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Visual perceptual and handwriting skills in children with Developmental Coordination Disorder

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ABSTRACT

Objective: Children with Developmental Coordination Disorder demonstrate a lack of automaticity in handwriting as measured by pauses during writing. Deficits in visual perception have been proposed in the literature as underlying mechanisms of handwriting difficulties in children with DCD. The aim of this study was to examine whether correlations exist between measures of visual perception and visual motor integration with measures of the handwriting product and process in children with DCD.
Method: The performance of twenty-eight 8–14 year-old children who met the DSM-5 criteria for DCD was compared with 28 typically developing (TD) age and gender-matched controls. The children completed the Developmental Test of Visual Motor Integration (VMI) and the Test of Visual Perceptual Skills (TVPS). Group comparisons were made, correlations were conducted between the visual perceptual measures and handwriting measures and the sensitivity and specificity examined.
Results: The DCD group performed below the TD group on the VMI and TVPS. There were no significant correlations between the VMI or TVPS and any of the handwriting measures in the DCD group. In addition, both tests demonstrated low sensitivity.
Conclusion: Clinicians should execute caution in using visual perceptual measures to inform them about handwriting skill in children with DCD.

1. Introduction

Difficulties with the skill of handwriting is cited as one of the most common reasons for the referral of school aged children to paediatric occupational therapy services worldwide (Doyle & Goyen, 1997; Feder, Majnemer, & Synnes, 2000). One group in particular who are known for their difficulties in this area is children with Developmental Coordination Disorder (DCD). These children present with motor coordination difficulties unexplained by a general medical condition, intellectual disability or neurological impairment (American Psychiatric Association (APA), 2013). They fail to develop age appropriate motor coordination skills, with significant difficulties in manual dexterity, ball skills and/or balance (Zoia, Barnett, Wilson, & Hill, 2006). The motor difficulties are commonly accompanied by a range of psychological and social difficulties including low self-esteem, anxiety and depression (Lingham et al., 2012; Missiuna, Moll, King, King, & Law, 2007; Poulsen, Johnson, & Ziviani, 2011). As a result of their coordination deficits meaningful participation in activities of daily living, leisure and play

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are affected (APA, 2013; Polatajko & Mandich, 2004). In particular, the task of handwriting is significantly impacted which is reflected in its inclusion in the formal diagnostic criteria for the disorder (American Psychiatric Association (APA), 2013). Given the high incidence of handwriting difficulties among children with DCD there is a need for a robust evidence base to inform effective assessment and intervention. Although previous work has focused on the assessment of handwriting difficulties in children, including those with DCD (Bo et al., 2014; Volman, van Schendel, & Jongmans, 2006), there remains a debate over the exact nature of their handwriting difficulties. For example, assumptions have been made about the underlying mechanisms which relate to coordination ability and/or difficulties with visual perception (Rosenblum & Livneh-Zirinski, 2008; Volman et al., 2006). However the extent to which visual perceptual ability actually relates to difficulties with handwriting has rarely been investigated and research has traditionally focused on the handwriting product (overall speed and legibility) rather than the process (real-time movement of the pen and time spent pausing) (Volman et al., 2006).

In recent years a knowledge base surrounding the underlying mechanisms of handwriting performance in children with DCD has emerged with the use of digitizing writing tablets. This has enabled researchers to examine not only the product but also the on-line process of handwriting in children with DCD. Specialized software and high speed recording of the position of the pen tip has provided detailed descriptions of spatial and temporal features of handwriting (Jolly & Gentaz, 2014; Prunty, Barnett, Wilmut, & Plumb, 2013; Rosenblum & Livneh-Zirinski, 2008). Prunty and colleagues (Prunty, Barnett, Wilmut, & Plumb, 2014; Prunty et al., 2013) used this approach to examine the handwriting product and process of 28 children with DCD by completing the Detailed Assessment of Speed of Handwriting (DASH) (Barnett, Henderson, Scheib, & Schulz, 2007) on a writing tablet. They found that while children with DCD produced fewer words per minute during the DASH handwriting tasks, this was not attributed to slow movement of the pen but rather a result of excessive 'pausing' during writing (Prunty et al., 2013, 2014). This 'pausing phenomenon' in the handwriting of children with DCD was initially revealed by Rosenblum and Livneh-Zirinski (2008) in Israel, where children with DCD were found to spend considerably more time than controls with the pen in the air. Since then, further studies have characterised these pauses in greater detail and found that children with DCD are more likely to pause for longer periods of time (over 10 s) and pause more frequently within words (suggesting a lack of automaticity) (Prunty et al., 2014). Rosenblum and Livneh-Zirinski (2008) proposed that the inability to retrieve the correct letter form from memory; and/or to visualise the letters prior to forming them might contribute to poor performance in this population. However, neither of these possible explanations were examined by Rosenblum and Livneh-Zirinski (2008) and it remains unclear whether deficits in these areas relate to handwriting performance in children with DCD.

