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Running Head: EXECUTIVE FUNCTIONING AND MOTOR DIFFICULTIES

Executive functioning, motor difficulties and Developmental Coordination Disorder

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Running Head: EXECUTIVE FUNCTIONING AND MOTOR DIFFICULTIES

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Abstract

The current study assessed a comprehensive range of executive functions (EFs) in children with poor motor skills, comparing profiles of children with a diagnosis of developmental coordination disorder (DCD) and those identified with motor difficulties (MD). Children in both groups performed more poorly than typically-developing controls on *nonverbal* measures of working memory, inhibition, planning and fluency, but not on tests of switching. The similar patterns of strengths and weaknesses in children with MD and DCD have important implications for parents, teachers and clinicians, as children with MD may struggle with EF tasks even though their motor difficulties are not identified.

KEYWORDS: Executive functioning, motor skills, Developmental Coordination Disorder, screening, child development

WORD COUNT: 6,964 (inc. references)

Executive functioning, motor difficulties and Developmental Coordination Disorder

Developmental Coordination Disorder, (DCD, sometimes referred to as 'dyspraxia') is diagnosed on the basis of motor difficulties that significantly interfere with activities of daily living and academic achievement, that are not related to an intellectual disability or a neurological condition affecting movement (APA, 2013: DSM-5). Despite the relatively high prevalence of DCD (2-5%: APA, 2000; Lingam, Hunt, Golding, Jongmans, & Emond, 2009), teachers and practitioners have limited knowledge of the disorder and its potential impact on academic skills (Kirby, Davies & Bryant, 2005). There is also relatively little known about the neural underpinnings of the motor dysfunction in DCD, although underactivation of the right dorsolateral prefrontal cortex (DLPFC) during the practice of a motor task (Zwicker, Missiuna, Harris & Boyd, 2011) might relate to the difficulty individuals with DCD have in acquiring new motor skills (Geuze, 2005). The DLPFC is also closely linked to the cerebellum, a central structure in motor control, suggesting that motor impairments could have concomitant effects on cognitive functioning (Diamond, 2000). This relationship between motor and cognitive functioning is the focus of the present study.

One area of cognitive functioning that may be affected in DCD, with particular implications for academic achievement, is that of 'executive functioning' (EF; Best, Miller, & Naglieri, 2011; St Clair-Thompson & Gathercole, 2006). This term covers a range of high-level abilities, including planning, switching between tasks, inhibiting responses and storing information in memory while processing another task (Henry & Bettenay, 2010; Hill, 2004), all of which direct cognition and behaviour toward a particular goal (Isquith, Crawford, Andrews Espy & Gioia, 2005). Characteristics of executive control are evident even in infancy (Johnson, 2012), and EF development continues into adulthood (Best & Miller, 2010)

and is related to measures of intelligence (Friedman et al., 2006). Evidence for EF difficulties has been associated with a number of neurodevelopmental disorders, including Attention Deficit-Hyperactivity Disorder (ADHD; Castellanos, Sonuga-Barke, Milham, & Tannock, 2006), Autism Spectrum Disorder (ASD; Hill, 2004), and Specific Language Impairment (SLI; Henry, Messer, & Nash, 2012). However, research investigating EF in Developmental Coordination Disorder (DCD) is sparse, despite the fact that individuals with DCD report difficulties with EFs in their daily lives, such as problems planning or organising work, or remembering to complete particular tasks (e.g., Kirby, Sugden, Beveridge, Edwards, & Edwards, 2008). While most previous research on individuals with DCD has focused on the three 'core' EF functions of working memory, inhibition and switching (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), the present study also assesses two further aspects of EF, planning and fluency, which have traditionally been studied in research with frontal lobe patients and those with other neurodevelopmental disorders (Pennington & Ozonoff, 1996). The current paper provides a detailed picture of the strengths and weaknesses of EF in children with DCD.

