Research in Developmental Disabilities 35 (2014) 1579–1587

Contents lists available at ScienceDirect

Research in Developmental Disabilities

ELSEVIER

# The effect of motor load on planning and inhibition in developmental coordination disorder

Michelle L. Pratt [a], Hayley C. Leonard [b], Hanna Adeyinka [b], Elisabeth L. Hill [b,*]

[a] Department of Psychology, Royal Holloway, University of London, London, UK
[b] Department of Psychology, Goldsmiths, University of London, London, UK

ARTICLE INFO

*Article history:*
Received 18 December 2013
Received in revised form 1 April 2014
Accepted 1 April 2014
Available online 25 April 2014

*Keywords:*
Executive function
Developmental coordination disorder
Planning
Inhibition
Motor development

ABSTRACT

Previous research has reported mixed findings regarding executive function (EF) abilities in developmental coordination disorder (DCD), which is diagnosed on the basis of significant impairments in motor skills. The current study aimed to assess whether these differences in study outcomes could result from the relative motor loads of the tasks used to assess EF in DCD. Children with DCD had significant difficulties on measures of inhibition and planning compared to a control group, although there were no significant correlations between motor skills and EF task performance in either group. The complexity of the response, as well as the component skills required in EF tasks, should be considered in future research to ensure easier comparison across studies and a better understanding of EF in DCD over development.



## 1. Introduction

Executive function (EF) is an umbrella term that includes a range of top-down processes of cognitive control, characterised by Miyake, Friedman, Emerson, Witzki, and Howerter (2000) as comprising three core functions, namely response inhibition, shifting between tasks or mental sets, and updating/monitoring of working memory representations. These core functions provide the basis for higher-order functions such as planning and reasoning (Diamond, 2013). EFs develop over a protracted period, emerging before birth and continuing to develop throughout adolescence and into early adulthood (e.g., Anderson, 2002; Best & Miller, 2010). In a variety of psychological and medical conditions, executive dysfunction has been associated with significant negative consequences for daily life functioning, academic achievement, and employability (Altshuler et al., 2007; Biederman et al., 2004; Garcia-Villamisar & Hughes, 2007; Gilotty, Kenworthy, Sirian, Black, & Wagner, 2002). Various patterns of executive dysfunction have been reported across a number of clinical disorders (see reviews by Hill, 2004; Sergeant, Guerts, & Oosterlaan, 2002). For example, Ozonoff and Jensen (1999) reported poor planning and cognitive flexibility but typical inhibitory skill in children/adolescents with autism spectrum disorder (ASD), and the reverse profile in children/adolescents with Attention Deficit-Hyperactivity Disorder (ADHD). Similarly, Happé, Booth, Charlton, and Hughes (2006) reported specific and differing profiles of executive functioning in children and adolescents diagnosed with ASD vs. ADHD, with individuals with ADHD showing a more widespread and general

* Corresponding author at: Department of Psychology, Goldsmiths, University of London, New Cross, London SE14 6NW, UK. Tel.: +44 020 7078 5464.
*E-mail addresses:* h.leonard@gold.ac.uk, hayleyleonard@gmail.com (H.C. Leonard).

http://dx.doi.org/10.1016/j.ridd.2014.04.008
0891-4222/

impairment, particularly in response inhibition, whereas those with ASD showed greater difficulties with response selection and monitoring.

The literature regarding EF across neurodevelopmental disorders has paid less attention to developmental coordination disorder (DCD), which is diagnosed on the basis of movement difficulties that interfere with academic achievement or activities of daily living, such as dressing or eating (DSM-5, American Psychiatric Association, 2013). These movement difficulties cannot be the result of any known intellectual disability or medical condition such as cerebral palsy. As in ASD and ADHD, reports suggest that individuals with DCD have difficulties in many aspects of EF (see Wilson, Ruddock, Smits-Engelsman, Polatajko, & Blank, 2012), particularly in the three key components of EF identified by Miyake et al. (2000) of *response inhibition* (e.g., Mandich, Buckolz, & Polatajko, 2002; Michel, Roethlisberger, Neuenschwander, & Roebers, 2011; Piek et al., 2004; Piek, Dyck, & Francis, 2007; Querne et al., 2008; Wisdom, Dyck, Piek, & Hay, 2007), *working memory* (e.g., Alloway & Archibald, 2008; Alloway, 2007, 2011; Michel et al., 2011; Piek et al., 2004, 2007; Wisdom et al., 2007), and *switching* (e.g., Michel et al., 2011; Piek et al., 2004, 2007; Wisdom et al., 2007; Wuang, Chwen-Yng, & Su, 2011). These studies have suggested that children with DCD perform more poorly or with more variability than their typically developing counterparts on a range of tasks, although the patterns of impairments and variability in DCD groups are not always the same, with areas of relative strength in some studies appearing to be relative weaknesses in others. For example, when testing switching, Michel et al. (2011) and Piek et al. (2004) found no differences between children with motor difficulties and controls in terms of the numbers of errors made, while Wuang et al. (2011) and Piek et al. (2007) reported significantly more errors in children with motor difficulties than controls. Differences between studies may be due to the age ranges and tasks used across research groups, or may rely on the recruitment method used (e.g., screening using different percentile cut-offs for motor difficulty vs. recruitment of clinically referred children). The current study includes only children with a clinical diagnosis of DCD in order to better understand this group in terms of their executive functioning profile.

