

**Accuracy and consistency of letter formation in children with Developmental Coordination Disorder: an exploratory study**

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**Abstract**

Background: Handwriting difficulties are frequently mentioned in descriptions of Developmental Coordination Disorder (DCD). Recent studies have shown that children with DCD pause more and produce less text than typically developing (TD) peers. This temporal dysfluency indicates a lack of automaticity in handwriting production. One possible contributing factor is the accuracy and consistency of letter formation. The aim of this study was to gain a better understanding of handwriting dysfluency by examining the accuracy and consistency of letter production both within and across different writing tasks.

Method: Twenty-eight 8-15 year-old children with DCD participated in the study, with 28 typically developing (TD) age and gender matched controls. They completed the alphabet writing and copy fast tasks from the Detailed Assessment of Speed of Handwriting on a digitising writing tablet. The accuracy and consistency of letter production were examined.

Results & Discussion: The DCD group had a higher percentage of errors within their letterforms than TD peers. Letter production was also less consistent between tasks. Children with DCD appear to have difficulties with the ‘allograph’ (motor program) aspect of handwriting and may require explicit teaching of letter formation.

The skill of handwriting plays an important role in the overall task of writing as there is substantial evidence to support the relationship between transcription skills (handwriting and spelling) and the quality of written composition (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994). Handwriting speed (the number of letters or words written per minute) is thought to reflect automaticity of writing and has been shown to predict compositional quality in typically (Berninger et al., 1994; Graham, Berninger, Abbott, Abbott, & Whitaker, 1997; Puranik & Otaiba, 2012) and atypically (Connelly, Dockrell, Walter, & Critten, 2012; Prunty, Barnett, Wilmut, & Plumb, 2016; Sumner, Connelly, & Barnett, 2014) developing children. Therefore if a child has difficulties with producing handwriting which is fast and legible it may impact on their academic performance (Graham, Harris, & Fink, 2000).

One group known for their difficulties with handwriting are children with Developmental Coordination Disorder (DCD) which is the term used to describe children who have motor coordination difficulties, unexplained by a general medical condition, intellectual disability, sensory or neurological impairment (American Psychiatric Association [APA], 2013).

Handwriting difficulties are mentioned in the formal diagnostic criteria for DCD (APA, 2013) and are frequently reported as the most common reason for referral to occupational therapy services for this group (Asher, 2006). In the few studies that have examined handwriting in any detail in children with DCD, difficulties with both handwriting speed and legibility were reported (Prunty, Barnett, Wilmut, & Plumb, 2013; Rosenblum & Livneh-Zirinski, 2008). In addition, some studies examined the handwriting process using writing tablet technology to explore the real-time movements of the pen. These have found that children with DCD spend a greater percentage of time pausing during writing compared to typically developing (TD) peers (Prunty

et al., 2013; Rosenblum & Livneh-Zirinski, 2008). In our previous work we have attempted to characterise this pausing behaviour by analysing the location of pauses. We found that the DCD group produced a higher percentage of within word pauses compared to TD peers (Prunty, Barnett, Wilmut, & Plumb, 2014). According to Kandel and colleagues (Kandel, Soler, Valdois, & Gros, 2006) within word pauses are an indication of a lack of automaticity or ‘fluency’ in handwriting. They argue that skilled writers have the ability to programme the spelling and movement components for a word prior to commencing it, followed by an ability to execute the word without stopping (Kandel et al., 2006). Given that children with DCD do not seem to acquire this level of skill (Prunty et al., 2014), it is important to investigate the reasons for this in order to inform effective interventions for this group.

According to Fitts and Posner (1967) a learner becomes automatic or fluent at a skill following extensive practice of movement patterns. From 2-3 years of age children produce ‘writing’ that is generally distinguishable from their drawing (Mortensen & Burnham, 2012; Treiman, 2017). At three years) they produce simple linear strokes, segment (often pretend) letter forms and produce simple written units (small clusters of letters) (Puraninik & Lonigan, 2011). With the natural development of language and motor skill, together with formal instruction these movement patterns become more refined to express meaning through specific letter shapes.

According to Van Galen’s (1991) theoretical model of handwriting the motor commands required to form a letter are referred to as ‘allographs’. This is where the activation of the motor program occurs – which is a set of motor commands that defines the essential details of the action. This requires knowledge about the movement patterns involved in a letterform including where the letter starts, the sequence of the strokes and the direction in which the strokes are formed (Van Galen, 1991). Problems with allograph selection may be a contributing factor to

handwriting difficulties in children with DCD as poor letter formation and a tendency to over-write or add elements to already formed letters have been reported in the literature (Rosenblum & Livneh-Zirinski, 2008). There is also evidence that children with DCD encounter difficulties when learning new motor patterns (Bo & Lee, 2013) including letterforms, which is manifested through variability and inconsistency in the velocity and trajectory length of pen strokes (Chang & Yu, 2010; Huau, Velay, & Jover, 2015). Indeed, the real time movement of the pen can be used to quantify the accuracy and consistency of letterform production which may shed more light on allograph selection. By examining the patterns involved in letterform production, factors such as whether the child starts a letter in the correct place, moves in the correct direction or executes too few or too many letter strokes can be analysed. Analysing handwriting in this way will help to establish a better understanding of the handwriting process in children with DCD.

