is that of free-writing. As previously discussed in Chapter 2, free-writing incorporates all aspects of the writing process and assesses the child's ability to produce legible text, while simultaneously attending to the higher level writing processes. This is the most challenging type of handwriting task and differences have been found between the quality of handwriting produced between copying and free-writing tasks, where copying was found to be more legible than expository or narrative tasks (Graham et al, 1998). However, it is worth noting that in copying tasks, the rater is already familiar with the content of the text without having to decipher the message. This may influence the perceived legibility of a copying task if the reader already knows what is being written. Despite the ecological validity in assessing legibility in compositional free-writing tasks, only four of the assessments reviewed here have included free-writing. These include the Test of Legible Handwriting (TOLH: Larsen & Hammill, 1989), the Diagnosis and Remediation of Handwriting Problems (DRHP; Stott, Moyes & Henderson, 1985), the ETCH (Amundson, 1995) and the DASH (Barnett et al, 2007).

In addition to the type of tasks chosen to measure legibility, the instructions given to the child particularly around speed might affect the outcome due to the trade-off relationship between handwriting speed and legibility that has been well established in the literature (Weintraub & Graham, 1998). For example, when a child writes in their best handwriting, legibility increases while the speed at which it is produced decreases. Similarly, when writing quickly, the legibility may decrease (Weintraub & Graham, 1998). Practitioners should therefore expect to see a difference in legibility between a child's best handwriting and their handwriting under exam constraints. Therefore the rationale for measuring legibility needs to be carefully considered before assessment and in choosing an appropriate task. Assessors should also exercise caution in comparing results from one task with those from another.

Table 5.2

Description of handwriting tools that examine legibility

Test	Author(s)	Country	Age Range	Writing Tasks
ETCH	Amundson, 1995	USA	6-8(un-joined) 11-14 (joined)	Alphabet in lower and upper case from memory, writing numerals, Near and far point copying, writing from dictation, and composing a sentence
SOS	Van Waelvelde et al, 2012	Belgium	7-12	Copy a sample of writing within 5 min
BHK	Hamstra-Bletz et al, 1987	Belgium & Netherlands	Primary school age	Copy a sample of writing within 5 min
HHE	Erez & Parush, 1999	Israel	School age	Copying the letters of the Hebrew alphabet. Copying a short story (of 30 words). Write a short story from dictation (30 words)
MHT	Reisman, 1993	USA	6-8	Near-point copying task
TOLH	Larsen & Hammill, 1989	USA	7-16	A copying task and two compositional tasks (narrative and expository)
DRHP	Stott et al, 1985	USA	School age	3 Comic book style pictures with word cues provided. Child given 20 minutes to write about topics
CHES	Phelps & Stempel, 1987	USA	8-14 (join) 6-8(un-join)	Copy two sentences for a period of two minutes

Note. ETCH= The Evaluation Tool of Children's Handwriting , S.O.S= Systematic Screening of Handwriting Difficulties, BHK= Concise Assessment Methods of Children's Handwriting, HHE=Hebrew Handwriting Evaluation, MMT=Minnesota Handwriting Test, TOHL=Test of Legible Handwriting, DRHP=Diagnosis and Remediation of Handwriting Problems, CHES=Children's Handwriting Evaluation Scale

5.2.4.3 How Robust are Legibility Assessment Tools?

Another aspect that needs to be considered in relation to the assessment of legibility is the psychometric properties of the tools used. Table 5.3 provides a summary of the reported psychometric properties of tools which measure legibility.

Inter-Rater Reliability

While most assessments exhibit good inter-rater reliability, it is important to consider how much time and training it takes to achieve good inter-rater reliability on some of the assessments. For example, the BHK (Hamstra-Bletz et al, 1987) requires extensive training and the scoring takes up to 20 minutes to complete. The CHES (Phelps & Stempel, 1988) demonstrated good inter-rater reliability (a speech therapist and a teacher evaluated the scripts) and it is one of the quicker measures to implement, taking only 2 minutes to administer and 3-7 minutes to score (Collins, Candler & Sanders, 2008). However, although a quicker screening tool may seem ideal for the busy classroom teacher, it is not known whether it actually measures legibility, which is problematic and will be discussed in relation to validity below. The ETCH (Amundson, 1995) demonstrated low inter-rater reliability, suggesting that in order to test the child reliably during a follow up assessment, the child would need to be assessed by the same examiner. In general, the inter-rater reliability is satisfactory in most cases, although factors such as the time it takes to achieve reliable scoring combined with issues surrounding validity pose difficulties when utilising these tools in practice.

Test-Retest Reliability

Four of the assessments reviewed in this chapter did not report test-re-test reliability (see Table 5.3). The ETCH (Amundson, 1995) is one test that reported low test, re-test reliability (within a 7 day period), which Collins et al (2008) argued was the result of a holistic approach to evaluation, rather than analytical. The authors therefore did not recommend the ETCH for documenting change over time or for determining eligibility for service provision (Amundson, 1995). The test re-test reliability for the SOS (Van Waelvelde et al, 2012) was fair to moderate based on the re-assessment of 199 children two weeks after the initial test. The MHT (Reisman, 1993) has been shown to have poor to moderate test, re-test reliability (within 5 to 7 days), which according to Collins et al (2008) questions its ability to measure change over time. The Test of Legible Handwriting (Larsen & Hammill, 1989) reported good test re-test reliability on children who were tested four times in a three-week period. However, the sample size was small (n=35). In general, test re-test reliability of the above measures is problematic, especially in services that are driven by outcome measures in evaluating change.

Validity

Another important property to consider is test validity, to establish the extent to which a test actually measures what it sets out to measure. The BHK has been shown to correlate well with teachers' evaluations of handwriting (see Table 5.2) as has the ETCH (Amundson, 1995), the TOHL (Larsen & Hammill, 1989) and the Minnesota Handwriting Test (MHT) (Reisman, 1993). The HHE demonstrated construct validity through comparing the differences between typically developing children and those with handwriting difficulties (Dvash et al 1995 cited in Rosenblum et al, 2003). However, three of the tests did not report any measure of validity.

Regardless of the psychometric properties exhibited in Table 5.3, none of the tools were developed in the UK, therefore failing to represent the diverse profile of handwriting styles in this country. The only standardised tool that accounts for legibility to some degree in the UK is the DASH (Barnett et al, 2007). Although the DASH was developed to measure speed of handwriting, it does include a count of the number of illegible words, as only legible words are included in the calculation of speed of performance. It is therefore possible to determine the percentage of illegible words produced by children but without further elaboration of the nature of the legibility issues.

Table 5.3

Psychometric properties of handwriting tools that examine legibility

Test	Inter-rater reliability	Test re-test reliability	Content Validity
ETCH	.63-.91	.63-.71	Good
SOS	.73-.82	.61-.76	None reported
BHK	.71-.89	None reported	Good
HHE	.75-.79	None reported	Good
MHT	0.87-0.98	0.58-0.94	Good
TOLH	.95	.80-.90	Good
DRHP	.61-.65	None reported	None reported
CHES	0.85-0.95	None reported	None reported

Note. ETCH= The Evaluation Tool of Children's Handwriting, S.O.S= Systematic Screening of Handwriting Difficulties, BHK= Concise Assessment Methods of Children's Handwriting, HHE=Hebrew Handwriting Evaluation, MMT=Minnesota Handwriting Test, TOHL=Test of Legible Handwriting, DRHP=Diagnosis and Remediation of Handwriting Problems, CHES=Children's Handwriting Evaluation Scale

5.2.5 Style & its Relationship with Speed and Legibility

Individual and school differences in handwriting style have already been mentioned above. Another factor, sometimes related to the adopted style of writing, is the degree to which letters are joined together in handwriting. In some styles, letters are un-joined within words, whereas in others they are all fully joined within words. Many styles lie somewhere between these two extremes, with some joining of letters. There has been limited research to investigate the effects of the degree of joining on legibility and speed of handwriting in the UK. However, in the USA, Graham et al (1998) examined the handwriting of 600 students in grade 4-6. To date, this is the largest study to examine handwriting style in school-aged children. The authors used three handwriting tasks including a copying task and two compositional tasks (narrative and expository). Legibility was assessed using the TOHL (Larsen & Hammill, 1989), which had inter-rater reliability greater than .80 on all three handwriting tasks. The handwriting style was classified in one of four ways; all un-joined, mixed mostly un-joined (50% un-joined, or more), mixed mostly joined (50% joined, or more) and all joined. However, if a student used an equal mixture of both joined and un-joined it was unclear how this would be classified in terms of style. Graham et al (1998) reported inter-observer reliability for the three tasks including .99 for copying, .98 for narrative writing and .99 for expository writing. Speed was only examined on the copying task.

The results showed that the mixed, mostly un-joined style was the quickest, producing 16-19 more words in the copying task than all joined and all un-joined styles (Graham et al, 1998). Similarly, the mixed mostly joined style was quicker than all joined and all un-joined. In terms of legibility on the copying task, the mixed mostly joined style was rated as more legible than mixed mostly un-joined. No other differences were found for the copying task. For the narrative compositional task, mixed mostly joined scored higher on legibility than all three alternative styles, while on the compositional expository task, mixed mostly joined was only more legible than un-joined. No other differences were found on the expository task. However, despite the fact that the mixed styles were quicker, they were the least commonly used. The majority of students (60%) either used exclusively joined or un-joined, with only 40% using a combination of both. When students did use mixed styles, they were three times more likely to use mainly un-joined. Graham et al (1998) argued in their discussion that the mixed styles were a 'deviation' from what was taught in schools.

In the UK, the curriculum states that students should be able to join their writing by Key Stage 2 (8 years old) (DfE, 2011) and be able to use joined and un-joined where necessary. However, in Graham et al's (1998) study a deviation from all joined resulted in quicker handwriting speed and more legible writing (Graham et al, 1998). The reasons for deviating from strictly joined or un-joined remain unknown. However, a deviation should be expected in the UK, given that children, particularly in secondary school, develop an individual handwriting style (Scheib et al, 2003). This lack of uniformity surrounding handwriting style adds to the complexity of measuring legibility in handwriting. However research is underway to develop the Handwriting Joining Scale (HJS) to investigate this area in greater detail (Barnett, Scheib & Henderson, 2013). The HJS is indeed timely, as handwriting style tends to be a popular topic of discussion at handwriting events, where practitioners often ponder on what style is the most appropriate to teach. This is particularly of interest to practitioners who work with children with handwriting difficulties, as the question of whether joining is too difficult to enforce on vulnerable writers is often raised.

In terms of children with DCD, it is not known whether their handwriting speed or legibility difficulties relate to handwriting style, or whether they are more inclined to use more joined or un-joined handwriting. Graham et al (1998) suggested that deviating from all joined or all un-joined handwriting may be a way of modifying the task to be more efficient. This may well be the case in children with DCD, as they may choose a less joined style to reduce the additional strokes between letters, or a more joined style to carry momentum between letters. However, to begin with, it would be beneficial to investigate whether there is a style preference between children with DCD and TD peers and in doing so to examine whether style relates to scores on speed and legibility.

5.2.6 The Development of Legible Handwriting

In a study on 900 children in the US, Graham et al (1998) examined the development of legibility using three different tasks (copying, narrative and expository writing task). The TOHL (Larsen & Hammill, 1989) was used to score the tasks. The TOLH offers a variety of perspectives on legibility as it is scored by closely matching a handwriting sample to one of three scoring exemplars. Graham et al (1998) found that over a four-year period (grade 1-4) little improvement in legibility was observed. However, towards the end of elementary school (age 10-11 years) legibility increased and was generally maintained during the secondary school years (age 11+ years). On all three tasks, girls produced more legible handwriting than boys. This gender difference in legibility is frequently reported in the literature (Greifeneder et al, 2012; Feder, Majnemer, Bourbonnais, Blayney & Morin, 2007; Blote & Hamstra-Bletz, 1991). The degree of legibility was influenced by the type of writing task, as free-writing consistently revealed poorer performance than that of copying. This relates to the point raised above that when using copying tasks the letterforms are provided to the child and imitation of letterforms can occur (Levene, 1993). In contrast, when using free-writing tasks the child is fully engaged in the writing process having to process the demands of a free-writing task. Executing legible letterforms becomes more demanding in this instance, where retrieving the letterform is only one of many other processes occurring at once. However, the use of different tasks has made it difficult to characterise handwriting difficulties in children. This is evident through the many different writing tasks that have been included in legibility assessment tools. Although there have been many attempts to develop tools to assess handwriting legibility, many issues still remain concerning what exactly should be measured and what aspect of legibility best relates to handwriting difficulties. There has also been very little systematic study of handwriting legibility in children with DCD and most of the data available comes from the Hebrew language rather than in the Latin base.

5.2.7 Handwriting Legibility in children with DCD

Anecdotal evidence from teachers and parents suggest that children with DCD have significant difficulties with legibility. From an empirical perspective, the literature on handwriting in DCD has reported that children with DCD in Israel demonstrate difficulties with global legibility, frequently overwrite on letters, produce unrecognisable letters and have poor spatial arrangement (Rosenblum & Livneh-Zirinski, 2008). The study by Rosenblum and Livneh-Zirinski (2008) is the only work to detail legibility issues in children with DCD. Other studies such as Smits-Englesman et al (2001) measured legibility as an inclusion measure for a wider study on the kinematics of drawing. In their study they used the BHK (Hamstra-Bletz et al, 1987) as a measure of handwriting quality. The group with handwriting difficulties, which included children with DCD, scored within the high range, indicating difficulties with legibility. However, the BHK includes 13 separate items and it would have provided insight into specific aspects of legibility difficulties had more information been provided on the individual items. In addition to research evidence, clinical descriptions of children with DCD have provided insight into specific aspects of legibility difficulties. Polatajko and Mandich (2004) described legibility issues in children with DCD who were seen in occupational therapy clinics in Canada. In particular, poor letter formation was commonly reported (Polatajko & Mandich, 2004). However, in terms of studies specifically addressing legibility in children with DCD, a more detailed description particularly in the Latin based alphabet is needed.

5.3 Predictions based on the literature

Part 1

Children with DCD have significant motor deficits, which are known to present difficulties in a range of activities including that of handwriting (APA, 2013). Anecdotal, clinical and limited empirical evidence suggests that children with DCD have difficulties with legibility. It is therefore hypothesised that the children with DCD in the current study will have a higher percentage of illegible words on the DASH (Barnett et al., 2006) handwriting tasks, including copying and free-writing tasks.

Part 2

In the second part of this study the development of the Handwriting Legibility Scale (HLS) is described in detail. It is hypothesised that the DCD group will score below the TD group on the overall HLS score and on each individual item. This prediction is based on findings from Rosenblum and Livneh-Zirinski (2008), where children with DCD demonstrated difficulties in many areas of legibility.

5.4 Part 1: The Study

The main aim of this study was to assess the legibility of handwriting performance in children with DCD in English using a range of writing tasks including free-writing. In addition, the style of handwriting (the degree of letter joining) used by children with DCD was analysed to ascertain whether this was similar to their typically developing peers. Table 5.4 presents the specific research questions addressed in Part 1 of this chapter.

Table 5.4

Specific research questions in Part 1

	Compared to Typically Developing Peers, Do children with DCD:
1	Have fewer letter joins in their handwriting?
2	Demonstrate poorer legibility?
	The following questions were examined across both groups:
1	What is the relationship between the degree of joining, legibility and handwriting speed?
2	Does reading, spelling or vocabulary skill relate to measures of handwriting legibility?
3.	Does legibility relate to the findings on pausing from Chapter 4?

5.5 Method

The same 56 participants used in the handwriting speed study (Chapter 4) were used in part one of this study.

5.5.1 Measures

Handwriting Style:

Handwriting Joining Scale (HJS; Barnett, Scheib & Henderson, 2013)

The HJS was developed for the UK context and used to analyse handwriting style in the current study. It is comprised of a four-point scale similar to that of Graham et al (1998). The categories consist of 1=all un-joined, 2=mixed mostly un-joined, 3=mixed mostly joined and 4=all joined. The scale was developed using scripts taken from the first two minutes of the DASH free-writing task.

All scripts were rated by a teacher with over 30 years experience and particular expertise in working with children with literacy difficulties. The rater was blind to group membership (DCD or TD group) and rated the first two minutes of the free-writing task on two different occasions, separated by 7-10 days. Test-retest reliability was .88.

In the current study the percentage of children with each style of handwriting was calculated separately for both groups.

Handwriting Legibility:

The Detailed Assessment of Speed of Handwriting (DASH; Barnett et al, 2007)

Although the DASH (Barnett et al, 2007) was developed to measure handwriting speed, in order to do so, all illegible words must be identified. Therefore the DASH was used to examine handwriting legibility on a range of writing tasks, which are often required in the classroom or in written examinations. The DASH was described in detail in the previous chapter on handwriting speed (Chapter 4). It includes tasks that are ecologically valid (free-writing) and provides an opportunity to examine a range of different types of handwriting tasks (copying and writing from memory). The four main DASH tasks were used in this study and were scored for legibility using the instructions in the manual. The criteria from the DASH manual for identifying illegible words were applied in this analysis and included the following:

Copy Best: Totally illegible words. An illegible word was defined as a word that could not be recognised outside the context of the sentence. This was calculated as a percentage of all words produced during the 2 minute task.

Copy Fast: As Copy Best.

Alphabet: Letters were scored for correctness rather than just legibility. A letter was considered incorrect if it was out of sequence, reversed, capitalised (if it was a different form in uppercase) or could not be recognised outside of the context of the task. Letters written in capitals (uppercase) that had a very different form than lowercase i.e A and B were counted as incorrect. The percentage of incorrect letters based on all letters produced during the one-minute task was calculated.

Free-writing: Unlike both copying tasks, words that could not be read even given the context of the sentence were not counted.

The number of illegible words for each task were calculated as a percentage of each participant's total word production (illegible plus legible words).

5.5.2 Data Analysis

5.5.2.1 Handwriting Style

An analysis of frequency was initially conducted followed by a Chi-Squared test of independence to ascertain whether the proportion of children with DCD using un-joined handwriting differed to the TD group.

5.5.2.2 Legibility

For the analysis of illegible words using the DASH scoring criteria, the percentage of illegible words on each task were calculated using the scoring criteria from the manual. For the analyses across the groups Mann-Whitney-U tests were employed, as the data were not normally distributed for this measure. Spearman's bi-variate correlation analyses were used to examine the relationship between legibility and age due to the wide age range of participants. Only the DCD group was included in the analysis due to the lack of range in the TD data in the free-writing task. In addition, the previous chapter on handwriting speed reported that children with DCD paused for a greater percentage of time in all DASH tasks with the exception of the alphabet task. To ascertain whether there was a relationship between the percentage of pausing (process measure) and the percentage of illegible words, Spearman's bi-variate correlation analyses were conducted on all tasks for the DCD group only.

5.5.2.3 Style and Legibility

Since the percentage of illegible words on the DASH tasks were not normally distributed, the Kruskal-Wallis test was used to evaluate differences among the three handwriting styles (un-joined, mixed and all-joined) on the percentage of illegible words on the DASH free-writing task.

5.5.2.4 Handwriting Speed

In the previous chapter on speed it was shown that the DCD group produced less text than their peers. However it was not known whether they produced less text due to discounted illegible words on the DASH, or whether they would have still produced fewer words when all text was included. All words were included for each task on the DASH (including illegible words). Group differences were examined using t-tests.

5.5.2.5 Style and Speed

A one-way ANOVA was used to evaluate differences among the three handwriting styles (un-joined, mixed and all-joined) on the mean number of words written in the first 2 minutes of the free-writing task and the mean execution speed (cm/s) from the writing tablet data.

5.6 Results

5.6.1 Handwriting Style

Analyses of frequency indicated that over half (58%) of the DCD group used an exclusively un-joined handwriting style, compared to 29% of the TD group. Just under half (46%) of the TD group used an all-joined style, compared to 15% of the DCD group. Using the four point scale revealed that none of the children with DCD used a mixed mostly un-joined style while only 4 of the TD children were in this category. It was therefore deemed appropriate to reduce the four point scale to three categories: all un-joined, mixed and all joined. As can be seen by the frequencies cross tabulated in Table 5.5, the type of handwriting style most frequently used differed by group, as the DCD group were more likely to use an all un-joined style compared to the TD group X^2 (2, $N = 50$) = 6.18, $p = .045$. Figure 5.2 provides an example of all un-joined handwriting by a 13 year old male in the DCD group, while Figure 5.3 illustrates all joined handwriting by a 13 year old TD male.

Table 5.5

Percentage of children from the DCD and TD groups using all un-joined, mixed script and all joined on the Handwriting Joining Scale (Barnett et al, 2013)

Type of Script	DCD n=26[a]	TD n=24[a]
All un-joined	58%	29%
Mixed	27%	25%
All joined	15%	46%

Note. [a] Data missing, as not all scripts were evaluated by rater.

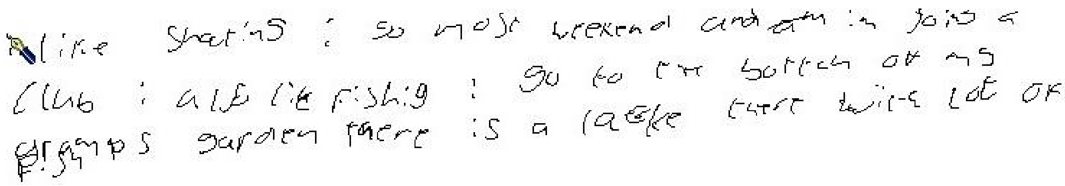


Figure 5.2. An example of un-joined handwriting in a 13-year-old male with DCD.

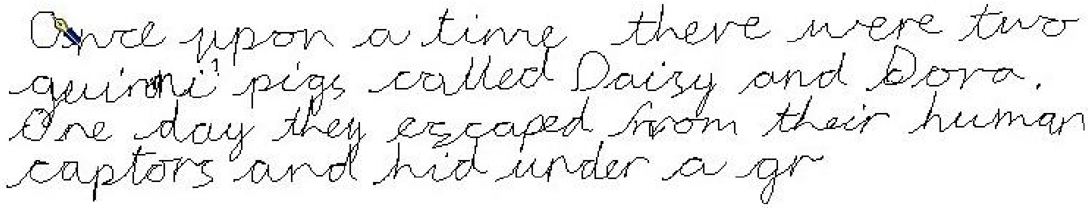


Figure 5.3. An example of all joined handwriting in a 13-year-old TD male.

5.6.2 Legibility

There was a significant effect of group for percentage of illegible words on all DASH handwriting tasks including the alphabet task (U= 203.5, Z = -2.97, p=.003), copy best (U= 252.0, Z = -3.19, p=.001), copy fast (U= 151.5, Z = -4.37, p=.001) and the free-writing task (U= 97.0, Z = -5.30, p<.001). Table 5.6 illustrates the mean percentage of illegible words on the DASH tasks.

Table 5.6

A comparison of the mean percentage of illegible words on the DASH raw scores (SD) for the DCD and TD groups

Measures	DCD n=28	TD n=28
Dash % of illegible letters/words		
Alphabet Task (l)	12.79 (3.35)	2.97 (.728) *[a]
Copy Best (w)	4.18 (1.51)	.296 (.296) *[a]
Copy Fast (w)	10.27 (2.37)	.428 (.269) *[a]
Free-Writing (w) (10 minute task)	7.69 (2.12)	.115 (0.76) *[a]

Note. **p*≤ .050, w= words, l= letters

[a] Significance based on median values used in Mann-Whitney U test.

Spearman's bi-variate correlation analyses revealed a significant negative relationship between age and the percentage of illegible letters on the alphabet task for the DCD group (r=-.45, p=.017). Age was not significantly correlated with the percentage of illegible words on any of the other DASH tasks. There was no significant relationship between the pausing percentages on any of the DASH tasks with the percentages of illegible words for the DCD group.

5.6.3 Style and Legibility

The DCD and TD groups were analysed separately and together using the Kruskal-Wallis test. However, none of the tests were significant; indicating no effect of style for handwriting legibility on the free-writing task (p values ranged from p= .154 to p= .890).

5.6.4 Handwriting Speed

For the total number of words (including illegible words) there was a significant effect of group on copy best (t(54) = -2.57, p = .013), copy fast (t(54) = -2.82, p = .007) and the DASH free writing task (t(54) = -2.07, p= .043). There was also a significant effect of group for the alphabet task (t(54) = -2.95, p = .005). Table 5.7 illustrates the mean number of words or letters on the DASH tasks.

Table 5.7

The mean number words/letters produced on the DASH tasks inclusive of illegible words/letters (SD) for the DCD and TD groups

Measures	DCD n=28	TD n=28
Total Number of DASH words inclusive of illegible words		
Alphabet Task (l)	42.28 (15.16)	55.0 (17.03) *
Copy Best (w)	26.3 (2.19)	34.1 (2.04) *
Copy Fast (w)	33.9 (2.76)	44.8 (2.67) *
Free-Writing (w) (10 minute task)	127.17 (11.6)	156.6 (8.23) *

Note. *$p \leq$ .050, w= words, l= letters

5.6.5 Style and Speed

A one-way ANOVA was used to evaluate differences among the three handwriting styles (un-joined, mixed and all-joined) on the mean number of words written in the first two minutes of the free-writing task and the mean execution speed (cm/s). The DCD and TD groups were analysed separately and together. There were no significant effects of style (degree of joining) on handwriting speed or execution speed.

5.7 Discussion

The first part of this analysis considered handwriting style and whether there was a difference in the degree of letter joining between the groups. The results indicated that a majority of children in the DCD group used un-joined handwriting, while a majority of the TD group joined all of the letters within words. This may indicate that the DCD group chose to use an un-joined style to reduce the complexity of the task through avoiding additional strokes between letters. However, given the wide range of handwriting styles taught in the UK, it is possible that the children with DCD may have been taught un-joined handwriting at school. Future research could investigate this further by gathering information from schools regarding the style of handwriting taught, prior to investigation. This would also shed light on whether the children with DCD were initially taught joined handwriting at school, but then shifted to un-joined to reduce the demands of the task. This could be addressed in a longitudinal study of style in children with DCD and would be valuable in terms of informing an evidence base for teaching handwriting in children with DCD early in their education.

Despite the group differences in handwriting style, this did not appear to effect handwriting legibility or speed of production. An examination of legibility using the DASH scoring criteria (Barnett et al, 2007) as a means of investigation indicated that the DCD group had a higher percentage of illegible letters/words on all DASH handwriting tasks. For copy best and copy fast, the same sentence was presented to both groups but under different speed instructions. The speed-accuracy trade off was evident, insofar as the DCD group had a higher percentage of illegible words during the copy fast task compared to their performance on copy best (10% versus 4%). In the previous chapter it was found that the DCD group were able to increase the speed of the pen during the copy fast task. However, judging by the high percentage of illegible words and despite the provision of the sentence to be copied, it appears as though the DCD group had difficulties with executing the correct letter forms. Whether this was due to difficulties controlling the pen at speed or whether the motor program (see Van Galen's model) was incorrect remains to be seen. These issues will be discussed in greater detail in Chapter 9. Similar issues were also evident in the alphabet task, which would be considered to be highly practiced and rehearsed in school aged children, yet letters produced in the alphabet task were discounted in the DCD group. It was therefore apparent that writing the letters of the alphabet was not an automatic skill in children with DCD. However, age seemed to play a role in this, as there was a relationship between age and the percentage of illegible letters in the alphabet task, such that the older children with DCD had fewer discounted letters. This was not found to be the case for any other task, suggesting that integrating the letters into handwriting tasks remained an issue for the DCD group regardless of age.

One area that may shed light on legibility issues in children with DCD relates to research on velocity profiles. Previous research in graphonomics has explored the concept of velocity profiles in handwriting to measure automaticity. According to Teulings (1996) single strokes of automated movements can be completed in a smooth, automatic manner, evident through a small number of velocity peaks present in a letter stroke. On the other hand, if a letter stoke contains a high number of velocity peaks it is indicative of a less automated handwriting profile (Tucha, Tucha & Lange 2008). As a consequence, handwriting is dysfluent, with frequent changes in velocity. As discussed in Chapter 2, two studies in the literature on DCD have investigated velocity profiles in DCD. Smits-Engelsman et al (2001) observed the velocity peaks in children with DCD by using a drawing trail task from the MABC test (1st edition). This required the child to draw a line between two parallel lines in the shape of a flower, as accurately as possible. A decrease in velocity peaks compared to the control group was observed. In addition, the DCD group executed more errors and performed the task using a faster execution speed than the control group. However, as debated in Chapter 2, the drawing trail cannot be directly compared to a handwriting task, based on the absence of linguistic content and the fact that drawing a continuous line is a relatively simple movement compared to the complexity of letter formation. In a similar method of investigation, Chang and Yu (2010) compared the velocity profiles of children with DCD to two control groups (one with handwriting difficulties and one without) through executing Taiwanese letterforms. The results demonstrated that the children with DCD used a higher velocity while writing and had multi-peaked velocity profiles, which according to Chang and Yu (2010) was a sign of handwriting that lacked automaticity. The reasons for this lack of automaticity have yet to be investigated in detail. Indeed by doing so within an ecologically valid handwriting task, it may shed light on the underlying mechanisms of poor legibility. However such an analysis would be complex, as there are a range of handwriting styles and substantial variance in the amount of handwriting practice children engage with in schools in the UK (Molyneaux et al, 2013). It would therefore be a challenge to tease apart whether atypical velocity profiles are due to factors such as lack of practice, low motivation, low self-esteem or indeed underlying deficits of motor control. Knowing how much handwriting practice has been completed would eliminate this as a possible reason for the problem and shift the focus to underlying mechanisms in the literature such as motor learning difficulties and perceptual motor deficits (Rosenblum & Livneh-Zirinski, 2008).