In terms of inhibition and working memory, some tasks are used to assess both functions (e.g., the trailmaking/updating task used by Piek et al., 2004, 2007), while Michel et al. (2011) used separate tasks for these two functions. The tasks also differ in the extent to which they rely on motor skills, with tasks such as the trailmaking/updating task requiring button press responses, while the 'Fruit Stroop' task used by Michel et al. having no motor demands. Studies within normative samples have reported a significant relationship between motor abilities and response inhibition (Livesey, Keen, Rouse, & White, 2006; Rigoli, Piek, Kane, & Oosterlaan, 2012), and motor skills in DCD have been reported to significantly predict working memory (Michel et al., 2011; Piek et al., 2004). The level of impairment or variability in the DCD group could therefore be affected by the extent to which the EF task relies on complex motor responses. A study by van Swieten et al. (2009) supported this suggestion, demonstrating developmentally inappropriate *motor* planning in 6–13-year-old children with DCD, but appropriate *executive* planning (using a Tower of London task) in 7–11-year-olds in this group. The present study aims to address this issue by comparing performance on tasks that require a greater motor load to those that have a reduced motor load.

Two EF components were selected for the current investigation, namely planning and inhibition, both of which have previously been tested in DCD with tasks that require greater or reduced motor output. While planning is not one of the core EFs identified by Miyake et al. (2000), it is suggested to build on core functions such as working memory (Diamond, 2013), and deficits in the planning and control of motor actions are likely to be key to the movement difficulties seen in DCD (see Hill, 1998, for a review). Inhibition is often investigated using tasks that involve button presses or other motor responses, and so it is important to assess the extent to which any difficulties or additional processing load associated with producing these responses affects inhibition performance in children with DCD. In the current study, tests of planning and inhibition were taken from different executive functioning measures, and were chosen according to their relative motor loads (i.e., high vs. reduced motor response required). Each executive function was therefore measured using two tasks: Planning was assessed by the NEPSY Tower task (Korkman, Kirk, & Kemp, 1998; reduced motor-load) and the Rotational Bar task (Rosenbaum et al., 1990; high motor-load). Inhibition was assessed by the Stroop task (Stroop, 1935; reduced motor-load) and by the NEPSY Knock-Tap task (Korkman et al., 1998; high motor-load). These tasks are described in more detail in Sections 2.2.1 and 2.2.2, and the high motor-load tasks are presented graphically in Fig. 1.

The NEPSY Tower task was used to measure planning with a reduced motor load, in line with van Swieten et al. (2009), and was compared to a motor planning task. Specifically, the Rotational Bar task developed by Rosenbaum et al. (1990) was used, in which participants are required to pick up and rotate a bar so that a coloured end of the bar is placed on a specific coloured disc on a table. This requires participants to plan their grips in order to end in a comfortable position (achieving 'end-state comfort'). Using this task, Smyth and Mason (1997) found no significant differences between 4- and 8-year-old children screened for movement difficulties and a control group with typical movement skills in the proportion of grips ending in a comfortable state, although van Swieten et al. (2009) found increasing differences with age between children with DCD and controls in grip selection on a related task. Given that the children in the current study were of a similar age range to those tested by van Swieten et al. (6–14 years and 6–13 years, respectively), the hypotheses were based on the latter study. Specifically, it was predicted that children in the DCD group would perform more poorly than the control group on the Rotational Bar task (high motor-load) but not on the NEPSY Tower task (reduced motor-load). In the inhibition tasks, participants with DCD were expected to perform more poorly than the control group in the Knock-Tap task (high motor-load), but not in the Stroop task (reduced motor-load).

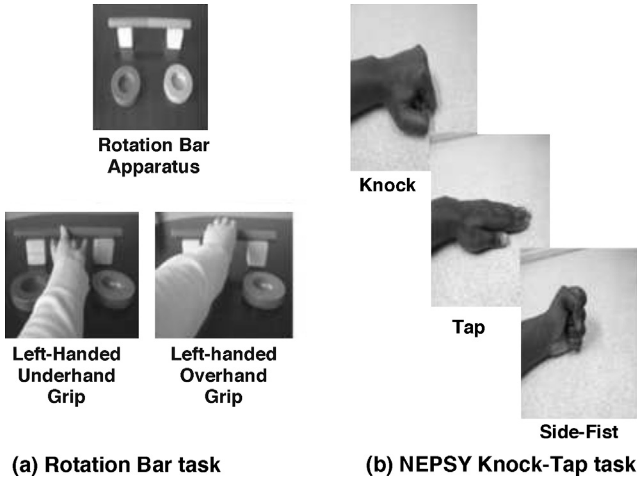


**Fig. 1.** Graphical illustrations of the high motor-load tasks in the current study, measuring (a) planning, and (b) inhibition. (a) The Rotation Bar task: participants use an overhand or underhand grip to pick up the bar and to place the end on a specified coloured disc on the table; (b) The NEPSY Knock-Tap task: participants are required to complete one of the above actions or not respond at all, depending on the action of the experimenter.