Previous research investigating EF in DCD has reported mixed results. In measures of *response inhibition*, which require participants to either respond or inhibit their responses depending on the stimulus presented, children with a diagnosis of DCD make a similar number of errors to TD controls (e.g., Pratt, Leonard, Adeyinka, & Hill, 2014; Querne et al., 2008). However, when comparing button presses that were either congruent or incongruent with a visually-presented target, Mandich, Buckolz, and Polatajko (2002) reported that differences in errors between these two conditions were greater for those with DCD compared to TD controls. In tests of *switching* (e.g., "press button 'a' when you see stimulus X, press button 'b' when you see stimulus Y"), children with a diagnosis of DCD make significantly more errors than TD children (Piek, Dyck, & Francis, 2007; Wuang, Chwen-

Yng, & Su, 2011) and those with ADHD (Piek et al., 2007), but perform at a similar level to those with ASD (Wisdom, Dyck, Piek, & Hay, 2007). *Executive-loaded working memory (ELWM)* has been assessed by tasks requiring participants to process increasing amounts of information, either assessing the veracity of a number of statements (verbal ELWM) or identifying the 'odd one out' in a visual display (visuospatial ELWM), and then recalling the order or position in which the information was presented. Alloway and colleagues (Alloway 2007, 2011; Alloway & Archibald, 2008) have reported specific patterns of difficulties in those with DCD on visuospatial as opposed to verbal ELWM, when compared to TD controls, individuals with ADHD and those with SLI. This is in line with evidence for impairments in visuospatial processing in DCD (see Wilson & McKenzie, 1998; Wilson, Ruddock, Smits-Engelsman, Polatajko & Blank, 2013, for meta-analyses). Finally, in tests of *planning* in children with DCD, both Pratt et al. (2014) and van Swieten et al. (2010) reported significantly more errors compared to controls in a task with significant motor demands, which involved planning arm movements to end in a comfortable position. On the other hand, using a classic Tower of London task produced different results: Pratt et al. reported an increased number of errors compared to controls; whereas van Swieten et al. did not. No studies, to our knowledge, have investigated *fluency* in DCD.

Several methodological and interpretational difficulties arising from previous research into EF in DCD were addressed in the current study. One key issue is that many EF tasks require a motor response (such as pressing a button) or complex visuospatial processing, both of which may cause individuals with DCD to perform poorly due to impairments in these (and not EF) skills. This interpretation is supported by Alloway and colleagues: weaknesses were found in visuospatial but not verbal ELWM in those with DCD. A second issue concerns the EF tasks: individual measures often assess multiple EFs (e.g., Piek et al. 2007), and this lack of task purity could affect results (e.g., Miyake et al., 2000). A final issue

concerns the recruitment of individuals with a clinical diagnosis of DCD, who may have diagnoses/subclinical symptoms of other co-occurring conditions such as ADHD, SLI or ASD (Bishop, 2002; Kadesjo & Gillberg, 1999; Wilmut, 2010). These factors might affect their performance on EF tasks, especially given EF difficulties reported in many neurodevelopmental disorders (Castellanos et al., 2006; Henry et al., 2012; Hill, 2004).

In order to address the first two issues, the present study adopted a battery of EF tasks from research conducted by Henry et al. (2012) on children with SLI. The test battery was carefully selected to minimise the task impurity problem and to provide verbal and nonverbal measures of a comprehensive range of EFs: ELWM; response inhibition; switching; planning; and fluency. The comparison of measures with different task demands was designed to aid interpretation of the impact of poor motor skills or visuospatial processing on previously reported EF performance in children with DCD.