The deficits proposed by Rosenblum and Livneh-Zirinski (2008) are often considered in paediatric occupational therapy practice under the umbrella of 'visual perceptual' skills. For many clinicians these are viewed as skills that underlie everyday functional performance and are therefore a key focus for assessment and intervention. This 'bottom-up', or information processing approach (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012) is frequently embedded in paediatric occupational therapy (OT) practice. In relation to handwriting assessment, tests of visual perception and visual motor-integration have been reported as the most commonly used tests among paediatric OTs worldwide (Burtner, McMain, & Crowe, 2002; Feder et al., 2000; Roger, Brown, & Brown, 2005). Although not designed to assess handwriting performance, the Beery-Buktenica Developmental Test of Visual Motor Integration (VMI: Beery & Beery, 2004) and the Test of Visual Perceptual Skills (TVPS: Gardner, 1982; Martin, 2006) are two measures commonly used with children with handwriting difficulties (Doyle & Goyen, 1997). In a survey by Doyle and Goyen (1997) the VMI was identified as the most popular tool in working with children with handwriting difficulties in paediatric occupational therapy practice in Australia with similar results also found in Canada (Feder et al., 2000). The TVPS (Gardner, 1982; Martin, 2006) has also proven popular in similar surveys (Burtner et al., 2002; Chu & Hong, 1997; Feder et al., 2000; Reid & Jutai, 1997; Roger et al., 2005). According to surveys, therapists use these assessments to either screen children for handwriting difficulties (Wallen & Walker, 1995) or identify possible underlying deficits contributing to their handwriting performance (Goyen & Duff, 2005). In the case of the VMI, the ability of a child to copy the first 9 shapes on the test has been shown to predict handwriting legibility in young children (Daly, Kelley, & Krauss, 2003). It is therefore used to investigate this aspect of handwriting performance in particular. However the relationship between the VMI and handwriting legibility does seem to diminish after the age of 5 years (Pinto & Camilloni, 2012). The TVPS on the other hand does not require a motor component but it measures seven aspects of visual perception in subtests including visual discrimination, visual memory, spatial relationships, form constancy, sequential memory, visual figure-ground and visual closure (Martin, 2006). While there is no mention of handwriting within the test manual, visual perceptual deficits identified by the TVPS are often assumed by practitioners to underlie and contribute to handwriting difficulties, particularly with legibility. For example, according to Schneck and Amundson (2010) if a child has poor visual perception in form constancy, they would not be able to recognise errors in their own handwriting. Similarly, if a child has difficulties with figure-ground or visual closure they may have difficulties copying and producing letters of an appropriate shape or size (Schneck & Amundson, 2010). While most of the subtests have been linked to legibility of handwriting, performance on the visual memory and visual sequential memory subtests have been found to relate to handwriting speed in typically developing children (Tseng & Chow, 2000).

Although popular in clinical practice, these tests have come under scrutiny in recent years with some studies examining their role in detecting handwriting difficulties in children. While no study seems to have examined this in the TVPS, Goyen and Duff (2005) examined the efficacy of using the VMI to identify children with handwriting difficulties. They investigated 35 children aged 9–12 years with handwriting difficulties using a range of handwriting product assessments including the Evaluation Tool of Children's Handwriting (ETCH: Amundson, 1995), the Test of Legible Handwriting (TOHL: Larsen &

Hammill, 1989), and the Handwriting Speed Test (Wallen, Bonney, & Lennox, 1996). Of the 35 children, the VMI identified only 12 of them (sensitivity of 34%) calling into question the use of the measure as a diagnostic tool for handwriting difficulties (Goyen & Duff, 2005).

Despite the wide spread use of these tests and the prevalence of handwriting difficulties in children with DCD, few studies have investigated the role of these tests in explaining handwriting difficulties in this population. This is surprising not only based on the popularity of these measures in practice, but also given the visual perceptual deficits noted in the DCD literature (Volman et al., 2006). Indeed in a meta-analysis by Wilson and colleagues (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013) numerous studies demonstrated that children with DCD exhibit difficulties with visual-perceptual skills and have significant deficits in visual motor integration, particularly in tasks which require speed. However, few studies have examined the relationship between these skills and handwriting performance in children with DCD and the clinical utility of these popular measures in detecting handwriting difficulties. Klein, Guiltner, Sollereder, and Cui (2011) examined the VMI and the TVPS in relation to handwriting speed and legibility in 99 children with a range of disabilities including children with DCD ($n = 15$). They reported that the variance in handwriting explained by both of these measures was $\leqslant$20% for legibility and $\leqslant$26% for speed on copying tasks. As a result, Klein et al. (2011) urged occupational therapists to consider additional factors that may impact on handwriting. However, the analyses conducted by Klein et al. (2011) included children with a variety of diagnoses including learning disability, attention deficit hyperactivity disorder, oppositional defiant disorder and Autism Spectrum Disorder. As a result, the findings are difficult to generalise to children specifically with DCD.