## 2. Method

### *2.1. Participants*

Twenty-six children and adolescents diagnosed with DCD, and 24 children and adolescents without a DCD diagnosis (hereafter, 'typically developing group') were recruited through schools and DCD support groups. In the DCD group, only those with a clinical diagnosis of DCD made according to the full DSM-IV-TR criteria (American Psychiatric Association, 2000) and without additional diagnoses, such as ADHD, ASD or dyslexia, were included. The following criteria were necessary for a diagnosis of DCD to be given under DSM-IV-TR: (A) performance in daily activities that require motor coordination was substantially below that expected, given the child's chronological age and measured intelligence; (B) the disturbance in Criterion A significantly interfered with academic achievement or activities of daily living; (C) the disturbance was not due to a general medical condition (e.g., cerebral palsy, hemiplegia, or muscular dystrophy) and did not meet criteria for a Pervasive Developmental Disorder; (D) if mental retardation was present, the motor difficulties were in excess of those usually associated with it.

All participants completed the Movement Assessment Battery for Children – 2nd edition (Movement ABC-2; Henderson, Sugden, & Barnett, 2007) to further document their level of movement skill and the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV; Wechsler, 2004) to measure their IQ (see Section 2.2 for further details of these tests). Children were included in the typically developing (TD) group only if they had not received a diagnosis of any neurodevelopmental disorder prior to participation in the study, and if they performed above the 15th centile on the Movement ABC-2. Children were only included in each group if they had WISC-IV Verbal Comprehension scores above 70 (an IQ below this cut-off suggests intellectual disability). The Verbal Comprehension scores were used rather than a full IQ score, as Full-Scale IQ measures encompass tasks with a high motor load or executive functioning component, and may therefore disadvantage children with DCD by giving a pessimistic estimate of their full IQ. Differences were indeed found between groups in WISC-IV Perceptual Reasoning scores (see Table 1), and so these scores were taken into account in the analyses. Participant characteristics, including Verbal Comprehension and Perceptual Reasoning, are presented in Table 1.

**Table 1**
Participant characteristics of the DCD and TD groups, including means (standard deviations) and *ranges* of chronological ages and scores on the WISC-IV Verbal Comprehension (VCI) and Perceptual Reasoning Indices (PRI), and the Movement ABC-2 (MABC-2).

| Group | Male:female | CA (yrs;mths) | WISC-IV VCI | WISC-IV PRI | MABC-2 percentile |
|---|---|---|---|---|---|
| DCD | 22:4 | 9;11 (2;6)<br>*6;1–14;11* | 92.69 (9.98)<br>*80–116* | 89.96 (16.63)<br>*61–121* | 3.12 (4.20)<br>*0.10–16* |
| TD | 13:11 | 9;7 (2;0)<br>*7;2–14;7* | 94.00 (6.39)<br>*85–109* | 100.25 (15.18)<br>*79–137* | 58.25 (25.13)<br>*25–98* |

### 2.2. Materials

The Movement ABC-2 (Henderson et al., 2007) is a standardised test of motor skills suitable for children aged 3–16. It consists of three subtests: Manual Dexterity, Aiming and Catching, and Static and Dynamic Balance, each of which comprises a series of speeded and non-speeded motor tasks. Scores for each component can be converted to standard scores and percentile ranks, and a Total Standard Score can also be calculated from the components ($M = 10$, $SD = 3$). The Total Score percentile can be used as an indicator of motor difficulties, with scores below the 5th percentile suggesting a significant motor difficulty, and between the 6th and 15th percentiles signifying a borderline motor difficulty.

The WISC-IV (Wechsler, 2004) is a standardised test of verbal and nonverbal abilities and is suitable for children aged 6–16. There are 10 subtests that contribute to a number of indices of intellectual functioning. For the current report, only the Verbal Comprehension Index (VCI) and Perceptual Reasoning Index (PRI) scores are reported. Both indices have a mean of 100 and a standard deviation of 15.

#### 2.2.1. Tests of planning

The NEPSY Tower task (Korkman et al., 1998; hereafter, 'Tower task') required participants to move a set of three balls on three pegs from a start to a target configuration while following certain rules. Participants were shown a target picture of the apparatus, with the coloured balls in specific positions across the pegs, and were asked to copy the picture using their equipment. Participants first completed a practice trial in which they moved a ball so that the model matched the picture, and were assisted if necessary in order to ensure that they understood the task. Participants were asked to complete the trial in a set number of moves while adhering to several rules, namely: (1) a move was finished once the hand was removed from the ball; (2) only one ball could be moved at a time; (3) balls that were not being moved must remain on their pegs at all times and must not be placed anywhere else. Each time a participant broke one of these rules they scored one mark for a violation and automatically scored zero for the trial in question, but were allowed to continue with the task. A score of one point was awarded for each correct trial. The task had seven stages, with each stage becoming progressively more difficult in terms of planning complexity and the number of moves required to complete the trial. The first stage could be completed in one move, and the last stage could be completed in seven moves. The task was stopped once a participant had obtained four consecutive scores of zero on trials, or if they had completed all 20 trials. Although the standardised task was timed, participants were not automatically stopped at the cut-off point of 45 s for later trials, as it was felt that it was important to assess if the task was too difficult for participants in the DCD group, even once the time limit had been passed. The number of violations committed during the task provided one dependent variable in the analyses. Raw score (out of 20) was the other dependent variable for this task.