The aim of the current study was to examine legibility in children with DCD using tools available for practitioners and clinicians. Therefore an exploration of the velocity profiles exhibited through the use of a writing tablet was not investigated here. However despite this, it is evident from the previous chapter on speed that the excessive pausing in children with DCD was not a result of pausing at the letter level. Therefore although there may be differences in the velocity profiles of children with DCD, it seems it may be a separate issue to the pausing phenomenon. This is supported in the current study by the lack of association between the percentage of pausing and the percentage of illegible words on the DASH tasks.

The previous chapter on speed also found that children with DCD produced less text than their TD peers. However, it was not known whether this occurred solely as a result of excluding illegible words from the calculation or whether they still produced less text when all words were included. The current study found that even when illegible words were included in the analysis, the DCD group still produced less text. This suggests that the lack of handwriting productivity was not solely to do with legibility, but also to do with pausing. Based on this premise, it appears as though there are two separate issues emerging, one being the excessive pausing and the second relating to accurate pen control to form legible letters and words.

From the point of view of intervention, teachers and therapists need to know where the difficulties with legibility lie. By calculating the percentage of illegible words on the DASH (Barnett et al, 2007) it does not provide information on the exact nature of the legibility issues. Therefore practitioners in the UK need a robust tool to measure legibility so they can decipher what areas need to be addressed. Part 2 of this chapter presents the Handwriting Legibility Scale (HLS; Barnett et al, 2013), which was developed as part of this research programme in order to address legibility in more detail.

Part 2

The Handwriting Legibility Scale (HLS)

There is currently no specific assessment tool available in the UK for practitioners who want to examine legibility within a UK context. The Handwriting Legibility Scale (HLS: Barnett et al, 2013) was developed as part of the current programme of research in order to provide a quick and easy tool to assess handwriting legibility in a reliable and valid way. The focus for this work was on children from the age of 8 years and upwards, who by this age will have received at least three years of handwriting instruction in the UK and should be developing effective skills in written communication (DfE, 2012).

5.8 Part 2: The Study

The main aim of this study was to describe the development of the Handwriting Legibility Scale including the establishment of the HLS items, content and expert validity, internal consistency and inter-rater reliability and finally, construct validity. In addition to the development of the HLS, specific questions in relation to handwriting legibility in children with DCD were also addressed. Table 5.8 outlines the research questions which were addressed in addition to the development of the HLS.

Table 5.8

Specific research questions in Part 2 using the HLS

	Research Questions
1.	Is there a relationship between legibility (measured by the HLS) and:
a	The percentage of illegible words on the DASH free-writing task for children with DCD?
b	Percentage of pausing during free-writing for children with DCD?
c	Age in children with DCD?
2.	What factors predict performance on the HLS in children with DCD?

5.9 Development of the HLS

5.9.1 Participants

The same 56 participants from this research programme were used to develop the HLS. In addition, two children who participated in a pilot study during this research programme were also included in the analyses for the HLS (n=58).

5.9.2 Establishing the HLS items, content and expert validity

Phase One was based on professional experience of the authors, validated by a review of the literature. Five legibility criteria were established to form the basis of the new assessment tool, the Handwriting Legibility Scale (HLS). In addition, a 5-point Likert scale–scoring format was established, such that 1 refers to *good* and 5 always refers to *poor*. A 3-point scale did not appear to be detailed enough in terms of rating severity of performance, while a 7 point scale was considered too detailed for reliable scoring and might have increased the duration of time to score the assessment. Since the aim was to ensure a quick and easy method of screening legibility, the 5-point scale was chosen.

The five criteria:

The first three criteria focused on a global/holistic evaluation and included the following:

1. Global legibility:

This measure was chosen from the literature on children with DCD, where Rosenblum and Livneh-Zirinski (2008) found global legibility to be one of the best predictors of handwriting difficulties in children with DCD and separately in children with ADHD (Rosenblum et al, 2008) and those without movement difficulties (Rosenblum et al, 2003).

In the HLS, global legibility is assessed based on the overall readability of the text on first reading. A score of 1 is given if on first reading, all words are legible. A score of 5 is given if on first reading, only few words are legible. Figure 5.4 illustrates the scoring for global legibility.

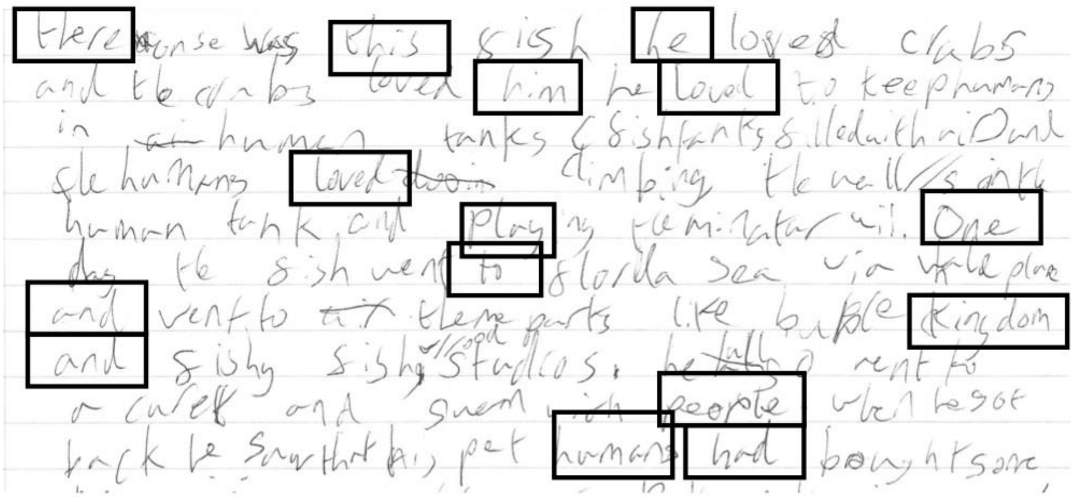


Figure 5.4. An example of a rating of 4 on global legibility: only some words are legible on first reading (those marked are examples of legible words).

2. Effort required to read the script:

This measure was included due to evidence to suggest that legibility bias can sometimes influence academic performance if the rater/examiner has to exert effort and spend time trying to read the writing (Greifeneder et al, 2010; Greifeneder et al, 2012).

In the HLS, an overall impression of the amount of effort required to read the script is asked of the rater. A score of 1 is given if *no* effort is required to read the script, while a score of 5 is given if reading the script is *extremely* effortful. Figure 5.5 illustrates a rating of 4. Some words are effortful to read. They cannot be deciphered or require two or three readings before they can be deciphered (those marked and others).

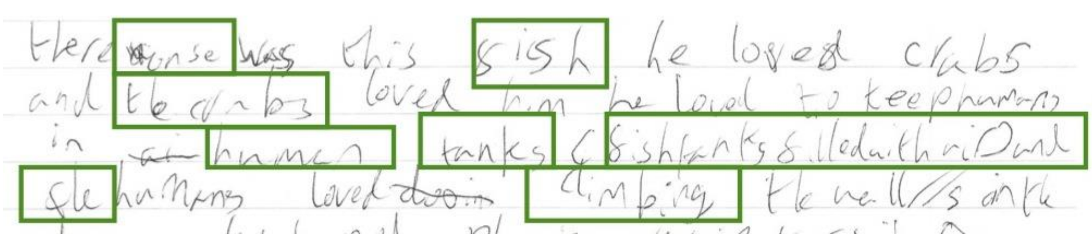


Figure 5.5. An example of a rating of 4 on effort required to read the script: Some words are effortful to read.

3. Layout on the page:

This includes an overall impression of the layout of writing on the page. The way in which the words are laid out and organized on the page has an impact on the ease with which it can be read. This relates to alignment of the writing with the margin, spacing between the words and positioning of letters and words on the base line (Parush et al, 2010). Well organised handwriting is consistent, with elements appropriately positioned in relation to each other.

In the HLS a score of 1 is given if there is very good layout on the page while a score of 5 is given if there is very poor layout on the page. Figure 5.6 illustrates the scoring a score of 4 for layout on the page. There is no regular margin, spaces between letters/ words are not consistent (circles and lines), letters/words are not placed on the line (boxes).

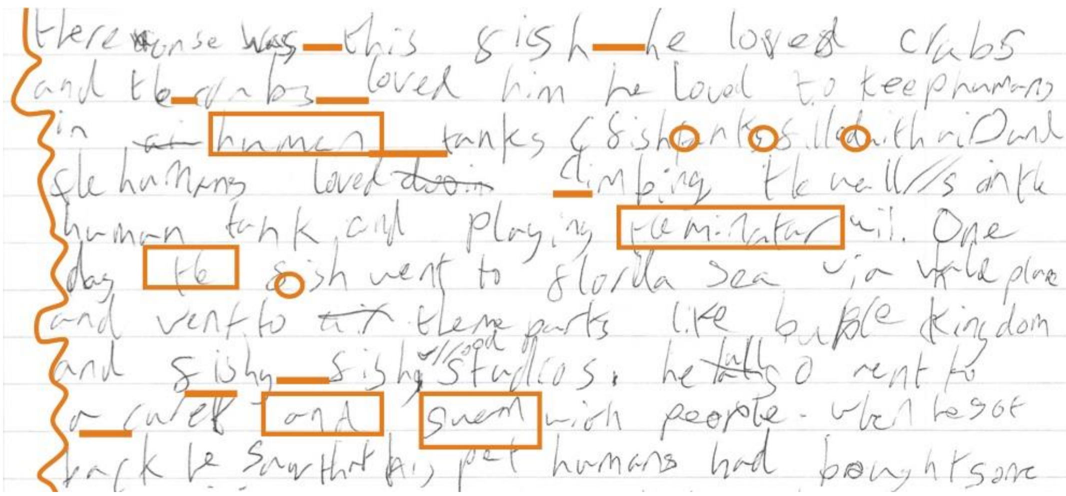


Figure 5.6. An example of a rating of 4 on layout on the page

The last two criteria focused specific evaluation at the letter level and included the following:

Letter formation:

This involves an overall impression of letter formation. Letters which are correctly and consistently formed are easy to read. Looking at specific letters allows us to see: poor formation, poor closure, missing elements and inconsistent/varied size or slope (Rosenblum & Livneh-Zirinski, 2008).

In the HLS a score of 1 is given if there is very good letter formation while a score of 5 is given if there is very poor letter formation. Figure 5.7 illustrates a score of 3 on letter formation. Some letters are not clearly formed (those marked and others). Rating: 3

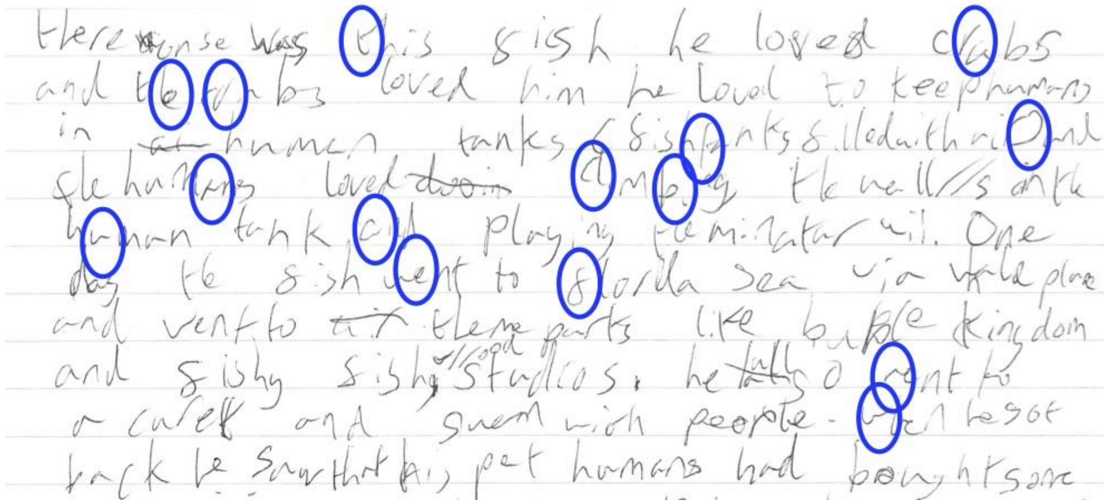


Figure 5.7. An example of a rating of 3 for letter formation

<u>Alterations to the writing:</u>

This includes an overall impression of the attempts made to rectify written work. It includes the addition of elements, re-tracing, re-writing and crossing out. Alterations to the writing can impact on the ease of reading (Rosenblum & Livneh-Zirinski, 2008). Research has found alterations of writing to be a significant predictor of handwriting difficulties (Rosenblum et al, 2011; Rosenblum et al, 2004).

In the HLS a score of 1 is given if there are no additional elements, re-tracing, over-writing or crossing out. A score of 5 is given if most words contain additional elements, re-tracing, over-writing or crossing out. Figure 5.8 illustrates a score of 3 for alterations of writing as some letters have been re-traced or overwritten and words are crossed out.

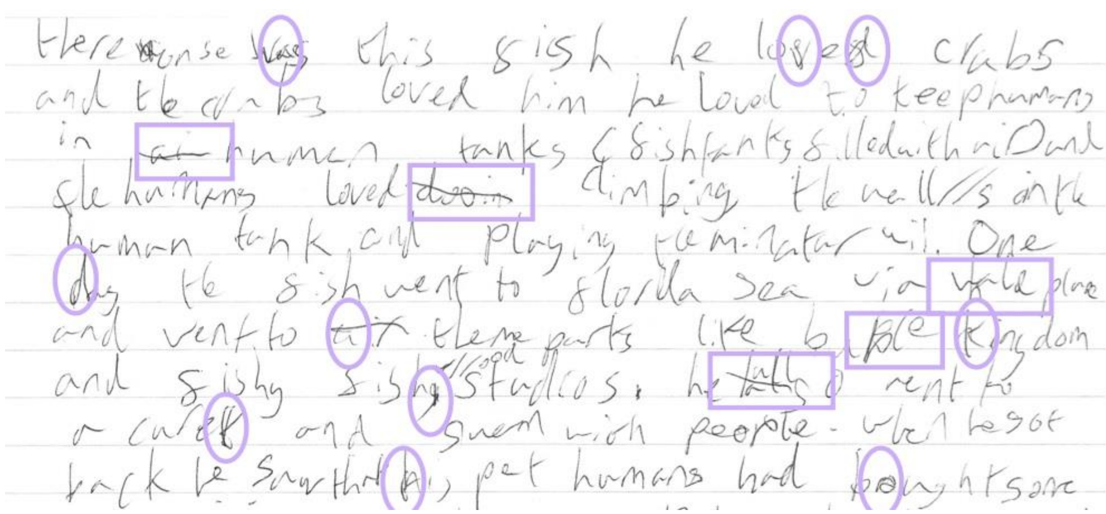


Figure 5.8. An example of a rating of 3 for alterations to writing

Instructions for scoring emphasised gaining an 'overall impression' of each of the criteria in deciding on scores for each component. Scoring instructions, examples and a 5-point Likert scale (from 1–good, to 5-poor) were developed to assess each of the criteria in samples of 'free writing' gathered as part of an assessment on the Detailed Assessment of Speed of Handwriting (DASH; Barnett et al., 2007). Children had written on lined paper on the topic of 'My Life', with instructions to use their 'everyday' handwriting but to try to write continuously for a period of 10 minutes, marking their script every two minutes. The HLS was applied to writing produced in the first six minutes, which was at least ten lines of handwriting. Total scores ranged from 5 to 25, with higher scores reflecting poorer legibility. A one-page scoring sheet (see Appendix 7) was drafted and scores were summed to provide a global legibility score.

Ten scripts from children aged 10-12 years (including those with and without handwriting difficulties) were initially scored independently by each of the authors. This led to clarification of the wording and layout of the scoring sheet to improve ease of use.

Phase Two

The content validity which assesses whether the substance of the test items covers a representative sample of the behaviour (Kaplan & Saccuzzo, 2012) (legibility) was examined by asking 12 experts from different professions (7 occupational therapists, 3 teachers, 2 psychologists) to independently provide feedback on the content and wording of each of the criteria.

5.9.3 Establishing internal consistency and inter-rater reliability

Internal consistency which measures whether items that propose to measure the same construct produce similar scores (Kaplan & Saccuzzo, 2012) (using Cronbach's alpha coefficient) was calculated from the scores of the 58 children aged 8-14 years mentioned above. The writing scripts were obtained from the children in this research programme and included those with and without handwriting difficulties. Inter-rater reliability was investigated on the original version of the scale by asking two new raters to independently score the scripts from 20 randomly selected children aged 8-14 years (10 with DCD, 10 without). The total HLS scores and individual item scores were divided into three categories: low (scores of 5-10), medium (scores of 11-15) and high (scores of 16-25) and inter-rater agreement was calculated using Cohen's Kappa.

5.9.4 Establishing construct validity

The children from the current study were used to examine the construct validity which focused on the ability of the test scores to discriminate between the TD children and those with DCD.

Construct validity which refers to the degree to which a test measures what it sets out to measure (Kaplan & Saccuzzo, 2012) was examined in three ways; firstly by comparing the HLS scores of the children with and without DCD using a Mann Whitney U test. Secondly a Chi-squared analysis was undertaken on the HLS category scores (low, medium and high) to determine whether the number of children falling into each category was significantly different across the two groups. Finally a discriminant analysis was undertaken to examine the extent to which the total HLS scores accurately classified children to the DCD or TD group.

5.9.5 Correlations between HLS and other measures

Illegible words on the DASH

Spearman's bi-variate correlation analyses were conducted to ascertain whether there was a relationship between the percentage of illegible words on the 10 minute free-writing task and the HLS (total score and the five individual components of the HLS) for the DCD group only due to lack of range in the TD group data.

Pausing

Spearman's bi-variate correlation analyses were conducted to ascertain whether there was a relationship between the percentage of pausing on the 10 minute free-writing task and the HLS (total score and the five individual components of the HLS) for the DCD group only since excessive pausing was only an issue for them.

Age

Given the relationship with handwriting speed and age, it was also necessary to investigate whether there was a relationship between age and the scores on the HLS. This was investigated using Spearmans bi-variate correlations with both groups together and separately.

Literacy Skills

Pearsons bi-variate correlational analyses were also conducted between the HLS total score and measures of spelling, reading and vocabulary to examine whether there was a relationship between the legibility of the text and other skills necessary for writing.

Manual Dexterity & Production of the Alphabet

Manual dexterity is often considered an important component of handwriting difficulties (Hamstra-Bletz & Blote, 1993) and was a significant predictor of the longer pauses found in Part 2 of chapter 4. In addition, the alphabet task is commonly used in the writing literature to ascertain the level of handwriting automaticity. It was hypothesised that if children with DCD scored poorly on the alphabet task, then it would likely impact on legibility within other handwriting tasks. This correlational analysis (Spearmans) sought to examine whether there was a relationship between the total HLS score and the raw score of the alphabet task for the DCD group, with the view of informing a regression analysis to examine the best predictors of the HLS total score in children with DCD.

5.10 Results

5.10.1 Content and expert validity

Expert opinion supported the inclusion of the five criteria and feedback led to clarification of the descriptions and scoring instructions. For example, the explanation of 'layout on the page' was clarified.

5.10.2 Establishing internal consistency and inter-rater reliability

Internal consistency was high for the total score (Cronbach's alpha 0.92). Inter-rater reliability for total scores was acceptable (Intra-class correlation .92, Kappa 0.67, $p<.001$). Inter-rater reliability on the original version, based on the three categories for the individual components were: global legibility (Kappa .30, $p=.024$), effort to read (Kappa 0.40, $p=.002$), letter formation (Kappa .34, $p=.002$), layout on the page (Kappa .06 $p=.567$) and alterations (Kappa .63 $p<.001$).

5.10.3 Establishing Construct Validity

Total HLS scores obtained from the scripts of children with DCD (Mean=17.28, SD= 3.66) were significantly higher than those for the TD group (Mean=9.83, SD= 2.59), U=42.50, z=-5.89, p<.001.). There was also a statistically significant difference between the groups on each of the five criteria (Table 5.9).

The number of scripts from the DCD and TD group scoring in the low, medium and high HLS categories are shown in Table 5.10. The Chi-square analysis revealed a statistically significant difference in this distribution of scores (χ^2 = 31.1 (df=2), p<.001). In the discriminant analysis, one discriminant function was found for the group classification of all participants according to the HLS final score (Wilks Lamda = .41 p<.0001). Based on this function 88% of the children in the entire sample were correctly classified to their groups, 86% of the children with DCD and 89.7% of the TD children. A Kappa value of .759 (p<0.001) was calculated, demonstrating that the group classification did not occur by chance.

Table 5.9

Mean (SD) scores for legibility criteria for the DCD and TD groups

	DCD Group n=29	TD Group n=29	p
Global legibility	2.86 (1.19)	1.31 (0.71)	<.001*
Effort required to read	3.52 (1.12)	1.89 (0.62)	<.001*
Layout on the page	3.86 (0.79)	2.17 (0.85)	<.001*
Letter formation	4.00 (0.76)	2.28 (0.65)	<.001*
Alterations	3.04 (0.82)	2.17 (0.34)	<.001*
Total	17.28 (3.66)	9.83 (2.59)	<.001*

Note. * p<.001

Table 5.10

Number (%) of children from the DCD and TD group with low, medium and high HLS scores

HLS total scores	DCD Group N=29	TD Group N=29
Low scores (5-10)	0	19 (65.5%)
Medium scores (11-15)	13 (45%)	8 (28.5%)
High scores (16-25)	16 (55%)	2 (7.0%)

5.10.4 Relationship between HLS and other measures

Illegible words on the DASH

All of the dependent variables from the HLS, with the exception of alterations, significantly correlated with the percentage of illegible words on the DASH free-writing task. The results of the analyses revealed four significantly positive relationships indicating that the higher the percentage of illegible words on the DASH, the higher the HLS component scores (higher HLS scores indicate poor performance). The correlations are presented in Table 5.11.

Table 5.11

Correlations between percentage of illegible words on the 10 minute DASH free-writing task and the HLS scores

	DCD (n=29)
HLS total score	.81**
Global legibility	.84**
Effort required to read	.77**
Layout on the page	.43*
Letter formation	.70**
Alterations	.32

Note. * p <.05, ** p <.01 (two-tailed)

Pausing

Spearman's bi-variate correlation analyses revealed four significant relationships between the percentage of pausing and the HLS items for the DCD group. The relationships indicated that the percentage of pausing increased, as did the scores on the HLS components. The correlations are presented in Table 5.12.

Table 5.12

Correlations between percentage of pausing on the 10 minute DASH free-writing task and the HLS

	DCD (n=28)
HLS total score	.38*
Global legibility	.13
Effort required to read	.14
Layout on the page	.53**
Letter formation	.42*
Alterations	.48**

Note. * p <.05, ** p <.01 (two-tailed)

Age

Spearman's bi-variate correlation analyses with both groups together and separate, revealed only one significant relationship between age and the HLS. In the DCD group only, there was a relationship between age and the item of overwriting on the HLS ($r(26) = -.39$, $p < .039$) indicating that as age increased, the scores for the HLS components decreased. For the non-significant analyses the p values ranged from p= .067 to p= .905.

Literacy Skills

Pearson bi-variate correlations were conducted between the HLS total score and the standard scores of the BAS-II reading and spelling measures and the BPVS. No significant correlations were found between the HLS and any of the literacy measures when both groups were analysed together and separately (p values ranged from p= .226 to p= .929).

Manual Dexterity & Production of the Alphabet

Spearmans bi-variate correlations with both groups separately revealed a moderate correlation between the MABC-2 manual dexterity score and HLS total score in the DCD group ($r(28) = -.41$, $p < .032$) and similarly in the TD group ($r(28) = -.50$, $p < .007$). When both groups were combined, the relationship between manual dexterity and the HLS total score was also significant ($r(56) = -.80$, $p < .001$), indicating better manual dexterity being associated with more legible writing (as the HLS has a higher score for poor performance). Pearsons bi-variate correlations revealed a significantly negative relationship between the raw score of the alphabet task and the HLS for the DCD group ($r(28) = -.65$, $p < .001$) indicating that higher scores on the alphabet task were associated with lower scores (better performance) on the HLS.

5.10.5 What predicts performance on the HLS

Regression analyses were computed for children with DCD to ascertain what factors best predict the total score of the HLS. The MABC-2 manual dexterity standard score was entered into the step-wise regression along with the raw scores on the DASH alphabet task and the percentage of pausing on the free-writing task, as they were all found to correlate with the HLS total. The results of the regression analysis revealed only one significant predictor, the raw scores on the DASH alphabet task, which explained 39.1% of the variance ($R^2=.39$, $F(1, 26)=16.72$, $p< .001$). It was found that higher alphabet raw scores increased the HLS total score. Coefficients can be found in the table below

Table 5.13

Regression analysis: predictors of performance on the HLS

	Standardised coefficients		Unstandardised	
	Beta	Standard error	coefficients	*p*
DASH alphabet raw scores	-.62	.033	-.135	<.001

Note. * p <.05

5.11 Discussion

In order to support children with handwriting difficulties, assessment tools are needed to assist identification and to describe and quantify the difficulties. The degree of legibility or ease of reading a handwritten script may be different for different readers and therefore difficult to quantify, especially in free-writing tasks where the reader cannot anticipate the content of the text. Development of the HLS was an attempt to identify those aspects of the text that contribute to global legibility, without the need for detailed letter by letter analysis. The aim was to produce a quick and easy, practical tool for teachers and clinicians.

The five elements included were supported by expert opinion as relevant components. Overall readability and effort required to read the script is based on the extent to which the script can be easily read on the first attempt, without relying on the context of the work. The way in which the words are laid out and organised on the page also has an impact on the ease with which it can be read. This relates to alignment of the writing with the margin, spacing between the words and positioning of letters and words on the base line (Parush, Lifshitz, Yochman & Weintraub, 2010). The accurate and consistent formation of letters is another important element, with errors often relating to missing elements of letters, poor closure or varied size (Rosenblum & Livneh-Zirinski, 2008). Finally, alterations to the writing can also impact on the ease of reading (Rosenblum & Livneh-Zirinski, 2008). These include crossing out, the addition of strokes and re-tracing of letters. In the examination of internal consistency, these five elements were found to be closely related to the total score.

In order to examine initial inter-rater reliability the total scores were categorised into three groups: low, medium and high scorers. Inter-rater reliability based on these classifications was acceptable for the total score but not as high as usually required for assessment tools for the individual items. From subsequent discussion with the raters, it emerged that they were somewhat unclear about the detail on some elements and so further refinement and clarity of the instructions is underway with more examples for scorers.

With any new assessment tool it is important to demonstrate its construct validity, the extent to which it actually measures the construct that it is designed to measure. This was examined by checking the ability of the test to discriminate between the scripts from a group of typically developing children and those with DCD. Not only did the HLS scores differ significantly between the DCD and TD groups, they could also be used to correctly classify over 85% of children into each of the groups. This provides strong evidence to support the construct validity of the HLS. In addition, the HLS total score correlated highly with the percentage of illegible words on the DASH free-writing task, indicating concurrent validity. In future work, a similar examination should be undertaken with other groups of children with handwriting difficulties such as children with ADHD or ‘dysgraphia’. This would provide information surrounding the flexibility of the tool for use with other populations other than DCD.

If a test is to be used to identify those with difficulties then it is necessary to select a cut-off score to denote poor performance. When the total HLS scores were divided into low, medium and high it was found that none of the scripts from children in the DCD group fell into the ‘low’ category (scores of 5-10), compared to 65% of those from the TD group. Further work is needed to confirm an appropriate cut off point to identify those with poor legibility and, as for many tests, it would be appropriate to also establish a ‘borderline’ range to suggest where monitoring of handwriting would be appropriate.