Previous analyses of letterforms in children with DCD have tended to focus on the handwriting product with either a global description of handwriting legibility (spatial arrangement) (Rosenblum & Livneh-Zirinski, 2008) or an analysis of the shape of individual letters (Chang & Yu, 2010). To date, no study has examined each of the individual letters of the alphabet taking into account the process of letter production. This type of analysis would help determine whether children with DCD have difficulties with forming specific letters or letter groups ('families') with similar movement patterns. It would also inform focused interventions and approaches to teaching in the classroom. The aim of this study was therefore to understand handwriting production in children with DCD through an examination of the accuracy of letter formation using the real-time movement of the pen. Two letter production tasks were used to allow for an additional analysis of consistency of letter formation. Our predictions were that children with

DCD produce a higher percentage of errors in letterform production and are less consistent in letterform production compared to TD children. Our aim was to identify in this exploratory study which letters in particular were problematic to inform the teaching of handwriting.

## **Methods**

### *Research Design*

A non-experimental between group design was used to evaluate the accuracy and consistency of letter formation in children with and without DCD on two handwriting tasks.

### *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. The children ranged from 8 to 15 years and were also matched on handedness. To select participants for both groups we used the same procedure as described in our earlier studies (Prunty et al., 2013; 2014).

Children in the DCD group were recruited through advertising at parent support groups, schools and through the research group website. The four DSM-5 criteria (APA, 2013) were used to assess children with DCD in line with the current European guidelines (Blank, Smits-Engelsman, Polatajko, & Wilson, 2012). All children scored below the 10<sup>th</sup> percentile on the Movement Assessment Battery for Children 2<sup>nd</sup> edition Test (MABC-2) (Criterion A). These motor difficulties had a significant impact on their activities of daily living (Criterion B), as reported by their parents and evident on the MABC-2 Checklist (Henderson, Sugden & Barnett, 2007). A developmental, educational and medical history was taken from the parents, which confirmed that there was no history of neurological or intellectual impairment and no medical condition that might explain the motor deficit (Criteria C & D).

The control group was recruited through local primary and secondary schools in Oxfordshire, England. They had a score above the 16<sup>th</sup> percentile on the MABC-2 Test and no evidence of a reported physical, sensory or neurological impairment. Children were included in the control group if they scored at the level expected for their age on all measures outlined below (no more than one standard deviation below the mean).

### *Exclusion Criteria*

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

### *Selection Measures*

The Movement Assessment Battery for Children 2<sup>nd</sup> edition (MABC-2; Henderson et al., 2007) was used to identify children with significant motor difficulties, with performance below the 10<sup>th</sup> percentile (24 below the 5<sup>th</sup>, 4 below the 10<sup>th</sup>) on the Test component. The MABC-2 examines three components of motor competency: manual dexterity, aiming and catching and balance in children aged 3-16 years. These motor difficulties had a significant impact on their activities of daily living, as reported by their parents and evident on the MABC-2 Checklist (Henderson et al., 2007). Reliability of the Total Test Score has been reported as good at .80 (Henderson et al., 2007).

The British Picture Vocabulary Scale 2<sup>nd</sup> 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). It is a standardized test with UK norms and it is commonly used to examine the level of receptive vocabulary in children. Reliability of the BPVS-2 has been reported as good at .86 (Dunn et al., 1997). Performance on the BPVS-2 was 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 deficits (Blank et al., 2012). 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. 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). Seven children in the DCD group had a 'slightly raised' profile in hyperactivity. However, no child had a diagnosis of ADHD.

The British Ability Scales 2<sup>nd</sup> Edition (BAS-II; Elliott, 1996) were used to examine performance on single word reading and spelling tasks. The BAS-II has UK norms for children aged 5-18 years. The reading and spelling tasks have high internal reliability ( $\alpha = .84$  to  $.95$ ). The BAS-II revealed that eight children with DCD had literacy difficulties (one in reading, seven 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.

See Table 1 for performance profiles of both groups.

INSERT TABLE ONE HERE

### *Handwriting Measures*

The Detailed Assessment of Speed of Handwriting (DASH; Barnett, Henderson, Scheib, & Schulz, 2007) is a standardised handwriting speed test with UK norms for 9 to 16 year olds. The product scores (number of letters/words per minute) for both groups were reported in Prunty et al (2014). In this study two tasks from the DASH were implemented, both of which were deemed appropriate for children aged 8 years and above. The inter-rater reliability for both tasks is .99. The tasks included the following:

*Alphabet Writing:* 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.