The Rotational Bar task (Rosenbaum et al., 1990) required participants to move a coloured rod that rested on a tripod on the tabletop and place one end of the rod onto one of two coloured discs (see Fig. 1a). One side of the bar was blue, and the other side was red, and these ends of the bar were placed in front of the matching coloured disc on the table (in Fig. 1a, the blue parts of the apparatus are represented by the darker tones, and the red parts by the lighter tones). Participants were required to pick up the bar and place one of the coloured ends of the bar onto one of the coloured discs. In order to complete this task, participants could use an underhand grip, with their palm facing up, or an overhand grip, with their palm facing down, to pick up the bar, and this choice would affect how comfortable their final arm position would be, i.e., their level of 'end-state comfort' (ESC; Rosenbaum et al., 1990). Participants completed four practice trials before the task began. There were 8 trials in which an overhand grip would achieve ESC and 8 in which an underhand grip would be the most comfortable. Two marks were given for each trial in which a participant used the correct grip to pick up the bar and also placed the correct end of the bar onto the coloured disc. If they began with the wrong grip, but adjusted it to place the correct end of the bar onto the coloured disc, one mark was awarded. If participants used the wrong grip throughout the trial, and thus did not achieve ESC, they did not receive any points for that trial. A total of 32 points was therefore available for each participant, and the raw score (out of 32) provided the dependent variable for this task.

#### 2.2.2. Tests of inhibition

The Stroop task (Stroop, 1935) required participants to name the colour of the ink in which a colour word was printed (e.g., the word 'blue' printed in red ink; response 'red'). Participants had a maximum of 2 min to read out 112 words that were either congruent (set 1) or incongruent (set 2) with the ink in which they were printed. The number of correct responses in congruent and incongruent trials (both out of 112) was recorded and provided the dependent variables for this task. Before the task, participants were asked to read a list of words in order to ensure that any reading difficulties would not affect performance, and also read an example word in an incongruent colour to ensure that they understood the task.

The NEPSY Knock-Tap task (Korkman et al., 1998; hereafter, 'Knock-Tap task') required participants to lay their non-preferred hands on the table and to use their preferred hands to complete certain actions, which the experimenter explained at the beginning of each set of trials (see Fig. 1b). The actions were: knocking on the table with knuckles, tapping the table with the palm of the hand, placing the side of the fist on the table, or no response. In the first set of 15 trials, only the knock and tap responses were used, and participants were required to do the opposite action to the experimenter (i.e., if the experimenter knocked, the participant should tap). In the second set of 15 trials, the participant response to the experimenter's knock was the side fist, and the response to the side fist was a knock. If the experimenter tapped, the participant should provide no response. Before each set of trials, participants completed a series of practice trials in which the possible action–response pairs were presented twice each. Once the participant understood the task, the main trials began. One point was awarded for each correct response, providing a score out of 30, which was entered as the dependent variable in the analyses.

### 2.3. Procedure

Participants were part of a larger study into the relationships between movement abilities, cognition and emotional well-being. They were visited in their own homes or at school to complete the testing battery, which could be administered in one session over the course of a day or over several shorter sessions, depending on the needs of the child and the constraints of the testing setting. The executive functioning tasks detailed in the current paper were always completed in one session, and in a quiet room without distractions. Tasks were presented to participants in a randomised order, and the session lasted approximately 30–40 min. Breaks and rewards were given throughout the testing session as necessary. Parents signed consent forms and the participants gave informed verbal consent to take part in the tasks. The experimenter explained the rules to the participant before each task and answered any questions arising from the description.

## 3. Results

Two main methods of analyses were conducted on the data. First, hierarchical regressions were carried out, with chronological age and WISC-IV Perceptual Reasoning score entered as predictors in the first step, and Group (DCD vs. TD) in the second step. This meant that any group differences in EF performance revealed in the analyses would be evident even after differences or changes in performance related to age and Perceptual Reasoning had been taken into account. Chronological age was included to account for the improvement of EF ability within the relatively wide age range of the two groups. Perceptual Reasoning scores were included because the DCD group had significantly poorer scores than the TD group, and it was important to account for these differences before assessing the groups on EF performance. Second, within-group correlations were conducted to assess the relationship between motor abilities and EF performance within each group. There were six dependent variables in total: Tower task total raw score, Tower task violations, and Rotational Bar task total score; Stroop correct congruent responses, Stroop correct incongruent responses, and Knock-Tap total raw score. The means, standard deviations and ranges of these six variables are presented in Table 2. As some of these dependent variables were not normally distributed in one or both groups, non-parametric Spearman correlations were conducted on the data. For the regression analyses, bootstrapping procedures were applied, allowing an assessment to be made of the representativeness of the relatively small sample to the population from which it was drawn. Bootstrapping provides estimates of the confidence intervals around the regression coefficients, and relies on fewer assumptions about the distribution of the data and residuals than traditional statistical approaches, which is particularly useful in clinical samples (Wright, London, & Field, 2011).