In terms of understanding the handwriting performance in children with DCD, additional analyses using the HLS were conducted. The results from Part 1 of this chapter revealed no correlation between the percentage of illegible words on the DASH and the percentage of pausing from the previous chapter on handwriting speed. In Part 2 there were significant, moderate correlations found between the HLS total score, alterations to writing, layout on the page and letter formation with the percentage of pausing on the free-writing task. However, when considered within a regression analysis, pausing did not emerge as a significant predictor of performance on the HLS. This was surprising, as pausing indicates a lack of automaticity in the handwriting of children with DCD, which might be expected to be related to the production of poorly formed letters This finding may support the notion that there are two separate issues in the handwriting of children with DCD; a temporal issue related to speed of production (pausing) and the quality of the movement itself (legibility).

With regards to the development of legibility in either group, there was no relationship between legibility on the HLS and age. This suggests that unlike speed, legibility scores did not appear to improve as children got older. However, this was not surprising, as previous research on the development of legibility in typically developing children has not shown the same linear trend as that of speed. In a study by Graham et al (1998) over a four-year period (6-9 years), little improvement in legibility was observed, but towards the end of elementary school (age 10-11 years) legibility increased and was generally maintained during the secondary school years (age 11+ years). One possible explanation for the lack of relationship between age and the HLS could be attributed to skill acquisition. For example, the TD group may have acquired the skills to write legibly from an early age (8 years) and maintained them as they got older, whereas the children with DCD may not have learned how to form letters correctly during the early stages of skill acquisition and therefore continued to reinforce the same errors during practice. This issue would be another reason to investigate school policies and the amount of handwriting practice achieved prior to further investigation. However, given the emergence of the alphabet task as a significant predictor of performance on the HLS, it is evident that the ability to form letters correctly and quickly supports legibility within free-writing.

Another relationship which was examined in Part 2 was between measures of literacy and the HLS total score. The findings revealed no significant relationship between the HLS and measures of vocabulary, spelling or reading indicating that legibility. However, the percentage of spelling errors is examined in Chapter 6 and may reveal

The overarching aim of this chapter was to examine legibility using clinical tools available in the UK. However, due to the lack of a robust tool to measure legibility, the HLS was developed. It was found to provide an easy to use global score of handwriting legibility. Initial examinations suggested good internal consistency and construct validity of the tool. However, further refinement of instructions is needed to improve the reliability of scoring and additional data collection to establish a cut off point to accurately identify those with poor legibility. The HLS may be a useful tool to identify those with poor legibility, to quantify levels of performance and to help plan how best to support individuals with poor handwriting. The next step is to understand the impact of the pausing and illegible words on the quality of the written product. After all, the purpose of handwriting is to communicate thoughts and knowledge, and it is therefore important to understand the impact of lower level writing processes on the overall quality of writing. The following chapter will investigate the writing quality of both groups.

5.12 Practical implications from this chapter

1. Joined versus un-joined writing style did not seem to impact on speed or legibility in children with DCD. Therefore, a preference for teaching one or the other in children with DCD did not seem to be supported. However, further research needs to investigate this in more detail.

2. Legibility (as measured by the DASH) appears to decrease with task demands, for example children with DCD performed poorer on tasks which required speed (copy fast and alphabet) and cognitive load (free-writing) compared to copying in their best handwriting. Practitioners need to emphasise the importance of generalisation and transfer when intervening with handwriting.

3. Speed and legibility seem to be separate issues in children with DCD, as pausing impacts on speed of production but was not found to be a predictor of legibility (on the HLS). It is important to examine both speed and legibility in children with DCD in order to get a holistic perspective on their handwriting ability.

4. Initial work suggests that, with further refinements the HLS may serve as a quick and useful tool for practitioners in order to describe in more detail the difficulties with legibility in children with DCD.

5. Literacy skills (vocabulary, spelling, reading) have not been shown to relate to handwriting performance. However, spelling performance within the context of a writing task will be examined in the following chapter.

Chapter 6

The Quality of Written Compositions in Children with DCD

6.1 Introduction

The quality of the written text is vital to academic performance, so much so that the 2012 Key Stage 2 (8-11 years) English tests awarded 37 out of 40 points for writing ability and reserved only 3 points for handwriting quality (legibility) (DfE, 2012). This suggests that the majority of the assessment relates to writing ability with much less emphasis placed on the skill of handwriting (see Table 6.1 for English Test Scoring Criteria.). However, there is substantial evidence to support the relationship between transcription skills (handwriting and spelling) and the quality of the written composition (Berninger et al, 1994; Berninger et al, 1996). If a child has difficulties with handwriting, it can impact on the quality of the written text, which in turn may influence academic performance. However, despite the emphasis on writing ability within the educational system, very few studies have examined the quality of writing in children with DCD and its relationship with handwriting difficulties. This is an important area to investigate, as it would shed light on the wider implications of their motor difficulties.

Based on the above premise, the purpose of this chapter was to examine the written ability of children with DCD in order to ascertain whether their difficulties with handwriting constrain compositional quality. To examine the quality of the written composition the Wechsler Objective Language Dimensions (WOLD; Rust, 1996) scoring criteria was implemented on the DASH (Barnett et al, 2007) free-writing compositions. The areas assessed on the WOLD included *ideas and development, organisation, vocabulary, sentence structure, grammar, and capitalisation and punctuation* all of which are assessed on the Key Stage 2 English tests (see Table 6.1) (DfE, 2012). In addition, performance in spelling and vocabulary were examined, as spelling is not only assessed in the English curriculum (DfE, 2012), but is also a transcription skill at the same level as handwriting, while vocabulary is an important higher level skill of writing. While the overall theoretical framework to support this chapter was presented in Chapter 2, a literature review specifically focusing on the previous studies on writing quality in DCD will follow.

Table 6.1

2012 Key Stage 2 English Test Scoring Criteria: 37/40 points available

	The Aspects of Writing Assessed
1	Write imaginative, interesting and thoughtful texts
2	Produce texts which are appropriate to task, reader and purpose
3	Organise and present whole texts effectively, sequencing and structuring information, ideas and events
4	Construct paragraphs and use cohesion within and between paragraphs
5	Vary sentences for clarity, purpose and effect
6	Write with technical accuracy of syntax and punctuation in phrases, clauses and sentences
7	Select appropriate and effective vocabulary
8	Use of correct spelling

6.2 Literature Review

6.2.1 Writing Quality in Children with DCD

In one of the only studies to examine writing quality in the English language in children with DCD, Dewey, Kaplan, Crawford and Wilson (2002) examined writing within the context of investigating difficulties in attention, learning and psychosocial adjustment. In their Canadian study a battery of assessments were implemented to quantify performance and compare the abilities of children with DCD to typically developing controls. To address writing ability, the subtests of the Woodcock–Johnson Psycho-educational Battery-Revised (WJ-R) (Woodcock & Johnson 1989 cited in Dewey et al, 2002) were used and included tasks involving dictation, writing samples (unspecified by authors), proofreading, writing fluency, punctuation and capitalization, spelling and word usage. One of the barriers to interpreting the results of Dewey et al (2002) was the lack of information provided with regards to the exact nature of the writing tasks/samples and in particular, how the variables were specifically measured and scored. In addition, the sample of 45 children with DCD used in Dewey et al (2002) were not screened for dyslexia but scored lower as a group on a measure of spelling. This poses issues in terms of applying the findings to the current study, as it is unclear whether the children in Dewey's group were those with diagnosed co-occurring disorders. For example, in this thesis, the DCD group scored below the TD group on the BAS-II measure of spelling, however as a group they were within the average range and none had a diagnosis of dyslexia. Therefore, while Dewey et al's (2002) findings indicated that the children with DCD performed below their TD peers on punctuation, capitalisation and word usage (vocabulary) this may have been attributed to formally recognised co-occurring disorders such as dyslexia or ADHD. As a result, in order to understand in greater detail the impact of motor difficulties on writing quality without the limitations of literacy or attentional deficits, it is important to control for confounding factors which may impact writing performance.

The only other study to examine writing in children with DCD was conducted in Taiwanese (Cheng, Chen, Tsai, Shen & Cherng, 2011). Since Cheng et al's (2011) study was based on a writing system outside of the Latin base, applying the findings to English is challenging given the differences in the linguistic makeup of sentences. Nevertheless, Cheng et al (2011) examined spelling, orthography, vocabulary, grammar and reading using the Chinese Reading Achievement Test (CRAT) (Chou & Yeh 2007 cited in Cheng et al, 2011) and the Basic Reading and Writing Comprehensive Test (BRWCT) (Hung et al 2003 cited in Cheng et al, 2011). The DCD group included 37 children with DCD aged between 7-8.5 years and they were compared to a group of 93 typically developing children. The results indicated that the DCD group scored below their TD peers on the writing composite score, character writing and dictation, while there was no difference in reading, phrase making or character pronunciation. However, beyond these findings, there was no information given about performance on specific areas of writing such as spelling, vocabulary and grammar.

Cheng et al's (2011) discussion centered on the differences between examining writing within a logographic writing system such as the Chinese script compared to the Latin base. They suggested that difficulties with reading and spelling manifested in different ways. For example, in the English language grapheme to phoneme mapping can pose difficulties in children who have difficulties with reading, whereas this concept does not exist within the Chinese script. Moreover, according to Cheng et al (2011) reading Chinese involves mapping the orthographic form of the character to the syllable. According to Cheng et al (2011) this difference may have contributed to the absence of reading difficulties found in their sample, as the Chinese writing system by nature does not demand the same processes as the Latin base.

6.2 Predictions based on the literature

Based on the previous chapters which have found difficulties in both handwriting speed and legibility in children with DCD, and given the importance of transcription skills in influencing writing quality, it was anticipated that the DCD group would demonstrate a poorer quality of writing than TD peers. In addition, Sumner et al (2013) demonstrated that difficulties with spelling acted as a constraint on handwriting production in children with dyslexia. Based on this premise, it was queried whether difficulties with handwriting as demonstrated in the DCD group would constrain spelling ability in children with DCD based on the limited capacity model of writing (Berninger & Amtrann, 2003). As a consequence, the cognitive resources consumed by handwriting may not have been appropriately applied to the retrieval of spelling. This would be evident through a larger number of spelling errors made during the free-writing task, despite spelling ability being within the average range when tested on the BAS-II (Elliott et al, 1997). Table 6.2 presents the specific research questions addressed in this chapter.

Table 6.2

Specific research questions addressed in this chapter

	Compared to Typically Developing Peers, Do children with DCD:
1	Demonstrate poorer quality of written compositions?
2	Have a higher percentage of misspelled words in their compositions?
	The following question were examined across both groups:
1	What is the relationship between the handwriting product / process and writing quality?
2	Which variables best predict quality of written compositions?

6.3 Method

6.3.1 Participants

The same cohort of 56 children examined in chapters 5 and 6 were used in this study (28 children with DCD, 28 TD peers). Information about participant selection can be found in Chapter 3.

6.3.2 Measures

6.3.2.1 Written Composition – the writing task and scoring criteria

The main focus of this research programme was to examine handwriting ability in children with DCD using tools commonly used in clinical settings. The DASH (Barnett et al, 2007) is one such assessment that measures handwriting within an education and clinical environment and is the most robust measure in the UK for examining handwriting production. Given the range of assessments implemented with the participants in this programme, it was deemed excessive and unnecessary to examine the quality of written composition using a separate writing task. Therefore the free-writing task in the DASH was used for the evaluation of writing quality in this study.

The DASH free-writing task involves writing about the topic of 'my life' for 10 minutes and the content does not have to be factual. 'My life' was selected as a topic to be broad enough that any child could relate to, with a range of sub-topics that could be addressed to encourage the child to write continuously throughout the 10-minute period. This topic was considered relevant to anyone, with a focus on concrete aspects of a child's life. Pilot work in the development of the DASH showed that children produced more words to this prompt compared to others, such as 'my favourite person' (Barnett et al, 2009). Before commencing the task, a spider diagram is presented to the child containing different facets/topics of life such as family, friends, holidays, school, pets, music, sport, dance and clubs etc. The child is reassured that the topics are only suggestions and that he/she can write about one topic or several, but should aim to write continuous text rather than produce a list (Barnett et al, 2007). They are given one minute to think of ideas to write about and make notes on the page if they wish. They were instructed to use their everyday handwriting, 'nothing special'.

The WOLD (Rust, 1996) criteria were used to evaluate the quality of the DASH free-writing scripts. The WOLD has standardised scores for its own writing task, which was not used here, but involves the composition of a letter describing an ideal place to live. The task is completed over a 15-minute period, with no spider diagram or prompts provided. The six WOLD criteria are then applied to the text and are comprised of *ideas and development*, *organisation*, *vocabulary*, *sentence structure*, *grammar*, and *capitalisation and punctuation* (Rust, 1996). Each one is scored on a scale from 1 to 4. Table 6.3 illustrates a score of 1 and 4 for each of the six criteria. The scores from each area are added together to form a total raw score. Usually when using the WOLD writing tasks the raw score is used to ascertain a standard score. However, in this case the groups were compared using the raw scores only, as it was not appropriate to obtain standard scores while using the non-standardised writing task from the DASH (free-writing). Reliability of the WOLD analytical scoring is reported as .89 when used in the standardised way (Rust, 1996).

Prior to analysing the quality of writing using the WOLD criteria, each 10-minute free-writing sample from the DASH was typed on a computer and misspelled words were corrected. This was done to control for legibility bias or bias due to misspelled words. Illegible words were removed from the text when typed. The principal investigator initially scored all of the typed compositions. Twenty scripts (10 DCD, 10 TD) were then randomly selected and scored by an external rater (a psychologist with particular expertise in children's writing). The rater had extensive experience in applying the WOLD criteria to the scripts of children with and without writing difficulties and was blind to the nature of the study and group allocation of the scripts.

Inter-Rater Reliability

An acceptable level of inter-rater reliability would be over .70 but preferably over .80 (Landis & Koch, 1977). Initially the inter-rater reliability (Cronbach's alpha) between the principal investigator and second expert rater for the analytic ratings was not acceptable for all criteria, particularly for ideas and development (.57), vocabulary (.45) and capitalisation and punctuation (.71). However, others were satisfactory; organisation, unity, and coherence (.75); sentence structure and variety (.74); grammar and usage (.78). Based on these findings, additional training was completed on ideas and development, vocabulary and capitalisation/punctuation through discussion with the expert rater and examination of scripts in relation to the scoring criteria. The 20 compositions were then re-scored by the principal investigator for ideas and development, vocabulary and capitalisation/punctuation. A second analysis of inter-rater reliability was conducted on the three items resulting in acceptable reliability (ideas and development=.84, vocabulary=.94 and capitalisation/punctuation=.93). The inter-rater reliability for the total raw score of the WOLD (the sum of the 6 items) was .89. Following this process, the remaining compositions (n=36) were scored by the principal investigator.

Table 6.3

The WOLD scoring criteria for a score of '1' and '4' - taken from the test manual, Rust (1996)

Item	Scoring Criteria	
	Score of 1	Score of 4
Ideas and Development	Weak ideas, minimally supported with little or no extension of details	Extensive development of ideas. Uniqueness, interest to audience, strong support of main idea
Organisation, unity and coherence	Lack of plan, incoherent	Organised, smooth flow using transitions and sequences. No wandering from the theme/plan
Vocabulary	Very simplistic, lacks variety. May be unclear or inappropriate	Precise, appropriate, accurate. Imaginative and appealing to the reader
Sentence structure and variety	Poor sentence structure. Many errors that inhibit fluency and clarity	Excellent control and formation of sentences. Variety of structure and length. Few errors in structure
Grammar and usage	Poor grammar & word usage, frequent errors	No errors or very few in proportion to amount of text
Capitalisation and punctuation	Frequent/serious errors that interfere with communication	No errors or very few in proportion to amount of text which do not interfere with clarity

6.3.2.2 Spelling Errors:

The spelling scores from the British Ability Scales (BAS-II; Elliott et al, 1997) were used to determine spelling ability in both groups. The BAS-II was described in detail in Chapter 3. In addition, spelling errors were recorded from the original DASH free-writing scripts before typing them up. Illegible words were not included as misspelled words. The total number of misspelled words was summed for each participant and then calculated as a percentage of the number of words produced on the DASH free-writing task.

6.3.3 Data Analysis

6.3.3.1 Sub Group Analysis

Initially, the DCD group was divided into two sub-groups in the same way as described in Chapter 4, one including those with at least average literacy skills (DCD, n=20) and the other including those with literacy difficulties (standard score below 85 on BAS-II reading, spelling or both) (DCD+, n=7). This was to ascertain whether there were differences between the DCD and DCD+ group on writing quality and spelling of words in the script.

6.3.3.2 Group Comparisons

Differences between the TD and DCD group were initially explored for each of the WOLD components illustrated in Table 6.3 as well as for the overall total raw scores. T-tests were used to investigate group differences for all components that were normally distributed. In cases where variables were not normally distributed, Mann-Whitney U tests were conducted. For the percentage of spelling errors, descriptive statistics were calculated and groups were compared using t-tests or a non-parametric equivalent (Mann Whitney U).

6.3.3.4 Correlation and Regression

In order to examine the relationship between writing quality and the handwriting product and process measures, bi-variate correlations were initially conducted with each group separately. Variables that were significantly related to writing quality in each group were then entered into a step-wise regression analysis to ascertain whether any of the handwriting measures had a predictive relationship with writing quality.

6.4 Results

6.4.1 Sub Group Analysis

The results of the sub-group analysis revealed no significant difference between the DCD and the DCD+ groups on any of the WOLD criteria including the individual items and the total raw score. However, there was a significant effect of group for the percentage of misspelled words ($U= 27.0$, $Z = -2.46$, $p=.012$), with the DCD+ group scoring below those in the DCD group. However, since there was no significant difference on the overall WOLD raw score, both groups were combined to form one DCD group.

6.4.2 Written Composition

There was a significant effect of group for the total WOLD raw score $t(54) = -3.53$, $p = .001$ and five out of the six analytical components of the WOLD including organisation (U= 246.0, Z = -2.57, p=.01), vocabulary (U= 262.0, Z = -2.25, p=.024), sentence structure (U= 260.5, Z = -2.37, p=.018), grammar (U= 190.0, Z = -3.62, p<.001) and, capitalisation and punctuation (U= 180.5, Z = -3.64, p<.001). There was no effect of group for ideas and development (U= 317.0, Z = -1.28, p=.200). The WOLD raw scores and analytical scores are presented in Table 6.4.

Table 6.4.

A comparison of the mean scores using the WOLD scoring criteria (SD) for the DCD and TD groups

WOLD Scores	DCD n=28	TD n=28
WOLD raw score	11.35 (3.49)	14.85 (3.90)*
Ideas & Development	2.14 (.89)	2.50 (1.07)
Organisation	1.50 (.63)	2.03 (.79)*
Vocabulary	2.32 (.90)	2.89 (.83)*
Sentence Structure	1.78 (.73)	2.25 (.64)*
Grammar	1.71 (.71)	2.42 (.57)*
Capitalisation & Punctuation	1.89 (.78)	2.75 (.84)*

Note. $*p \leq .050$

6.4.3 Spelling Errors

Since the data were not normally distributed a Mann-Whitney U test was used. This revealed that the DCD group had a higher percentage of misspelled words on the DASH free-writing task (*Mdn* = 6.25) compared to the TD group (*Mdn* = 1.99), U= 197.0, Z = -3.19, p=.001. This could not be totally accounted for by the inclusion of children with spelling difficulties, as a separate analysis between the TD group and the 20 children with DCD who had no spelling difficulties identified on the BAS revealed a similar pattern of performance (U= 173.0, Z = -2.44, p=.014).

6.4.4 Correlations:

6.4.4.1 Handwriting product and Selection Measures

Bi-variate Spearman correlations were conducted to ascertain whether a relationship existed between the WOLD raw scores and the measures of transcription skills taken from the BAS-II (spelling) and the DASH free-writing 10 minute task (number of words written, words per minute, number of spelling errors, HLS score). In addition age, reading, vocabulary and MABC-2 total and manual dexterity scores were also included in the analysis to determine their relationship with the WOLD raw scores. Table 6.5 shows the Spearman correlations for the WOLD raw scores.

For children with DCD, six of the dependent variables noted above significantly correlated with the WOLD raw score. The strongest correlation for this group was with the number of words produced per minute on the free-writing task, followed by the total score of the HLS and percentage of misspelled words. Age, total score of the MABC-2 and the manual dexterity score were also significant. The relationship between legibility and the MABC-2 with text quality was only found within the DCD group. Age, words per minute and spelling were significantly related to text quality in both groups.

Table 6.5

WOLD raw score correlations with transcription skills, reading, vocabulary and manual dexterity for the DCD and TD groups

	DCD n=28	TD n=28
Age	.49**	.69**
DASH		
Words per minute [b]	.58**	.63**
% of spelling errors	-.54**	-.62**
% of illegible words [b]	-.41	-.28
HLS total score	-.55**	-.14
BAS-II spelling [a]	.30	-.03
BAS-II reading [a]	.31	.04
BPVS [a]	.25	.07
MABC-2 Total [a]	.45*	-.04
MABC-2 Manual Dexterity [a]	.43*	-.09

Note. *$p \leq .050$ ** $p \leq .010$ [a] standard score [b] raw score

6.4.4.2 Handwriting process

The handwriting process measures from the handwriting speed chapter were analysed in order to ascertain whether a relationship exists between the process measures and the WOLD raw scores. The percentage of overall pausing on the DASH free-writing task (threshold 30 ms), the execution speed on the free-writing task (cm/s) and the percentage of time pausing over 10 seconds were included in the analysis. Table 6.6 presents correlations for the WOLD raw scores. For those variables that were not normally distributed Spearmans bi-variate correlations were conducted, otherwise Pearson's test was used.

Table 6.6

WOLD raw score correlations with handwriting process measures for the DCD and TD groups

	DCD n=28	TD n=28
Overall pausing (%)	-.40*	-.46*
Pausing over 10 seconds (%)	-.18	-.55**
Pausing within words (%)	-.43*	.09
Execution speed free-writing (cm/s)	.24	.33

Note. **p*≤ .050, ** *p*≤ .010, %=percentage

The results indicated a significantly negative relationship between the overall percentage of pausing and the WOLD raw scores for both groups. A significantly negative relationship was found for percentage of pausing that occurred within words for the DCD group only. The percentage of pausing above 10 seconds was related to text quality for the TD group only.

6.4.5 Regression Analysis

The final stage of analysis uses the results from the correlations in Table 6.4 and 6.5 to determine which of the measures were predictive of the compositional quality of the writing produced by each of the groups. Separate regressions were conducted for each group as a result of the different patterns of results found for the correlations.

For children with DCD, the step-wise multiple regressions were conducted using the number of words per minute on the free-writing task, percentage of misspelled words, HLS score, percentage of within word pausing and MABC-2 total standard score. The MABC-2 manual dexterity score was not included as it correlated too highly with the total test score (r=.93) indicating a problem with multicollinearity. The results of the regression indicated that two predictors explained 55% of the variance (R^2=.58, F(2,25)=17.38, p<.001). It was found that the number of words per minute significantly predicted writing quality (β = .497, p=.001), as did the percentage of misspelled words (β = -.494, p=.001). The other variables did not add to the amount of variance explained by these two measures. Coefficients can be found in the table below.

Table 6.7

Regression analysis: predictors of performance on the WOLD for the DCD group

	Standardised coefficients		Unstandardised coefficients	*p*
	Beta	Standard error		
Number of words per minute[a]	.49	.076	.286	.001
% Spelling errors [a]	-.49	.074	-.279	.001

Note. $^{*}p \leq .050$, [a] DASH free-writing task

For the TD group a step-wise multiple regression was conducted using the number of words per minute on the free-writing task, percentage of pausing above 10 seconds, and percentage of misspelled words. The results of the regression indicated that only one variable explained the most variance in TD group. In the model, the number of words per minute explained 38% of the variance (R^2=.40, $F(1,26)$=17.50, p<.001). Coefficients can be found in the table below.

Table 6.8

Regression analysis: predictors of performance on the WOLD for the TD group

	Standardised coefficients		Unstandardised coefficients	*p*
	Beta	Standard error		
Number of words per minute[a]	.339	.091	.588	.001

Note. $^{*}p \leq .050$, [a] DASH free-writing task

6.5 Discussion

Very few studies have investigated handwriting in children with DCD, but even fewer have examined their written compositional skills. Those that have investigated writing ability have done so solely to investigate whether DCD was related to co-occurring deficits such as difficulties in attention, reading, learning and psychosocial adjustment (Dewey et al, 2002, Cheng et al., 2011). These studies used more general assessment tools, usually a battery of educational assessments rather than a specific, comprehensive assessment of writing. The purpose of this chapter was to examine the written ability of children with DCD in an exploratory manner by applying the WOLD (Rust, 1996) scoring criteria to the DASH (Barnett et al, 2007) free-writing compositions. The results indicated that the DCD group performed significantly below their TD peers on all analytical items with the exception of ideas and development. In addition, their overall total score for writing quality was below their TD peers and they had a higher percentage of misspelled words, despite performing within the average range as a group in the BAS-II spelling test.

Examining writing quality using the WOLD scoring criteria, which are closely aligned to the English National Curriculum grading system (DfE, 2012) for English, was a stepping-stone in terms of providing insight into difficulties with writing in children with DCD. However, initially there were some issues with applying the WOLD criteria to the DASH free-writing task, as the first analysis of inter-rater reliability proved to be unacceptable for some of the criteria. This raised issues with regards to the task and whether the topic of ‘my-life’ was suitable for the application of the WOLD criteria. For example, there may have been temptation for children to follow a list format when writing about their favourite hobbies. They may have been tempted to merely state the activities they enjoyed doing without elaborating on them. This type of writing would impact on ‘ideas and development’, but given the lack of group differences within this criterion it would suggest that both groups were able to expand on the writing topics appropriately allowing for an analysis of the other WOLD criteria i.e. grammar and punctuation.

In addition to the task, the professional background and experience of the rater may also be an issue. The principal investigator, whose background is in occupational therapy, initially had some difficulty in applying the scoring criteria reliably. An expert rater, with a background in psychology and extensive experience in examining children’s written compositions was employed to provide some training and support in order to improve the reliability of scoring. This resulted in an increase in inter-rater reliability to an acceptable level for all six criteria and the total score. This suggested that that the experience and training of raters would need to be carefully considered in future studies using a similar method.

The WOLD criterion relating to the generation and development of ideas was the only aspect in which ratings for the two groups were similar. In all other respects the scripts from the DCD group were rated more poorly. This was an interesting finding, as it would suggest that something other than the higher-level process of idea generation was impacting on the overall writing quality of the text. However, it is also important to consider the nature of the task here, as the DASH free-writing task involves the provision of time to think of ideas prior to commencing the task. In contrast, the formal WOLD task arguably promotes more opportunity to be creative with ideas as it involves writing about an ideal place to live. In addition, the DASH task provides a spider diagram containing ideas to write about, which is placed beside the child for the duration of the task. This is not a feature of the formal WOLD writing task as children are not given time before the task to think of ideas. However, despite this assistance with generating ideas on the DASH, the participants still had to develop the ideas and think of specific content to write about within the context of the writing topic. In doing so, there were clear difficulties in areas such as sentence structure and grammar, which suggests that the DCD group had difficulties expressing their ideas within appropriately composed sentences. In addition, Chapter 4 demonstrated that the DCD group paused for over 10 seconds at times. Previous research on longer pauses in the typical adult population using eye-tracking technology suggested that long pauses were likely due to planning (Alamargot et al, 2010). However, despite the excessive pausing for long periods, this did not seem to increase the quality of writing in the DCD group.

One reason for the poor written compositions within the DCD group could stem from the findings in Chapters 4 and 5 where the DCD group demonstrated difficulties with handwriting speed (words per minute) and had a higher percentage of illegible words. Given their difficulties with handwriting, it would be appropriate to suggest that this influenced their overall writing performance based on the ‘simple view of writing’ (Berninger & Amtrann, 2003) model discussed in Chapter 2. In fact, on closer inspection through regression analyses, handwriting production measured through words per minute was found to explain a significantly large proportion of the variance in compositional quality, as did the percentage of misspelled words produced in their text. As shown in models of writing, both spelling and handwriting are at the level of transcription, which suggests that writing quality is significantly affected by difficulties at the transcription level for children with DCD. Based on the ‘simple view of writing’ model (Berninger & Amtrann, 2003) and the results of this study, it may be plausible to suggest that the cognitive resources available for writing are consumed at the level of transcription in children with DCD and therefore there is a lack of resources available to concentrate on compositional quality.