*Copy Fast:* The child copied the sentence “The quick brown fox jumps over the lazy dog”, as quickly as possible for two minutes. This sentence includes all letters of the alphabet therefore providing an opportunity to examine each individual letterform.

### *Apparatus*

When completing the two DASH tasks the participants wrote with an inking pen on paper placed on a Wacom Intuos 4 digitising writing tablet (325.1mm x 203.2 mm) to record the movement of the pen during handwriting. The writing tablet transmits information about the spatial and temporal data of the pen as it moves across the surface. The data was sampled at 100 Hz via a laptop computer. Eye & Pen version 2 (EP2) software (Alamargot, Chesnet, Dansac, & Ros,



2006) has a video function which allows researchers to replay the handwriting production in real-time on a laptop.

### *Procedure*

The handwriting component of this study took place over one 60-minute session. Each child was assessed individually by the first author who is a trained Occupational Therapist. 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.

### *Ethics Statement*

The study was approved by the Institutional Research Ethics Committee. Parents were required to sign a consent form and children were asked to either assent (below 11 years), or counter sign the parent consent form (over 11 years).

### *Data Analysis*

#### *Accuracy of Letter Formation*

In the UK, children may be taught different handwriting styles at school, which include variations of joined or un-joined letterforms. In this study coding of errors in letter formation did

not reflect handwriting style but focussed on universal aspects of letter formation that apply across all handwriting styles taught in the UK school system. The focus here was to examine the accuracy of the allograph (Van Galen, 1991) therefore handwriting style did not impact on analysis.

The handwriting production was viewed by the first author and coded for accuracy and consistency of letter formation. Letter production was played and replayed in slow motion and was paused if needed to allow for accurate coding of the process. In order to classify the errors in letter formation the following categories were used:

Incorrect direction of letter stroke: For example a clockwise rather than anti-clockwise direction when forming the letter 'a' or 'o' (letters that may have appeared appropriate on paper but when production was replayed, incorrect letter stroke directions were revealed).

Incorrect start place: For example, the letters 'r', 'n' or 'i' starting at the baseline rather than in the middle of the lines.

Letters with missing strokes: For example, the letters 't' and 'f' written without the cross stroke or 'r', 'n', 'u' completed with one stroke rather than two.

Letters with added strokes: For example, over writing on strokes already formed.

Letter reversals: For example, the letter 'b' appearing as 'd'.

Using these categories, the following variables were calculated for the alphabet task for each child:

1. Percentage of letters with production errors.
2. Percentage of production errors in each category. It was also noted whether each child displayed production errors in more than one of the error categories.

### *Consistency of Letter Formation*

The consistency of letter formation was established by comparing performance on the alphabet task to performance on the copy fast task. Only those letters produced in the alphabet task were examined in the copy fast task for each child. For example if a child only produced the first 14 letters of the alphabet (a to n), the same 14 letters were examined in the copying task. As above, the letters were played and replayed in slow motion to allow for the categorisation of errors. The consistency of letter formation was examined for each child by calculating the following:

1. The percentage of letters with production errors in the alphabet task that had the same errors recorded in the copying task.
2. The percentage of letters with production errors in the alphabet task that had different errors recorded in the copying task.

### *Production of Letter Groups/Families*

The letters of the Latin based alphabet are sometimes grouped together into letter ‘families’ for the purpose of teaching letter formation (Department for Education [DfE], 2001). The groups are usually defined by either the shape of the letters (ascenders and descenders) or the movements required in forming them (curves). While there are variations of letter families, this study applied those recommended by the DfE (2001) which are grouped according to movement patterns. Figure 1 illustrates four families of letterforms including the ‘c family’, ‘r family’, ‘l family’ and ‘z family’.

INSERT FIGURE 1 ABOUT HERE

For the final analysis, each letter that was produced on the alphabet task was examined for accuracy and the number of children in each group who made an error in each letter was calculated. The nature of the errors were categorised and the frequency of the error types were reported for any letter that yielded a significant group difference.

#### *Inter-Rater Reliability*

Since the scoring criteria for identifying errors in the production of letterforms were novel it was important to assess the reliability of scoring. An acceptable coefficient for inter-rater reliability would be over .70 but preferably over .80 (Landis & Koch, 1977). The first author initially scored all of the alphabet task files on EP2. To check the reliability of scoring, ten files (5 DCD, 5 TD) were randomly selected and scored by an external rater (a psychologist with

particular expertise in children's writing). The rater was blind to the group allocation of the scripts. The inter-rater reliability (Intraclass Correlation Coefficient) for the number of letters in the alphabet task with a process error was .89.

### *Statistical Analysis*

T-tests or the Mann-Whitney-U test were used to examine differences between the DCD and TD groups, depending on the normality of distributions. For categorical data Chi-Squared tests of independence were used to examine group differences in the proportion of production errors. Significance was set at  $p < .05$  in all cases.