In a more focused study on children with handwriting difficulties Volman et al. (2006) examined 29 children, 26 of whom had motor difficulties consistent with DCD. They found that the best and only significant predictor of handwriting quality on a copying task was visual motor integration, which explained 22% of the variance. No significant relationships were found between visual perceptual skill and handwriting speed. However this sample of children was not assessed in line with the formal diagnostic criteria for DCD. While the children were assessed for motor competency, there was no indication of other measures taken to ensure the children were free from factors which may cause motor impairment (medical condition, neurological impairment or intellectual disability). The impact of the movement difficulties on the child's daily activities which would be necessary for a diagnosis of DCD (American Psychiatric Association (APA), 2013) was also absent. In addition, the study focused specifically on the writing product within a copying task only, even though children are expected to engage in a range of handwriting tasks in the classroom including free-writing and writing from dictation and/or memory. Therefore, there is a need to examine the relationship between these popular visual perception measures across a variety of handwriting tasks in order to understand the extent to which these skills contribute to difficulties in children with DCD. In addition, it is important to examine the relationship between these skills and the handwriting process as the temporal aspects of handwriting are known to be different in children with DCD evident through the pauses in writing described in the literature (Prunty et al., 2014; Rosenblum & Livneh-Zirinski, 2008). Therefore, the aim of this study was to examine the relationship between visual perception and visual motor integration, and a range of handwriting measures including both the product (speed, legibility) and the writing process (pausing during writing). This was investigated in children with DCD across a range of handwriting tasks. The children completed a series of handwriting tasks on a digitizing writing tablet and completed two commonly used tests of visual perception and visual motor integration. The group performances on these measures were used to ascertain the relationship between visual perception and handwriting measures. In addition, sensitivity analyses were conducted on both the VMI and TVPS to determine their role in detecting difficulties with legibility as most of the assumptions made in the literature and within clinical practice relate to this aspect of handwriting (Schneck & Amundson, 2010).

In line with clinical assumptions and a review of the literature, our predictions were that:

1. Visual perceptual skills are poorer in children with DCD compared to TD children.
2. There is a significant relationship between (a) visual motor integration and (b) visual perception with both process and product measures of handwriting performance.
3. The VMI and TVPS have low sensitivity in detecting poor performance on a measure of handwriting legibility.

2. Method

2.1. Participants

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

2.1.1. DCD group

Children for the DCD group were recruited through advertising at parent support groups, schools and through the research group website. All children were assessed in line with European guidelines (Blank et al., 2012) and met the DSM-5 diagnostic criteria for DCD (American Psychiatric Association (APA), 2013). The children had significant motor difficulties, with performance below the 10th percentile (24 below the 5th, 4 below the 10th) on the test component of the Movement Assessment Battery for Children 2nd edition (MABC-2; Henderson, Sugden, & Barnett, 2007). This examines three components of motor competency; manual dexterity, aiming and catching and balance. The motor difficulties had a significant impact on the children's activities of daily living, as reported by their parents and evident on the MABC-2 Checklist (Henderson et al., 2007). A developmental, educational and medical history was taken from parents, which confirmed that there was no history of neurological or intellectual impairment and no medical condition that might explain the motor deficit. The British Picture Vocabulary Scale 2nd edition (BPVS-2, Dunn, Dunn, Whetton, & Burley, 1997) was used to give a measure of receptive vocabulary, which correlates highly with verbal IQ (Glenn & Cunningham, 2005). This was at least in the average range for all children, confirming the absence of a general intellectual impairment. The Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997) was also used to note other behavioural difficulties reported by the parent, which commonly occur with DCD such as attention deficit hyperactivity disorder (ADHD) (Miller, Missiuna, Macnab, Malloy-Miller, & Polatajko, 2001). No child had a formal diagnosis of ADHD, but hyperactive behaviour was noted on the SDQ for seven children. The children were also assessed on the reading and spelling components of the British Ability Scales 2nd Edition (BAS-II; Elliot, 1996). These revealed that eight children with DCD had literacy difficulties (1 in reading, 7 in spelling), as defined by a standard score of less than 85 on the BAS-II components, although none had a formal diagnosis of dyslexia or other language impairment. The performance of the children with low scores on the SDQ and/or BAS had previously been investigated to ascertain whether they performed differently to other children in the DCD group on measures of handwriting (see Prunty et al., 2013). Since no significant difference was found, in the current study all children were analysed together.

2.1.2. Typically developing (TD) control group

The control group was recruited through local primary and secondary schools in Oxfordshire, England. Teachers were asked to use their professional judgement to identify children without any motor, intellectual or reading/spelling difficulties. To ensure the children identified were free of these difficulties, they were individually tested on the MABC-2 Test (Henderson et al., 2007), BPVS-2 (Dunn et al., 1997) and the reading and spelling components of the BAS-II (Elliot, 1996). Children were included in the control group if they scored at least at the level expected for their age on all measures (standard score 85 plus).

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

The study was approved by the University Research Ethics Committee at Oxford Brookes University.