The finding of misspelled words as a significant predictor of writing quality was also an interesting finding, as the DCD group performed within the average range when formally tested on spelling ability, yet made a higher percentage of spelling errors during the writing task. While the spelling task involved writing single words under no time constraints, the free-writing task involved integrating and managing all the processes of writing together. This may have placed excessive demand on working memory resources, therefore impacting on the process of retrieving spellings and the overall quality of writing. However, an important aspect to consider here is the relationship between spelling and handwriting, as both skills are at the level of transcription, yet surprisingly few studies have examined the nature of the relationship between these two aspects of transcription. However, this has been investigated in children with dyslexia (Sumner et al., 2013). It was found that handwriting skill was constrained by spelling ability, evident through excessive pausing within misspelled words and the emergence of spelling-ability as a predictor of handwriting speed (Sumner et al, 2013). These findings suggest a more complex link between spelling and handwriting than previously thought and the possibility that difficulties with handwriting impact on spelling performance, particularly in a task as demanding as free-writing. This again may be attributed to reduced working memory resources, where the demands of handwriting are so great in children with DCD, that spelling performance along with the higher level processes of writing are negatively impacted. This is supported by findings from the current study, where spelling errors in the text, rather than word spelling ability were found to predict compositional quality. In addition, the within word pausing demonstrated in Chapter 4 would suggest a breakdown in the online planning of handwriting, which may be related to limited availability of working memory resources. It seems that in children with DCD the cognitive load of handwriting not only jeopardises the overall compositional quality, but spelling performance as well. However, this is an area that warrants further investigation, as the type of spelling errors made by the children with DCD were not investigated here. This would provide information surrounding the nature of the spelling errors such that phonological errors may suggest a more general spelling/language difficulty, compared to errors in orthography. Poor performance on both spelling and handwriting have been repeatedly shown to impact on the higher level processes in numerous studies in the typically developing population (Berninger et al, 1994; Berninger et al, 1996). However, the precise link between handwriting and spelling remains an area for future examination, as this current study together with the research by Sumner et al (2013) suggests a complex relationship, where difficulties with one may impact the other.

One of the strengths of using the WOLD scoring criteria in this study was its close alignment with the national curriculum for English. This was interesting from the perspective of DCD, as the European guidelines mention academic achievement and school productivity as areas affected by the disorder (EACD, 2011). Although academic performance is a complex factor to measure and was not the focus of the current study, it could be proposed that there is a link between handwriting dysfunction and academic achievement, at least within the English writing curriculum. One method that could have strengthened this study would have been to ascertain school grades for the Standard Assessment Tests (SATs) for English in the participants with DCD (outlined in Table 6.1). Since the criteria for the SATs align with the WOLD, it would have been interesting to see whether the children with DCD were below their TD peers on a formal measure of academic achievement. However, this would not be a straight forward process, as there are many factors that could be at play when considering academic performance. Indeed a study by Lyth (2004) investigated handwriting speed and its role in predicting outcomes in examinations in high school students. The study discussed the complexity of measuring handwriting speed as a predictor of academic achievement as performance could be attributed to overall ability of students rather than the execution of handwriting. More needs to be done to unpick this area in greater detail in children with DCD.

In summary, the aim of this study was to examine the compositional quality of children with DCD in an exploratory manner. Given the results and the difficulties experienced by the DCD group, it appears that this aspect of writing ability warrants a more detailed investigation in the future. This study has shown that difficulties with handwriting are not just issues of aesthetics or speed, but have real implications for the quality of text produced by children. The quality of the written composition is what is judged in the educational system, yet handwriting serves as the crucial medium through which it is produced. The following chapter will explore handwriting performance on an individual basis and will report the impact of handwriting dysfunction on the overall compositional quality in individual children, as it is not known whether all children with DCD have difficulties with handwriting.

6.6 Practical implications from this chapter

1. It is important to develop skills in handwriting speed such that children are able to write an age appropriate number of words per minute. This has been shown to be the biggest predictor of writing quality in this study, therefore an important area to attend to in children with DCD.

2. Therapists need to think beyond handwriting skill to consider the broader aspects of writing and consider assessing the compositional skill of children rather than focusing on the perceptual-motor aspects of handwriting only.

3. Children with DCD may need support with writing skills as well as handwriting in order to develop strategies to support the development of their compositional writing.

4. Handwriting intervention should consider the ‘load’ associated with handwriting tasks and that ultimately the goal is for children to be able to write high quality texts independently. Therefore the

emphasis should be on working towards transfer and generalisation of newly acquired handwriting skills into free-writing tasks in order to improve performance on writing.

Chapter 7

Do Children with DCD have Difficulties with Handwriting? An Examination of Individual Performance Profiles

7.0 Introduction

Handwriting is reported as one of the most significantly impacted activities in children with DCD (Miller et al., 2001). So much so that handwriting difficulties have been included in the recent DSM-5 (APA, 2013) diagnostic criteria. However, it is unclear whether all children with DCD have difficulties with handwriting or only a proportion of them. It is also unclear whether children who have difficulties in one area of handwriting such as legibility also have difficulties in other areas such as speed. The perspective of key individuals such as the child and the teacher is also important from a clinical perspective. For example, if a child scores poorly on tests of legibility and speed, but neither the child nor the teacher thinks handwriting is an issue, then what are the clinical implications of this? To what extent is there agreement between the results from clinical tests and the views of the child and teacher?

The aim of this chapter is to characterise the handwriting performance of children with DCD by profiling the performance of each child in the DCD group across the different handwriting measures used in this investigation. This includes their scores on the handwriting product (speed and legibility) plus the views both of the teacher and the child. In addition, their individual performance on the compositional quality of writing is examined in order to gain an insight into the possible impact of handwriting difficulties on academic performance. Firstly, a literature review on approaches to assessment in children with DCD is presented.

7.1 Literature Review

7.1.1 Defining Handwriting Difficulties in DCD:

Despite few empirical studies specifically focusing on the skill of handwriting in children with DCD, a substantial amount of evidence has been gathered through intervention studies (Miller, Polatajko, Missiuna, Mandich & McNab, 2001), case studies (Martini & Polatajko, 1998) and qualitative studies (Mandich et al, 2003) to support the inclusion of handwriting within the formal diagnostic criteria for DCD. These studies have documented the clinical presentation of children with DCD and in doing so have raised important issues in relation to the range of ways in which handwriting difficulties can manifest. Clinical case studies have shown that while some children with DCD may present with difficulties forming letters (Polatajko & Mandich, 2004) others may present with slow and laboured handwriting (Chambers et al., 2006). However, little is known about the overall profile of handwriting difficulties in children with DCD and whether all children with DCD have some level of handwriting impairment. In the literature on DCD there is a tendency to report results at a group level. This may be to do with the fact that DCD is a relatively new field of study and little is known about children at a group level on many different aspects of performance. However, in order to inform assessment and intervention within a clinical context, it is important to understand performance at an individual level, as service provision nowadays is centred on the person.

Assessment of children with DCD generally involves the systematic gathering and integration of information about the child to form a better understanding of their strengths and difficulties (Barnett, 2008; Wilson, 2005). For the assessment of handwriting, in order to gain a holistic perspective of the child's difficulties, this could involve using a variety of different assessment strategies and techniques (Barnett, 2008) in order to broaden our view of the child (Wilson, 2005). The following section will discuss issues surrounding quantitative assessments and the usefulness of seeking perspectives from key individuals.

7.1.2 Quantitative Assessments as a Source of Information

In order to evaluate a child's handwriting in a thorough manner, one method could be to investigate whether children with DCD can produce text at a speed appropriate for their age and if so, whether they have difficulties with legibility. Taking a holistic view of handwriting performance in children with DCD would help determine specific areas of difficulties. In cases where only one of these areas are assessed it could be argued that children are at risk of losing an opportunity to access services. Taking a holistic view of the task is particularly important in services where cut off points are used to inform models of service delivery. Indeed Missiuna et al (2006) discussed the issue of service delivery models where children qualify for service provision based on the 'severity' of impairment. Often specific 'cut offs' on one test or poor performance on a range of tests can determine whether a child receives intervention or not (Missiuna et al, 2006). However, it is not known whether both legibility and speed are an issue in all children with DCD or whether they present with a varied profile. In addition, although the use of specific 'cut-offs' as a means of qualifying for treatment is common, it is also important to consider limitations of such an approach. For example, Missiuna et al (2006) raised an important issue in relation to this practice and stressed the difference between achieving the *performance* criteria on a test, versus the *quality of* the *performance*. According to Missiuna et al (2006) children with DCD may achieve within the average range on an assessment, but in doing so may demonstrate poor quality of movement, resulting in impaired functional performance. An example of this could exist in handwriting, where a child with DCD scores in the average range on the Detailed Assessment of Speed of Handwriting (DASH) (Barnett et al, 2007) for speed, but in doing so they produce poor quality movements. This profile of performance would likely impact on the legibility of the text which would result in impaired functional performance, evident through a lack of readability and a low score on the Handwriting Legibility Scale (HLS) (Barnett et al, 2013). However, despite handwriting being a frequently impacted activity in DCD there has been limited investigation into the profile of different aspects of handwriting performance in this population. The proportion of children with both speed and legibility difficulties remains unknown. This raises issues with regards to assessment and what quantitative assessments should be used. If only one test is used to examine handwriting in a service, then important information could be missed. It would therefore seem practical to investigate the performance of children with DCD across a range of quantitative handwriting assessments and ascertain whether more than one test is needed to gain a better description of their difficulties.

7.1.3 Key Individuals as a Source of Information

The Child

Alternative, qualitative assessments are frequently used among occupational therapists in particular, where interviews involving the child are conducted pre and post intervention for use as outcome measures (Missiuna et al., 2006). Recently, this type of assessment has been formally recommended in the European guidelines for the assessment of children with DCD, where the views of the child are encouraged to be sought where possible (EACD, 2011). This is in line with the philosophy of many health professions such as occupational therapy, where a client-centered ethos underpins their clinical practice (Law, 1998). Indeed the Occupational Therapy Code of Ethics and Professional Conduct (COT, 2010) for UK clinicians reminds therapists that services should be client centered and needs led. Client centered practice recognises that the person/child brings their own perspective to the therapeutic relationship and has a unique insight into how their disability affects their everyday life (Parker, 2008). Therefore in the context of assessing whether a child has difficulty with handwriting, it is important from a therapist's perspective to ascertain whether the child identifies handwriting as an issue for them. When an activity is meaningful to a person, they are more likely to identify the activity as a therapy goal, which will aid the therapist in facilitating interventions to improve it (Polatajko & Mandich, 2004; Parker, 2008). This can also give an indication as to how motivated the child is to engage in interventions related to handwriting.

In terms of whether children with DCD identify handwriting as an issue for them, there is evidence to suggest that this is the case. Previous studies have examined therapy goals in children with DCD and handwriting has emerged in many of them (Dunford et al, 2005, Dunford, 2011, Mandich et al, 2003). The largest study was conducted by Dunford et al (2005), where 35 children aged 5 to 10 years with DCD were interviewed using the Perceived Efficacy Goal Setting System (PEGS) (Missiuna, Pollock & Law, 2004) to ascertain the child's perception of their ability to perform everyday tasks. Ten out of the 35 children selected handwriting as a goal for them and an additional 5 selected cursive writing as an area for improvement. Dunford et al (2005) also sought the opinion of the parents and teachers and found that in 30 percent of the cases the teacher, child and parent agreed that handwriting was an issue, meaning in 70% of cases they did not. In 2011, Dunford combined parental goals with those of the children, by interviewing eight children with DCD using the PEGS (Missiuna et al, 2004), while their parents were interviewed using the Canadian Occupational Performance Measure (COPM, Law et al., 2005). Dunford's study identified five children who had the goal of writing neater and three who wanted to write faster and form their letters correctly. However it was unclear whether all of the children in this study stated handwriting as an area of difficulty for them or whether the parents initiated it as a goal. It was also unclear the degree to which the parents and children agreed on the same goals. Mandich et al (2003) used in-depth interviews with the parents of children with DCD (aged 7-12 years) and found that 8 out of the 12 children had handwriting as a therapy goal. However, according to Polatajko & Mandich (2004) parents often want their children to choose academic goals such as handwriting, while children prefer activities that help them fit in with peers i.e. being the goalkeeper in football. It is therefore possible that since it was not explicitly stated that the children chose the goals in Dunford (2011) and Mandich et al (2003), the therapy goals may have been driven by parental involvement rather than by the children themselves.

In a study more specific to handwriting, Banks et al (2008) examined the efficacy of the Cognitive Orientation to (daily) Occupational Performance intervention (Polatajko & Mandich, 2004) on four children with DCD. Although it was not stated which evaluative tool was used to generate the goals, all four boys (aged 6-11 years) wished to address handwriting, particularly letter formation, neatness and speed. From the above studies there is evidence to suggest that children with DCD frequently include handwriting as one of their therapy goals. However, some of these studies used small sample sizes of 12 (Mandich et al, 2003), 8 (Dunford, 2011) and 4 (Banks et al, 2008) and did not all include detailed descriptions of the goals chosen by the children themselves. Moreover, it was not clear in some of the studies who chose the goal of handwriting or whether it was chosen by both the parent and the child. In addition performance on quantitative handwriting assessments were not reported, so it was unclear as to how severe the handwriting difficulties were. In order to gain a better understanding of handwriting performance in this population, it would be beneficial to ascertain whether the children themselves think handwriting is an issue for them and if so, whether difficulties are also identified using quantitative clinical tools.

The Teacher:

Another method of using qualitative measures to investigate handwriting performance in children with DCD would be to seek the opinion of the child's teacher. In the European guidelines for DCD (EACD, 2011) it was recommended that the teachers' views be sought in order to ascertain whether the child's motor difficulties interfered with academic performance. According to the EACD (2011), teachers are in an ideal position to comment on school-based behaviours such as attentional issues, learning disorders, environmental factors, participation and academic achievement. Teachers hold a source of valuable information that can help in contextualising information about the child (EACD, 2011). In relation to the assessment of handwriting, a similar strategy may be useful, as the teacher would be familiar with the child's handwriting and be well placed to detect differences between a child and his/her classroom peers (Rosenblum, 2008; Dunford et al, 2005).

Taking the teacher's opinion on a child's performance is not a straight forward process. Indeed, there are a number of issues to consider when involving educators in the information gathering process or in the process of identifying handwriting difficulties. One issue surrounds the level of agreement between clinical practitioners and that of educators in terms of what constitutes poor handwriting. For example, in several studies the level of agreement between occupational therapists and teachers on handwriting evaluation was found to be low (Daniel & Froude, 1998; Sudsawad et al, 2001). Sudsawad et al (2001) found almost no relationship between the teachers' evaluations and the Evaluation Tool of Children's Handwriting (ETCH) (Amundson, 1995) test scores on legibility. In some cases the teachers rated students as much-below the average range on handwriting legibility, but when assessed by occupational therapists using the ETCH (Amundson, 1995), the same children were found to have moderate to high scores on legibility (Sudsawad et al., 2001). However both of these observations were based on ratings of legibility, which in itself can vary widely depending on the criteria used to define it (Graham, 1986).

According to Rosenblum (2008), teachers need to have a structured format that can easily transmit information to occupational therapists. This can either be done through tools that give clear criteria for scoring, or through questionnaires that address more than one factor related to handwriting (Rosenblum, 2008). Indeed providing clear criteria to teachers for assessing aspects of handwriting is particularly important in the UK context, as newly trained teachers receive very little formal training on the topic of handwriting (Barnett et al., 2006). In Barnett et al's (2006) study, only 33 percent of teachers reported receiving some training on handwriting during their initial teacher training. In addition, over half of the teachers felt they had not received sufficient training in their work environment (Barnett et al., 2006). This undoubtedly adds to barriers in achieving accurate identification of handwriting difficulties in children, as teachers have very little training in how to teach handwriting and what to look for when identifying difficulties. In addition there is a lack of quick, clear, screening tools for teachers to use in the UK and as a result, valuable information from a teacher's perspective is often lost and left unrecorded (Rosenblum, 2008).

In the context of DCD it is important to ascertain the teacher's perspective on the child's handwriting for two reasons. First of all it would provide a holistic representation of the child's handwriting profile and secondly; it would evaluate whether teachers can accurately identify handwriting difficulties in children with DCD. The level of agreement between the teacher's evaluation, the child's evaluation and the clinician's evaluation could then be determined. This would be important for planning an effective intervention, especially if the teacher has a role to play in implementing part of the intervention during school hours (Sugden & Chambers, 2003).

The purpose of the present study was to use a new method to further the understanding of handwriting difficulties in children with DCD. The children's views of handwriting along with those of the teachers were sought and compared to clinical descriptive tests of handwriting speed and legibility. In addition, the quality of writing was assessed in order to build a knowledge-base around the possible impact of handwriting difficulties on written composition. These questions are imperative to providing effective intervention, as occupational therapists are required to adopt a client centered and holistic approach in their practice and work collaboratively with key individuals (COT, 2010).

7.2. Method

7.2.1 Participants

The same 56 participants as described in Chapter 3 were included in this study. Some of the research questions were examined using the full DCD (n=28) and TD group (n=28). However, to examine individual performance, the DCD group and TD group were each divided into two age groups 8-11.5 years (primary school children) and 11.6-14 years (secondary school children). This was due to the wide age range (8-14 years) of participants in this research programme. Table 7.1 provides performance profiles for the younger DCD and the TD groups on the selection measures, while Table 7.2 provides performance profiles for the older DCD and the TD groups.

Table 7.1.

Mean (SD) Age and Performance scores of the younger DCD and TD groups on selection measures

Selection Measures	DCD n=14	TD n=14	p
Age in years	8.75 (.89)	9.12 (1.04)	.320
M-ABC-2 Test percentile	2.68 (3.08)	50.4 (24.4)	<.001*
BPVS-2 Standard Score	104.1 (10.2)	109 (12.3)	.194
BAS-II Spelling Standard Score	98.3 (11.9)	113 (14.5)	.005*
BAS-II Reading Standard Score	109.6 (10.5)	124 (14.4)	.005*

*$p \leq .05$. MABC-2: Movement Assessment Battery for Children 2nd Edition Test . BPVS: British Picture Vocabulary Scale, BAS: British Ability Scale

Table 7.2.

Mean (SD) Age and Performance scores of the older DCD and TD groups on selection measures

Selection Measures	DCD n=14	TD n=14	p
Age in years	12.48 (1.44)	12.75 (1.05)	.571
M-ABC-2 Test percentile	4.21 (2.74)	41.3 (27.0)	<.001*
BPVS-2 Standard Score	113.7 (16.7)	111.3 (13.6)	.697
BAS-II Spelling Standard Score	93.4 (15.5)	109.2 (10.1)	.004*
BAS-II Reading Standard Score	109.4 (17.0)	120.9 (10.8)	.045*

*$p \leq .05$. MABC: Movement Assessment Battery for Children test component. BPVS: British Picture Vocabulary Scale, BAS: British Ability Scale

7.2.2 Measures

7.2.2.1 The Child's Perspective on Handwriting Performance

The Canadian Occupational Performance Measure (COPM: Law et al., 1994)

The COPM (Law et al., 1994) is a semi-structured interview aimed at identifying difficulties in everyday activities. It is a criterion measure comprised of three sections: self-care (activities of daily living), productivity (education and work) and leisure (play, leisure etc). It is commonly used in UK occupational therapy practice as a client-centered tool, which can form the basis for assessment and intervention (Law et al., 1994). It was used in this study to ascertain whether children with DCD identified handwriting as an area of difficulty for them. Both groups were interviewed using the productivity component of the COPM, as the focus of this study was their performance at school. The child was asked about areas that they perceived themselves as having difficulty with. In this study it was recorded whether or not the children stated handwriting difficulties during the COPM interview.

When implementing the COPM in this study the children were first asked to list the curriculum subjects they study at school. This was asked in order to engage the child in conversation and to build rapport. After the subjects were listed, the child was then asked to list their favourite lessons and explain why they liked them. This was asked in order to promote self-esteem and to continue building a positive rapport with the child. Following a conversation about their favourite lessons, the child was asked whether there were any they did not like, or whether they found anything particularly "tricky" at school. If it appeared as though the child was not considering aspects of a particular subject such as, the components of literacy (reading, spelling, handwriting), the child was prompted to think about these areas. For example, "lets think about what you need to do in your literacy class, what about reading, spelling and handwriting, what are they like for you?" The specific word of "handwriting" was not mentioned in isolation, as it was important that the child considered handwriting for themselves and not as a result of a specific prompt. If the child stated difficulties with "writing" they were asked whether they were referring to thinking of ideas to write about or handwriting in particular.

The data for the COPM was categorical in terms of whether or not the child mentioned handwriting as an issue for them (yes or no). Those who did mention handwriting as an issue were then asked to rate how important handwriting was to them, how good they thought they were at it and whether they were satisfied with their handwriting ability. The child rated handwriting importance, performance and satisfaction on a scale of 1-10 (1=not very good/important at all, 5=ok, 10=very good/important). A visual representation of the 10 point scale was used with the participants (see Appendix 8).

7.2.2.2 The Teacher's Perspective on handwriting performance

The Handwriting Proficiency Screening Questionnaire (HPSQ: Rosenblum, 2008)

The HPSQ (Rosenblum, 2008) is a screening questionnaire that was developed in Israel to address the lack of screening tools available to identify non-proficient handwriting in schools. Educators and health care clinicians use the HPSQ to identify handwriting difficulties among children aged 7 to 14 years. It consists of ten items rated on a 5-point scale (0-4) with 0 indicating 'never' and 4 indicating 'always' (Rosenblum, 2008). Lower scores indicate good performance, while higher scores indicate good performance, with 40 as the maximum score. The items are listed in Table 7.3. The HPSQ is currently being investigated for use in the UK (Barnett, Cumines & Rosenblum, in prep), however due to the lack of time/resources to validate the HPSQ within the UK for use in this study, the original, Israeli version was used. Since there is a distinct lack of similar tools available in the UK, the HPSQ was selected to ascertain whether the teachers of the children with DCD thought the children had difficulties with handwriting. The internal reliability of the Israeli version of the HPSQ is α=.90.

For the children in the DCD group a copy of the HPSQ was given to the participants' parents who then forwarded the HPSQ to their child's school. The HPSQ was filled out by the class teacher, or in the case of secondary school it was completed by either the English teacher or History teacher, as these subjects tend to require more handwriting than others. The school returned the HPSQ on completion and in cases where it was not returned the parent was contacted and asked to encourage the teacher to respond. The parent was contacted due to the Data Protection Act (1998), as most children in the DCD group were recruited through the community it was not appropriate to contact the school directly. There was an 85.7% response rate for the DCD group.

For the TD children a copy of the HPSQ was given to the class teacher during the recruitment process in local schools. The teacher returned the form directly to the researcher. If a questionnaire was not returned, the teacher was contacted twice with a reminder to return the form. There was a 60.7% response rate for the TD group.

The total score of the HPSQ (Rosenblum, 2008) was used in the current study for comparisons between the DCD and TD groups and to profile the performance of individual children with DCD. The individual items of the HPSQ were examined separately to investigate the ratings given by teachers to children with DCD on individual components of handwriting.

Table 7.3.

The Items evaluated in the HPSQ (Rosenblum, 2008)

Item	Item Description
1	Is the child’s writing unreadable?
2	Is the child unsuccessful in reading his/her own handwriting?
3	Does the child not have enough time to copy tasks from the blackboard?
4	Does the child often erase while writing?
5	Does the child often feel he/she does not want to write?
6	Does the child not do his/her homework?
7	Does the child complain about pain while writing?
8	Does the child fatigue while writing?
9	Does the child need to look at the page/blackboard often when copying?
10	Is the child unsatisfied with his/her handwriting?

Note. The items are scored on a scale of 0-4, 0=Never, 1=Rarely, 2=Sometimes, 3=Often, 4=Always

7.2.2.3 The Handwriting Product:

Handwriting Speed

The Detailed Assessment of Speed of Handwriting-Free Writing Task (DASH: Barnett et al, 2007)

This test was used to examine the speed of performance during the DASH (Barnett et al, 2007) free-writing task. The DASH is commonly used among practitioners in the UK and has been described in detail in chapter four on handwriting speed. The free-writing task requires the child to write about the topic of ‘my life’ for 10 minutes 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 one minute to plan their writing and are asked to write continuously once the task starts

(Barnett et al, 2007). The total number of legible words produced on the free-writing task was used to describe handwriting speed.

Handwriting Legibility

The Handwriting Legibility Scale (HLS: Barnett et al, 2013)

This test was used to examine the legibility of handwriting during the DASH free-writing task. It was developed due to a lack of alternative tools to examine legibility in the UK. The development of this test was described in detail in chapter five on legibility. The HLS requires the scorer to rate a sample of handwriting using five criteria 1) global legibility 2) effort to read 3) layout on the page 4) letter formation 5) alterations. Each criterion is given a rating between 1 and 5 with 1 representing good performance while 5 represents poor performance. The five scores are summed to give a total test score. The total score for the HLS was used in the current study to describe handwriting legibility.

7.2.2.4 The Quality of the Written Composition

The Wechsler Objective Language Dimensions (WOLD; Rust, 1996)

To examine whether the children with handwriting difficulties also had poor compositional quality compared to their TD peers, the six analytical scoring criteria of the WOLD (Rust, 1996) were used to examine the quality of the written text on the DASH free-writing task. The WOLD has been described in detail in chapter six on writing quality. The six analytical criteria include *ideas and development, organisation, vocabulary, sentence structure, grammar* and *capitalisation and punctuation* (Rust, 1996). Each criterion is rated on a scale of 1 to 4 with 1 indicating poor performance, while 4 indicates good performance (Rust, 1996). The six scores are summed to give a total raw score, which was used in the present study.

7.3 Data Analysis

7.3.1 Defining Poor Performance

7.3.1.1 The Child

For the children's perspective using the COPM (Law et al., 1994) the children either mentioned difficulties with handwriting or they did not. Therefore categorical scores were generated for either 'handwriting is an issue'= 1 or 'handwriting is not an issue'= 0. Descriptive statistics were generated and group comparisons analysed. For the ratings of importance, performance and satisfaction on the COPM (Law et al, 1994) for handwriting, the mean rating and standard deviation was calculated for the children with DCD only, who rated handwriting as an issue for them.

7.3.1.2 The Teacher

For the teachers' ratings using the HPSQ (Rosenblum, 2008) group differences on the total score of the HPSQ were calculated using a t-test. The percentage of children in the DCD group who performed in each performance category (1-4) on each of the 10 HPSQ items was then calculated. Finally, to profile the individual performances of the children in the DCD groups (younger and older) the HPSQ total score was included in the performance profiles, as explained in the following section.

7.3.1.3 Performance Profiles

For the COPM, it was noted whether each child mentioned handwriting as an issue for them. This was done for both DCD age groups. The categorical scores were denoted as follows: the letter 'Y' indicated that 'yes, handwriting is an issue' while the letter 'N' indicated that 'handwriting is not an issue'.

In order to ascertain whether the children in the two DCD groups were performing below typically developing peers on performance measures, the mean and standard deviation from the typically developing groups (younger and older) were used to denote typical or average performance. Through using the TD mean and standard deviation on each measure, it was possible to calculate whether the children in the DCD groups were close to the TD group mean, or whether they were below it. The number of standard deviations below the TD mean was also calculated, in order to demonstrate the severity of difficulties in the DCD group.

The number of standard deviations (SDs) below the mean of the TD group was calculated for the DCD group on the following descriptive measures:

1. Total score of the HPSQ (Rosenblum, 2008)
2. Speed: Number of legible words written on the free writing task on the DASH (Barnett et al., 2007).
3. Legibility: Total score of the HLS (Barnett et al., 2013)
4. Compositional quality: Total raw score of the WOLD (Rust, 1996).

The term ‘standard deviation’ was used instead of ‘z-scores’ in line with language commonly used within an occupational therapy clinical setting.

7.3.2 Reporting Poor Performance

Initially the numbers and percentages of participants who were poor on each measure (at least below 1 SD of the TD mean) were calculated. This was then extended across the measures to ascertain the number and percentage of participants who were poor on two, three and four measures.

7.3.3 Correlations

Correlations between each measure were conducted to ascertain whether there were significant relationships between tests/measures. In addition, correlational analyses were conducted to investigate the relationship between the formal measures of speed and legibility with specific items from the teachers’ perceptions on the HPSQ.

7.4. Results

7.4.1 The Child's Perspective on Handwriting Performance

In the DCD groups 9/14 (64%) of the younger children and 11/14 (79%) of the older children identified handwriting as an occupational performance issue for them. Both age groups combined resulted in 20/28 (71.4%) children with DCD rating handwriting as an issue for them. A higher percentage of the DCD group mentioned handwriting as an issue compared to the TD group, $X^2(1, N = 56) = 28.5$, $p<.001$. In the TD groups, 2/15 (13%) of the younger children and none of the older children mentioned handwriting as an issue for them.

Table 7.4 illustrates the ratings of importance, performance and satisfaction with handwriting in the 20 children with DCD who rated handwriting as an issue. Table 7.6 and 7.7 illustrate the individual profiles of handwriting performance.