## **Results**

### *Accuracy of Letter Formation*

All children in the DCD group made production errors compared to (23/28) 82% of the TD group. As shown in Table 2, the DCD group had a higher median percentage of production errors in the alphabet task compared to the TD group ( $U = 141.0$ ,  $Z = -4.13$ ,  $p < .001$ ).

Analysis of the error categories (see Table 2) showed higher median scores for the DCD group across all categories except for 'incorrect start place' where the TD group exhibited higher median scores than the DCD group. However, the only significant group differences were for 'added strokes' ( $U = 238.5$ ,  $Z = -3.22$ ,  $p < .001$ ) and 'letter reversals' ( $U = 294.0$ ,  $Z = -3.22$ ,  $p$

=.005). The percentage of these two types of errors in the DCD group were lower compared to other error types that they displayed. Also, no child in the TD group made ‘added strokes’ or ‘letter reversals’. There was no effect of group for incorrect direction of strokes ( $U= 335.5, Z = -.961, p=.337$ ), incorrect start place ( $U= 346.0, Z = -.764, p=.445$ ) or missing strokes ( $U= 311.0, Z = -1.36, p=.172$ ). There was no effect of group for incorrect letters with more than one error indicating that both groups (DCD,  $Mdn = 6.50$ ; TD,  $Mdn = .001$ ) made the same amount of errors within a letter ( $U= 299.0, Z = -1.75, p=.079$ ).

INSERT TABLE TWO HERE

#### *Consistency of Letter Formation*

There was no effect of group when comparing the percentage of letters with errors in the alphabet task to the percentage of letters with the same errors recorded in the copying task ( $U = 299.0, Z = -1.75, p = .079$ ). This suggests that when both groups performed a letter incorrectly in the alphabet task, the same letter was still incorrect in the copying task. However, the DCD group had a significantly greater percentage of errors that were different in type between the alphabet and copying task ( $U= 182.0, Z = -4.41, p <.001$ ). They had a tendency to produce inconsistent errors within the same letter, between the two tasks. Medians can be found in Table 3.

INSERT TABLE THREE HERE

### *Production of Letter Families*

Table 4 reports the percentage of children in each group who made a production error in each letter. As can be seen, a higher percentage of children in the DCD group made errors in 11 letters across the four letter families. These include ‘**i**’ ( $X^2(1, N = 56) = 6.72, p = .010$ ) and ‘**j**’ ( $X^2(1, N = 56) = 4.08, p = .043$ ) within the ‘l family’; ‘**a**’ ( $X^2(1, N = 56) = 4.30, p = .038$ ), ‘**d**’ ( $X^2(1, N = 56) = 16.04, p = <.001$ ) and ‘**g**’ ( $X^2(1, N = 56) = 5.49, p = .019$ ) within the ‘c family’; ‘**r**’ ( $X^2(1, N = 56) = 5.40, p = .020$ ), ‘**n**’ ( $X^2(1, N = 56) = 7.52, p = .006$ ), ‘**m**’ ( $X^2(1, N = 56) = 12.34, p = <.001$ ), ‘**h**’ ( $X^2(1, N = 56) = 4.38, p = .036$ ) and ‘**b**’ ( $X^2(1, N = 56) = 6.17, p = .013$ ) within the ‘r family’ and ‘**z**’ ( $X^2(1, N = 56) = 9.55, p = .002$ ) within the ‘z family’. From Table 4 it seems that it was within the ‘r family’ that a greater proportion of children with DCD showed errors, with 5 of the 7 letters more affected in this group compared to the TD group. Table 5 reports the percentage of error types within the 11 troublesome letters. The most common type of error was incorrect starting place in 9 of the 11 letters followed by errors in the direction of strokes and missing strokes in 7 of 9 letters.

INSERT TABLE FOUR HERE

INSERT TABLE FIVE HERE

## Discussion

In this study we used a novel analysis to code and categorise errors in handwriting production through an analysis of the real-time movement of the pen. From a theoretical perspective we were interested in examining the level of the allograph (the motor commands which define essential details of letter production) in Van Galen's psychomotor model of handwriting in children with DCD. As predicted, our findings revealed that children with DCD produced a significantly higher percentage of production errors compared to TD peers. This indicated some difficulties with producing standard motor patterns required for letter formation. While this may not fully explain their difficulties with handwriting, it may contribute to some of the issues described in the literature including poor letter formation and a tendency to over-write on letters (Rosenblum & Livneh-Zirinski, 2008; Prunty et al, 2016). We attempted to categorise the types of errors performed during the production of letterforms which revealed a similarity in error types between both groups. The most frequent error to emerge for both groups was the non standard start position closely followed by missing letter strokes in the DCD group. Indeed the issue of start position is interesting as it seems most of the errors in the TD group occurred in this category. One possible reason for this could have been attributed to the letter 'x' where an error was coded if the participant started from the right side rather than the left side as outlined by the DfE (2001). On reflection this criteria may have been too strict as the letter 'x' appeared to pose the most issues for the TD group. Subsequently, this may have inflated the errors in start position reported in the TD group. However, an alternative explanation for this finding may relate to a possible lack of emphasis by classroom teachers of the correct starting position for letters. While a description of classroom practice surrounding letter formation was beyond the scope of this



study, it would be useful to explore this in future to help understand the influence of teaching practices on letter formation.