2.2. Measures

2.2.1. Visual perception

2.2.1.1. Beery-Buktenica Developmental Test of Visual Motor Integration (VMI: Beery, Beery, & Buktenica, 2010). The VMI test (excluding the supplementary tests) was used to examine visual motor integration as defined by Beery et al. (2010). The 30 item VMI suitable for those up to age 18 was individually administered according to the manual, taking 10–15 min. The children were required to copy a set of 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. The VMI has US norms and has a reported inter-rater reliability of 0.92, internal consistency of 0.96 and test re-test reliability of 0.89 (Beery et al., 2010). Other authors in Australia (Brown & Hockey, 2013) have found internal consistency of 0.85 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).

2.2.1.2. Test of Visual Perceptual Skills (TVPS: Martin, 2006). The TVPS was used to measure visual perception as defined by Martin (2006). The 112 item test was individually administered, taking 30–45 min for participants to complete. The TVPS utilizes black-and-white designs as stimuli for all of the perceptual tasks. Items were presented in a multiple-choice format;

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

Selection Measures	DCD n = 28	Control n = 28	p
Age in years	10.61 (2.23)	10.95 (2.12)	0.441
MABC-2 Test percentiles:			
Total test score	3.45 (2.96)	43.37 (25.4)	<0.001*
Manual Dexterity	6.41 (8.12)	51.07 (26.82)	<0.001*
Aiming & Catching	21.55 (23.64)	64.67 (20.41)	<0.001*
Balance	5.98 (4.67)	30.42 (19.85)	<0.001*
BPVS-2 Standard Score	108.9 (14.4)	110 (12.2)	0.655
BAS-II Spelling Standard Score	95.8 (13.7)	111 (12.7)	<0.001*
BAS-II Reading Standard Score	109.5 (13.8)	122 (12.6)	<0.001*

* $p \leqslant 0.05$. MABC-2: Movement Assessment Battery for Children test component. BPVS-2: British Picture Vocabulary Scale, BAS-II: British Ability Scale.

and item responses were made vocally or by pointing. The child responded to each stimulus until they either complete each sub-test or made three errors in a row. If a participant made three errors in a row within a subtest, the next subtest was administered. Raw scores were converted into scaled scores for each individual subtest and an overall total standard score for the test was obtained (with a mean of 100 and standard deviation of 15). Both the individual subtests and overall standard scores were used as dependent measures in this study. The TVPS (Martin, 2006) has US norms and reported internal consistency ranging between 0.75 and 0.88 for sub tests and 0.96 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.

2.2.2. The handwriting product

2.2.2.1. Handwriting speed

2.2.2.1.1. The Detailed Assessment of Speed of Handwriting (DASH; Barnett et al., 2007). The DASH 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 9–16 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 (copying and writing from memory). The handwriting product scores for the DCD and TD groups on this measure have been previously reported by Prunty et al. (2013) but the tasks are described below. The number of words produced per minute was used to examine the relationship between visual perception and handwriting speed.

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

Copy Best: The child copied the sentence "The quick brown fox jumps over the lazy dog", in their best handwriting for two minutes. 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 quickly as possible, ensuring every word was readable.

Alphabet: The child wrote the alphabet repeatedly from memory as fast as possible for one minute. They were instructed to write it in the correct order using lower case letters, making sure that every letter was readable. The number of correctly sequenced letters per minute was recorded. This is a commonly used measure of handwriting speed uncontaminated by more complex aspects of writing.

Free-writing: The child wrote on the topic of 'my-life'. A spider diagram, offering suggestions of what to write about, was presented prior to writing, to elicit ideas from the child. The content of their writing was not assessed, but they were instructed to try and write continuously for a 10-min period using their everyday handwriting. They were given one minute prior to starting the task to think of some ideas. The number of words per minute averaged over the 10-min period was recorded.

The internal reliability of the total score for the DASH is between $\alpha = 0.83$ and 0.89 and the inter-rater reliability for all four tasks is 0.99, as reported in the test manual.

2.2.2.2. Legibility

2.2.2.2.1. 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 and the percentage of illegible words within each task is calculated. These measures have previously been reported for the DCD and TD groups (Prunty et al., 2013) but here were used to examine the relationship between visual perception and handwriting legibility. The criteria listed in the DASH test manual for identifying illegible words in each task were applied.

2.2.2.2.2. The Handwriting Legibility Scale (HLS; Barnett, Prunty and Rosenblum, 2013). The HLS was used to examine the legibility of the product within the DASH free-writing task in more detail. The HLS was designed to examine performance on five different components of legibility including global legibility (overall readability of the text on first reading), effort to read the script, layout on the page, letter formation and alterations to writing (attempts made to rectify written work). Each component is scored on a scale of 1–5 with 1 representing good performance and 5 representing poor performance. Each component is summed to give a total score for legibility with total scores ranging from 5 to 25, with higher scores reflecting poorer legibility. Inter-rater reliability and internal consistency have been reported to be high ($\alpha = 0.92$ in each case), with all components loading on just one factor. The total HLS score for both groups has previously been reported by Barnett, Rosenblum, and Prunty (2013) but was used here to examine the relationship between visual perception and handwriting legibility. Children were categorised as performing poorly on the HLS if they scored less than 1SD below the typically developing group mean.