In order to address the third issue, namely the possible bias in clinical samples, some researchers have used a screening approach to identify individuals 'at risk' of DCD or who exhibit motor difficulties (e.g., Asonitou, Koutsouki, & Charitou, 2010; Michel, Roethlisberger, Neuenschwander, & Roebers, 2011; Piek et al., 2004). As well as providing a more 'pure' group with motor difficulties, this method could have important implications for screening, as these individuals may demonstrate similar functional impairments in skills such as EF, but may not have been identified for clinical referral. In general, research with these samples suggests that they tend to perform at a more similar level to controls on measures of planning, ELWM, inhibition and switching compared to the rather weaker performance seen with DCD groups in other studies. However, it is difficult to compare performance between groups across studies due to differences in a number of key factors, such as age and task demands, as well as the screening processes and measures. The current research addressed this methodological concern by including different recruitment methods within one study. In

particular, two groups of children with motor problems were recruited: one with a clinical diagnosis of DCD ('DCD group'), and one identified with motor difficulties using a standardised motor assessment ('Motor Difficulties (MD) group'). Investigating EF in both these groups is important because of the relationships between EF and academic achievement (e.g., Best et al., 2011; St Clair-Thompson & Gathercole, 2006). If children with MD have EF problems, this may mean that they fall behind in the classroom, because they have not been identified for clinical referral and appropriate interventions.

Based on previous research investigating the two groups in separate studies, it was hypothesised that children with DCD would perform more poorly on tests of EF than TD controls, and that children in the MD group may be relatively less impaired than children in the DCD group. Given the central impairment of motor skills in DCD, along with studies suggesting that some visuospatial EF tasks are performed more poorly than verbal tasks in children with DCD (e.g., Alloway 2007, 2011; Alloway & Archibald, 2008), it was predicted that children in the DCD group would show poorer performance on nonverbal tasks than verbal tasks in the battery. For children in the MD group, predictions were less certain: it was expected that EF difficulties may only be present for EF tasks requiring a motor response.

Method

Participants

Participants were recruited through two main methods: those with an existing diagnosis of DCD were recruited through an advert placed with a charitable foundation, requesting the participation of children aged 7-11 years with a confirmed diagnosis of DCD /

dyspraxia[1]. Parents responded to the advert by emailing the research team. The research team corroborated the diagnosis of DCD using DSM-5 criteria, standardised tests and parent reports, including scores from the Movement Assessment Battery for Children-2 (MABC-2; Henderson, Sugden, & Barnett, 2007) and the MABC-2 Checklist (participants should score at or below the 16th percentile on the MABC-2[2] and below the 15th percentile on the Checklist; see Materials for details of these measures). Children with a diagnosis of ASD or ADHD were not included in order to maintain as 'pure' a DCD group as possible (subclinical symptoms of these disorders, along with reading difficulties, were nevertheless taken into account; see analyses). Including one child recruited via the school route (see below), 27 children were initially assigned to the DCD group. Further screening was conducted to ensure that no children had IQ, language and reading skills more than two standard deviations below the mean, which might affect their performance on the EF tasks (see Materials for details of these measures). Three children with IQ scores below this cut-off, and one further child with reading scores more than two standard deviations below the mean, were excluded from the group. The final group of 23 children included 16 males and 7 females, with a mean age of 10.0 years (*SD*: 1.1 years, range: 8.1-11.9) and a mean IQ of 101.4 (*SD*: 19.5, range: 71-151).

Children without a diagnosis of DCD (TD and MD groups) were recruited through local schools, with permission from Headteachers. Information sheets and consent forms were sent out to the parents of 250 children aged 7-11 years via their class teachers, along with a set of questionnaires which included the MABC-2 Checklist (see Materials). Children with a diagnosis of any neurodevelopmental disorder or medical condition were not included in any further testing, and one child reported by the parent to have a clinical diagnosis of

[1] In the UK, the term 'dyspraxia' is widely used amongst practitioners who give a diagnosis for DCD and is often more recognised by parents, and therefore children with a diagnosis of 'dyspraxia' were included in the study as long as a diagnosis of DCD was corroborated by the research team.

[2] The 16th percentile was used here rather than the 15th percentile, as usually reported, because it is not possible to score on the 15th percentile in the MABC-2 test (a standard score of 6 corresponds to the 9th percentile, while a standard score of 7 corresponds to the 16th percentile).