**Table 2**
Mean, standard deviations and (confidence intervals) of scores on high motor-load vs. reduced motor-load measures of planning and inhibition in the DCD and TD groups, based on 1000 bootstrap samples.

| Measure | Group | |
|---|---|---|
| | *DCD* | *TD* |
| Planning | | |
| Tower raw score | | |
| *M* | 7.76 (6.00–9.55) | 10.79 (9.29–12.46) |
| *SD* | *4.38 (3.89–4.68)* | *4.18 (3.18–4.69)* |
| Tower violations | | |
| *M* | 2.29 (1.43–3.24) | 0.54 (0.00–1.08) *1.98 (0.82–2.62)* |
| *SD* | *2.24 (2.00–2.40)* | |
| Rotation Bar score | | |
| *M* | 17.52 (16.24–19.10) | 26.21 (23.96–28.46) |
| *SD* | *4.03 (1.01–5.36)* | *6.22 (4.91–6.98)* |
| Inhibition | | |
| Stroop congruent scores | | |
| *M* | 104.05 (92.55–110.57) | 109.71 (106.02–111.67) |
| *SD* | *18.33 (2.93–26.25)* | *7.73 (0.78–12.59)* |
| Stroop incongruent scores | | |
| *M* | 52.24 (41.22–62.95) | 64.38 (57.25–72.46) |
| *SD* | *24.22 (18.40–28.26)* | *19.02 (13.86–23.28)* |
| Knock-Tap raw score | | |
| *M* | 27.14 (26.03–28.01) | 28.21 (27.25–29.08) |
| *SD* | *2.29 (1.36–2.90)* | *2.13 (1.41–2.57)* |

### 3.1. DCD vs. TD group differences

Six separate hierarchical regressions were conducted on the data, with one planning or inhibition score as the dependent variable in each case. Chronological Age and Perceptual Reasoning scores were entered in Step 1, with Group entered in Step 2. Sections 3.1.1 and 3.1.2 report the summaries of the full models for each of the EF tasks, along with the unstandardised coefficients, standard errors (SEs) and confidence intervals (CIs) for each of the predictors in Step 2 of the regression, based on 1000 bootstrap samples.

#### 3.1.1. Planning tasks

The final model significantly predicted the Tower task total raw score, $F(3,46) = 26.82$, $p < .001$, Adj $R^2 = .61$. The coefficients were significant for Chronological [Age, $B = 0.09$ (CI = 0.07–0.13), SE $B = 0.01$, $p = .001$], Perceptual Reasoning [$B = 0.10$ (CI = 0.04–0.14), SE $B = 0.02$, $p = .001$], and Group [$B = 3.26$ (CI = 1.76–5.00), SE $B = 0.85$, $p = .002$]. For the number of violations in the Tower task, the final model was again significant, $F(3,46) = 6.49$, $p = .001$, Adj $R^2 = .25$, although the only significant predictor was Group [$B = -1.76$ (CI = −2.99 to −0.47), SE $B = 0.66$, $p = .02$]. The coefficients for Chronological Age [$B = -0.02$ (CI = −0.04 to 0.002), SE $B = 0.01$, $p = .11$], and Perceptual Reasoning [$B = -0.03$ (CI = −0.06 to 0.01), SE $B = 0.02$, $p = .12$], were not significant. Finally, the final model predicted a significant amount of the variance in scores on the Rotational Bar task, $F(3,46) = 15.74$, $p < .001$, Adj $R^2 = .47$, with Group again emerging as the only significant predictor of performance [$B = 9.81$ (CI = 6.70–12.55), SE $B = 1.36$, $p < .001$]. Chronological Age [$B = 0.06$ (CI = 0.01–0.11), SE $B = 0.013$, $p = .053$], and Perceptual Reasoning [$B = -0.05$ (CI = −0.14 to 0.03), SE $B = 0.04$, $p = .18$], were not significant. To summarise, the DCD group performed significantly worse than the TD group on all three measures of planning, even once the effects of Chronological Age and Perceptual Reasoning on planning performance had been taken into account.

#### 3.1.2. Inhibition tasks

The final model significantly predicted the number of correct responses in the Stroop task on both the congruent trials, $F(3,42) = 4.62$, $p = .01$, Adj $R^2 = .19$, and the incongruent trials, $F(3,42) = 9.59$, $p < .001$, Adj $R^2 = .36$. For the congruent trials, none of the coefficients of the predictors were significant: Chronological Age [$B = 0.21$ (CI = 0.05–0.41), SE $B = 0.09$, $p = .08$]; Perceptual Reasoning [$B = 0.13$ (CI = −0.06 to 0.33), SE $B = 0.10$, $p = .23$], and Group [$B = 7.65$ (CI = 0.03–16.38), SE $B = 4.48$, $p = .26$]. For the incongruent trials, Perceptual Reasoning was not a significant predictor of correct responses [$B = 0.17$ (CI = −0.12 to 0.49), SE $B = 0.15$, $p = .26$], but both Chronological Age [$B = 0.45$ (CI = 0.22–0.70), SE $B = 0.11$, $p < .001$], and Group [$B = 15.73$ (CI = 3.03–27.82), SE $B = 5.79$, $p = .01$], had significant coefficients. Finally, the final model did not significantly predict performance on the Knock-Tap task, $F(3,45) = 2.04$, $p = .12$, Adj $R^2 = .06$, and none of the coefficients were significant: Chronological Age [$B = 0.02$ (CI = −0.01 to 0.05), SE $B = 0.01$, $p = .17$]; Perceptual Reasoning [$B = -0.02$ (CI = −0.06 to 0.02), SE $B = 0.02$, $p = .36$]; Group [$B = 1.31$ (CI = 0.05–2.52), SE $B = 0.65$, $p = .052$]. In summary, the DCD group performed significantly worse than the TD group in the reduced motor-load task (the Stroop incongruent trials) but the difference in performance in the Knock-Tap task (high motor-load) was only a non-significant trend.