2.2.2.2.3. The Handwriting Process. When completing the DASH tasks the participants wrote with an inking pen on paper placed on a Wacom Intuos 4 digitizing writing tablet (325.1 mm × 203.2 mm) 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 and temporal data about the pen as it moves across the surface. Eye and Pen version 1 (EP1) software (Alamargot, Chesnet, Dansac, & Ros, 2006) was used to analyze the data and the following measures were examined.

Execution Speed: (cm/s): This is 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). While previously there were found to be no group differences on execution speed (Prunty et al., 2013) this measure was used in the current study to examine the relationship between measures of visual perception and handwriting execution speed.

Pausing during writing: This is 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). In our previous work it was reported that the DCD group paused for a greater percentage of the task than typically developing peers. In particular the DCD group had a tendency to pause for longer, with more pauses over 10 s. The DCD group also paused within words which is an indication of lack of automaticity in writing (Kandel, Soler, Valdois, & Gros, 2006; Prunty et al., 2014). These measures reported in Prunty et al. (2014) were used in the current study to examine the relationship between measures of visual perception and pausing during writing.

2.3. Procedure

Each child was seen individually and completed the VMI (Beery et al. (2010)) and the TVPS (Martin, 2006) either at the child's home, school or at Oxford Brookes University. This study was part of a larger research programme and involved more extensive testing than reported here. All handwriting measures were previously collected in a separate session. Since not all children completed all assessments, the results reported are based on different numbers of children across the range of tests.

2.4. Data analysis

For comparisons between the DCD and TD groups, tests of normality were initially conducted 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 $p < 0.05$.

Bivariate correlations were conducted to examine the relationship between results from the visual perceptual tests with the handwriting product and process measures (words per minute, legibility and pausing during writing). The correlations were calculated with the DCD and the TD groups separately and again with both groups combined. When combined, partial bivariate correlations were conducted with MABC-2 total standard score as the co-variate in order to control for group membership and allow us to examine the relationship over and above motor ability.

The sensitivity and specificity of the VMI and TVPS tests were examined using the HLS to ascertain whether children who performed poorly on legibility were detected by the assessments. Both tests were examined in relation to legibility as they are often used in practice in this way. For example children who can correctly copy the first nine shapes of the VMI are thought to perform better on measures of legibility (Daly et al., 2003). In both analyses children were categorised as poor on the HLS if they scored below 1 SD of the typically developing group mean on the HLS total score.

3. Results

3.1. Group performance on measures of visual perception

Prediction 1: Visual perceptual skills are poorer in children with DCD compared to TD children.

3.1.1. VMI

There was a significant effect of group on the VMI, 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 ($M = 98.37$, $SD = 13.98$), $t(43) = -3.85$, $p < 0.001$, $d = 1.16$. Eleven children with DCD scored below a standard score of 85 compared to three in the TD group.

3.1.2. TVPS

There was a significant effect of group on the TVPS as the DCD group ($M = 90.00$, $SD = 11.08$) had a significantly lower total standard score than the TD group ($M = 103.3$, $SD = 10.06$), $t(42) = -4.17$, $p < 0.001$, $d = 1.25$. Nine children with DCD scored below a standard score of 85 compared to none in the TD group. There was a significant effect of group in six of the seven subtests of the TVPS including visual discrimination ($t(42) = -3.46$, $p = 0.001$, $d = 1.04$), visual memory ($t(42) = -2.36$, $p = 0.023$, $d = 0.71$), spatial relationships ($t(42) = -2.17$ $p = 0.035$, $d = 0.65$), sequential memory ($t(42) = -2.76$, $p = 0.009$, $d = 0.83$), visual figure-ground ($t(42) = -4.15$, $p < 0.001$, $d = 1.25$) and visual closure ($t(42) = -2.74$, $p = 0.009$, $d = 0.82$) in each case the children with DCD scored significantly lower than the TD children. There was no effect of group for form constancy ($t(42) = -1.37$ $p = 0.178$, $d = 0.39$). See Table 2 for mean scaled scores for both groups.

3.2. Correlations between tests of visual perception with handwriting measures

Prediction 2: There is a significant relationship between (a) visual motor integration and (b) visual perception with both process and product measures of handwriting performance.

There were no significant correlations between the VMI and any of the handwriting measures when the groups were considered separately (see Table 3) or when controlling for group membership and considering the group as a whole (see Table 4). The same pattern was found for the TVPS. In addition, there were no significant correlations between the subtests of the TVPS and any of the handwriting measures.

Table 2
Mean (SD) scaled scores for DCD and TD groups on sub-tests of the TVPS.