DCD / dyspraxia was assigned to the DCD group (see above). 131 children who returned a consent form and had no reports of any condition were assessed on the MABC-2 (see Materials), and were assigned to groups based on their scores on the motor assessment. Children who had motor difficulties (MD group) were identified as those scoring at or below the 16th percentile on the MABC-2 (*N*=30). The TD group consisted of 40 children who scored above the 16th percentile on the MABC-2 *and* above the 15th percentile on the MABC-2 Checklist (the Checklist does not provide an exact percentile but states whether the child is within the typical range, i.e., above the 15th percentile). The inclusion of the Checklist data for the TD group ensured that parents had not identified any functional motor difficulties in everyday life in their children, providing strict inclusion criteria of no motor difficulties in this group. The Checklist was not used for the MD group as motor difficulties were evident from the standardised assessment and were considered sufficient for inclusion in the group. The remaining 61 children did not meet the above criteria for inclusion in either of the two school groups (i.e., scores on the MABC-2 and Checklist were not *both* above the cut-off required [TD group], or the score on the MABC-2 was not at or below the 16th percentile [MD group]). Using the same inclusion criteria as for the DCD group, one child was excluded from the TD group for low IQ and a further child in this group was excluded for having both low reading and language scores. The final TD group consisted of 38 children, including 17 males and 21 females, with a mean age of 9.3 years (*SD*: 1.0 years, range: 7.2-11.1) and a mean IQ of 103.9 (*SD*: 12.5, range: 78-138). The 30 children in the MD group included 17 males and 13 females, with a mean age of 8.9 years (*SD*: 1.2 years, range: 7.1-11.3) and a mean IQ of 96.0 (*SD*: 15.6, range: 71-138).

Materials

Parents completed two questionnaires, the MABC-2 Checklist (Henderson et al., 2007) to measure functional movement ability in everyday life, and the Strengths and Difficulties Questionnaire (SDQ: Goodman, 1997), which was used to measure subclinical symptoms of ADHD. The MABC-2 Checklist consists of 30 statements requiring parents to judge their child's level of motor competence in a static/predictable environment and in a dynamic/unpredictable environment in comparison to other children their age. Parents respond to the statements on a scale from 'Not at all like my child' to 'Very much like my child' (scoring 0-5 points), and a Total Score is calculated, along with a percentile band (below 5th percentile or below/above 15th percentile). Scores from this measure were used as part of the inclusion criteria for group membership (see Participants). The SDQ is a freely available screening measure comprising 25 items which assess five behavioural dimensions, of which only the hyperactivity / inattention scale was used in the present study. This scale consists of 5 items that are directly related to the key symptom domains in the diagnostic criteria for ADHD, namely inattention (2 items), hyperactivity (2 items) and impulsivity (1 item), and has internal reliability and test-retest reliability of .75, and good concurrent and predictive validity (Goodman & Scott, 1999). The questionnaire is relatively short and parents in a low-risk sample preferred it to another more in-depth measure, the Achenbach (1991) Child Behavior Checklist (Goodman & Scott, 1999). Scores from the hyperactivity / inattention scale were included in the analyses (see Statistical Analyses) in order to take into account any subclinical symptoms of ADHD that may be evident in children with DCD (e.g., Kadesjo & Gillberg, 1999) and that could affect EF performance.

Inclusion in the three groups was based on performance on a number of standardised tests as described earlier. ***Movement ability*** was assessed using the MABC-2 (Henderson et al., 2007), a test of motor performance composed of 8 subtests grouped over three domains: manual dexterity; aiming and catching; and static and dynamic balance. The test provides