Table 7.4.

Mean ratings of importance, performance and satisfaction of handwriting using the COPM for the DCD group (n=20).

COPM Items	Mean (SD)
Importance of handwriting	6.80 (2.14)
Performance of handwriting	3.45 (1.90)
Satisfaction with handwriting ability	4.60 (2.45)

Note. The items are scored on a scale of 1-10, 1=Not very important/good/happy at all, 10= very important/good/happy.

7.4.2 The Teacher's Perspective on Handwriting Performance

On the HPSQ (Rosenblum, 2008) there was a significant group difference between the DCD (n=24) and TD group (n=17) ($t(39) = 6.61$, $p < .001$) as the DCD group had a significantly higher score (M =17.25, SD = 6.10) than the TD group (M = 5.68, SD = 4.14) indicating poorer performance. Table 7.5 illustrates the ratings on the items of the HPSQ for the DCD group, while Tables 7.6 and 7.7 illustrate individual performance on the total score of the HPSQ for each of the DCD participants.

Table 7.5.

The Teachers' ratings of children with DCD (n=24) on the individual items of the HPSQ (Rosenblum., 2008)

Item	Item Description	Never %	Rarely %	Sometimes %	Often %	Always %
1	Is the child's writing unreadable?	4.3	17.4	47.8	26.1	4.3
2	Is the child unsuccessful in reading his/her own handwriting?	8.7	21.7	43.5	26.1	0
3	Does the child does not have enough time to copy tasks from the blackboard?	4.5	36.4	22.7	22.7	13.6
4	Does the child often erase while writing?	4.3	56.5	26.1	13.0	0
5	Does the child often feel he/she does not want to write?	26.1	4.3	30.4	34.8	4.3
6	Does the child not do his/her homework?	47.8	30.4	4.3	4.3	13
7	Does the child complain about pain while writing?	60.9	30.4	8.7	0	0
8	Does the child tire while writing?	8.7	30.4	21.7	21.7	17.4
9	Does the child need to look at the page/blackboard often when copying?	4.3	17.4	17.4	43.5	17.4
10	Is the child not satisfied with his/her handwriting?	4.3	21.7	34.8	21.7	17.4

Note. The items are scored on a scale of 0-5, 0=Never, 1=Rarely, 2=Sometimes, 3=Often, 4=Always

7.4.2.2 Group profiles on the (HPSQ: Rosenblum, 2008)

A high score on the HPSQ indicates poor performance, while low scores represent good performance. Based on 1SD of the TD mean, 11/13 (85%) of the younger DCD group and 10/11 (90%) in the older DCD group scored above 1SD. There was one questionnaire missing in the younger DCD dataset and three in the older DCD group. In the TD groups 2/9 (22%) children in the younger age group and 1/7 (14%) children in the older age group fell more than 1SD above the mean. There were 12 questionnaires missing in the TD groups.

7.4.3 Performance profiles across the handwriting measures

7.4.3.1 The Handwriting Product

Handwriting Speed

*The Detailed Assessment of Speed of Handwriting-Free Writing Task (*DASH: Barnett et al, 2007)

In order to be identified as having difficulties with handwriting speed, the total number of legible words written on the DASH free-writing task had to be below 1SD from the mean of the TD groups.

Based on 1SD, 11/14 (79%) participants in the younger age DCD group had difficulties with speed, as did 7/14 (50%) participants in the older DCD group. 1/14 (7%) in the younger TD group performed below 1SD, as did 3/14 (21%) in the older TD group.

Handwriting Legibility

The Handwriting Legibility Scale (HLS: Barnett et al, 2013)

In order to be identified as having difficulties with legibility, the total HLS score had to be 1SD above the TD mean. As documented in the chapter five on legibility a high score on the HLS indicates poor performance, while low scores represent good performance.

12/14 (86%) children in the young DCD group were above 1SD as were 13/14 (93%) in the older DCD group. Three children in the younger age TD group were above 1SD on the HLS (21%) as were 2 of the older TD children (14%).

7.4.3.2. The Quality of the Written Composition

The Wechsler Objective Language Dimensions (WOLD; Rust, 1996)

Based on 1SD of the TD mean 8/14 (57%) children with DCD in the younger age group were below their TD peers as were 12/14 (86%) children in the older group. For the TD groups 2/14 (14%) of the younger age were below 1SD as were 3/13 (23%) of the older group.

7.4.4 Results Across Measures

7.4.4.1 Performance Across All Measures

Out of the 24 children with DCD with full data sets (completed 5 measures) 9 of them (38%) scored below 1SD on all five measures of handwriting. All 28 children had data for at least four measures and out of these, sixteen (57%) were poor on four measures and 25 (89%) were poor on three. There was only one child (no. 42) with DCD who was not poor on any of the measures.

A closer look at the performance profiles indicated one child was poor on everything except on the teacher questionnaire (HPSQ) (no. 28). Three children were poor on all measures except the COPM (they did not identify handwriting as a problem for them).

Tables 7.6 and 7.7 indicate the performance profiles of the DCD groups on all 5 measures. This indicates whether children identified handwriting as an issue for them on the COPM (Law et al., 1998) and how many standard deviations (SDs) the DCD children were below/above the TD range on the descriptive measures and the teacher's opinion. Tables 7.6 and 7.7 also indicate whether a child with DCD was within 1 SD of the TD mean, indicating a level of performance typical for their age (zero in the tables).

Table 7.6.

Performance profiles of children with DCD in the younger age group (8-11 years) across five measures

TD Mean (SD)	=Y/N	126.5 (30.77)	10.35 (3.13)	6.44 (4.77)	18.07 (3.45)
Participant	Child (COPM)	Speed (DASH)	Legibility (HLS)	Teacher (HPSQ)	Writing (WOLD)
40.	Y	-2	-3	-3	-2
41.	Y	-1	-3	-1	-2
39.	Y	-2	-4	-2	-2
66.	Y	-2	-2	-4	0
54.[a]	Y	-1	-2	-3	0
38.	N	-3	-4	-2	-3
23.	N	-1	-1	-1	0
25.[a]	N	-2	-3	-1	-1
02.	N	-1	-1	0	-1
20.	Y	0	-2	-1	-1
01.[a]	Y	-1	-2	M	-1
42.	N	+1	0	0	0
18.	Y	-1	0	-3	0
19.	Y	+1	-1	-1	0

Note. N= Child does not mention handwriting as an issue, Y= Child mentions handwriting as an issue, M=missing data, 0= Within 1SD of the TD mean, [a]= Below a standard score of 85 on BAS=II spelling.

Table 7.7.

Performance profiles of children with DCD in the older age group (12-14 years) across five measures

TD Mean (SD)	=Y/N	189.3 (32.37)	9.28 (2.13)	4.71 (3.25)	22.71 (1.63)
Participant	Child (COPM)	Speed (DASH)	Legibility (HLS)	Teacher (HPSQ)	Writing (WOLD)
24.	Y	-1	-4	-5	-4
53.[a]	Y	-2	-5	-3	-8
33.	Y	-2	-6	-5	-4
15.	Y	-2	-6	-3	-4
21.	N	-1	-1	-5	-1
03.	Y	0	-2	-3	-1
65.	Y	0	-3	-4	-3
28.	Y	-2	-2	0	-2
30.	Y	0	-2	M	0
67.[a]	Y	+1	-3	-5	-4
05.	Y	0	-2	M	-4
43.[a]	N	0	-2	-5	-4
72.	N	-2	0	-1	0
06.[a]	Y	0	-2	M	-6

Note. N= Child does not mention handwriting as an issue, Y= Child mentions handwriting as an issue, M=missing data, 0= Within 1SD of the TD mean, [a]= Below a standard score of 85 on BAS=II spelling.

7.4.5 Correlations

7.4.5.1 Relationships Between Measures

For the DCD group Spearman's bi-variate correlation analyses revealed a significantly negative relationship between the number of words produced on the DASH free-writing task and the HLS total score (r = -.53, *p* = .004), showing that a higher number of words was associated with better legibility. There was a significant positive correlation between the number of words produced on the DASH free-writing task and the WOLD total score (r = .53, *p* = .003), showing that a higher number of words was associated with higher compositional quality. There was no significant relationship between the COPM or HPSQ with any of the measures.

For the TD group (n=28) there was also a significant positive correlation between the number of words produced on the DASH free-writing task and the WOLD total score (r = .49, *p* = .007). There was also a significant positive correlation between the total score of the HLS and the HPSQ (r = .63, *p* = .008), showing that better legibility was associated with lower teacher ratings. There was no significant relationship between the COPM and any of the measures or between the total legible words on the DASH free-writing task and the HLS total score.

7.4.7.2 Relationship Between formal Measures & specific items on the HPSQ

There was no correlation between the 'global' legibility score on the HLS with the HPSQ legibility items 1 (r = .155, *p* = .314) and 2 (r = .183, *p* = .441) for the DCD group. There was no relationship between the total words written on the DASH free-writing task and time taken to copy from the board, item 9 on the HPSQ (r = -.173, *p* = .466).

7.5 Discussion

The purpose of this study was to examine the profile of handwriting difficulties in children with DCD, to ascertain the nature and extent of handwriting difficulties of individual children in this group. In addition, the previous chapters in this thesis found significant group differences on all of the main measures. However in order to understand the performance of children with DCD in detail, it is important to consider individual data. In doing so the combination of evaluative assessments using the children's and teachers' opinions, with quantitative tests of handwriting speed and legibility indicated that only one child in the DCD group performed well across all measures. The remaining 27 had some level of difficulty with at least two aspects of handwriting.

The first measure examined whether the children themselves perceived handwriting as an area of difficulty for them. This was to ascertain whether the children with DCD would be likely to identify handwriting as a goal within a therapy setting. The results from the COPM (Law et al., 1998) revealed that a majority of children with DCD perceived handwriting as an issue. As a group, handwriting was rated as important, they rated their handwriting performance as poor and ratings of satisfaction were below a score of 5, which would indicate a level of dissatisfaction with their performance. Based on the high score for the importance of handwriting it would suggest that handwriting was a meaningful activity for 71% of the DCD group. However, not all of the children in the DCD group were able to report a difficulty with handwriting despite being poor on at least two other measures. In three of the children with DCD who did not mention handwriting in the COPM they were poor on every other measure, scoring between 1 and 3 SDs below the TD mean. This raises possible issues for goal setting and intervention, as difficulties were found on clinical measures of handwriting, but not raised by the children themselves.

According to Polatajko and Mandich (2004) not all children are good at identifying skills to improve upon and in addition, not all therapists can enable children to do so. There are alterative tools available for goal setting with children, some of which use picture prompts such as the PEGS (Missiuna et al, 2004), rather than relying on verbal communication through the COPM (Law et al., 1998). Indeed, it may be that a pictorial goal setting tool such as the PEGS (Missiuna et al, 2004) may have been more effective for the four younger children who scored poorly on at least three measures but did not think handwriting was an issue for them. However, the lack of relationship between the child and the tests raises issues in terms of how to assess handwriting in children with DCD and whether a range of different perspectives need to be sought. In instances where the child does not recognise their difficulties, alternative strategies to goal setting may need to be applied.

Although it is important to incorporate the child's goals into therapy as much as possible, this is not always feasible. For example, Polatajko and Mandich (2004) documented cases where the child wanted to learn how to snowboard in the summer, which the treatment setting was unable to support. In these instances and in cases where there are different goals being forwarded by the parent and the child, the therapist can negotiate with the child and offer to combine goals to work on, for example, one parent goal and two of the child's goals. This way, handwriting can be incorporated as a therapy goal along with two other goals that are more meaningful to the child (Polatajko & Mandich, 2004). One limitation of the current study was the lack of information sought from parents, as some children with DCD did not mention handwriting as an area of concern, but their parents may have done so. In the intervention programmes which have demonstrated efficacy for children with DCD, therapy goals were established using both the parent and the child's opinions (Sugden & Chambers, 2003; Polatajko & Mandich, 2004).

Although this study did not consider the parent's opinions, the teachers' perspectives were examined in detail. Teachers see these children on a daily basis and are in a valuable position to comment specifically on handwriting (Rosenblum, 2008; Dunford et al, 2005). In this study, there was a significant difference between the DCD and TD groups, with the DCD group scoring below the TD group on the HPSQ (Rosenblum, 2008). In previous studies, teachers were found to be more severe in their ratings of children's handwriting compared to OTs (Sudsawad et al., 2001) and the children themselves (Dunford et al., 2005). In the current study, teachers appeared to be able to identify difficulties in a majority of the children with DCD who scored poorly on descriptive measures. According to the teachers, 26% of children's handwriting was 'often' unreadable, with 47% 'sometimes' and 4% 'always'. In terms of handwriting speed however, the only item on the HPSQ (Rosenblum, 2008) that addressed this was in relation to time taken to copy from the board. The teachers reported that 13% of the children 'always' required extra time to copy from the board, while 22% needed extra time 'sometimes' and 'often'. In addition to information on speed and legibility, the teachers provided valuable information about the child's participation level at school and potential issues within the environment. For example, 13% of the children with DCD never did their homework, while 8% ranged between 'often not doing homework' to 'sometimes not doing homework'. In terms of pain during handwriting, over 90% of children rarely or never experienced pain, but over 50% experienced fatigue either 'sometimes', 'often' or 'always'. This type of information is important for assessment and intervention, as it gives therapists an insight into the child's school environment and areas that the child has difficulty with. It could also provide information for specific considerations such as the amount of handwriting practice a child engages with at home. For example, if a child never does their homework then this may suggest that little practice of handwriting is occurring at home. Similarly, if a child is complaining to the therapist of pain while writing, it is beneficial to know whether this has been noted at school.

The additional information that teachers provide is important for building a picture of the child (Sugden & Chambers, 2003). However, there are issues with this approach, especially when considering awareness of handwriting difficulties and the agreement between clinical measures and teachers' perspectives. For example, one child in the older DCD group scored at least 2SDs below the TD group on all measures, but was rated as within the typical range on the teacher questionnaire. In children with DCD it is common for difficulties to be under-recognised until academic performance begins to decline (Fox & Lent, 1996; Miller et al., 2001). However in this case, the child was below

2SDs even on the compositional quality of writing; yet, he was not reported to have difficulties with handwriting according to the teacher. In terms of intervention for this particular child, it would appear that the therapist would have to bring the difficulties noted by the child and the outcomes of clinical measures to the attention of the teacher. That is, if the child was referred to a health professional in the first instance, as the school can frequently be a source of referrals. If the teacher does not suspect deficits, then this particular child may not be referred to a professional unless the parents raise an issue themselves. In another example, a participant in the DCD group scored below 1SD on three measures, but the child and the teacher did not recognise a difficulty. This may raise issues in terms of whether a referral to health professionals would be made for that child and if so, whether the parent would encourage handwriting to be a therapy goal on behalf of their child. If the teacher is not aware of the child's difficulties and the child is not willing to participate in a handwriting intervention, then much needed support may be missed. In addition, the fact that the teacher was unable to recognise difficulties in their student perhaps suggests a need for further training in the area of handwriting and handwriting difficulties in teachers in order to raise awareness of poor performance.

In terms of whether the clinical tests related to the teachers' scores on the HPSQ (Rosenblum, 2008), this was not found to be the case here. There was no relationship between the total score of the HPSQ and any of the other measures. In addition, when considering individual items of the HPSQ such as legibility and speed with specific tests of that construct (DASH & HLS), there was again no significant relationship between the measures. This is a similar issue to that raised by Sudsawad et al (2001) where teachers seem to base legibility ratings on criteria other than that used in tests. The teachers do not appear to be using similar strategies to those used in tests of legibility such as the HLS (Barnett et al., 2013). Although the HLS remains in the early stages of development and has not yet been published for general use it is anticipated that HLS will go some way in bridging the clinical/education gap. The HLS offers a quick screening tool with specific information for teachers to follow, which may aid in promoting accurate cross communication between clinicians and teachers in the future.

In terms of compositional quality of their writing, eight children in the younger DCD group and 12 children in the older DCD group were at least one standard deviation (SD) below the TD means, with a total of 14 children with DCD below at least 2SDs for writing quality. This suggests that half of the DCD group had substantial difficulties with producing good quality text, which would likely impact on their academic performance.

One of the questions raised in the introduction to the current study was based on Missiuna et al (2006) where an important issue of *performance* versus *quality of performance* was discussed. According to Missiuna et al (2006) children with DCD may achieve performance criteria on a particular activity, but in doing so may demonstrate poor quality of movement. This study sought to investigate whether there were children who were able to perform within the expected range for their age on the DASH (Barnett et al, 2007) while scoring low on the HLS (Barnett et al, 2013) due to poor quality movement. Using the profile analysis, the results of this study indicated that 9/28 children with DCD performed within the typical range for handwriting speed, but scored below 1 SD of the TD group on legibility. Moreover, the results also indicated that two of the children in the DCD group were 1 SD above the TD mean for speed, but between 1-3 SDs below the mean on legibility. This seems to support the discussion raised by Missiuna et al (2006), as nine children met the performance criteria for speed, but the quality of the movement was so poor that it impacted on the functional performance measure of legibility. If handwriting is difficult to read it defeats the communicative purpose of handwriting and is therefore failing to serve a functional purpose. Interestingly however, there were two children with DCD who were within the TD range for legibility, but below the TD range on speed. These children may have demonstrated functional skills in terms of readability, but placed in an exam environment where speed is required, the functional requirements of the task would not be met.

In summary, a majority of children with DCD indicated handwriting as an issue for them, which was verified using a range of descriptive measures. The teachers' opinions largely overlapped with that of the children, but there were instances where perhaps a lack of awareness surrounding handwriting difficulties was apparent. In terms of the profile of performance using descriptive tests, only one child performed well on all measures, the rest of the children seemed to have significant difficulties with legibility more often than speed. However, there were 16 children who had difficulties on both. In terms of severity, the difficulties noted in the DCD group ranged from below 1 SD from the TD mean to 6-8 SDs on quality of writing and legibility, indicating a range in the severity of impairments. Although there were nine children who scored poorly on all measures, there were some who scored poorly on fewer. This may support the use of more than one measure when investigating handwriting difficulties, as if only one measure is used then teachers or occupational therapists may run the risk of difficulties going un-noticed. This is also important to consider in health care settings where 'cut-off' points on particular tests are used as a qualifier for intervention. Practitioners may need to consider the use of more than one measure and in doing so, recognise that both the child and the teacher offer valuable information into building a holistic picture.

This study has raised possible issues in terms of the heterogeneity of handwriting difficulties in children with DCD. Since only one child performed well on everything and there was no test that everyone was poor on, it may be fair to suggest that each child needs to be considered using a holistic approach which incorporates the opinions of the child, parent and teacher with objective measures of legibility and speed. This would be a particularly beneficial protocol in services which only assess and offer advice to parents/schools (Dunford & Richards, 2003), as the more information that can be gathered and pieced together by a professional, the more likely the teacher and parent will be able to incorporate the advice into everyday situations (Sugden & Chamers, 2003). In addition, in order to support applications for access arrangements at school (i.e. extra time in examinations) the use of a holistic approach to the assessment of handwriting would be beneficial. This would promote a thorough investigation of the child's handwriting ability and in turn, ensure that difficulties with the different aspects of the task are captured. The following chapter will examine underlying mechanisms of handwriting difficulties from a clinical perspective and examine whether tools commonly used in occupational therapy practice to assess issues such as visual perception and strength can predict or explain handwriting deficits.

7.6 Practical Implications from This Chapter

1. The majority of children with DCD have difficulties with at least two measures of handwriting be it through a clinical test of handwriting or emerging through an interview with the child or teacher. Only one child in this study scored within range on all measures therefore most children demonstrated difficulties of some sort. This emphasises the need to include a measure of handwriting when assessing children with DCD.

2. A majority of children in the DCD group had difficulties with compositional quality. Therefore therapists need to be aware of the broader aspects of writing and the possible impact that difficulties with handwriting may have on the child's performance at school. This emphasises the importance of intervention and that perhaps simply providing advice to parents and teachers may not be enough.

3. Most children with DCD considered handwriting as an issue for them, rated it as important and something they would like to improve. This suggests that handwriting is a meaningful activity in children with DCD and is something they are generally motivated to improve.

4. Since not all children with DCD were aware of their difficulties with handwriting it is important for teachers to be able to identify difficulties in students. Cases where children score poorly on clinical assessments but are not reported by either themselves or the teacher to have difficulties are problematic. This type of scenario would mean a child continuing to have difficulties with the skill with no opportunity for referral to intervention services.

5. The lack of relationship between the teacher questionnaire and the clinical measures of handwriting suggested that teachers and therapists are looking at different things. This needs to be addressed and with the development of the HLS this may go some way in bridging the teacher-therapist divide.

6. In order to capture handwriting difficulties therapists may need to use a battery of tests in order to accurately identify the areas of weakness. This is supported in the findings of this study where not all children had difficulties with both legibility and speed. Therefore by only examining legibility, the therapist will be unaware of difficulties related to speed. Both of these areas need to be assessed either separately, or together in order to get a complete picture.

Chapter 8

Visual Perception and Force Control: their role in handwriting performance

8.0 Introduction

The chapters in this thesis so far have examined different aspects of handwriting and writing in children with DCD which has had implications for assessment and intervention. Previous research in DCD has attempted to reveal specific deficits underlying the motor difficulties, to provide a better understanding of the condition and to inform interventions. Many different factors relating to motor control have been considered including kinaesthetic perceptual skills, visual perceptual skills, temporal aspects of motor control, force control and strength, all of which were mentioned in Chapter 1. Various assessments and intervention approaches have developed around these ideas, although some have a stronger evidence base than others (EACD, 2011). In this chapter, two frequently mentioned factors in paediatric occupational therapy practice were considered and evaluated including visual perceptual skills and force control/strength.

To produce handwriting it is necessary to visually discriminate between different letter-shapes and be able to execute them appropriately. It has been hypothesised that problems with the visual discrimination of letters are associated with handwriting difficulties (Rosenblum and Livneh-Zirinski, 2008). For many years an 'information processing' approach to identify processing deficits at the ICF level of *body functions* has been adopted. In a meta-analysis by Wilson and McKenzie (1998), numerous studies demonstrated that children with DCD have difficulties with visual-perceptual skills and have significant deficits in visual motor integration, particularly in tasks which require speed. In a task such as handwriting which involves the integration of all three of these areas (visual perception, visual motor integration and speed), it is important to consider whether difficulties in these areas impact on the production of handwriting. When considering possible explanations for the pausing phenomenon in the handwriting of children with DCD, Rosenblum and Livneh-Zirinski's (2008) suggestions ranged from the inability of children with DCD to retrieve the correct letter form from memory or visualise the letters prior to forming them. However, neither of these theories were examined by Rosenblum and Livneh-Zirinski (2008), therefore it remains unclear whether deficits in visual perception or visual motor integration impact on the handwriting process in children with DCD.

Despite the lack of clarity surrounding the role of visual perceptual deficits in contributing to handwriting difficulties, visual perception is an area commonly assessed in paediatric occupational therapy practice worldwide (Feder et al, 2000; Butner et al, 2002; Rodger et al, 2005). This practice is often embedded in a 'bottom-up', or information processing approach to assessment, where it is hypothesised that the improvement at the ICF level of *body function* such as visual-motor integration, will lead to improvements at the ICF level of *activity* through the impact on functional skills (EACD, 2011). However, it is a controversial topic within the occupational therapy profession at present, as it remains unclear whether popular clinical measures which are thought to evaluate visual perception and visual motor integration can predict or explain handwriting difficulties (Klein et al., 2011). In addition, there are practical issues in relation to the use of visual perceptual tests, as many therapists use them, but not always in the way test developers had intended (Goyen & Duff, 2005). For example, some therapists use the Beery-Buktenica Developmental Test of Visual Motor Integration (VMI: Beery, 2004) to ascertain whether the child can accurately copy shapes, with the premise that difficulties with copying shapes would explain difficulties with forming letters. However according to the test authors, the VMI (Beery, 2004) was designed to assess the extent to which visual and motor abilities can be integrated in individuals, rather than specifically to address the skill of handwriting.

Another important aspect of motor control is the control of force production and physical strength. In handwriting, strength and force control in the arm, hand and fingers are needed to hold the pen, exert appropriate pressure on the page to make a mark and to sustain writing over short and longer periods of time. Chang and Yu (2010) proposed a lack of strength and endurance for the decrease in work surface pressure observed in the DCD group. However, although strength has been examined in the lower body by Raynor (2001), it has not been measured in detail in the upper extremities. It therefore remains unclear to what extent strength relates to handwriting performance. From a practical perspective, many occupational therapists use hand strengthening exercises with children who have difficulties with handwriting. Whether this is a worthwhile practice in children with DCD in the UK remains to be seen.

This chapter will consider both theoretical and practice based questions in relation to the handwriting product (clinical measures of handwriting) and the handwriting process (percentage of pausing). Two factors that might relate to handwriting performance will be investigated: visual perceptual skills and force control/strength. These factors have been derived from the literature on DCD as possible explanations for deficits in the handwriting process and are commonly considered as areas for intervention in paediatric occupational therapy practice. These will be investigated to ascertain their role in predicting or explaining handwriting difficulties in children with DCD. A literature review on the use of visual perceptual measures in practice and the assessment of strength and force control in DCD will follow.

8.1 Why Visual Perception is Considered Important in relation to Handwriting Difficulties

Schneck (2010) discussed the importance of measuring visual perceptual skills in paediatric occupational therapy practice in relation to handwriting, emphasising that in order for a child to write independently, they need to be able to revisualise letters and words without visual cues. Rosenblum and Livneh-Zirinski (2008) also suggested that children with DCD may have difficulties retrieving the correct letter form from memory. According to Schneck (2010) if a child has poor visual perception in areas such as form constancy, they would not be able to recognise errors in their own handwriting. However, studies by Rosenblum and colleagues have shown that one of the biggest predictors of handwriting difficulties in children is the amount of over writing or editing of already formed letters (Rosenblum & Livneh-Zirinski, 2008). This would therefore suggest an element of self-regulation or an ability to recognise some poorly formed letters if there are attempts to correct them. Schneck (2010) also discussed other problematic scenarios related to poor visual perception such as a child having difficulty recognising different scripts outside of the one they use. For example if a child writes using un-joined writing, they may have difficulty copying joined writing. A child with figure-ground difficulties may have difficulty copying, while a child with poor visual closure may lack uniformity in letter size or shape (Schneck, 2010). According to Schneck (2010), failure on visual motor tests may be indicative of more general visual perceptual difficulties including visual discrimination, fine-motor skills or difficulties with integrating these. These reasons provided by Schneck (2010) appear to form part of the rationale for the use of visual perceptual tests in relation to handwriting difficulties in therapy settings and have proven to be very popular. Two commonly used tests of visual perception and visual motor integration are reviewed below.

8.2 Tests of Visual Perception in Clinical Practice: Purpose versus Application

The relationship between handwriting and visual perception has historically been applied in two ways; to measure the readiness of young children to commence handwriting/identify difficulties (Beery, 1989) and secondly, to examine the role of visual and kinaesthetic feedback in handwriting performance (Smits-Engelsman, Niemeijer & Van Galen, 2001). There are many tests which claim to measure visual perceptual skills, however two of the most commonly used in paediatric occupational therapy practice include the Test of Visual Perceptual Skills (TVPS: Gardner, 1982; Martin, 2006) and the Beery-Buktenica Developmental Test of Visual Motor Integration (VMI: Beery, 2004). Several studies have demonstrated that they are frequently used in occupational therapy practice in a variety of different countries including Canada (Reid & Jutai, 1997; Feder et al, 2000), Australia (Rodger et al, 2005) the USA (Butner et al, 2002) and the UK (Chu & Hong, 1997). One of the issues surrounding the use of these tests is the difference between what they were originally designed to measure, versus what they are used to measure in practice. In the following section the VMI (Beery & Beery, 2004) and

TVPS (Martin, 2006) are reviewed and differences between how they were intended to be used and how they are currently applied in practice are discussed.

8.2.1 Beery-Buktenica Developmental Test of Visual Motor Integration (VMI: Beery, 2004)

The first version of the VMI was produced in 1967 (Beery & Beery, 2004), since then, it has been re-standardised five times, with the most recent 6th edition published in 2010 (Beery, Beery & Buktenica, 2010). The VMI has two additional, supplemental tests, one for visual perception without a motor component and another for motor coordination where the child traces shapes without going outside the lines. The main test is the VMI itself which presents a developmental sequence of geometric forms which have to be copied on paper with a pencil (Beery & Beery, 2004). The test starts with simple forms like drawing a circle or a square and ends with complex shapes such as three dimensional forms (i.e. a cube). According to the authors, it was designed to examine the extent to which visual and motor abilities can be integrated in individuals (Beery & Beery, 2004; 2010). According to Kaiser, Albaret and Doudin (2009) the term visual-motor-integration is controversial in its own right, as there is no solid definition of what exactly the term refers to. However, according to the authors, the Beery VMI measures the coordination between the fingers and visual perception. Geometric shapes rather than letters or numbers were included in the test in order to avoid cultural constraints due to different alphabetic systems (Beery & Beery, 2004).