TVPS Sub-Test	DCD n = 22	Control n = 22	p
Visual Discrimination	6.73 (2.62)	10.27 (4.02)	0.001*
Visual Memory	7.18 (3.39)	9.55 (3.24)	0.023*
Spatial Relationships	10.27 (3.34)	12.32 (2.87)	0.035*
Form Constancy	7.55 (4.78)	9.27 (3.85)	0.178
Sequential Memory	8.82 (2.38)	10.82 (2.42)	0.009*
Visual Figure-ground	6.59 (3.61)	11.27 (3.87)	<0.001*
Visual Closure	9.05 (2.44)	11.32 (3.03)	0.009*

* $p \leqslant 0.05$. TVPS: Test of Visual Perception Skills.

Table 3
Correlations between the VMI and TVPS total test standard scores with the handwriting measures for the DCD and TD groups.

Measure	VMI (DCD)		VMI (TD)		TVPS (DCD)		TVPS (TD)	
	r	p	r	p	r	p	r	p
Product measures								
Handwriting Speed								
Copy Best words per minute	0.174	0.396	−0.214	. 0.376	−0.12	0.956	−0.17	0.121
Copy fast words per minute	0.167	0.414	−0.34	0.149	−0.026	0.907	0.286	0.197
Alphabet letters per minute	0.190	0.352	−0.391	0.098	−0.017	0.940	0.083	0.713
Free-writing words per minute	0.033	0.874	−0.254	0.294	−0.07	0.726	0.198	0.378
Legibility								
Copy Best % illegible words	−0.345	0.084	0.215	0.376	0.126	0.566	−0.121	0.593
Copy Fast % illegible words	−0.100	0.626	−0.013	0.957	0.208	0.342	−0.046	0.838
Free-writing % illegible words	−0.265	0.191	−0.259	0.285	0.359	0.092	0.007	0.977
HLS total score	−0.311	0.122	−0.368	0.121	0.156	0.476	0.135	0.549
Process Measures								
Pausing								
Copy Best Pause %	−0.158	0.442	−0.111	0.652	−0.071	0.746	−0.104	0.647
Copy Fast Pause %	0.012	0.954	−0.095	0.699	−0.144	0.511	−0.115	0.609
Alphabet Pause %	−0.157	0.444	0.047	0.847	−0.261	0.229	0.205	0.360
Free Writing Pause %	−0.118	0.567	0.014	0.954	0.037	0.866	0.159	0.480
% pauses above 10 s (Free-writing)	−0.193	0.345	0.217	0.372	−0.076	0.730	0.005	0.981

Note. $^{*}p \leqslant 0.05$.

Table 4
Correlations between the VMI and TVPS total test standard scores with the handwriting measures for both groups together.

Measure	VMI (controlling for group)		TVPS (controlling for group)	
	r	p	r	p
Product measures				
Handwriting Speed				
Copy Best words per minute	0.036	0.819	0.190	0.217
Copy fast words per minute	−0.013	0.933	0.233	0.129
Alphabet letters per minute	−0.079	0.610	0.148	0.338
Free-writing words per minute	−0.119	0.442	0.077	0.621
Legibility				
Copy Best % illegible words	−0.132	0.394	0.097	0.531
Copy Fast % illegible words	−0.116	0.452	0.048	0.756
Free-writing % illegible words	−0.145	0.348	0.068	0.660
HLS total score	−0.160	0.299	0.078	0.615
Process Measures				
Pausing				
Copy Best Pause %	−0.186	0.226	−0.113	0.466
Copy Fast Pause %	−0.125	0.419	−0.213	0.165
Alphabet Pause %	−0.077	0.619	−0.018	0.909
Free Writing Pause %	−0.047	0.760	0.059	0.702
% pauses above 10 s (Free-writing)	−0.073	0.638	−0.053	0.733

Note. $^{*}p \leqslant 0.05$.

3.3. Sensitivity and specificity of the VMI and TVPS in identifying children with poor legibility

Prediction 3: The VMI and TVPS have low sensitivity in detecting poor performance on a measure of handwriting legibility.

There were 45 children with VMI, TVPS and HLS data. The results reported in both analyses are based on different children as not all children had full data sets on all three measures.

3.3.1. VMI

There were 45 children with VMI and HLS data, twenty-four children in this analysis scored below 1SD of the TD mean on the HLS total score. The results indicated that the VMI identified 10 children below 1SD of the TD mean on the HLS total score (taking a standard score below 85 (−1SD)). However, 14 of these 24 children scoring below 1SD of the TD group on the HLS were not identified 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 the VMI and HLS, and 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 5 represents the distribution of scores for the HLS and VMI.

3.3.2. TVPS

There were 45 children with TVPS and HLS data, twenty-four of the children in this analysis scored below 1SD of the TD mean on the HLS total score. The results indicated that the TVPS identified 7 children below 1SD of the TD mean on the HLS total score. However, 17 of the 24 children scoring below 1SD of the TD group on the HLS were not identified by the TVPS. Therefore the TVPS had a sensitivity of 29.1% which falls below the suggested level for clinical utility of 80% and above (Glascoe cited in Volkmar et al., 2005).