An interesting finding in the DCD group was the high percentage of errors in the missing strokes category. It seems that some letters which started in the incorrect place i.e 'm' also contained fewer letter strokes. While this is not a method taught in schools (DfE, 2001) it occurred more frequently in the DCD group. This may have been related to difficulties in learning the correct sequence of the letters (Bo & Lee, 2013), but on the other hand it may have been an 'economic' strategy employed by the DCD group to compensate for their movement difficulties. Future studies could examine this in more detail as it may have implications for the teaching and learning of handwriting in this group.

Another type of error explored in this study was letter reversal as there is anecdotal evidence that children with DCD produce reversals in their writing (Benbow, 2002), However, this was not one of the main errors seen in the current study. Indeed although the DCD group appeared to make slightly more letter reversals and produce additional strokes compared to their TD peers, these errors did not occur frequently and not at all in the controls. This was an interesting finding as these two categories were the only two that yielded a statistically significant group difference, yet occurred less frequently than any other error type. As such, this raises a general point about the implications of our findings on practice as while high frequency errors did not yield significant group differences, the errors that were statistically different may be too infrequent to warrant attention in the classroom.

In terms of consistency of letter production, we compared letter formation across the two writing tasks. Although not all children produced the full alphabet within the one minute time limit it was evident that letters that were incorrectly formed on the alphabet task were also incorrectly formed in the copying task in both groups. However, the types of errors produced in the DCD group were not always consistent. For example, if a letter was performed in an incorrect way in the alphabet task, it was likely to remain incorrect in the copying task for both groups. However, the type of error made within the letter sometimes differed in the DCD group. This inconsistency may have implications for handwriting fluency given that in order to acquire automaticity in a skill, similar movement patterns need to be executed consistently (Fitts & Posner, 1967).

The reasons for the lack of accuracy and consistency of letter production in children with DCD are unclear. One theory within the literature proposes deficits related to motor sequence learning (Bo & Lee, 2013). While Wilson and colleagues (Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2013) suggest that children with DCD can learn simple sequential movements, handwriting involves 26 different letter-forms of varying style (joined, un-joined and capitalised). Therefore it may be more difficult for children with DCD to learn and retain such a variety of letterforms. This may be reflected in the types of errors that the DCD group made as they were more likely to perform errors associated with the initial pattern of letter formation (start position and missing strokes) rather than errors such as adding unnecessary strokes. It seems that they have failed to learn the basic sequence of movements required for correct letter formation. Further investigation of the relationship between different errors may also help to understand the characteristics of the errors seen. For example, it may be that once a letter is incorrectly started, that there is a reduced likelihood of (or opportunity for) the addition

of strokes, or that children with DCD are less likely to detect and/or correct errors. Huau et al (2015) also reported difficulties with *consistency* in children with DCD when learning a new letterform. They found that despite a lengthy learning period children in the DCD group exhibited more variability and inconsistency in performance (Huau et al., 2015). According to the authors this instability of the motor program may be related to neuro-motor noise in the system preventing and disturbing the correct execution of motor patterns (Huau et al., 2015; Smits-Engelsman & Wilson, 2013). However, further research is needed to explore this issue in more detail. One important environmental factor to consider is the way in which children are taught handwriting in schools. Indeed although handwriting is of growing importance in the UK educational system (DfE, 2013), the way in which it is taught can vary widely (Barnett et al., 2007). Given that practice and correct movement patterns are key elements in skill acquisition (Fitts & Posner, 1967), it is important to capture this when studying handwriting difficulties. Despite some emerging literature on difficulties with motor sequence learning in the DCD population (Wilson et al., 2013), it is not clear whether some of the issues explored in this study were linked to differences in teaching and opportunities for practice.

From an applied perspective we tried to ascertain whether specific letters were more problematic than others in order to inform intervention and strategies for teaching children with DCD. We found that children with DCD had particular issues with the ‘r family’ of letters with 5 of the 7 letters affected. The main issue with these letters tended to be a combination of an incorrect starting place, missing stroke (letters n, m, r) or incorrect direction of strokes (b, h). The ‘c family’ was the second most affected with a, d and g mainly affected. Here issues with direction were most apparent in a and g followed by the correct starting place for d. This type of

information may serve as useful guidance for teachers and therapists when deciding on where to focus intervention.