The VMI test serves four purposes (Beery & Beery, 2004; 2010). The first purpose is to identify those who have difficulties with visual-motor integration. The second and third purpose is to justify service provision and assess effectiveness of intervention, and the fourth is for use as a research tool (Beery & Beery, 2004). Thus the tool is not described as relating directly to handwriting skill but rather, it refers to a correlation with ‘reading readiness’ (.56) and ‘letter identification’ (.52). However, studies have shown that there is a relationship between the VMI and handwriting ‘readiness’ in young children (Daly, Kelley & Krauss, 2003). The construct of handwriting ‘readiness’ is controversial in nature as there are many factors which are likely to impact on whether a child is ready to engage with handwriting, such as, differing rates of maturity and environmental experiences (Schenck & Amundson, 2010). In terms of empirical investigation of handwriting ‘readiness’ considering performance on the VMI and handwriting legibility, Daly et al (2003) examined 54 typically developing children aged 4-6 years in the USA and investigated the relationship between their performance on the VMI and their ability to copy 34 letter forms (all letters of the alphabet in lower case followed by A, K, M, N, V, W, Y, Z in capital letters). They found a strong correlation (.64) between the two measures. In the same study, the children who could correctly copy the first nine shapes of the VMI were shown to perform better on measures of legibility (Daly et al., 2003). However, beyond the early years this relationship has been shown to diminish. According to a study by

Pinto and Camilloni (2012) which examined 124 children aged 3-5 years, there was a significant correlation in the 3 and 4 year olds between writing their name and their performance on the VMI. However, there was no relationship between the two tasks for the 5 year olds. According to the authors, this is because until the age of 5 years, children draw and write using the same visual motor pathways. After this, writing and drawing separate and develop in different directions (Pinto & Camilloni, 2012). In order to learn how to write, the child needs to become familiar and aware of the function of letters as language. Here, the child learns how to translate a word into the representative letters, in order to produce them on the page (Pinto & Camilloni, 2012). Pinto & Camilloni (2012) emphasised that letters are never produced in isolation. For example, the individual letters of 'm' and 'u' are combined together to form the word 'mum'. According to Pinto & Camilloni (2012) the orthography of language dictates how marks on a page 'look' and it does not involve the simple process of producing shapes.

Despite the fact that the VMI was not developed to assess handwriting performance, it is commonly used in occupational therapy practice, particularly in relation to handwriting. In a survey by Doyle and Goyen (1997) the VMI was identified as the most popular tool for the examination of handwriting in paediatric occupational therapy practice in Australia. Similar results were found in Canada in a study by Feder et al (2000). Based on the VMI's popularity, Goyen and Duff (2005) examined the efficacy of using the VMI in relation to handwriting assessment. They investigated 35 children aged 9-12 years with handwriting difficulties using a range of handwriting assessments including the Evaluation Tool of Children's Handwriting (ETCH: Amundson, 1995), the Test of Legible Handwriting (TOHL: Larsen & Hammill, 1992), and the Handwriting Speed Test (Wallen et al, 1996) (see Chapters 5 and 6 for reviews). Of the 35 children who had poor handwriting, the VMI identified 12 of them (sensitivity of 34%) (Goyen & Duff, 2005). Based on the results, Goyen and Duff (2005) suggested that the VMI is not appropriate for use as a diagnostic tool for handwriting difficulties, nor is it appropriate to infer causation.

In another study, Klein et al (2011) in Canada examined the relationship between the VMI and handwriting speed and legibility. The authors had a sample of 99 children all with some form of disability (ADHD, DCD, learning disability, ASD and functional difficulties in motor, language and learning). The analysis focused on correlations with all children together rather than separate sub groups. The results demonstrated weak, negative correlations with near point copying for visual processing errors in handwriting (reversed letters) (-.21), motor errors (illegible letters) (-.27) and handwriting speed (letters per minute) (-.28). Weak to moderate correlations were found for far point copying for visual processing errors (-.17), motor errors (-.38) and speed (-.04). Based on these findings, Klein et al (2011) recommended a top-down approach to the assessment of handwriting, where the interaction between the child, environment and task is considered, rather than searching for underlying mechanisms of impairment.

Recently, guidelines for best practice in assessing and intervening with handwriting difficulties have been developed in The Netherlands (Nijhuis-van der Sanden & Overvelde, 2010). An extensive review of the literature surrounding handwriting was undertaken, which included investigating the usefulness of the VMI in the context of handwriting assessment. Based on the findings of their review, the Dutch project group advised that the Beery VMI should only be administered when history-taking or an analysis of handwriting reveals difficulties with visual-motor integration or difficulties with learning letters. In terms of use as a screening tool for handwriting, the Dutch group recommended that the Beery VMI should not be used in this context (Nijhuis-van der Sanden & Overvelde, 2010). These guidelines were based on a number of studies which either suggested than the VMI should not be used beyond kindergarten (Weil & Amundson, 1994) or that based on correlation coefficients it was deemed inappropriate for use in detecting poor performance (Cornhill & Case-Smith, 1996; Marr & Cermak, 2003). Based on the literature, the Dutch guidelines proposed that the VMI should not be implemented in a test battery for children with handwriting difficulties (Nijhuis-van der Sanden & Overvelde, 2010).

8.2.2 Test of Visual Perceptual Skills (TVPS: Gardner, 1982; Martin, 2006)

The second test of visual perception commonly used in occupational therapy practice is the Test of Visual Perceptual Skills (TVPS: Gardner, 1982; Martin, 2006). The TVPS was initially developed by Gardner in 1982 and the updated third edition published by Martin in 2006. According to Martin (2006) the TVPS assesses an individual's visual perceptual abilities without the use of motor skills. The test is intended to be used by a range of professionals for clinical and research purposes in order to measure various aspects of visual perceptual ability. The TVPS (Martin, 2006) is comprised of 112 black and white designs and includes seven subtests; visual discrimination, visual memory, spatial relationships, form constancy, sequential memory, visual figure-ground and visual closure all of which are presented in greater detail in Table 8.1.

With regards to the structure of the test, there are 16 items which increase in complexity in each sub test and the child selects the correct choice from a multiple choice format. The TVPS (Martin, 2006) has USA norms from 4 to18 years of age. According to a review of the TVPS by Brown and Hockey (2013), it is not clear whether the seven sub tests represent exhaustive components of visual perception or whether they relate to specific types of learning difficulties.

One barrier which could perhaps be a catalyst for the misuse of the TVPS in clinical practice is the lack of rationale provided by Martin (2006) for the assessment of visual perceptual skills (Brown & Hockey, 2013). For example, it is unclear in the test manual exactly what the test should be used for. Yet, alongside the VMI (Beery & Beery, 2004) the TVPS is commonly used among occupational therapy practitioners, particularly in relation to handwriting (Reid & Jutai, 1997; Feder et al, 2000; Rodger et al, 2005; Butner et al, 2002; Chu & Hong, 1997). In the same study by Klein et al (2011) which examined the use of the VMI with handwriting difficulties, the TVPS was also investigated. The results were similar to the use of the VMI where weak, negative correlations with legibility and speed measures were reported.

The VMI and TVPS have not been investigated in the context of the UK, specifically within the DCD population. By investigating whether the tests can explain or predict handwriting difficulties it would aid practitioners in the UK to make an informed decision about whether or not to include these measures in their clinical practice.

Table 8.1.

The seven subtests of the TVPS (Martin, 2006)

	Sub Test	Description
1	Visual Discrimination	The child identifies matching designs
2	Visual Memory	The child is shown a stimulus for 5 seconds then asked to find the same design on the next page
3	Spatial Relationships	The child chooses a design which is different from the others
4	Form Constancy	The child finds a design among others on the page
5	Sequential Memory	The child is shown a stimulus of designs presented in a specific order, when the page is turned, they must identify the design from the previous page
6	Visual Figure-ground	The child must find one design among many
7	Visual Closure	The child is shown a completed design and is asked to match it to an incomplete form

Besides tests of visual perception, there are other factors which are thought to impact on handwriting performance within the clinical domain. In the search for underlying mechanisms of impairment, assessments and interventions relating to strength and force control have been applied in clinical practice with regards to handwriting remediation. These are also important to consider alongside visual perception in order to investigate their role in handwriting performance, a review of which follows in the next section.

8.3 Force control and Strength in children with DCD

Handwriting requires the ability to manipulate the pen using the thumb and fingers using precise control of dynamic forces (Smits-Engelsman, Westenberg & Duysens, 2008). This has been shown to be impaired in children with DCD in other tasks outside of writing. There are various aspects of force control that are important in handwriting, but the focus from a clinical perspective has been on the pressure exerted on the page. This may be due to the characteristics of the written trace observed by clinicians, but has more recently been measured objectively with digitising tablets.

A common assumption particularly related to children with DCD is that they exert too much pressure on the page while writing (Cermak & Larkin, 2002). According to Cermak and Larkin (2002) children with DCD have difficulty regulating the amount of pressure they exert on the page. They often press too hard, resulting in fatigue while writing (Cermak & Larkin, 2002). However, these assumptions were not been empirically tested by Cermak and Larkin (2002). When they were tested by Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010), this was not found to be the case. In fact, children with DCD were shown to exert less pressure than their typically developing peers in both studies.

Based on their findings of decreased pressure exerted on the work surface in children with DCD during handwriting, Chang and Yu (2010) suggested that this may be due to decreased strength and endurance. In their study they referred to Raynor (2001) to suggest that children with DCD have reduced strength compared to typically developing peers in the upper extremities. However, the findings of Raynor (2001) were based on decreased power in the group with DCD in the vastus lateralis and biceps femoris muscles in the legs. It is therefore questionable whether such findings can be applied to the upper extremities, or indeed to a task such as handwriting. However, the notion of strength being a contributing factor to handwriting dysfunction is not uncommon. In fact, the use of hand strengthening activities has been used in occupational therapy practice to address handwriting difficulties (Cermak & Larkin, 2002). Cermak and Larkin (2002) reported that many occupational therapists use a sensory integration frame of reference for handwriting intervention, which may involve activities such as manipulating Play-Doh or Theraputty or completing wall push ups to increase hand and shoulder strength. The rationale for this according to Schneck and Amundson (2010) is that some children present with poor proximal stability and strength. In order to promote co-contraction of the muscles in the neck, shoulders, elbows and wrists Schneck and Amundson (2010) proposed that some children may benefit from strengthening exercises. These are examples of approaches that have been used to address handwriting difficulties, despite limited evidence to support this practice (Hoy et al, 2011).

Despite the findings in Hebrew and Taiwanese by Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010), pen pressure on the work surface and grip strength have not been tested in children with DCD in the UK. It is important to measure these factors, not only to examine possible underlying mechanisms of handwriting dysfunction, but also to examine the relationship between handwriting and clinical approaches to intervention such as those which involve hand strengthening exercises.

Based on the above premise, the purpose of this study was to examine visual perception, work surface pressure and grip strength in children with DCD to examine theories proposed as reasons for handwriting deficits in the DCD literature. These three areas were also examined in terms of their role in the assessment of handwriting difficulties in children with DCD in the UK. Table 8.2 presents the specific research questions in this chapter.

Table 8.2

Specific research questions in this chapter

	Compared to their TD peers, do children with DCD:
1	Score below TD peers on measures of visual perception?
2	Perform below their TD peers on measures of grip strength?
3	Exert more pressure on the work surface than TD peers?
	The following questions were examined across both groups:
1	Do tests of visual perception predict performance on tests of legibility and speed?
2	Is there a relationship between the handwriting measures and grip strength?

8.4 Method

8.4.1 Participants

28 children with DCD and 28 TD peers participated in this study. Information about participant selection can be found in Chapter 3. Due to time constraints within schools, it was not possible to test every participant on the visual perception measures, resulting in some missing data.

8.4.2 Measures

8.4.2.1. Visual Perception

Beery-Buktenica Developmental Test of Visual Motor Integration (VMI: Beery, 2004)

The VMI test (excluding the supplement tests) was used to examine visual motor integration as defined by Berry and Beery (2004). The 30 item VMI (Beery & Beery, 2004) suitable for those up to age 18 was individually administered, taking 10-15 minutes (DCD n=26, TD n=19). The participants copied the geometric forms which increased in complexity until they either finished all 30 forms, or they made errors on three forms in a row. The raw scores were converted to a total standard score (with a mean of 100 and standard deviation of 15) and used as a dependent measure in this study. These scores were taken from the VMI norms which were developed using 2,512 children across the USA. The VMI has a reported inter-rater reliability of .92, internal consistency of .96 and test re-test reliability of .89 (Beery & Beery, 2004). Other authors in Australia (Brown & Hockey, 2013) have found internal consistency of .85 and good convergent validity with other tests of visual perception including the TVPS (Martin, 2006) and the Developmental Test of Visual Perception (Hammill, Pearson & Voress 1993).

Test of Visual Perceptual Skills (TVPS: Martin, 2006)

This was used to measure visual perception as defined by Martin (2006). The 112 item test was individually administered, taking 30-45 minutes for participants to complete (DCD n=23, TD n=22). Following the manual guidelines, the children responded to each stimulus until they either completed each sub-section or made three errors in a row. If a participant made three errors in a row within a sub-set, the next sub-set was implemented. Raw scores were converted into standard scores for each individual sub-test and an overall total standard score for the test was obtained (with a mean of 100 and standard deviation of 15) and used as a dependent measure in this study. These scores were taken from the TVPS norms which were developed using 2,008 children across the USA. The TVPS (Martin, 2006) has reported internal consistency ranging between .75-.88 for sub tests and .96 for the overall test. Brown and Hockey (2013) found internal consistency similar to that published in the manual and good convergent validity with other tests particularly the Developmental Test of Visual Perception (Hammill et al., 1993), which also requires no motor responses.

8.4.2.2. Grip Strength

Palmar grip strength was measured to ascertain the level of strength in the upper extremities, particularly the forearm to see if strength was a factor in handwriting performance. Many of the extrinsic muscles of the hand are located in the forearm (Winkelstein, 2012) therefore a measure of palmar grip strength was used to engage all of the extrinsic muscles responsible for flexion of the hand. Pincer strength was not considered here as many children can adopt different types of pencil grasps away from the dynamic tripod which involves thumb and index finger control; therefore not all children utilise a traditional pincer grip while writing (Schneck & Amundson, 2010). In addition, the main reason for addressing palmar grasp was in relation to gaining a more global measure of strength, to address the hypothesis proposed by Chang & Yu (2010).

The grip strength was measured using a North Coast (manufacturer) Jamar hand dynamometer (DCD n=23, TD n=19). Each participant was instructed to stand with feet shoulder-width apart, with knees slightly bent. The participants held the dynamometer using a palmar grasp, with their elbow flexed to approximately 90 degrees, shoulder abducted slightly (making sure the elbow was not tucked against the torso), with medial rotation of the forearm (in a similar position to handwriting). The dynamometer was placed in the dominant (writing) hand first and the participant was asked to squeeze the handle as hard as they possibly could when instructed to do so. The participants were given a countdown '3-2-1, go!' and then encouraged to push as hard as they could during the activity. The dynamometer was squeezed for up to three seconds to make sure the child had an opportunity to recruit as much muscle force as possible. The non-dominant hand was then tested in the same manner. Each hand was tested three times. The dependent measure was measured in kilograms, mean kilograms were calculated for the three attempts on each arm (dominant and non-dominant). The Jamar dynamometer is a reliable method of measuring grip strength (0.85–0.98) and is recommended for use in clinical practice (Peolsson, Hedlund & Oberg, 2001).

8.4.2.3. Pressure on the writing tablet

Since it is thought in clinical practice that children with DCD have difficulty regulating force on the page, the measure of pressure on the writing tablet was captured. This was also analysed based on the literature where both Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010) examined this in writing systems outside the Latin base. The pressure on the shaft of the pen was not measured here, but it is thought that in order to push firmly on the writing surface one would need to exert pressure on the pen in order to do so.

The mean amount of pen pressure exerted on the writing tablet during the four handwriting tasks from the Detailed Assessment of Speed of Handwriting (Barnett et al, 2007) and when writing their own name. Chapter 4 describes the four handwriting tasks from the Detailed Assessment of Speed of Handwriting (Barnett et al, 2007) in detail. The tasks included two copying tasks (best and fast), a one-minute alphabet task and a 10-minute free-writing task therefore encompassing a range of tasks of varying lengths. The pressure was recorded by Eye and Pen 1 software, where the mean pressure exerted on the tablet surface was provided for each task. The mean pressure exerted on the writing tablet was obtained from Eye and Pen 1 software, which provided an average reading of pressure for each handwriting task. Formal investigations of writing tablet pressure in terms of reliability are not reported in the literature. However, it has been shown in some studies that the pressure sensitivity of writing tablets can vary based on the manufacturer. The same manufacturer (Wacom) used in Chang and Yu (2010) and Rosenblum and Livneh-Zirinski (2008) was used in this study.

8.4.3 Procedure

The tests of visual perception and grip strength were implemented over one 60-minute session. Each child met individually with the principal investigator and completed the TVPS (Martin, 2006), the VMI (Beery & Beery, 2004) and the grip strength measures. The sessions were completed either at the child's home, school or at Oxford Brookes University.

Pen pressure was recorded during the handwriting tasks, the protocol of which is detailed in Chapter 4.

8.5 Data Analysis

For comparisons between the DCD group and TD group, tests of normality were conducted initially and descriptive statistics for the dependent variables examined. Differences in the mean values between the groups for all normally distributed measures were examined using t-tests. Those measures which did not meet the normal distribution assumptions were compared using the nonparametric Mann-Whitney-U test. Significance levels for both tests were set at $p<.05$.

Bivariate correlations were also conducted to examine the relationship between the visual perception tests, pen pressure and grip strength with the handwriting process and product measures (pausing, words per minute and legibility) to ascertain whether there was a relationship between the measures at the ICF level of *body function* and the level of *activity*. The correlations were calculated with both groups together and also then separately for the DCD and the TD group. Significant correlations were then used to inform regression analyses to ascertain whether performance on the visual perception tests, pen pressure or grip strength predicted any of the handwriting measures.

8.6 Results

8.6.1 Visual Perception

Beery-Buktenica Developmental Test of Visual Motor Integration (VMI: Beery, 2004)

There was a significant effect of group on the VMI (Beery & Beery, 2004), as the DCD group were poorer on this measure (M = 84.19, SD = 10.69) with a significantly lower total standard score than the TD group (M = 98.37, SD = 13.98), $t(43) = -3.85$, $p < .001$. Eleven children with DCD scored below a standard score of 85 compared to three in the TD group.

Test of Visual Perceptual Skills (TVPS: Martin, 2006)

There was a significant effect of group on the TVPS (Martin, 2006), as the DCD group (M = 90.48, SD = 11.07) had a significantly lower total standard score than the TD group (M = 103.3, SD = 10.06), $t(43) = -4.06$, $p < .001$. Nine children with DCD scored below a standard score of 85 compared to none in the TD group.

8.6.2 Grip Strength

For the amount of kilograms of pressure measured using the hand dynamometer, there was a significant group difference. The TD group (M = 19.10, SD = 5.77) were stronger than the DCD group (M = 13.34, SD = 6.79) with the writing hand ($t(40) = -2.92$, $p = .006$). This was also the case in the non-writing hand, as the TD group (M = 17.54, SD = 5.80) were again stronger than the DCD group (M = 12.06, SD = 5.73), $t(40) = -3.06$, $p = .004$. The TD group were within the range expected for their age for grip strength according to norms in English school children (Cohen, Voss, Stasinopoulos, Delextrat & Sandercock, 2010).

8.6.3 Pressure on the writing tablet

There was no significant effect of group for pen pressure on any of the handwriting tasks. Table 8.3 provides the mean pen pressure exerted on the writing tablet by both groups for each task. The direction of the mean differences showed greater pressure in the control group, although these were not statistically significant.

Table 8.3.

Mean (SD) Pen Pressure exerted onto the Writing Tablet during the Handwriting Task s for the DCD and TD groups.

Task	DCD n=28	TD n=28	p
Copy Best	441 (166)	498 (99)	.130
Copy Fast	488 (162)	548 (125)	.195
Alphabet	467 (165)	518 (118)	.153
Free-writing (10 minutes)	468 (144)	517 (99)	.120
Name writing	512 (184)	580 (121)	.111

$^{*}p \leq .050$.

8.6.4 Correlations between Tests of Visual Perception with Handwriting Measures

8.6.4.1 Correlations between VMI and Handwriting Measures:

Bi-variate correlational analyses were examined between the VMI (Beery & Beery, 2004) and the handwriting legibility measures (percentage of illegible words on the four DASH tasks, total score of the Handwriting Legibility Scale (HLS)) and the handwriting speed measures (words per minute on the DASH tasks and percentage of pausing on the DASH tasks). Table 8.4 presents the correlations between the VMI and handwriting measures with both groups combined which indicated that poorer scores on VMI were associated with poor legibility and a higher proportion of pauses in the writing. There were no significant correlations between the VMI and any of the handwriting measures when both groups were considered separately (see Appendix 9).

8.6.4.2 Regressions between VMI and Handwriting Measures:

To ascertain whether the VMI could predict difficulties with handwriting, initially, bi-variate correlations were examined between the legibility measures. Since the percentage of illegible words on the DASH tasks were highly correlated with each other the HLS total score was used as the regression outcome measure. The VMI explained 31% of the variance (R^2=.31, $F(1,43)$=19.18, $p<.001$) on the HLS indicating that as the VMI scores increase, the HLS total score decreases (see Table 8.5).

For the percentage of pausing on the free-writing task as an outcome, the VMI only explained 7% of the variance (R^2=.07, F(1,43)=4.64, p=.037) (see Table 8.6).

Table 8.4.

Significant correlations between VMI total test standard score (Beery & Beery, 2004) and handwriting measures for both groups combined.

Measure	r	p
Product measures		
Handwriting Speed		
Copy Best words per minute	.238	.115
Copy fast words per minute	.243	.107
Alphabet letters per minute	.210	.186
Free-writing words per minute	.121	.427
Legibility		
Copy Best % illegible words	-.32	.032*
Copy Fast % illegible words	-.32	.030*
Free-writing % illegible words	-.52	<.001**
HLS total score	-.59	<.001**
Process Measures		
Pausing		
Copy Best Pause %	-.36	.015*
Copy Fast Pause %	-.41	.005*
Alphabet Pause %	-.174	.252
Free Writing Pause %	-.34	.022*
Name writing Pause %	-.35	.018*
% pauses above 10 seconds on Free-writing	-.251	.096

*Note. ** p < 0.01 level. * p < 0.05 level.*

Table 8.5

Regression analysis: HLS as a predictor of performance on the HLS for both groups

	Standardised coefficients		Unstandardised	
	Beta	Standard error	coefficients	*p*
VMI standard score	-.205	.047	-.555	<.001

Table 8.6

Regression analysis: HLS as a predictor of percentage of pausing on the free-writing task

	Standardised coefficients		Unstandardised	
	Beta	Standard error	coefficients	*p*
VMI standard score	-.242	.112	-.312	.037

8.6.4.3 Correlations between TVPS (Martin, 2006) and Handwriting Measures:

Bi-variate correlational analysis were examined between the TVPS (Martin, 2006) and the handwriting legibility measures (percentage of illegible words on the four DASH tasks, total score of the Handwriting Legibility Scale (HLS)) and the handwriting speed measures (words per minute on the DASH tasks and percentage of pausing on the DASH tasks). Some significant correlations were found with both groups combined; these are illustrated in Table 8.7. However, there were no significant correlations between the TVPS and any of the handwriting measures when each group was considered separately (see Appendix 10).

8.6.4.4 Regressions for TVPS (Martin, 2006) and Handwriting Measures:

To ascertain whether the TVPS could predict difficulties with handwriting legibility, initially, bi-variate correlations were examined between the legibility measures. Since the percentage of illegible words on the DASH tasks were highly correlated with each other and the TVPS correlated with the HLS total score the HLS total score was used as the outcome measure. The results indicated that the TVPS only explained 9% of the variance (R^2=.09, F(1,43)=4.62, p=.037) for the HLS score (see Table 8.8).

To see whether the TVPS predicted handwriting speed, the DASH alphabet task was chosen as the outcome variable for analysis, as it is a common test used for measuring handwriting speed (see Chapter 4). The results indicated that the TVPS only explained 9% of the variance (R^2=.09, F(1,43)=4.27, p=.045) for letters produced per minute (see Table 8.9).

In relation to pausing, the TVPS correlated with the percentage of pausing only on the copy fast task, therefore the pausing on the copy fast task was used as the outcome measure and explained 17% of the variance (R^2=.17, F(1,43)=9.14, p=.004) (see Table 8.10)

Table 8.7.

Significant correlations between TVPS total test standard score (Martin, 2006) and handwriting measures for both groups combined.

Measure	r	p
Product Measures		
Handwriting Speed		
Copy Best words per minute	.33	.028*
Copy fast words per minute	.38	.010*
Alphabet letters per minute	.32	.030*
Free-writing words per minute	.24	.108
Legibility		
Copy Best % illegible words	-.175	.251
Copy Fast % illegible words	-.212	.161
Free-writing % illegible words	-.246	.104
HLS total score	-.31	.036*
Process Measures		
Pausing		
Copy Best Pause %	-.249	.099
Copy Fast Pause %	-.43	.004*
Alphabet Pause %	-.146	.339
Free Writing Pause %	-.169	.267
Name writing Pause %	-.179	.240
% pauses above 10 seconds on Free-writing	-.181	.233

Note. ** $p < 0.01$ level. * $p < 0.05$ level.

Table 8.8

Regression analysis: TVPS as a predictor of performance on the HLS for both groups

	Standardised coefficients		Unstandardised coefficients	*p*
	Beta	Standard error		
TVPS standard score	-.150	.124	-.181	.037*

*Note. * p < 0.05 level.*

Table 8.9

Regression analysis: TVPS as a predictor of the number of letters produced on the alphabet task

	Standardised coefficients		Unstandardised coefficients	*p*
	Beta	Standard error		
TVPS standard score	.463	.224	.301	.045*

*Note. * p < 0.05 level.*

Table 8.10

Regression analysis: TVPS as a predictor of percentage of pausing during the free-writing task

	Standardised coefficients		Unstandardised coefficients	*p*
	Beta	Standard error		
TVPS standard score	-.325	.108	-.419	.004*

*Note. * p < 0.05 level.*

8.6.4.5 Correlations between Grip Strength and Handwriting Measures:

Bi-variate correlational analysis were examined between the grip strength measure for the writing hand and the handwriting legibility measures (percentage of illegible words on the four DASH tasks, total score of the Handwriting Legibility Scale (HLS)) and the handwriting speed measures (words per minute on the DASH tasks and percentage of pausing on the DASH tasks). Some significant correlations were found with both groups combined; these are illustrated in Table 8.11. There were some significant correlations between the TD group and the handwriting product measures, but no significant correlations between grip strength and any of the handwriting measures for the DCD group (see Table 8.12).

Table 8.11.

Correlations between Grip strength of writing hand and handwriting measures for both groups combined.

Measure	r	P
Product Measures		
Handwriting Speed		
Copy Best words per minute	.393	.010*
Copy fast words per minute	.439	.004*
Alphabet letters per minute	.381	.013*
Free-writing words per minute	.421	.006*
Legibility		
Copy Best % illegible words	-.220	.162
Copy Fast % illegible words	-.407	.007*
Free-writing % illegible words	-.302	.052
HLS total score	-.427	.005*
Process Measures		
Pausing		
Copy Best Pause %	-.196	.213
Copy Fast Pause %	-.396	.009*
Alphabet Pause %	-.023	.884
Free Writing Pause %	-.286	.067
Name writing Pause %	-.245	.119
% pauses above 10 seconds on Free-writing	-.274	.079

Note. ** $p < 0.01$ level. * $p < 0.05$ level.

Table 8.12

Correlations between Grip strength of Dominant and handwriting measures for both groups separately.

Measure	DCD		TD	
	r	p	r	p
Handwriting Product				
Handwriting Speed				
Copy Best words per minute	.221	.311	.562	.012*
Copy fast words per minute	.266	.219	.435	.063
Alphabet letters per minute	.170	.439	.206	.397
Free-writing words per minute	.217	.320	.512	.025*
Legibility				
Copy Best % illegible words	-.070	.750	-	-
Copy Fast % illegible words	-.369	.083	.180	.460
Free-writing % illegible words	-.139	.526	.210	.409
HLS total score	-.121	.582	-.161	.510
Handwriting Process				
Percentage of Pausing	.095	.668	-.200	.411
Copy Best Pause %	.072	.745	-.447	.055
Copy Fast Pause %	.199	.363	-.277	.252
Alphabet Pause %	.092	.678	-.385	.103
Free Writing Pause %	.031	.888	-.286	.235
Name writing Pause %	.029	.896	-.401	.089
% pauses above 10 seconds on Free-writing				

Note. ** $p < 0.01$ level. * $p < 0.05$ level.