### 3.2. Within-group relationships between motor and EF abilities

As some scores were not normally distributed, Spearman's correlations were conducted on all data and were Bonferroni-corrected for multiple correlations ($p < .004$). Correlation analyses were conducted within each group between Movement ABC-2 Total Standard Score and the six outcome measures of EF ability. There were no significant correlations between MABC-2 Total Standard Scores and any of the EF measures in the DCD group (all $r_s < 0.43$, $p > .03$), or in the TD group (all $r_s < 0.29$, $p > .16$). Separate analyses were also conducted for each group using the component standard scores of the Movement ABC-2 (Manual Dexterity, Aiming and Catching, and Balance). None of the components were significantly correlated with any of the EF outcome measures in the DCD group (Manual Dexterity: all $r_s < 0.42$, $p > .03$; Aiming and Catching: all $r_s < 0.43$, $p > .03$; Balance: all $r_s < 0.31$, $p > .12$), or in the TD group (Manual Dexterity: all $r_s < 0.26$, $p > .22$; Aiming and Catching: all $r_s < 0.40$, $p > .05$; Balance: all $r_s < 0.29$, $p > .16$).

## 4. Discussion

The current study aimed to assess the role of motor load on EF task performance in children with DCD. As in previous research, children with DCD had significantly lower scores than a control group on measures of planning, although some measures of inhibition did not differ significantly between groups. Contrary to predictions, the level of motor load did not seem to specifically affect performance on the tasks: the DCD group had significantly lower scores on both the high-motor and reduced-motor planning tasks than the TD group. In the measures of inhibition, the DCD group performed significantly worse than the TD group when there was a reduced motor-load, but any differences in performance in the high motor-load task did not reach significance. Within each group, motor ability did not correlate significantly with any of the EF tasks.

The poorer performance in the DCD group across 'motor planning' and 'executive planning' tasks is at odds with the previous study by van Swieten et al. (2009), which reported no deficits in planning on the Tower task in a group of children with DCD. Although there was no control group comparison in that study, the performance of children with DCD was compared to standardised means, and all children scored within the typical range (between a scaled score of 7 and 13). In the current study, children with DCD not only had lower scores overall than the TD group, but many also scored outside this typical range of standard scores (65% had a scaled score of less than 7, while only 27% of children in the TD group scored below 7). It is difficult to assess how these differences between studies may have arisen, as little information is given about the children who completed the Tower task in the van Swieten et al. study, apart from their chronological age range. It is possible that the current group had lower IQs or more severe movement difficulties than those in the van Swieten et al. sample, resulting in more difficulties in the executive planning task. However, all children in the current sample had a Verbal IQ in what is considered to be the normal range (all were above 70), and differences in Nonverbal IQ (or Perceptual Reasoning in the current study) were taken into account in the analyses, so the children in the present DCD group did not represent a particularly low-functioning group. In addition, motor abilities did not correlate significantly with performance on the Tower task in either the DCD or TD groups, suggesting (as predicted) that any motor skills required to complete the task did not have a significant impact on performance. It may be that the Tower task involves multiple processes over and above planning ability (producing a less ‘pure’ planning measure: Miyake et al., 2000), and it is the complexity of the task that affects performance in the current DCD sample. The fact that Perceptual Reasoning scores were a significant predictor of Tower raw scores in the DCD group may lend some weight to this suggestion. It is important to note that Perceptual Reasoning scores did not significantly predict any of the other measures, suggesting that the other EF measures used in this study are tapping into different underlying processes and constructs to the Perceptual Reasoning tasks. Future studies could compare ‘purer’ measures of executive planning (e.g., a maze or sorting task) with the Tower task in order to examine this hypothesis further in children with DCD.

The complexity of the task might also have been a factor in the inhibition performance of the DCD group. While children with DCD performed significantly worse than the TD group on the Stroop task during the incongruent trials, the difference between groups on the Knock-Tap task did not reach significance. It is possible that the high motor-load task actually taps into a simpler, more fundamental skill than the Stroop task, which requires reading a word, then coding (and ignoring) the colour in which the word is presented, and finally verbalising the word. The prepotent response might also be stronger for the Stroop task than the Knock-Tap task, as it involves the highly automatised skill of reading rather than a non-automatic pattern of motor responses that is built up over the task. Previous reports of poorer inhibition in children with DCD could therefore relate not just to the requirement for a motor response per se, but to the complexity of the motor response or the additional requirements of other complex processes (e.g., visuo-spatial processing skills), as well as the strength of the prepotent response to be inhibited. It is also important to remember that while there may be minimal differences between groups on basic motor inhibition tasks in terms of behavioural outcomes, the functional brain responses underlying this performance can be very different between TD and DCD groups (Querne et al., 2008). If even a simple task requires more effortful top-down control in children with DCD than their typically developing counterparts (Querne et al., 2008), this could explain why increasing complexity in a task could have a disproportionate effect on their performance.