scores for each component as well as a Total Score and percentile. ***Intellectual ability*** was assessed using the British Abilities Scales (BAS-3; Elliot & Smith, 2011). The Verbal Similarities and Word Definitions subtests were used to measure verbal reasoning, with the Matrices subtest used as a measure of nonverbal reasoning. The nonverbal subtest *T*-score was first doubled to ensure that the weight of verbal and nonverbal abilities was balanced in the final score, such that it reflected the two skills equally (Elliot & Smith, 2011). The average of the *T*-scores from the verbal subtests and the doubled nonverbal subtest was calculated, and then converted into a standard score (General Conceptual Ability (GCA)). Children with a GCA score below 70 were excluded from the samples. To assess ***language***, two subtests from the Clinical Evaluation of Language Fundamentals 4th Edition (CELF-4-UK, Semel, Wiig & Secord, 2006) were used, namely the Formulated Sentences and Word-Classes-Receptive subtests. Participants with scaled scores of 4 or below (M =10; SD = 3) on both subscales were excluded from the sample. Finally, ***reading*** was assessed with the Test of Word Reading Efficiency (TOWRE, Torgensen, Wagner & Rashotte, 1999). All children included in the final groups had a Total Word Reading Efficiency standard score of 70 or above (M = 100; SD = 15).

Executive functioning tasks.

All measures of EF included a verbal and a nonverbal version, matched as closely as possible for task demands and characteristics. Fuller details of the battery can be found in Henry et al. (2012). ***Executive-loaded working memory (ELWM)*** was assessed using the Listening Recall test from the Working Memory Battery for Children (WMTB-C, Pickering & Gathercole, 2001: verbal task) and the Odd-One-Out test (Henry, 2001: nonverbal task). For both tasks, children were presented with an increasing amount of information to process

and then asked to remember a particular aspect of it. In the verbal task, the child was asked to judge the veracity of one or more sentences read by the experimenter and was later asked to recall the final word of each sentence in the correct order. In the nonverbal task, the participant was asked to point to the odd-one-out of three abstract figures and then to recall the spatial location of the odd-one-out figure on a blank grid with identical dimensions to the original card. Total numbers of correct trials on both the tasks were used in the analyses.

The Delis-Kaplan Executive Function System (D-KEFS; Delis, Kaplan, & Kramer, 2001) was used to measure several areas of executive functioning. To assess ***Fluency,*** participants were given one minute to a) produce as many words as they could that began with a given letter or belonged to a particular category (Verbal Fluency), or b) draw as many different designs as possible in a series of boxes with patterns of filled and / or empty dots, following a number of rules (Design Fluency). A combined total from the different conditions in each task provided the measures of verbal and nonverbal fluency, respectively. ***Planning*** was measured using the D-KEFS Sorting test. Participants sorted 6 cards into two groups of three, based on either the words written on the cards (e.g., animals/transport: verbal sorts), or the perceptual features of the cards (e.g., blue/yellow: nonverbal sorts). The total number of verbal and nonverbal sorts identified across two sets of cards was used as the measure of nonverbal and verbal planning, respectively. The D-KEFS was also used to measure verbal ***Switching***, using the Trail-Making test. Participants were required to connect letters and numbers in sequence, switching between the two. Visual scanning, number sequencing, letter sequencing and motor speed were also assessed, as these might affect switching performance. The average number of connections per minute for number sequencing and letter sequencing was calculated and then subtracted from the number-letter switching condition, and the result was used as a measure of switching. The 'switching cost' used in the analyses was calculated using the *number of connections per minute* as opposed to

completion times, since this procedure allowed the inclusion of the children who partially completed the task. The nonverbal switching task was the Intra-Extra Dimensional Set Shift test (Cambridge Neuropsychological Test Automated Battery, Cambridge Cognition, 2006). Participants were required to choose between two simple colour-filled shapes appearing on a touch-screen, and learned from feedback the rule to obtain correct responses. After 6 consecutive correct responses new rules and/or stimuli were introduced. During the stages requiring an 'intradimensional shift', the colour-filled shapes were the only relevant stimuli and any peripheral white lines appearing with each stimulus could be ignored, as they were not central to the rule. During the 'extradimensional shift', the child was required to switch attention to these peripheral white lines. The Total Number of Errors was used as the measure of nonverbal switching.