8.6.4.3.6 Regressions for Grip Strength and Handwriting Measures:

To examine the relationship between grip strength of the writing arm and legibility, the HLS total score was used as the outcome variable for the analysis. This revealed that grip strength for the writing hand explained 17% of the variance (R^2=.17, F(1,40)=8.36, p=.006) (see Table 8.13).

For handwriting speed the alphabet task was used for analysis. Grip strength of the writing hand was found to explain 16% of the variance (R^2=.16, F(1,40)=7.39, p=.010) (see Table 8.14).

In terms of the pausing percentage, the Copy Fast pause percentage was used for the analysis since this was the only measure of pausing that correlated with grip strength. Grip strength was found to predict 16% of the variance (R^2=.16, F(1,40)=7.54, p=.009) (see Table 8.15).

Table 8.13

Regression analysis: Grip Strength as a predictor of performance on the HLS for both groups

	Standardised coefficients		Unstandardised	
	Beta	Standard error	coefficients	*p*
Grip strength	-.307	.106	-.416	.006 *

*Note. *p < 0.05*

Table 8.14

Regression analysis: Grip Strength as a predictor of the number of letters produced on alphabet task

	Standardised coefficients		Unstandardised	
	Beta	Standard error	coefficients	*p*
Grip strength	1.04	.385	.395	.010 *

*Note. *p < 0.05*

Table 8.15

Regression analysis: Grip Strength as a predictor of percentage of pausing during the free-writing task

	Standardised coefficients		Unstandardised	
	Beta	Standard error	coefficients	*p*
Grip strength	-.573	.209	-.398	.009 *

*Note. *p < 0.05*

8.6.5 Sensitivity of the VMI in identifying children with Poor Legibility

There were 45 children with VMI and HLS data. Twenty four of these children scored below 1SD of the TD mean on the HLS total score. The results indicated that the VMI identified 10 of these children, notable by a standard score below 85 (-1SD). Fourteen scored below 1SD of the TD group on the HLS but were not picked up by the VMI. Therefore the VMI had a sensitivity of 41.7% which falls below the suggested level for clinical utility of 80% and above (Glascoe cited in Volkmar, Paul, Klin, Cohen, 2005).

With regards to specificity, there were 18 children who scored within 1SD of the TD mean on both tests, but three who scored poorly only on the VMI. The specificity was therefore 85.7% which falls above the suggested level for clinical utility of 80% or above (Glascoe cited in Volkmar et al, 2005). Table 8.16 represents the distribution of scores for the HLS and VMI.

Table 8.16.

Distribution of scores for the HLS and VMI for both groups together

	HLS poor (<1SD TD mean)	HLS good (<1SD TD mean)	Total
VMI poor (<1SD TD mean)	10	3	13
VMI good (<1SD TD Mean)	14	18	32
Total	24	21	45

8.7 Discussion

The previous chapters in this thesis have highlighted difficulties with various aspects of handwriting and writing in children with DCD. One of the challenges in this area is identifying factors that might contribute to their difficulties. While some factors have already been assumed by clinicians to influence handwriting difficulties, many of these factors have not been tested empirically, yet have been used in clinical practice. However, the clinicians need to consider the evidence to ensure evidence based practice (COT, 2010). The literature on underlying mechanisms of DCD has referred to difficulties with visual-perception and significant deficits in visual motor integration, particularly in tasks which require speed (Wilson & McKenzie, 1998). However, the extent to which these deficits can explain difficulties with handwriting in children with DCD is something which has been queried in the literature by authors such as Rosenblum and Livneh-Zirinski (2008). The aim of this chapter was to examine the theories proposed by Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010) in relation to visual perception as a contributor to difficulties with handwriting. In addition, the suggestions that reduced physical strength and inappropriate force control might underlie poor handwriting performance (Chang & Yu, 2010) were also examined.

In terms of group differences, the DCD group performed below their TD peers on both visual perception measures and measures of grip strength, but did not exert more or less pressure on the writing surface than their TD peers. In terms of visual perception and strength, the findings of this study support previous research, where children with DCD were found to score below their TD peers on tests of visual perception (Tsai, Wilson & Wu, 2008) and strength (Raynor, 2010). However, in terms of pressure on the page, no significant group differences occurred on any of the handwriting tasks which were in contrast to Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010). This may have occurred for a variety of reasons including sensitivity of the writing tablet itself, but this is unlikely given that this study along with that of Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010) used the same tablet manufacturer (Wacom Intuos).

The main purpose of this study was to examine the relationship between measures of visual perception and grip strength, with measures of handwriting. One of the reasons for doing so was based on the use of visual perception tests in the context of handwriting assessment in paediatric occupational therapy practice. While a few studies have investigated the efficacy of using such measures in assessing handwriting, none have looked exclusively at the use of visual perception tests on children with DCD in relation to handwriting performance. Klein et al (2011) included a sample of children with DCD (n=15) in their study, but did not elaborate on their performance, or report correlations specifically for the DCD group. In the present study, both groups were analysed separately and together for the correlational analyses. However, for a majority of the analyses, relationships were found only when combining both groups together. This may have been attributed to the lack of range in the data of both groups and the possibility that the relationship was driven by both groups performing in a polarised way. Nevertheless, moderate to strong negative relationships were found between the VMI and the legibility measures (HLS total score and percentage of illegible words on the DASH tasks) and percentage of time spent pausing on copy best, copy fast and name writing. However, no significant correlations were found with speed. In relation to the TVPS, this study also found moderate to strong correlations between the TVPS and speed (words per minute), legibility (HLS) and pausing percentage (copy fast). However, correlations only provide information on the association between measures and it was important to investigate this further. The regression analyses revealed that the VMI explained 31% of the variance for legibility and only 7% of the variance of the percentage of pausing. While these findings imply that there is an overlap with the VMI and legibility, the fact that the test failed to explain 70% of the variance suggests that there are additional factors independent of visual motor integration that influence handwriting performance. The overlap between the VMI and legibility as measured by the HLS is in some ways expected, as the HLS examines factors such as letter formation and alignment on the page through the position of horizontal, vertical and circular strokes, similar to that required in the VMI. However, it is also important to recognise the nature of the norms for the VMI, as the test was developed on American children with no current norms available for the UK.

Irrespective of the overlap between the VMI and the HLS, the important clinical question lays in whether the VMI can identify difficulties with handwriting. In this study the VMI was found to be low on sensitivity as it failed to identify 14 children who were poor on the HLS. These findings appear to support the statement by the authors of the Dutch handwriting guidelines, where the VMI is not advocated for use in detecting poor handwriting (Nijhuis-van der Sanden & Overvelde, 2010).

Similar outcomes to that of the VMI were also found for the TVPS, where significant correlations were found between measures of speed, legibility and pausing. However the regression analyses indicated that the TVPS only explained between 10-17% of the variance for these measures. These findings suggest that factors other than motor-free visual perceptual skills contributed to the handwriting performance in this study.

Another aspect of performance which was evaluated in this study was related to grip strength, as this was an area proposed by Chang and Yu (2010) for investigation, but also an area which is often isolated for intervention in relation to handwriting. In this study, significant relationships were found between grip strength and measures of handwriting speed and legibility. However, the regression indicated that grip strength only explained between 15-17% of the variance in these areas. Similar to the issues which have emerged with the TVPS, this again appears to indicate that other factors are at play other than grip strength. In terms of the use of a sensory integration frame of reference, where activities are used to improve hand strength; the lack of variance explained by the grip strength measure would imply that this approach may be unnecessary.

In summary, this chapter has demonstrated that children with DCD are below their TD peers on popular measures of visual perception and visual motor integration. However, neither of these measures could explain a substantial amount of the variance, which suggests that there are other factors influencing handwriting performance in this population. In addition, although the children with DCD were weaker than their TD peers, this did not seem to explain much of the variance in their handwriting performance either. The DCD group were not found to press harder on the page than the TD group contrary to previous anecdotal evidence. Based on these findings which examined the ICF level of *body function*, it is suggested that the focus of clinical practice should remain embedded within top-down approaches at the level of *activity*, where the person, task and environment are considered (EACD, 2011) rather than the search for underlying mechanisms.

8.8 Implications for Practice from This Chapter

1. Children with DCD scored below their TD peers on measures of visual perception and grip strength, however although there are group differences this does not mean that they are underlying mechanisms of poor performance. Clinicians need to avoid implying causation based on group differences alone.

2. Despite anecdotal evidence to suggest otherwise, the children with DCD did not press any harder on the writing surface than TD peers. Therefore, therapists need to carefully consider the evidence when intervening at the level of *body functions* to rectify force, as this does not appear to be an issue when measured.

3. Given the lack of variance explained by the measures examined in this chapter, it is suggested that clinicians focus on using top-down approaches to intervention at the ICF level of *activity* (WHO, 2001) rather than bottom up, process orientated approaches embedded in the level of *body functions*.

Chapter 9

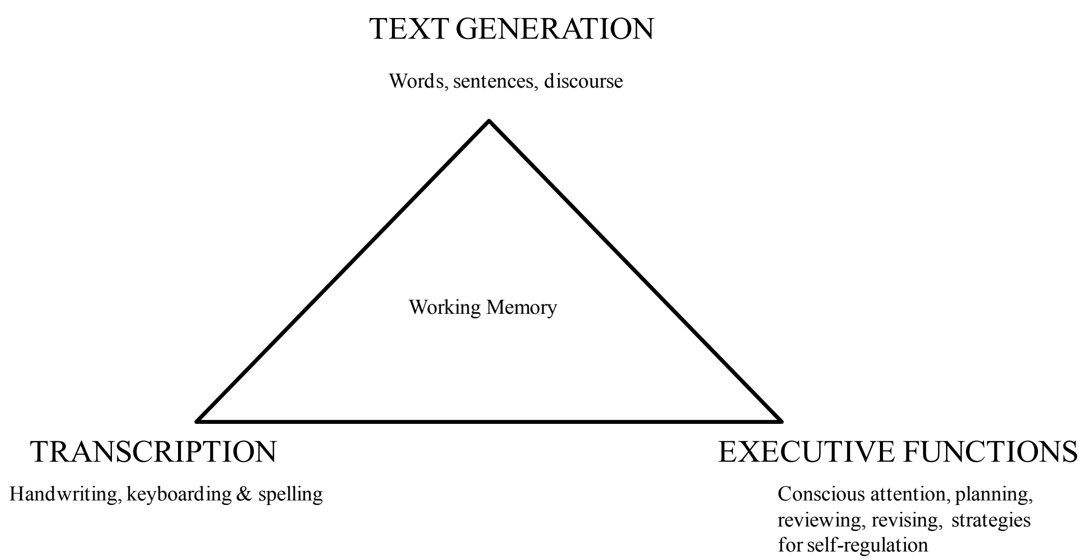
General Discussion: A Framework and Guidance for Practice

9.0 Introduction

The overarching aim of this thesis was to explore in detail the performance of children with DCD on a range of handwriting measures. This final chapter brings together the key findings from this thesis and proposes a framework through which handwriting difficulties in children with DCD can be considered. The findings from this thesis are discussed and consolidated through a proposed model of handwriting within a broader framework of writing. This is followed by discussion surrounding the practical implications of this thesis. The limitations of the four studies are also discussed, followed by final conclusions.

9.1 Theoretical Implications

An important component of this thesis was to consider handwriting in a holistic manner within the wider task of writing and to investigate handwriting performance in children with DCD within the context of an established writing model. In the absence of a holistic framework inclusive of the processes of handwriting, the 'simple view of writing model' (see Figure 9.1) (Berninger & Amtrann, 2003) was combined with Van Galen's model of handwriting (see Figure 9.2) to serve as a theoretical framework for the analyses in this thesis.



Note: Working memory activates long-term memory during composing; short-term memory during reviewing

Figure 9.1. A Simple View of the Berninger & Swanson (1994) model (taken from Berninger & Amtmann, 2003).

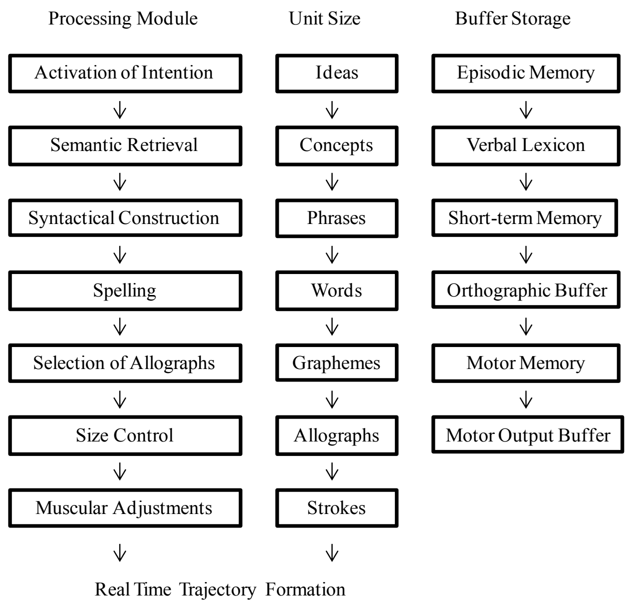


Figure 9.2. The process modules from Van Galen's (1991) Psychomotor Model of Handwriting.

At present, there is no single model which incorporates the literature from both writing and handwriting. Such a model would frame handwriting within the context of writing and serve as a lens through which therapists can consider performance. The application of theory to clinical practice in the field of handwriting is crucial, as although both the 'simple view of writing' (Berninger & Amtrann, 2003) and Van Galen's (1991) model of handwriting have been commonly applied in the fields of psychology, psycholinguistics and writing, it is often neglected in the literature on handwriting remediation. For example, many studies undertaken by occupational therapists have failed to mention any theoretical grounding in relation to handwriting. This suggests that handwriting is separate from the overall writing process and promotes the idea that it is an isolated motor skill. This is problematic, as it reinforces approaches to intervention which are embedded in the ICF level of *body functions* (WHO, 2001) rather than considering the whole task at the level of *activity*.

An important reason for creating a model for therapeutic use is to promote the relationship between the handwriting processes and writing quality, so therapists can consider a child's performance within the context of the whole task. By creating a more explicit link between handwriting performance and writing and discussing the findings of this thesis through such a framework, it may inform therapists about the nature of handwriting difficulties in children with DCD and their wider implications.

The following section proposes an integrated model of handwriting and writing skill. It will be used as a framework to discuss the findings of this thesis with the aim of assisting therapists to think holistically about handwriting difficulties in children with DCD.

9.2 Proposing an Integrated Model of Handwriting and Writing for Clinical Use

The application of both the 'simple view of writing' (Berninger & Amtrann, 2003) and Van Galen's (1991) model of handwriting in this thesis was useful, as both models offered a theoretical framework for different aspects of the investigation. However, a criticism of the 'simple view of writing' involves the lack of information surrounding the production of handwriting movements. While Van Galen's model of handwriting (1991) supplemented this and is the most complete model of handwriting in the literature (Connelly et al., 2012), evidence to support the model comes from typically developing handwriting. While the model helpfully outlines the processes of handwriting, it would be useful to expand it in order to describe in greater detail the processes affected by poor performance in children with DCD.

Figure 9.7 proposes a framework for considering writing and handwriting in unison in children with DCD. It integrates both Van Galen's handwriting model (1991) and the 'simple view of writing' (Berninger & Amtrann, 2003) with the findings from Chapters 4-8 in this thesis. The framework illustrates firstly the wider context of writing and how handwriting is not just an isolated motor skill, but is intrinsically related to the wider task of writing. Indeed the findings from this thesis indicated that children with DCD had difficulties with transcription skills, particularly handwriting, and this was shown to predict the compositional quality of their text.

Berninger and Swanson (1994) emphasised that transcription skills are the first skills to be learned in young writers and in the process, act as a constraint on the higher level processes of writing. Therefore transcription will be the first area to be considered for discussion. The model will be introduced section by section by using figures which provide a visual representation of each part of the model (see Figure 9.3 and 9.6). The complete model is presented in Figure 9.7. The first section to be introduced is that of transcription.

9.2.1 The Level of Transcription

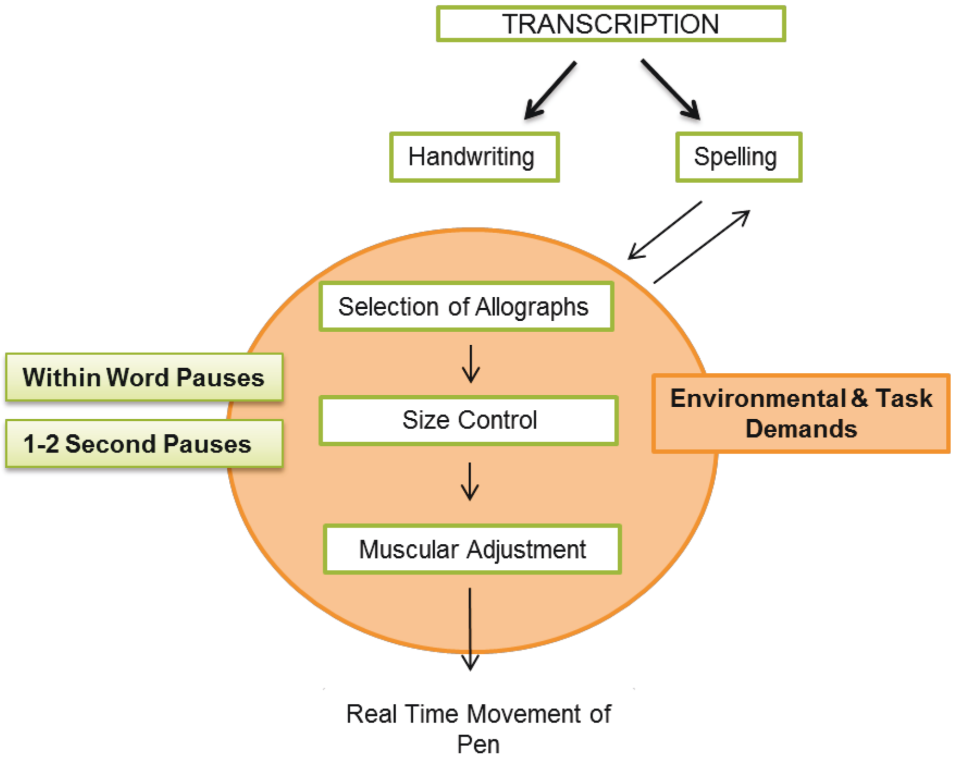


Figure 9.3 The transcription level of the model

Before discussing the individual modules within transcription, one area which was influenced by the processes of transcription appeared to be the pauses. Indeed, a lack of fluency in the writing process did emerge in the DCD group through within word pausing, as the DCD group spent a greater amount of time pausing within words compared to their TD peers. According to research by Kandel et al (2006), the spelling and movements necessary to produce text are programmed prior to execution and online thereafter. Since the DCD group spent a greater amount of time pausing within words, this would suggest that they had difficulties with processing information on-line (Kandel et al, 2006), which would indicate overloading of working memory resources.

Another interesting finding in relation to pausing was the pauses observed between 1-2 seconds in Chapter 4. In the analysis of pausing, the TD group was observed to pause for a greater percentage of time within 1-2 second time frames. In the literature on writing, the more experienced the writer, the more processes they are able to manage on-line or in small periods of pausing (Alamargot et al., 2010).

Since the TD group paused more within this timeframe it suggests that they were able to manage the sub processes outlined below in an effective manner needing only 1-2 second pauses to manage higher level processes. In contrast, the DCD group was forced to pause for greater periods, which may indicate failure on the part of the writing system in handling processes simultaneously. It is therefore proposed that although at an individual level the processes outlined under handwriting did not illicit a higher percentage of pausing, the combination of spelling along with the sub-processes of handwriting may have done so. By having to manage the processes of transcription which were under-developed in the DCD group, there was too much pressure exerted on the writing system and as a consequence, longer pauses were made as a result. This is supported by the fact that the TD group spent much of their pause time within small timeframes, indicating an ability to manage processes in parallel.

9.2.1.1 Spelling

In 'the simple view of writing' (Berninger & Amtrann, 2003) model and similarly in the model proposed here, transcription consists of two components; spelling and handwriting (Berninger & Swanson, 1994). In this research programme all participants were carefully assessed for spelling ability and those that scored below the average range on spelling were analysed separately before being integrated into the wider DCD group. This was to ensure that spelling ability did not confound the handwriting production measures. However despite performance within the average range on spelling as a group, the children with DCD made a higher percentage of spelling errors in the free-writing text compared to their TD peers. Although the reason for this is unclear and warrants further investigation, particularly in relation to the nature of the spelling errors, one possible influence on this could have stemmed from the reduced working memory resources as a result of underdeveloped handwriting. While it is recognised that spelling is usually programmed prior to the execution of handwriting (Kandel et al, 2006), it is possible that the pressure exerted on a vulnerable writing system through the demands of handwriting may have impacted on the execution of accurate spelling. On the other hand, this is something that should be examined in more detail in the future, as depending on the type of spelling errors (orthographical versus phonological) the likelihood of handwriting impacting at this level could be examined in a more robust way. However, based on the findings of this thesis, the main source of the difficulties in transcription lay within handwriting production itself.

9.2.1.2 Handwriting

The studies in this thesis revealed handwriting as a significant issue in children with DCD. The DCD group produced fewer words on the handwriting tasks compared to their TD peers. They also had a higher percentage of illegible words and were poorer on a test of legibility. The findings in relation to the handwriting product and process will be discussed under the appropriate subheadings below. The subheadings relate to three different areas for the production of handwriting (selection of allographs, size control and muscular adjustment).

9.2.1.2.1 Selection of Allographs

The first step in the production of handwriting is to select the appropriate allograph (letter), which according to Van Galen (1991) is the activation of the motor program (a set of motor commands that defines the essential details of a skilled action (Schmidt & Wrisberg, 2008). The higher percentage of illegible letters on the DASH handwriting tasks and the poor score for letter formation on the HLS (Barnett et al, 2013), would indicate that the 'selection of allographs' is affected in some way in children with DCD. For example, part of the scoring criteria for the HLS (Barnett et al, 2013) is to consider missing elements in letters within the component of letter formation. If a letter is missing an element it is likely to be an issue with the motor program, in that, the letter was not programmed correctly in the first instance. In addition, the DCD group had a greater amount of overwriting on letters in terms of trying to add or take away elements following production. This again suggests possible issues with the motor program, as if all elements of letters were produced, it would reduce the need for overwriting. However, the mechanism responsible for this is unclear. In the previous literature on handwriting in children with DCD, Rosenblum and Livneh-Zirinski (2008) suggested difficulties with retrieving the correct letter form from memory as a possible explanation for the pausing phenomenon. The same authors also proposed issues with visualising the letters prior to forming them. In this thesis, the issue of visual perception was addressed, and although the DCD group were poorer in the measures of visual perception and visual motor integration, neither of them explained a large amount of variance for performance on legibility. Missing elements of letters contributes to poor legibility and does not appear to be linked with issues to do with visual perception or visual motor integration.

At the level of *selection of allographs*, this is also where the type of script is activated (joined, un-joined, capital letters, small letters) (Van Galen, 1991). In this thesis, the frequency of handwriting style (joined versus un-joined) was analysed in both groups. The results revealed that a majority of the children in the DCD group opted for an un-joined style of handwriting. However this did not seem to relate to speed or legibility. Although a larger scale study is needed which includes an investigation of how handwriting is taught to children with DCD, it was apparent from the study in this thesis that handwriting style did not influence performance.

9.2.1.2.2 Size Control

Following the activation of the motor program the module of size control and speed is activated (Van Galen, 1991). In terms of handwriting speed, this was not an area of difficulty for the children with DCD, as Chapter 4 indicated that although the DCD group produced fewer words than the TD group on the handwriting tasks, this was not due to execution speed of the pen. The children with DCD were able to move the pen just as quickly as the TD group and were observed to increase in speed for the Copy Fast task.

Despite similar performance on execution speed compared to the TD group, there may be difficulties with the level of *size control* in relation to legibility, as inconsistent/varied letter size was an issue for the DCD group as measured by the component of letter formation on the HLS. However, this is an area that warrants further investigation, as although it is apparent that there are difficulties with letter size consistency, this could be measured in a precise way using writing tablet technology. For example, the distance travelled by the pen during a particular word could be calculated and compared between groups. This particular type of analysis was outside the scope of this thesis, but could be an area to examine in greater detail in the future. Figures 9.4 and 9.5 illustrate the difference in size control between the copy best task and when the demands of the task were increased during the copy fast task. Both figures are a sample from the same boy with DCD aged 10 years and 1 month and show the increase in size.

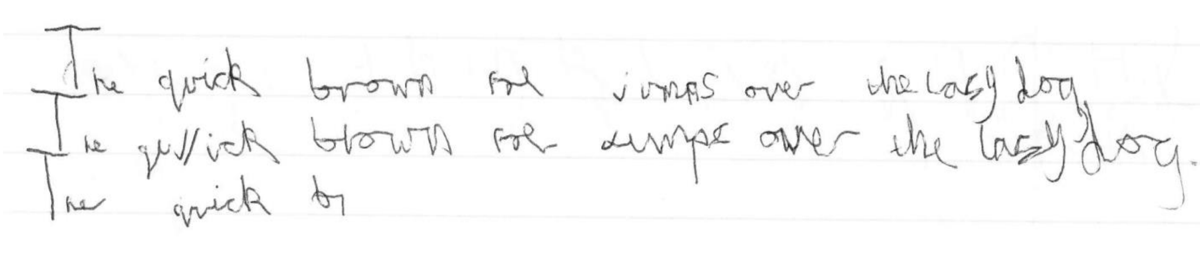


Figure 9.4 Letter size of 10.01 year old boy with DCD on Copy Best

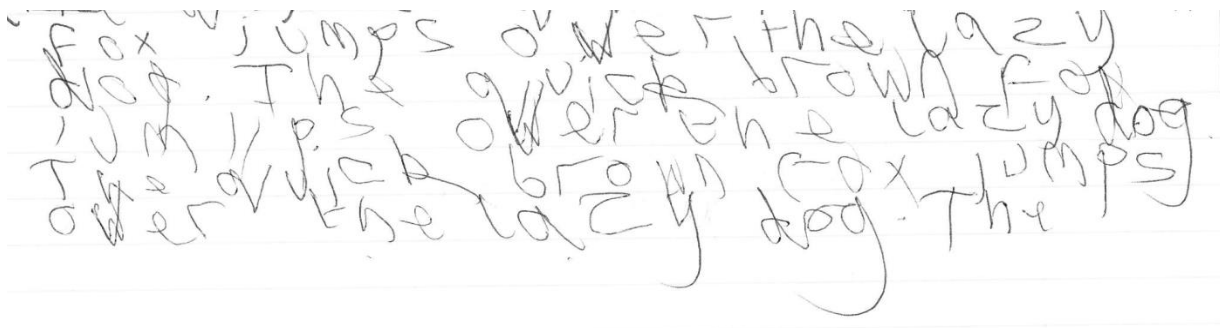


Figure 9.5 Letter size of 10.01 year old boy with DCD on Copy Fast

9.2.1.2.3 *Muscular Adjustment*

The module of *muscular adjustment* involves the recruitment of muscle synergies from both the agonist and the antagonistic muscles, which results in the real time movement of the pen (Van Galen, 1991). From the perspective of speed, given the lack of group differences for execution speed, the temporal aspects of muscular adjustment did not seem to be an issue for the DCD group. In addition, the analysis of pausing in Chapter 4 highlighted that the DCD group did not spend any more time than the TD group pausing within the smaller threshold of 30-250ms, which is thought to be representative of muscular adjustments between letters. However, in relation to legibility, the level of *muscular adjustment* seemed to be an issue, as although the DCD group could move the pen at speed, the quality of the output was poor, as the DCD group had a higher percentage of illegible words on the DASH tasks and were below the TD group on the HLS. There was also a strong correlation between manual dexterity scores and the total score of the HLS when both groups were combined, along with moderate correlations when the groups were separated.