With regards to specificity, there were 19 children who scored within 1SD of the TD mean on both the TVPS and HLS, and two who scored poorly only on the TVPS. The specificity was therefore 90.4% which falls above the suggested level for clinical utility of 80% or above (Glascoe cited in Volkmar et al., 2005). Table 5 represents the distribution of scores for the HLS and TVPS.

4. Discussion

Only a few research studies have focussed on the handwriting of children with DCD, despite the frequently reported difficulties in this group. However, there is now clear evidence of deficits both in the handwriting product and the handwriting process (Prunty et al., 2013, 2014; Rosenblum & Livneh-Zirinski, 2008). For clinicians, it is important to have an understanding of the mechanisms underlying these deficits to help guide appropriate approaches to assessment and intervention. The aim of this study was to examine the role of visual perception and visual motor integration in identifying and explaining handwriting difficulties (speed, legibility and excessive pausing) in children with DCD. These measures have emerged from the literature as possible contributors to handwriting difficulties (Rosenblum & Livneh-Zirinski, 2008) and are also very commonly used in clinical practice.

In this study we found that the DCD group performed significantly more poorly than the TD group on the VMI test and TVPS, which supports previous findings (Parush, Yochman, Cohen, & Gershon, 1998; Tsai, Wilson, & Wu, 2008; Volman et al., 2006). We also examined group differences in the subtests of the TVPS and found that the DCD group were poorer on all subtests with the exception of spatial relationships and form constancy. This was in contrast to Tsai et al. (2008) where the DCD group performed below peers on all subtests of the TVPS. However, in the current study we endeavoured to look beyond group differences and examine the extent to which these measures were related to different aspects of handwriting performance. No significant correlations were found between the visual perceptual measures and the handwriting measures within the individual groups or indeed when both groups were combined. When we combined the DCD and the TD groups we ran partial correlations to control for group membership. When doing this we found no relationship between VMI or TVPS (including subtests) and handwriting skill. Indeed, neither test appeared to explain additional variance in handwriting skill over and above group membership. Therefore, simply knowing a child has DCD provides as much information about

Table 5
Distribution of scores for the Visual Perceptual Measures and HLS 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 (>SD TD mean)	14	18	32
Total	24	21	45
TVPS poor (<1SD TD mean)	7	2	11
TVPS good (>SD TD mean)	17	19	34
Total	24	21	45

handwriting skill as the VMI test or TVPS. However, these findings are in contrast to results reported by Volman et al. (2006), which showed a correlation between visual motor integration and handwriting legibility in their sample of children with handwriting difficulties. While Volman et al.'s groups were assessed for motor skills and handwriting, they did not control for co-occurring deficits in language development, reading, spelling or attention which are known to impact on handwriting performance (Noda et al., 2013; Sumner, Connelly, & Barnett, 2014). In our own sample we controlled for co-occurring deficits both through strict inclusion criteria and also by running additional analyses to ensure that co-occurring difficulties such as attention deficits did not impact on handwriting performance (Prunty et al., 2013, 2014). In addition, this study considered a range of writing tasks and novel analyses of aspects of the handwriting process and found no relationship between the visual perceptual measures and any of the handwriting measures.

Outside of the relationship between the visual perceptual measures and handwriting performance the final focus of this study related to the important clinical question of the ability of the VMI and TVPS to detect handwriting difficulties in children with DCD. The results indicated that the sensitivity of both tests was low as they both failed to identify between 58% and 70% of the children who had poor scores on legibility. These findings appear to support the Evidence Statement produced in the Netherlands for the assessment and remediation of handwriting, where caution surrounding the application of visual perceptual tests such as the VMI as a screening tool has been urged based on an extensive review of the literature (Nijhuis-van der Sanden & Overvelde, 2010). Indeed the International Guidelines for DCD provide a list of useful tools for assessing handwriting difficulties in children with DCD, all of which require the completion of a handwriting task rather than visual perceptual measures (Blank et al., 2012).