The complexity of the tasks in the current study is one issue that arises from the adoption of tasks from standardised batteries and experimental measures previously used in the literature. This procedure also meant that it was necessary to manipulate motor load across tasks with different materials and methods, rather than within one task. While a focus of future research might be to manipulate the motor loads within tasks, the current study was important in terms of assessing the motor demands of a range of tasks that are widely used in the literature. In addition, it will be important for future investigations to consider the relationships between age and performance on the different executive functioning measures. In the current data, the relatively wide age range was taken into account in the regressions, as splitting the sample into smaller age bands would have affected the power of the analyses. However, it will be of great interest to assess the developmental trajectories of the different executive functions in children with DCD, as some EFs may develop linearly with age, while others may show different stages of development, and it will be important to know if these patterns could be atypical or delayed in children with DCD.

While previous research has reported significant correlations between components of the Movement ABC-2 and measures of response inhibition in normative samples (e.g., Livesey et al., 2006; Rigoli et al., 2012), no significant relationships were found between motor and EF abilities in either the TD or DCD group in the current study. As the development of EF is a protracted process (Anderson, 2002; Best & Miller, 2010), it is possible that its relationship with motor abilities changes over developmental time and that the varied ages of the samples across the studies may explain the different results (i.e., 5–6 years in Livesey et al., 12–16 years in Rigoli et al., 7–14 years in the current study). Interestingly, even the tasks classified as having a relatively high motor-load were not correlated with the Movement ABC-2 Total Score or its components. It is important to note that Rigoli et al. found a significant relationship between motor ability and the *time taken* to complete an inhibition task, whereas the current study assessed inhibition *errors*. However, there may be a more fundamental difference between studies in terms of the aspect of response inhibition being assessed. Livesey et al. reported that motor ability was more closely correlated with a modified Stroop task (which they argued measured ‘interference control’) than with a Stop-Signal task, which was regarded as a measure of inhibition of an ongoing response (cf. Nigg, 2000). In the current study, although the Knock-Tap task had a relatively increased motor-load in terms of the response required, differences found between it and the Stroop task in could be due to the fact that they were measuring different aspects of response inhibition. It will be important in future research to take this into account when selecting inhibition tasks to use with children with DCD, as there may be much closer links between neural pathways relating to motor and interference control than between motor control and the inhibition of an ongoing response (Livesey et al., 2006).

### *4.1. Conclusions*

The current study aimed to assess the role of motor load on EF performance in children with DCD compared to a control group with typical motor development, adding to the relatively limited literature regarding EF performance in DCD compared to other neurodevelopmental disorders. The DCD group performed significantly worse than the TD group on measures of both planning and inhibition, but the effect of the motor load of the response in the task was not clear-cut. It seems that while this may have an effect on the EF performance of children with DCD, other factors such as the executive 'purity' of the tasks, their interaction with age and the different aspects of response inhibition that may be measured could also play an important role. Given the reported negative consequences of executive difficulties on quality of life and achievements (e.g., Altshuler et al., 2007; Biederman et al., 2004; Garcia-Villamisar & Hughes, 2007; Gilotty et al., 2002), it is important that methodological problems are addressed in order to improve our understanding of EF in children and adults with DCD. Investigations considering EF across development in DCD, which take into account performance on different tasks measuring the same EF construct and assessing a range of compound skills, will be vital in this research. The incorporation of parent- and self-report measures of the effects of EF difficulties on functioning outside the laboratory will also help to provide a clearer picture of EF in DCD.

## Acknowledgements

We gratefully acknowledge the willing participation of all parents and children in this study. This research was facilitated by an ESRC PhD studentship awarded to the first author and the data were collected while she was at the Department of Psychology, Goldsmiths, University of London, UK.