Although the total score of the HLS measures different aspects of legibility, given the relationship with manual dexterity, the muscular adjustment necessary to control the pen may not be as accurate for children with DCD compared to the TD group. However, this may not be the source of the problem, as it is plausible that the difficulties stem from the motor program itself, where children with DCD failed to learn the details of the task when taught initially at school. Research in relation to the CO-OP intervention (Polatajko & Mandich, 2004) suggests that children with DCD are capable of adequate performance in everyday tasks, but struggle to do so unless they understand the steps involved in executing a skill (Polatajko, 2013). It is therefore possible that the children with DCD failed to understand the demands of letter formation from an early stage and as a consequence, continued to execute motor commands that lacked the essential details for appropriate letter formation. Interestingly, in terms of the process, the alphabet task which requires the correct formation of individual letters was the only task in which the DCD group did not differ on pausing. This suggests that the DCD group shared a similar handwriting ‘pausing’ profile to their TD peers for the production of letters, but failed to produce letters of similar quality to the TD group. This is an area that could be explored in more detail but would require an investigation of how children with DCD are taught handwriting, whether they understand the process of letter formation or indeed how much practice they engage with from the beginning.

Another area that was considered under the module of *muscular adjustment* was the pressure exerted on the work surface. This was of interest, as it is commonly perceived that pressures is a problematic area for children with DCD in clinical settings (Cermak & Larkin, 2002), but has not been supported in the literature (Rosenblum & Livneh-Zirinski, 2008; Chang & Yu, 2010). Until now, the research which examined work surface pressure in children with DCD was undertaken in languages such as Hebrew and Taiwanese, which require different movements compared to the Latin based alphabet. For example, Hebrew involves writing from right to left, which requires a pushing movement rather than a pulling movement needed in right handed, Latin base writers. However, the study in Chapter 8 in this thesis supported the previous findings by Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010) where children with DCD were not found to exert more force onto the page than their TD peers. The findings in Chapter 8 revealed no group differences for pressure on any of the handwriting tasks. This was an alternative finding to those in Taiwan and Israel, as both Rosenblum and Livneh-Zirinski (2008) and Chang and Yu (2010) reported less pressure in children with DCD. This may have been attributed to the mechanics of writing within alternative writing systems or indeed the type of writing tablet used.

The issue of pressure on the work surface which was examined in the previous literature informed an investigation of grip strength in this thesis. One of the theories proposed but not tested by Rosenblum and Livneh-Zirinski (2008) in relation to writing surface pressure was a lack of strength and endurance in children with DCD. Chapter 8 in this thesis demonstrated that the DCD group were below their TD peers on the measure of grip strength on both the writing and non-writing hand. However, this did not predict much of the variance in relation to the measures of handwriting. This finding suggests that any issues with legibility as a result of poor muscular adjustment did not stem from differences in strength. In addition, the lack of variance explained by grip strength goes some way to support a move away from interventions at the ICF level of *body functions,* as the source of the problem did not appear to stem from physical strength.

9.2.1.2.4 Environmental and Contextual Constraints

The inclusion of a range of handwriting tasks permitted an investigation of contextual and environmental issues. Figures 9.4 and 9.5 demonstrate the difference in size control in the handwriting of children with DCD depending on the demands of the task. However, Van Galen's (1991) model does not take into consideration environmental or contextual factors. The possible impact of increased task demand or environmental constraints on the handwriting processes (selection of allographs, size control and muscular adjustment) were not discussed in Van Galen's (1991) model. Given the findings of this thesis and particularly in relation to Figures 9.4 and 9.5, it is apparent that when the task was changed from writing in ones 'best' handwriting to writing as 'quickly as possible', the size of the letters and alignment on the page changed substantially. Both of these issues were measured during free-writing on the HLS (Barnett et al, 2013) which confirmed difficulties in these areas. However, factors such as alignment on the baseline and letter sizing are partially constrained by the environment, in that, the positioning of letters depends on the width of the lines on the paper. Indeed some assessment tools for handwriting do not provide lines at all, as the BHK (Hamstra-Bletz et al, 1987) and the SOS (Van Waelvelde et al, 2012) require the child to produce the handwriting on an unlined page. This would arguably have an effect on the production of handwriting in terms of parameterising the motor program. Although it is unclear whether the size control difficulties which emerge during task loading are due to incorrect motor programming, an inability to control the parameters of the motor program (letter size) or whether poor muscular adjustment is a factor, it is apparent that there are issues within these areas when adapting to task demands. Therefore, in the proposed model (Figure 9.3) the three sub-processes of handwriting are encapsulated within *environmental* and *task demands* (shaded in orange). This proposes that the handwriting performance of children with DCD should be considered within the context of both the task and the environment. Should these factors go un-noticed; therapists run the risk of misdiagnosing handwriting difficulties. Figure 9.4 and 9.5 illustrate this point; if a therapist only considers the child's best handwriting, they would not observe the difficulties presented in Figure 9.5. Equally, if a therapist considers only 'fast' handwriting, then they may be led to believe that the child cannot form letters correctly. We can see from Figure 9.4 that the child is able to form most letters in an adequate manner, but considering only the copy fast task would not allow for this observation.

The overall aim when providing interventions for children with handwriting difficulties is to enable them to engage in free-writing activities which are common in the classroom and required in examinations. Given the issues observed in relation to task demands, it may be best practice to include free-writing when assessing handwriting. This way, all of the processes of writing are at play and it can provide insight into how the child copes with the demands of writing. In addition, through examining free-writing tasks, the quality of the written text can be evaluated, which also provides insight into the possible limiting effect poor handwriting has on writing. Indeed this has been found to be the case in this thesis and as a result, the impact of handwriting on writing is embedded in the proposed model. The following section will discuss how the difficulties associated with the level of transcription had a limiting effect on compositional quality in this thesis.

The next section of the model to be introduced is that of Text Generation. See Figure 9.6.

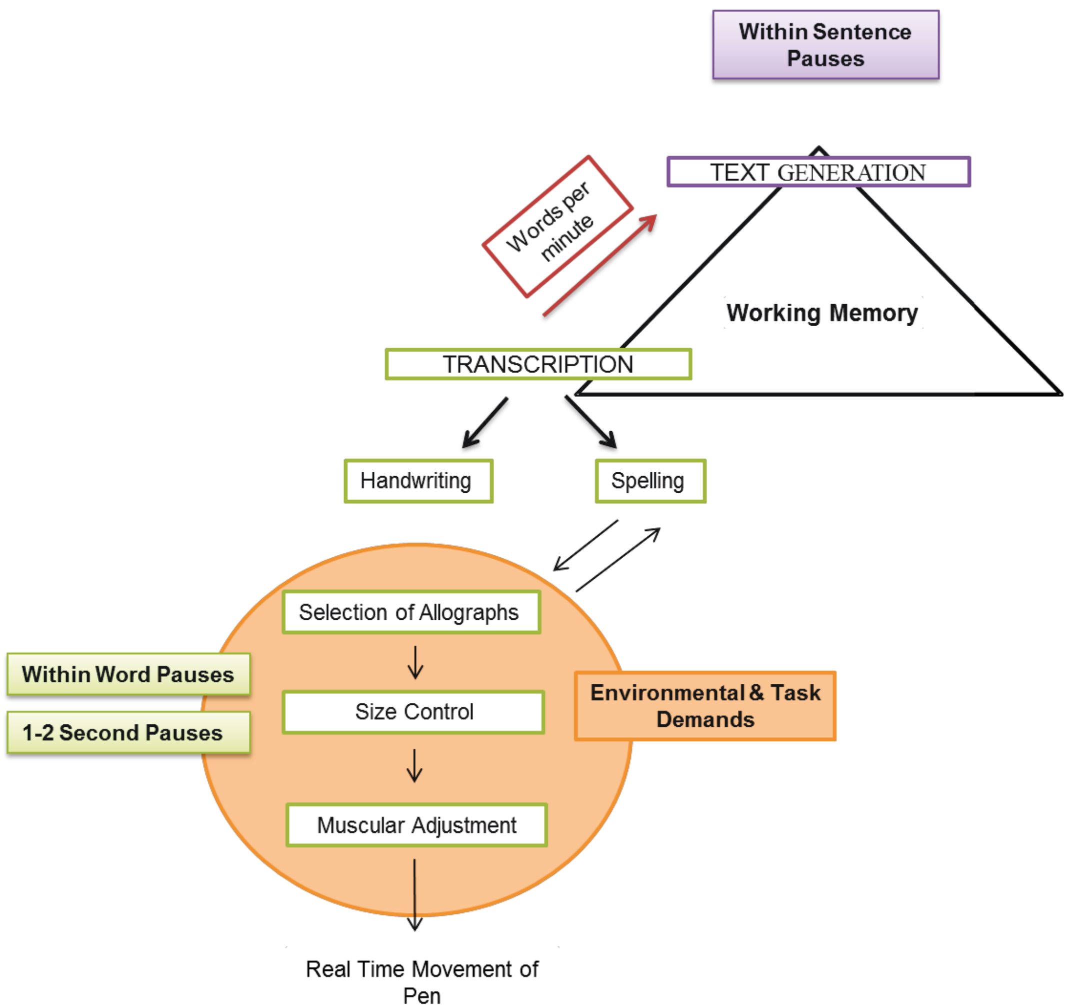


Figure 9.6 The addition of text generation to the model

9.2.2 The Impact on Text Generation

In comparison to the TD group, the DCD group produced texts that were graded as lower quality, with lower scores than peers on organisation of text, vocabulary, sentence structure, grammar and punctuation. Their difficulties at the level of transcription (highlighted in purple) were shown to impact on their overall writing quality, as regression analyses revealed the number of words per minute (presented in red) along with the percentage of misspelled words as significant predictors of writing quality in the DCD group. This suggests that the difficulties with the accurate production of handwriting had an effect on the overall quality of the writing.

From a process point of view, the children with DCD were found to pause for over 10 seconds and this was the driving factor not only in the production of fewer words, but also in the differences observed in the process profiles for both groups. Through coding the locations of the 10 second pauses it was found that the DCD group paused within sentences rather than before a brand new topic (shaded in purple). This indicates that the level of *text generation* was impacted by pausing, as a pause mid-sentence would suggest a disruption in the midst of generating text for production.

The only aspect of writing that was not affected in children with DCD was the generation and development of ideas. This was an interesting finding and went some way to support transcription as a source of the problem, as it indicated that something other than the higher-level process of idea generation was impacting on the overall writing quality of the text. In the other five areas of writing measured via the WOLD (Rust, 1996) scoring criteria, the DCD group demonstrated poorer performance than their TD peers. First of all, the use of vocabulary was below the TD group; yet, there were no group differences on the measure of receptive vocabulary. In the context of writing, the DCD group used simplistic vocabulary which lacked in variety. They demonstrated poor organisation of text, poor sentence structure and grammar and made errors in captalisation and punctuation. The total raw score of the WOLD, which was inclusive of six aspects of writing, was predicted by transcription, particularly words per minute and the percentage of spelling errors. This therefore implies that the difficulties with transcription, particularly the number of words produced per minute alongside spelling errors constrained the quality of writing in children with DCD (red arrow). The implications of this are potentially significant, as the WOLD criteria aligns closely with the national curriculum for writing and implies that handwriting may have a crucial connection with academic performance at school. One way of examining this in a more direct way would be to ascertain the academic grades of children with DCD in the subject of writing. This was not investigated here, as the purpose of examining writing using the WOLD criteria in this thesis was to ascertain whether a more detailed, robust study on writing quality would be warranted. Indeed given the findings from Chapter 6 of this thesis, that would appear to be the case.

The final section of the model includes executive function and completes the model. See Figure 9.7 for complete model.

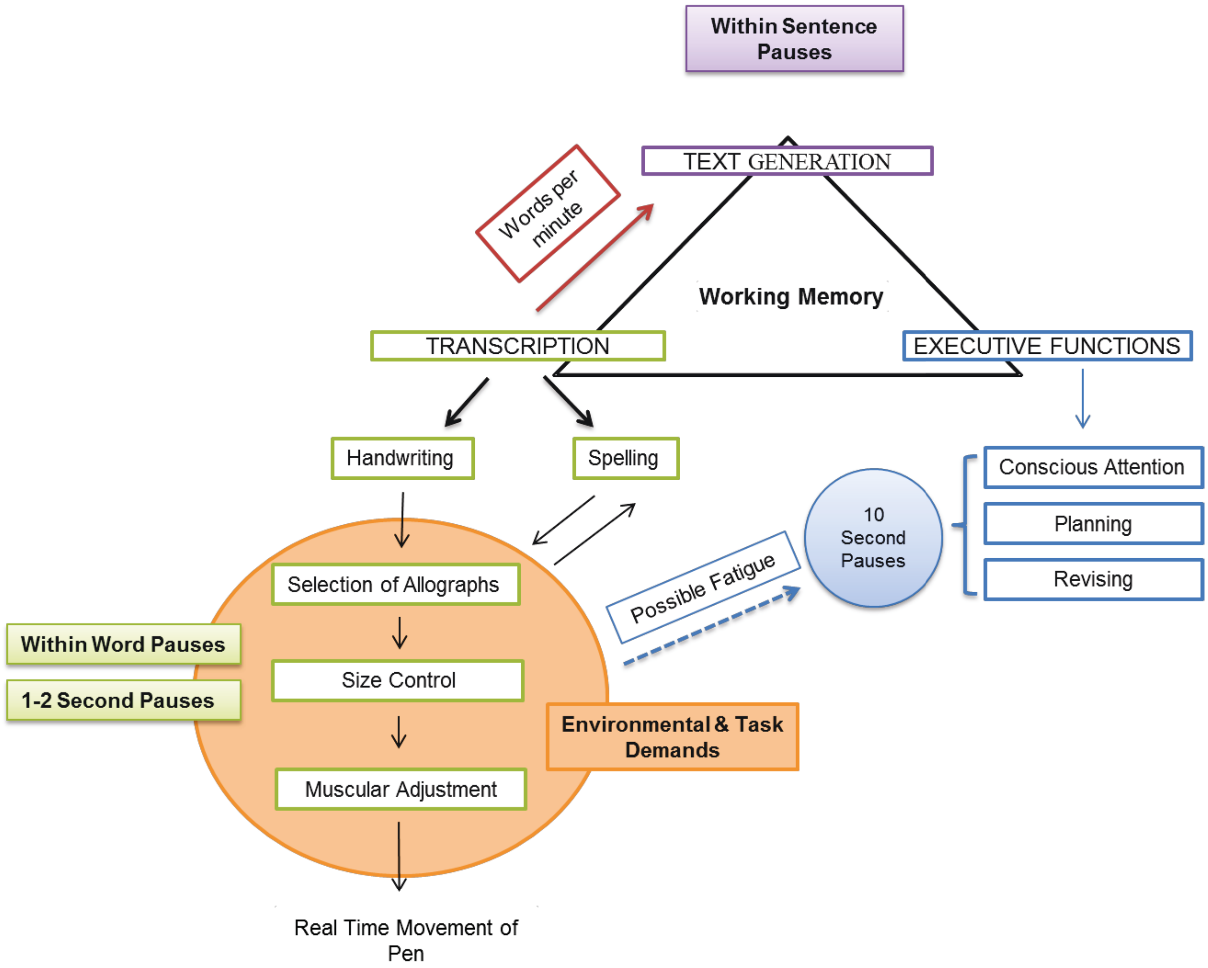


Figure 9.7 The Proposed model of handwriting/writing in children with DCD

9.2.3 Executive Functions

The final component of the proposed model encompasses Berninger & Swanson's (1994) heading of '*executive function*' (highlighted in blue). Executive function includes the higher-level processes such as planning (goal setting, generating and organising the text) and reviewing (reading, error detection and correction). These higher level processes develop once the lower level, transcription skills are established (Berninger & Swanson, 1994). In typically developing writers, the working memory resources, which were once consumed by laboured handwriting and spelling, can be used to self-regulate and modify text while writing. These processes usually occur in parallel, but sequential processing of information can occur if transcription is not yet automatic. Indeed this may be the case with the DCD group in this thesis, as the 10 second pauses which were responsible for reduced output may have been attributed to the area of executive function. One of the limitations of the analysis in this thesis was the lack of investigation surrounding executive functions and as a result, it remains unclear as to what process was driving the longer pauses. However possible theories are discussed in this section which should inform future investigations in this area.

There are three possible reasons as to what may be causing the 10 second pauses in children with DCD. Figure 9.7 presents the three areas within the context of the proposed model in this chapter. It illustrates theories proposed for investigation of executive functions.

9.2.3.1 Attention:

The first area within Berninger & Swanson's (1994) *executive function* is conscious attention. Chapter 1 in this thesis discussed the co-occurring disorders that are common among children with DCD, in particular ADHD. Indeed although the children in this research did not have a diagnosis of ADHD, some of them demonstrated elevated scores on the attention section of the SDQ (Goodman, 1997). However, the children in question were analysed separately to the main DCD group and were not found to execute more pauses above 10 seconds than the other children. Therefore, attention as measured by the SDQ did not seem to impact on the handwriting process. In addition, as part of the analysis in Chapter 4, the duration of task involvement was recorded. The findings revealed that the DCD group did not terminate the free-writing task any sooner than their TD peers. This indicates that they remained engaged in the task and did not appear to lose interest or abandon the task any sooner than the TD group.

9.2.3.2 Planning & Revising

The discussion in Chapter 4 revisited work by Alamargot et al (2010) in France, where longer pauses made by typically developing writers were investigated using eye-tracking technology. Based on gaze fixations the authors could hypothesis whether the participants were 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. This may be a possible explanation for the longer pauses in children with DCD, where parallel processing fails. As a result, sequential processing may occur, where the child needs to stop in order to access the higher-level writing processes within executive function such as planning and revision. This could be examined using eye-tracking technology in the future, where attention could be separated from processes such as planning and revision through analyses of gaze fixation. Given the impact of the longer pauses on the handwriting process, it would seem like an important area to expand on in future investigations.

9.2.4 Fatigue

An alternative hypothesis in relation to the longer pauses could be less to do with executive function and more to do with physical effort. Chapter 8 illustrated that the DCD group were poorer on a measure of grip strength, which although it is not a measure of endurance, it may have an impact on sustained writing. It may be that the constant physical effort at the level of *muscular adjustment* may have resulted in periods of rest. Indeed while doing so, higher level aspects of writing may have been processed further, but through short respite periods from the physical task of handwriting. One way of investigating this further would be to use biofeedback analysis such as electromyography which would examine the level of muscle activity involved in the production of handwriting over time. By examining how much muscle activation is required over the duration of the task, the issue of whether fatigue occurs during the process could be objectively considered. This is also an area which warrants further exploration and would be an important issue to consider from a therapeutic perspective. Chapter 8 discussed the common use of sensory based approaches to improve strength and endurance in the shoulders and arms of children with handwriting difficulties. By objectively measuring whether fatigue occurs during handwriting, the efficacy of sensory based approaches could be explored in more detail.

9.3 Practical Implications

9.3.1 Extra Time in Examinations

At the end of each chapter in this thesis, practical implications of the findings were proposed. One of the first findings in this thesis was in relation to the 10 second pausing, which was shown to impact the production of text and subsequently writing quality. One practical implication which follows from this particular finding is in relation to 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. However, schools need to seek approval from their local authority, which oversees education within their jurisdiction. Historically in order to gain approval, students had to undergo a formal assessment from a professional, for example, an educational psychologist or an occupational therapist (DfE, 2013). This was required in order to formally assess whether extra time was necessary. However, the mandatory assessment by a professional is no longer required (DfE, 2013). Instead, the teacher's knowledge of the child and their ability to assess the child's level of need is called upon when arranging access needs (DfE, 2013). Given the findings in Chapter 7 this new approach may be problematic, as some teachers in the study in Chapter 7 did not recognise handwriting difficulties in the children with DCD, despite difficulties highlighted by formal assessment measures.

In order to receive additional time in exams, the child needs to achieve below the average range for their age on a measure of handwriting speed. This raises two issues, firstly, whether teachers would opt to use a standardised and robust measure of handwriting speed such as the DASH (Barnett et al, 2007) and secondly, whether they would opt to rely on their own observations. If based on observations alone, the issue of whether teachers have the skills to accurately identify difficulties with handwriting poses an issue, as the lack of agreement between the teacher questionnaire and the handwriting measures in Chapter 7 was cause for concern. This leads to the second implication for practice in terms of the need for better cross communication between therapists and teachers to ensure that both disciplines are considering the same factors when evaluating handwriting. The development of the HLS (Barnett et al, 2013) may be influential in bridging that gap, as the total score of the HLS was shown to correlate highly with the DASH percentage of illegible words, while providing a quick, easy and informative assessment for teachers to implement.

9.3.2 Teacher Training

The topic of teacher training is also important to reinforce, as previous research revealed that only 33 percent of teachers reported receiving some training on handwriting during their initial teacher training (Barnett et al, 2006). In addition, over half of the teachers surveyed by Barnett et al (2006) felt they had not received sufficient training on handwriting in their work environment. This undoubtedly adds to barriers in achieving accurate identification of handwriting difficulties in children, as teachers have very little training in how to teach handwriting and what to look for when identifying difficulties. If training on handwriting is not implemented within the teacher training programmes then perhaps a tool such as the HLS (Barnett et al, 2013) would play a valuable role in focusing on the key aspects of handwriting that are needed to produce legible text. However this does not solve the issue of teaching children how to form letters in the early stages of schooling and is something that should be addressed within education itself. The model proposed above (Figure 9.3) discussed the level of *selection of allographs* as a possible issue with the motor program for letter formation. If indeed children with DCD have not learned how to form letters correctly, then the correct motor program is not reinforced.

Teaching children with DCD how to form letters in such a way that they retain it could mean the difference between developing functional or dysfunctional handwriting. Therefore it is imperative that teachers know how to teach these skills effectively.

9.3.3 Importance of Intervention

The model proposed in Figure 9.7 helped consolidate the findings of this thesis into a usable framework through which clinicians can consider handwriting in children with DCD. The findings highlighted the impact of poor handwriting on the wider task of writing and offered a template for the description of handwriting difficulties. Given the relationship between writing and handwriting, this suggests that intervention plays a vital role in improving performance in these areas.

Traditionally, many occupational therapists used a sensory integration frame of reference for handwriting intervention and these are still used in some clinics today. Sensory integration approaches involve activities such as manipulating Play-Doh or Theraputty or completing wall push-ups to increase hand and shoulder strength. The rationale for this was embedded in theories surrounding poor proximal stability and poor strength (Schneck & Amundson, 2010). In order to promote co-contraction of the muscles in the neck, shoulders, elbows and wrists, Schneck and Amundson (2010) proposed that some children may benefit from strengthening exercises. However, the findings from Chapter 8 in this thesis highlighted that some of the approaches used in clinical practice in relation to handwriting performance were not shown to relate to handwriting performance. Factors such as grip strength, pressure on the work surface or the measures of visual perception/visual motor integration did not explain the handwriting difficulties in the DCD group. These findings suggest that focusing on the ICF level of *body structures and functions* does not appear to be adequately supported. Therefore, alternative approaches at the ICF level of *activity* may be an area to focus given its emphasis on promoting skill acquisition rather than attending to underlying mechanisms.

Indeed top down approaches to intervention have been the most efficacious method of skill acquisition in children with DCD (Hoy et al, 2011). Three interventions in particular are advocated for use with children with DCD by the EACD (2011) and would appear to be the most appropriate given the findings of this thesis. The three interventions include Neuromotor Task Training (NTT) (Schoemaker & Smits-Engelsman, 2005) the Cognitive Orientation to daily Occupational Performance (CO-OP) (Polatajko & Mandich, 2004) and Ecological Intervention (EI) (Sugden & Henderson, 2007), all of which are embedded in motor learning theories. The evidence for these task-specific interventions is growing (Wilson, 2005; Sugden, 2007). However, more large scale intervention studies specifically on handwriting need to be undertaken, as handwriting is different to other motor tasks given its close association with language. Figure 9.7 illustrates this connection, while Figure 9.4 and 9.5 highlight the complexity of examining handwriting under different task demands. More research needs to examine the ability of children with DCD to generalise and transfer their newly learned letters into the ecologically valid task of free-writing. Through the use of writing tablet technology, it would be interesting to investigate the best ways to facilitate motor learning in handwriting. This way, an objective measure of the changes in performance that occur could be investigated in detail.

9.3.4 Child Centered Practice

Despite group findings, poor performance was not uniform across all children with DCD. In fact, different profiles emerged through an individual analysis of performance in Chapter 7. In addition, while a majority of children with DCD considered handwriting as an area of difficulty for them, not all children who scored poorly on clinical measures identified handwriting as an area of concern. This finding reinforces key attributes of occupational therapy practice, where client centeredness is fundamental to the profession (COT, 2010). The findings in Chapter 7 suggest that each child's views should always be considered in order to not only ascertain level of insight into their difficulties, but to examine the level of motivation to improve their handwriting. In addition, the fact that all children did not perform in a similar way suggests that assessment needs to be designed in such a way that difficulties can be detected. For example, only one child in the DCD group performed within the typical range on all measures, which suggests that most children had some form of handwriting impairment. While some children had difficulty with both speed and legibility, others only showed difficulties in one of these areas. It is therefore important to acknowledge this within clinical practice and promote the use of holistic, client centered frameworks such as Figure 9.7, through which, difficulties with handwriting can be captured. If only one type of assessment i.e. legibility is used, then issues with handwriting speed may go undetected. Moreover, Chapter 7 highlighted children with DCD who scored poorly on all measures, but they themselves did not consider handwriting an issue. In this instance, therapists could consider using specific strategies for goal setting with the child. For example, in cases where the child wants to work on something else, the therapist could negotiate with the child and combine the goals proposed by the therapist, parent and child. This way, handwriting can be incorporated as a therapy goal, alongside those which are more meaningful to the child (Polatajko & Mandich, 2004).

9.4 Limitations of the Empirical Studies

Different methods have been used in the literature to recruit children with DCD. One such method is that of Cairney et al (2005) where all children within a particular classroom were screened for motor difficulties using the MABC-2 test. In doing so, a random sample of the whole population was ascertained. A limitation of this research programme was the lack of resources to apply a similar recruitment strategy. Therefore, a majority of the children with DCD in this research programme were selected from a population of children with known motor impairments. However, in doing so they were a well assessed group of children who met the DSM-5 criteria for DCD.

The nature of recruiting children with DCD also meant that the children attended a variety of different schools. It was difficult to recruit the TD group from the same schools as the children with DCD, as many of the schols had other research commitments, were very busy or were preparing for an external audit. Therefore, the control group had to be recruited from schools willing to give their time to the project. This meant that the handwriting style taught to the children could not be controlled for. Chapter 5 highlighted that the DCD group had a tendency to use un-joined handwriting compared to the TD group. However, this finding may have been attributed to the specific handwriting policies of the schools the children attended.

In relation to inclusion measures, the DCD group performed within the average range for spelling, but below that of their TD peers. Since the participants were not matched on spelling ability, this may have been responsible for the group difference. This could have been a limiting factor when exploring the issue of percentage of misspelled words, as it is possible that the DCD group performed poorer on spelling within the free-writing task as a result of poorer spelling ability as a group. Future studies should consider controlling for this factor more carefully, given that spelling can act as a constraint on handwriting (Sumner et al, 2013). However, it is important to emphasise that the purpose of measuring spelling in this research programme was to control for dyslexia, rather than analyse spelling performance in great detail.

Another limitation lay in the use of the WOLD scoring criteria with the DASH free-writing task. Although the inter-rater reliability improved and was shown to be sufficient, it would have been a more robust measure of writing had the WOLD task been used in addition to the DASH assessment. However, the participants in this research programme underwent a time consuming assessment process and to have extended the handwriting into a second writing task would have been excessive. It is important to note that the purpose of measuring writing ability using the WOLD criteria was to ascertain whether it was an area worth exploring in greater detail. The results seem to indicate support for such a venture.

9.5 Final Conclusions

Overall, this thesis examined handwriting in children with DCD in extensive detail by considering the handwriting product, the process, the child's perspective, the teacher's perspective and the perspective of popular clinical measures. Understanding the pausing phenomenon in greater detail provides a stepping stone for informing clinicians that poor handwriting is not an issue of *body structures and functions*; children with DCD can move the pen at speed and engage in tasks for just as long as their TD peers. However, they have difficulties with legibility and with pausing for long periods of time. What is driving these longer pauses remains to be seen, but the findings of this thesis have provided a clear starting point for further investigation. By considering handwriting alongside writing, the impact of poor handwriting on the wider task of writing has been highlighted. Further research needs to build on this finding and examine the writing/handwriting relationship in greater detail. This thesis has shown that children with DCD demonstrate significant difficulties with handwriting and the children themselves frequently recognise it to be an issue for them. Not all children share the same handwriting profile and it is important that clinicians reflect this finding in their practice. Above all, this thesis informs the need for intervention and exposes gaps in the communication between therapists and teachers. In order to move forward, teachers and therapists need to be on the same page when evaluating handwriting. The handwriting legibility scale (HLS) (Barnett et al, 2013) developed as part of this thesis may go some way to bridge the health care/education divide. Future research needs to focus on intervention and knowledge exchange to gain an objective measure of handwriting efficacy and promote cross communication between therapists and schools.

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