Finally, the 'Verbal Inhibition, Motor Inhibition' task (VIMI: Henry et al., 2012) was used to assess ***Inhibition***. Each task consisted of eight blocks of 20 trials, with a block of 'copy' trials always followed by a block of 'inhibit' trials. In the verbal task, the child had to copy or inhibit one of two words (e.g., 'car' or 'doll') said by the experimenter in a set sequence. There were two stimulus words used for the first four blocks and two new words for the second four blocks. The nonverbal task followed an identical format, except participants had to copy or inhibit a hand gesture (e.g., a pointed finger or a fist) produced by the experimenter. The total numbers of errors committed in the verbal and motor tasks were used as measures of verbal and nonverbal inhibition respectively.

Procedure

For the children recruited through schools, the MABC-2 was administered in a spacious area, such as the playground or the sports hall, while all other tasks were completed

in a quiet room, such as an empty classroom or a library. Children were collected individually from their classrooms and attended 5-6 sessions of 30-40 minutes each, for a total of around 3.5 hours per child. Before each session, children were given a brief explanation of the type and length of tasks to be completed and were encouraged to ask questions and reminded that they could stop the session at any time. Parents completed the questionnaires at home and sent them back to the researcher. Participants in the DCD group were tested using a spacious and quiet room within the University or within an appropriate area of the child's house. The research project and each of the tasks were described to both the parent and the child, who were encouraged to discuss any further queries. Testing sessions started in the morning and lasted around 4-5 hours, which included a number of breaks and lunch. The length of the assessments was therefore the same for the children in the DCD and school groups, but included time in between tasks for breaks in order to avoid fatigue and boredom effects in those completing the tasks in one session. While the researcher was carrying out the assessment with the child, the parent was asked to complete the questionnaires. Children in all groups were offered stickers throughout the testing battery as encouragement, and all participants received a personalised certificate when testing was completed.

Statistical Analyses

In order to assess group differences in EF performance, a separate hierarchical multiple regression analysis was carried out with each of the 10 EF measures as the dependent variable. Dummy-coded group variables (MD *vs*.TD; DCD *vs*.TD) were entered at Step 2 of each regression (TD children were always the reference group), with key background variables entered in Step 1, thus assessing whether group differences in EF performance were evident after other measures were taken into account. For some variables,

the models did not meet the assumptions for regression modelling, therefore the more robust method of bootstrapping was applied, allowing an estimation to be made of the properties of the sampling distribution from the current data (Field, 2013). For ease of comparison across EF measures, only the standardised coefficients for each predictor will be reported, with significance values based on 1000 bootstrapped samples. The significance of the final models were considered in light of Bonferroni-corrected values for multiple comparisons (p=.005).

Results

To assess initial group differences in background measures that could have an impact on EF performance, group comparisons were conducted for chronological age, IQ (from the BAS-3), language (from the CELF-4-UK) and reading ability (from the TOWRE), as well as for SDQ hyperactivity / inattention scores. As Age and SDQ hyperactivity / inattention scores were not normally distributed across all three groups, non-parametric tests were used to compare scores on these measures. All comparisons were interpreted using Bonferroni corrections, and only significant effects are reported here for reasons of brevity. A significant group effect was found for reading scores, $F(2,88)=4.64$, p=.01, driven by significantly lower reading scores in the DCD group than the TD group (p=.01, r=.40). Children in the DCD group were also significantly older than the MD group, U=171.50, p<.01, r=-.43, and had significantly higher reported SDQ Hyperactivity / Inattention scores than children in the TD group, U=55.50, p<.001, r=-.72, and the MD group, U=73.50, p<.001, r=-.65. Based on these comparisons, age, reading ability and SDQ Hyperactivity / Inattention scores were entered at Step 1 of each regression to control for these group differences. In addition, IQ was included as a further control variable at Step 1, despite there being no significant difference between the groups, due to its documented relationship with EFs (Diamond, 2013; Friedman et al.,

2006). This produced a total of six predictors. A rule of thumb for sample sizes required in multiple regressions is around 15 participants per predictor (Field, 2013), thus the current sample size was appropriate for a multiple regression model with six predictors. The means, standard deviations and ranges of scores on the 10 EF measures are presented in Table 1. Table 2 summarises information for Step 2 of each regression, with all predictors included in the models.