### *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. While this study controlled for factors such as reading ability, spelling ability, language and attention, 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). This study was also limited in terms of ethnic diversity and sample size and had a smaller proportion of females than reported in other studies (Rosenblum & Livneh-Zirinski, 2008). In addition, the lack of information surrounding how the children in this study were taught handwriting at school could be noted as a limitation. Finally, our focus here was on two short writing tasks from the DASH, limiting some aspects of the analyses and generalisation of findings. The one minute alphabet task was not sufficient for all children to complete the full alphabet and the two minute copying task has more constraints than a longer free writing task.

### *Conclusion*

In conclusion, previous research has examined the quality of letter formation in children with DCD using the handwriting product which is an approach widely used in practice both in the classroom and in clinical settings. This exploratory study was the first of its kind to examine the accuracy of letter formation by analysing handwriting production in real time. The findings went some way in categorising issues with letter formation in children with DCD in a novel way.

Further research is needed to refine and develop this method further. However, it seems apparent that this population demonstrate difficulties with particular letter forms and explicit teaching of the skill should be considered in clinical and educational settings.

## References

- Alamargot, D., Chesnet, D., Dansac, C., & Ros, C. (2006). Eye and Pen: a new device to study reading during writing. *Behaviour Research Methods, Instruments and Computers*, 38(2), 287-299.
- American Psychiatric Association (APA) (2013). DSM-5. *Diagnostic and Statistical Manual of Mental disorders* (5th ed.). Washington: American Psychiatric Association.
- Asher, A. V. (2006). Handwriting instruction in elementary schools. *American Journal of Occupational Therapy*, 60, 461–471.
- Banks, R., Rodger, S., & Polatajko, H. (2008). Mastering handwriting: how children with developmental coordination disorder succeed with CO-OP. *OTJR: Occupation, Participation and Health*, 28(3), 100-109.
- Barnett, A., Henderson, S., Scheib, B., & Schulz, J. (2007). *The Detailed Assessment of Speed of Handwriting*. London: Harcourt Assessment.
- Berninger, V. W., Cartwright, A., Yates, C., Swanson, H., & Abbott, B. (1994). Developmental skills related to writing and reading acquisition in the intermediate grades. *Reading and Writing: An Interdisciplinary Journal*, 6, 161-196.
- Benbow, M, (2002). What is developmental coordination disorder? In S. Cermak & D. Larkin (Eds.), *Developmental coordination disorder* (pp. 248-279). Albany, NY: Delmar Thomson Learning.
- Blank R, Smits-Engelsman, B., Polatajko, H., Wilson, P. (2012). European Academy for Childhood Disability (EACD): recommendations on the definition, diagnosis and intervention of developmental coordination disorder (long version). *Developmental Medicine and Child Neurology*, 54(1), 54-93.

- Bo, J., & Lee, C. (2013). Motor skill learning in children with Developmental Coordination Disorder. *Research in Developmental Disabilities, 34* (6), 2047-2055.
- Chang, S., & Yu, N. (2010). Characterization of motor control in handwriting difficulties in children with or without developmental coordination disorder. *Developmental Medicine and Child Neurology, 52*(3), 244-250.
- Connelly, V., Dockrell, J., Walter, K., & Critten, S. (2012). Predicting the quality of composition and written language bursts from oral language, spelling and handwriting skills in children with and without specific language impairment. *Written Communication, 29*, 278-302.
- Dunn, L., Dunn, L., Whetton, C., & Burley, J. (1997). *The British Picture Vocabulary Scale* (2<sup>nd</sup> ed.). London: nferNelson Publishing Company Ltd.
- Department for Education (DfE). (2001). *Developing Early Writing*. DfE: London.
- Department for Education (DfE). (2013). *The national curriculum in England*. Retrieved March 2017, from, <https://www.gov.uk/government/collections/national-curriculum>
- Elliott, C. (1996). *British Ability Scales (II); Administration and Scoring Manual*. London: nfer Nelson Publishing Company Ltd.
- Fitts, P., & Posner, M. (1967). *Human Performance*. Belmont, CA: Brooks/Cole.
- Glenn, S., & Cunningham, C. (2005). Performance of young people with Down syndrome on the Leiter-R and British picture vocabulary scales. *Journal of Intellectual Disability Research, 49*, 239-244.
- Goodman, R. (1997). The strengths and difficulties questionnaire: A research note. *Journal of Child Psychology and Psychiatry, 38*, 581-586.
- Goodman, R. (2001) Psychometric properties of the strengths and difficulties questionnaire. *Journal of the American Academy of Child and Adolescent Psychiatry, 40*, 1137-1345.