The findings of this study indicate that tests of visual motor integration and visual perception do not appear to be sensitive to or related to poor handwriting performance in children with DCD. However, the use of these tests in practice is commonplace and problematic given that none of the purposes outlined in either manual propose using them in the context of handwriting (Beery & Beery, 2004; Beery et al., 2010; Martin, 2006). The TVPS is described as a non-motor test, which examines aspects of visual perception without the need for movement. According to Tsai et al. (2008) the seven subtests of the TVPS seem to examine aspects of the dorsal (visual spatial relationships on TVPS) and ventral (visual closure and visual discrimination) streams of visual perception where dorsal is concerned with action planning and ventral with object identity. These two streams of processing are thought by some to interact to provide information for action planning, which is why difficulties in visual perception are often considered to play a role in movement difficulties (Wilson & McKenzie, 1998). In the context of handwriting, assumptions are made about the role of figure-ground and visual closure in contributing to difficulties with copying and producing letters of an appropriate shape or size, while difficulties with form constancy are thought to impact on the child's ability to recognise errors in their handwriting (Schneck & Amundson, 2010). The VMI test on the other hand involves action and is described by the authors as having four purposes (Beery & Beery, 2004). 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). In the manual the test is not described as a means of assessing skills related to handwriting but rather, it refers to correlations with 'reading readiness' (0.56) and 'letter identification' (0.52). Indeed some studies have shown that there is a relationship between the VMI test and handwriting 'readiness' in young children (Daly et al., 2003). However, it is important to note that 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, environmental experiences (Schneck & Amundson, 2010), motor skills and orthographic coding (Berninger et al., 1992). In terms of empirical investigation of handwriting 'readiness', Daly et al. (2003) found a strong correlation (0.64) between performance on the VMI and the ability to copy 34 letter forms in typically developing children aged 4–6 years. In their 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 children aged 3–5 years, there was a significant correlation in the 3 and 4 year olds between performance on the VMI and writing their name. However, there was no relationship between the two tasks for the 5 year olds. According to the authors, this is because up 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. In this early stage of writing the child learns how to translate a word into the representative letters, in order to produce them on the page (Pinto & Camilloni, 2012). Pinto and Camilloni (2012) emphasised that letters are rarely produced in isolation and are usually combined together to form a word. They indicate that the orthography of language dictates how marks on a page 'look' and unfold on the page and it does not simply involve the production of shapes.

The role of language in constraining handwriting production is well documented in the literature. Examinations of the handwriting process have described writing pauses where fluent handwriters tend to pause less than those with handwriting difficulties (Connelly, Dockrell, Walter, & Critten, 2012; Sumner et al., 2014). However the explanations for these pauses seem to differ depending on the group. For example, Sumner et al. (2014) found that children with dyslexia pause more frequently than TD peers but this was related to spelling ability. Similar findings were reported in Connelly et al. (2012) who examined children with Specific Language Impairment. In both populations, the cognitive element of language was a constraint on handwriting performance. In our work with children with DCD we have reported a tendency to pause within words which seems to indicate a lack of automaticity in handwriting (Prunty et al., 2014). In the current study we tried to examine whether visual perceptual skills were related to this behaviour but found no evidence to support this. It seems therefore that there are other more significant factors that impact the handwriting process in children with DCD. Indeed one informal observation which we have yet to examine formally is the consistency of letter formation in the DCD group. While some letters were formed appropriately, others appeared to be formed with directional errors and/or too few or too many letter strokes. This type of behaviour may be better explained by difficulties with motor sequence learning (Bo & Lee, 2013), rather than deficits in visual perception. Wilson et al. (2013) concluded that children with DCD can learn simple sequential movements but it would be interesting to examine letter form consistency and accuracy to ascertain whether more complex letter forms are more problematic than others. In relation to handwriting fluency and pausing, correct directional movements would be an important factor in increasing automaticity in handwriting.

4.1. Limitations of the study

One limitation of this study is the ability to generalise the findings to children with DCD who have co-occurring disorders. This study controlled for factors such as reading ability, spelling ability, language and attention in order to understand handwriting difficulties in a sample of children with DCD. However, future research needs to consider children with co-occurring disorders given the constraints of language on handwriting production (Connelly et al., 2012; Sumner et al., 2014). In addition, the sample size used in this study meant that it was not possible to examine severity of motor impairment in the DCD group as most children were below the 5th percentile on the MABC-2. This study was also limited in terms of ethnic diversity and had a smaller proportion of females than reported in other studies (Rosenblum & Livneh-Zirinski, 2008).

4.2. Implications for practice

1. Although the DCD group scored poorly on measures of visual perception, these were not predictive of their handwriting performance. Clinicians need to avoid implying causation based on group differences alone.
2. The VMI and TVPS failed to identify 58–70% of children with handwriting difficulties, therefore their use as handwriting screening tools should be avoided.
3. Practitioners are encouraged to consider handwriting as 'language by hand' recognising the role of cognition and language in addition to the perceptual and motor components.
4. Assessment of children with handwriting difficulties should include a handwriting task given the poor sensitivity of the VMI and TVPS reported in this study.

5. Conclusion

Despite extensive literature in the field of writing linking language processes to handwriting production (Berninger et al., 1992; Kandel et al., 2006; Van Galen, 1991) there remains a focus on 'bottom-up' approaches to the assessment of handwriting in children, where underlying deficits are emphasised rather than understanding performance on the task itself. This is evident through the extensive use and popularity of tests such as the VMI and TVPS. However, the findings of the current study, particularly the low sensitivity of the tests, may support a shift towards a more contemporary theoretical and evidence-based approach when assessing handwriting in children with DCD. Although the DCD group scored more poorly than their TD peers on measures of visual perception and visual motor integration, neither of these measures related to their handwriting product or process. The findings of this study suggest that there are other factors which may explain handwriting difficulties in children with DCD and further investigation is needed.

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