----Tables 1 & 2 about here---

Significant group differences overall (indicated by a significant change in variance accounted for, R^2, at Step 2) were found for ***four*** of the 10 EF measures: **nonverbal** ELWM [final model: $F(6,80)=7.50$, $p<.001$, *r* (TD *vs* MD) =.33, *r* (TD *vs* DCD) =.33], **nonverbal** fluency [final model: $F(6,79)=5.07$, $p<.001$, *r* (TD *vs* MD) =.31, *r* (TD *vs* DCD) =.33], **nonverbal** inhibition [final model: $F(6,80)=6.40$, $p<.001$, *r* (TD *vs* MD) =.38, *r* (TD *vs* DCD) =.26] and **nonverbal** planning [final model: $F(6,80)=5.35$, $p<.001$, *r* (TD *vs* MD) =.24, *r* (TD *vs* DCD) =.21 (*ns*)]. For these tasks, children in the DCD and MD groups obtained significantly *poorer* scores (i.e., fewer items correct or more errors) than those in the TD group. There was one exception: for nonverbal planning, only the MD (and not the DCD) group differed significantly from the TD group. No significant group differences were found in either of the switching tasks, nor for any of the verbal EF tasks.

Discussion

The current study provided a comprehensive overview of executive functioning abilities in children with DCD, taking into account verbal and nonverbal skills and comparing

children with a clinical diagnosis of DCD to those who were highlighted as having motor difficulties on a standardised motor assessment, but who had not received a clinical referral. As predicted, children with DCD performed more poorly than TD children on several nonverbal measures of EF. Children with motor difficulties (the MD group, without a clinical diagnosis) presented a highly similar pattern of performance to the DCD group across the EF battery. Both motor impaired groups scored below the TD group on *nonverbal* tests of executive-loaded working memory, fluency and inhibition, with no differences in performance on tests of switching. Further, the MD group obtained lower scores than the TD group on nonverbal planning. The current results have implications for future EF research in children with motor problems, both in terms of the types of samples recruited and the tasks used to measure EFs. Specifically, researchers should ensure that they account for the visuospatial and motor demands of EF tasks when interpreting data relating to EF in children with DCD.

The fact that EF tasks with a visuospatial or motor demand were more difficult than verbal EF tasks for children with DCD strengthens the case for a relationship between poor motor skills and visuospatial difficulties (e.g., Wilson & McKenzie, 1998; Wilson et al., 2012), and replicates previous research reporting greater difficulties in visuospatial ELWM compared to verbal ELWM in children with poor motor skills (Alloway, 2007; Alloway, 2011; Alloway & Archibald, 2008). It is worth noting that the Odd-One-Out task (nonverbal ELWM) and the perceptual sorts in the Sorting task (nonverbal planning) had limited motor demands, but performance in children with motor impairments was nevertheless reduced compared to the TD children (for nonverbal planning, this difference just missed significance for the DCD group, p=.07). The nonverbal inhibition and fluency tasks, by contrast, required more complex motor responses (hand gestures and drawing, respectively), as well as visuospatial processing. Finding measures of nonverbal inhibition and nonverbal fluency that

do not require motor responses could be tackled in future research, although such tasks would be difficult to identify. One possibility would be to use eye-tracking measures to assess nonverbal inhibition in those with DCD. For example, the antisaccade task measures the ability to inhibit a reflexive eye movement towards a stimulus and look towards an alternative location (Luna, Velanova, & Geier, 2008).