- Graham, S., Berninger, V., Abbott, R., Abbott, S., & Whitaker, D. (1997). Role of mechanics in composing of elementary school students: A new methodological approach. *Journal of Educational Psychology, 89*, 170-182.
- Graham, S., Harris, K., & Fink, B. (2000). Is handwriting causally related to learning to write? Treatment of handwriting problems in beginning writers. *Journal of Educational Psychology, 92*, 620–633
- Huau, A., Velay, J. L., & Jover, M. (2015). Graphomotor skills in children with developmental coordination disorder (DCD): Handwriting and learning a new letter. *Human Movement Science, 42*, 318-332.
- Henderson, S., Sugden, D., Barnett, A. (2007). *Movement Assessment Battery for Children-2* (2<sup>nd</sup> ed.). London: The Psychological Corporation.
- Kandel, S., Soler, O., Valdois, S., & Gros, C. (2006). Graphemes as motor units in the acquisition of writing skills. *Reading and Writing, 18*, 313-337.
- Kandel, S., & Spinelli, E. (2010). Processing complex graphemes in handwriting production. *Memory and Cognition, 38*(6), 762-770.
- Landis, J., & Koch, G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*, 159–174.
- Mortensen, J.A., & Burnham, M.M. (2012). Preschool children’s understanding of the graphic features of writing. *Child Studies in Diverse Contexts, 2*, 45-60.  
doi:10.5723/csdc.2012.2.1.045
- Puranik, C. S., & Lonigan, C. J. (2011). From scribbles to scrabble: Preschool children’s developing knowledge of written language. *Reading and Writing, 24*(5), 567-589.



- Puranik, C. S., & Al Otaiba, S. (2012). Examining the contribution of handwriting and spelling to written expression in kindergarten children. *Reading and Writing: An Interdisciplinary Journal*, 25, 1523–1546.
- Rosenblum, S., & Livneh-Zirinski, M. (2008). Handwriting process and product characteristics of children diagnosed with developmental coordination disorder. *Human Movement Science*, 27(2), 200-214.
- Smits-Engelsman, B. C., & Wilson, P. H. (2013). Noise, variability, and motor performance in developmental coordination disorder. *Developmental Medicine and Child Neurology*, 55(4), 69–72.
- Sumner, E., Connelly, V., & Barnett, A. (2014). The influence of spelling ability on handwriting production: Children with and without Dyslexia. *Journal of Experimental Psychology: Learning, Memory, and Cognition*,
- Treiman, R. (2017). Learning to spell: Findings, theories, and issues. *Scientific Studies of Reading*; <http://dx.doi.org/10.1080/10888438.2017.1296449>
- Van Galen, G. (1991). Handwriting: Issues for a psychomotor theory. *Human Movement Science*, 10, 165-191.
- Wilson, P., Ruddock, S., Smits-Engelsman, B., Polatajko, H., & Blank, R. (2013). Understanding performance deficits in developmental coordination disorder: a meta-analysis of recent research. *Developmental Medicine and Child Neurology*, 55(3), 217-228.

Table 1

*Mean (SD) Age and Performance scores for DCD and TD groups on selection measures*

| Selection Measures             | DCD<br>n=28   | Control<br>n=28 | p      |
|--------------------------------|---------------|-----------------|--------|
|                                | Mean (SD)     |                 |        |
| Age in years                   | 10.61 (2.23)  | 10.95 (2.12)    | .441   |
| MABC-2 Test percentile         | 3.45 (2.96)   | 43.37 (25.4)    | <.001* |
| - Manual Dexterity             | 6.41 (8.12)   | 51.07 (26.82)   | <.001* |
| - Aiming & Catching            | 21.55 (23.64) | 64.67 (20.41)   | <.001* |
| - Balance                      | 5.98 (4.67)   | 30.42 (19.85)   | <.001* |
| BPVS-2 Standard Score          | 108.9 (14.4)  | 110 (12.2)      | .655   |
| BAS-II-Spelling Standard Score | 95.8 (13.7)   | 111 (12.7)      | <.001* |
| BAS-II-Reading Standard Score  | 109.5 (13.8)  | 122 (12.6)      | <.001* |

\* $p \leq .050$ . MABC-2: Movement Assessment Battery for Children test component. BPVS-

2: British Picture Vocabulary Scale, BAS-II: British Ability Scale

Table 2

*Median (inter-quartile range) percentage of errors in the alphabet task for DCD and TD groups*

| Measures                       | DCD<br>n=28                  | Control<br>n=28     | P      |
|--------------------------------|------------------------------|---------------------|--------|
| (%)                            | Median (interquartile range) |                     |        |
| Letters with production errors | <b>28.72</b> (11-40)         | <b>7.69</b> (4-12)  | <.001* |
| Incorrect direction of strokes | <b>25.00</b> (0-40)          | <b>.001</b> (0-45)  | .337   |
| Incorrect start place          | <b>40.00</b> (10-53)         | <b>50.00</b> (0-71) | .445   |
| Missing stroke                 | <b>39.00</b> (5-58)          | <b>12.50</b> (0-50) | .172   |
| Added stroke                   | <b>.001</b> (0-16)           | 0                   | <.001* |
| Letter reversals               | <b>.001</b> (0-9.75)         | 0                   | .005*  |

*Note.* \* $p \leq .05$ .