## References

Alloway, T. P. (2007). Working memory, reading, and mathematical skills in children with developmental coordiantion disorder. *Journal of Experimental Child Psychology, 96*, 20–36.
Alloway, T. P. (2011). A comparison of working memory profiles in children with ADHD and DCD. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Children and Adolescence, 17*, 483–494.
Alloway, T. P., & Archibald, L. (2008). Working memory and learning in children with developmental coordination disorder and specific language impairment. *Journal of Learning Disabilities, 41*, 251–262.
Altshuler, L., Tekell, J., Biswas, K., Kilbourne, A. M., Evans, D., Tang, D., et al. (2007). Executive function and employment status among veterans with bipolar disorder. *Psychiatric Services, 58*, 1441–1447.
American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed. – text revision). Washington, DC: Author.
American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington DC: Author.
Anderson, P. (2002). Assessment and development of executive function (EF) during childhood. *Child Neuropsychology, 8*, 71–82.
Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development, 81*, 1641–1660.
Biederman, J., Monuteaux, M. C., Dyle, A. E., Seidman, L. J., Wilens, T. E., Ferrero, F., et al. (2004). Impact of executive function deficits and attention-deficit/hyperactivity disorder (ADHD) on academic outcomes in children. *Journal of Consulting and Clinical Psychology, 72*, 757–766.
Diamond, A. (2013). Executive functions. *Annual Reviews of Psychology, 64*, 135–168.
Garcia-Villamisar, D., & Hughes, C. (2007). Supported employment improves cognitive performance in adults with autism. *Journal of Intellectual Disability Research, 51*, 142–150.
Gilotty, L., Kenworthy, L., Sirian, L., Black, D. O., & Wagner, A. E. (2002). Adaptive skills and executive function in autism spectrum disorders. *Child Neuropsychology, 8*, 241–248.
Happé, F., Booth, R., Charlton, R., & Hughes, C. (2006). Executive function deficits in autism spectrum disorders and attention-deficit/hyperactivity disorder: Examining profiles across domains and ages. *Brain & Cognition, 61*, 25–39.
Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2007). *Movement assessment battery for children* (2nd ed.). London: Pearson Assessment.
Hill, E. L. (1998). Cognitive explanations of the planning and organization of movement. In D. Sugden & M. Chambers (Eds.), *Children with developmental disorder*. London: Whurr Publishers Ltd.
Hill, E. L. (2004). Executive dysfrunction in autism. *Trends in Cognitive Sciences, 8*, 26–32.
Korkman, M., Kirk, U., & Kemp, S. (1998). *NEPSY. a developmental neuropsychological assessment*. China: Harcourt Assessment Inc.
Livesey, D., Keen, J., Rouse, J., & White, F. (2006). The relationship between measures of executive function, motor performance and externalising behaviour in 5- and 6-year-old children. *Human Movement Science, 25*, 50–64.
Mandich, A., Buckolz, E., & Polatajko, H. (2002). On the ability of children with developmental coordination disorder (DCD) to inhibit response initiation: The simon effect. *Brain and Cognition, 50*, 150–162.
Michel, E., Roethlisberger, M. R., Neuenschwander, N., & Roebers, R. C. M. (2011). Development of cognitive skills in children with motor coordination impairments at 12-month follow-up. *Child Neuropsychology, 17*, 151–172.
Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., & Howerter, A. (2000). The unity and diversity of executive functions and their contributions to complex frontal lobe tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49–100.
Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibtion taxonomy. *Psychological Bulletin, 126*, 220–246.
Ozonoff, S., & Jensen, J. (1999). Specific executive function profiles in three neurodevelopmental disorders. *Journal of Austism and Developmental Disorders, 29*, 171–177.
Piek, J. P., Dyck, M. J., & Francis, M. (2007). Working memory, processing speed, and set-shifting in children with developmental coordination disorder and attention-deficit-hyperactivity disorder. *Developmental Medicine and Child Neurology, 49*, 678–683.
Piek, J. P., Dyck, M. J., Nieman, A., Anderson, M., Hay, D., Smith, L. M., et al. (2004). The relationship between motor coordination, executive functioning and attention in school aged children. *Archives of Clinical Neuropsychology, 19*, 1063–1076.
Querne, L., Berquin, P., Vernier-Hauvette, M.-P., Fall, S., Deltour, L., Meyer, M.-E., et al. (2008). Dysfunction of the attentional brain network in children with Developmental Coordination Disorder: A fMRI study. *Brain Research, 1244*, 89–102.
Rigoli, D., Piek, J. P., Kane, R., & Oosterlaan, J. (2012). An examination of the relationship between motor coordination and executive functions in adolescents. *Developmental Medicine & Child Neurology, 54*, 1025–1031.
Rosenbaum, D. A., Marchak, F., Barnes, H. J., Vaughan, J., Slotta, J. D., & Jorgensen, M. J. (1990). Constraints for action selection: Overhand versus underhand grips. In M. Jeannerod (Ed.), *Attention and performance XIII. Motor representation and control* (pp. 321–342). Hillsdale, NJ: Lawrence Erlbaum Associates.

Sergeant, J. A., Guerts, H., & Oosterlaan, J. (2002). How specific is a deficit of executive functioning for attention-deficit/hyperactivity disorder? *Behavioural Brain Research, 130*, 3–28.
Smyth, M. M., & Mason, U. C. (1997). Planning and execution of action in children with and without developmental coordination disorder. *Journal of Child Psychology and Psychiatry, 38*, 1023–1037.
Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643–662.
van Swieten, L. M., van Bergen, E., Williams, J. H., Wilson, A. D., Plumb, M. S., Kent, S. W., et al. (2009). A test of motor (not executive) planning in developmental coordination disorder and autism. *Journal of Experimental Psychology: Human Perception and Performance, 36*, 493–499.
Wechsler, D. (2004). *Wechsler intelligence scale for children* (4th ed.). London: Pearson Assessment.
Wilson, P. H., Ruddock, S., Smits-Engelsman, B., Polatajko, H., & Blank, R. (2012). Understanding performance deficits in developmental coordination disorder: A meta-analysis of recent research. *Developmental Medicine and Child Neurology, 55*, 217–228.
Wisdom, S. N., Dyck, M. J., Piek, J. P., & Hay, D. (2007). Can autism, language and coordination disorders be differentiated based on ability profiles? *European Child and Adolescent Psychiatry, 16*, 178–186.
Wright, D. B., London, K., & Field, A. P. (2011). Using bootstrap estimation and the plug-in principle for clinical psychology. *Journal of Experimental Psychopathology, 2*, 252–270.
Wuang, Y.-P., Chwen-Yng, S., & Su, J.-H. (2011). Wisconsin Card Sorting Test performance in children with developmental coordination disorder. *Research in Developmental Disabilities, 32*, 1669–1676.