The lack of a group effect on the switching tasks stood in contrast to the other findings. It may be that variation in performance in the TD group on these tasks obscured differences in performance in the MD and DCD groups (see Table 1). On the other hand, good switching performance may be subserved by compensatory brain functioning in children with motor impairments, as was reported in the response inhibition task conducted by Querne et al. (2008). A tentative suggestion would be that the strengthened activation reported by Querne and colleagues in the anterior cingulate cortex could affect performance in the switching tasks used here, specifically by producing better conflict monitoring in children with DCD, as this seems to be an important factor in the typical development of switching performance (e.g., Rubia et al., 2006). Combining the behavioural measures of EFs studied here with functional neuroimaging in future research will provide a better insight into these data, and will be useful in cross-syndrome studies in order to assess whether behavioural similarities across disorders are reflected in similar brain functioning.

While we predicted that motor impairments would have an impact on EF performance, we expected that this effect might be attenuated in the group identified by the research team as having motor difficulties. Previous research had generally shown greater deficits in those with clinically-identified DCD compared to 'screened' groups on measures of EF (e.g., Piek et al., 2004, 2007). However, the current analyses revealed significantly poorer performance by both the MD *and* DCD groups compared to the TD children on nonverbal EF measures, suggesting that children with poor motor skills who have not been

identified or diagnosed could have similar difficulties with nonverbal EFs as children who are formally diagnosed with DCD. Such children may be struggling in the classroom when having to process visuospatial information or complete a motor task (such as writing) while taking in new information, generating ideas, inhibiting pre-potent responses or planning their actions. This has important implications for parents and teachers, as EF ability can impact on educational achievement (e.g., Best et al., 2011; St Clair-Thompson & Gathercole, 2006).

Given that EF performance was strikingly similar between the two motor impairment groups, it is unclear why children in the MD group had not been identified as having difficulties or referred for clinical diagnosis. One potential factor could be that, even though children with additional clinical diagnoses were excluded from the DCD group, this clinically-identified group still had significantly lower reading scores and higher levels of hyperactivity/inattention than the MD children. Poor reading and hyperactivity/inattention may be more likely to be flagged by teachers, and it may be that motor difficulties are identified as part of a secondary referral rather than providing the initial cause for concern. However, as the children in the MD group could be facing similar motor and EF challenges in the classroom as those diagnosed with DCD, it is vital that the relatively limited awareness concerning the impact of poor motor skills on other areas of functioning (Kirby et al., 2005) is addressed.

Finally, one explanation for the similarity of the profiles between the MD and DCD groups in the current study may be the strict exclusion criteria used for the DCD group, in which children with known co-occurring diagnoses were not included. As children who receive a diagnosis of DCD may also be more likely to have a number of other disorders (Wilmut, 2010), greater difficulties reported in a range of EF tasks in children with DCD might be due to this overlap in symptoms. While excluding children with these other diagnoses from our DCD group makes it more difficult to generalise the current findings to a

typical clinical sample, this strategy has the benefit of providing clearer insight into the relationship between motor impairments and EFs without the influence of these additional symptoms. Understanding how the overlap in symptoms between disorders affects EF profiles will be important for future research.

In summary, this investigation provided a comprehensive profile of EF in children with DCD, reporting for the first time significant difficulties in nonverbal fluency in children with poor motor skills. While DCD is a heterogeneous condition, with overlapping symptoms with a number of neurodevelopmental disorders (Dewey et al., 2002; Kadesjo & Gillberg, 1999), the current study addressed this complex issue by using strict exclusion criteria and statistically controlling subclinical symptoms of other disorders, providing a clearer understanding of the relationships between motor impairment and EF performance. Through these methods we have gone some way in addressing the "discriminant validity problem" (Pennington & Ozonoff, 1996, p. 51), allowing us to present more specific profiles of children with motor impairments compared to those reported previously for other neurodevelopmental disorders. The EF difficulties highlighted here in *nonverbal* measures of executive-loaded working memory, planning, inhibition and fluency provide key areas for future evidence-based intervention for children with motor difficulties.

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