Table 3

*Median (inter-quartile range) percentage of production errors on both tasks for DCD and TD groups*

| Measures                       | DCD<br>n=28                  | Control<br>n=28       | p       |
|--------------------------------|------------------------------|-----------------------|---------|
| Incorrect letters (%)          | Median (interquartile range) |                       |         |
| Similar errors in both tasks   | <b>90.01</b> (67-100)        | <b>63.33</b> (25-100) | .070    |
| Different errors in both tasks | <b>10.01</b> (0-23)          | 0                     | < .001* |

*Note.* \* $p \leq .05$ .

Table 4

*Percentage of children in each group who made production errors in individual letters*

| Group                      | Letter Family      |           |           |           |           |           |          |          |          |  |
|----------------------------|--------------------|-----------|-----------|-----------|-----------|-----------|----------|----------|----------|--|
|                            | Ladder Letters     |           |           |           |           |           |          |          |          |  |
|                            | <b>l</b>           | <b>i*</b> | <b>u</b>  | <b>t</b>  | <b>y</b>  | <b>j*</b> |          |          |          |  |
| DCD<br>(n=28) <sup>a</sup> | 28.57              | 21.4      | 39.1      | 18.2      | 13.0      | 21.5      |          |          |          |  |
| TD<br>(n=28)               | 14.29              | 0         | 25.0      | 10.7      | 3.57      | 3.6       |          |          |          |  |
|                            | Curly Caterpillars |           |           |           |           |           |          |          |          |  |
|                            | <b>c</b>           | <b>a*</b> | <b>d*</b> | <b>g*</b> | <b>q</b>  | <b>o</b>  | <b>e</b> | <b>s</b> | <b>f</b> |  |
| DCD                        | 3.57               | 14.29     | 57.14     | 17.86     | 21.7      | 11.5      | 0        | 8.70     | 35.7     |  |
| TD                         | 0                  | 0         | 7.14      | 0         | 7.14      | 7.4       | 0        | 3.60     | 25.0     |  |
|                            | One-armed Robots   |           |           |           |           |           |          |          |          |  |
|                            | <b>r*</b>          | <b>n*</b> | <b>m*</b> | <b>h*</b> | <b>b*</b> | <b>k</b>  | <b>p</b> |          |          |  |
| DCD                        | 43.5               | 44.0      | 50.0      | 28.6      | 53.57     | 25.90     | 40.0     |          |          |  |
| TD                         | 14.29              | 10.71     | 7.14      | 7.14      | 21.43     | 14.29     | 21.43    |          |          |  |
|                            | Zig Zag Monsters   |           |           |           |           |           |          |          |          |  |
|                            | <b>z*</b>          | <b>x</b>  | <b>v</b>  | <b>w</b>  | <b>y</b>  |           |          |          |          |  |
| DCD                        | 30.4               | 68.2      | 8.7       | 8.7       | 13.0      |           |          |          |          |  |
| TD                         | 0                  | 53.2      | 0         | 0         | 3.57      |           |          |          |          |  |

Note. \* $p \leq .050$ , <sup>a</sup>Not all children in the DCD group produced the full alphabet, results reflect the letters available for analysis.

Table 5

*A breakdown of the percentage of errors attributed to an error type for the DCD group.*

|                           | <b>a</b>             | <b>b</b> | <b>d</b> | <b>g</b> | <b>r</b> | <b>h</b> | <b>i</b> | <b>j</b> | <b>m</b> | <b>n</b> | <b>z</b> |
|---------------------------|----------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Type of Error             | Percentage of Errors |          |          |          |          |          |          |          |          |          |          |
| Direction                 | 75.0                 | 33.3     | 12.5     | 60.0     | -        | 25.0     | -        | -        | 7.7      | 9.1      | -        |
| Start place               | -                    | -        | 37.5     | 40.0     | 10.0     | 25.0     | 100.0    | 16.7     | 7.7      | 9.1      | 14.3     |
| Missing stroke            | -                    | 33.3     | 18.8     | -        | 10.0     | 12.5     | -        | -        | 23.1     | 9.1      | 14.3     |
| Added stroke              | -                    | -        | -        | -        | -        | 12.5     | -        | 16.7     | 7.7      | -        | -        |
| Letter reversals          | -                    | 13.3     | 6.3      | -        | -        | -        | -        | 66.7     | -        | -        | 71.4     |
| Start & Direction         | 25.0                 | 6.7      | 6.3      | -        | -        | 25.0     | -        | -        | -        | -        | -        |
| Start & Missing<br>stroke | -                    | 6.7      | 6.3      | -        | 70.0     | -        | -        | -        | 53.8     | 72.7     | -        |
| Start & Added<br>stroke   | -                    | -        | 6.3      | -        | 10.0     | -        | -        | -        | -        | -        | -        |