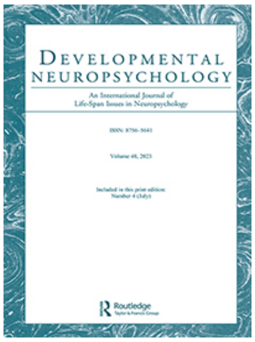

Developmental Neuropsychology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/hdvn20

Inhibition skills in children with developmental coordination disorder

Teresa Joyce, Serena Vanzan, Nichola Stuart & Anna Barnett

To cite this article: Teresa Joyce, Serena Vanzan, Nichola Stuart & Anna Barnett (2023) Inhibition skills in children with developmental coordination disorder, Developmental Neuropsychology, 48:4, 147-161, DOI: 10.1080/87565641.2023.2205139

To link to this article: https://doi.org/10.1080/87565641.2023.2205139

Published online: 09 May 2023.

DEVELOPMENTAL NEUROPSYCHOLOGY
2023, VOL. 48, NO. 4, 147–161
https://doi.org/10.1080/87565641.2023.2205139

Routledge
Taylor & Francis Group

OPEN ACCESS Check for updates

Inhibition skills in children with developmental coordination disorder

Teresa Joyce [a], Serena Vanzan [b], Nichola Stuart [b], and Anna Barnett [b]

[a]School of Nursing Midwifery and Health, Faculty of Health and Life Sciences, Coventry University, London; [b]Department of Psychology, Health and Professional Development, Faculty of health and life sciences, Oxford Brookes University, Oxford, UK

ABSTRACT

Background: Inhibition (Response Inhibition – RI and Interference Control – IC) have been inconsistently examined in Developmental Coordination Disorder (DCD) with response modalities often not considered.
Aims: To examine RI and IC in children with DCD.
Method: Twenty-five children 6-10 years with DCD, plus 25 matched typically developing peers completed motor and verbal RI and IC tasks.
Results: Children with DCD made significantly more errors in the motor and verbal RI tasks, had slower movement time and RT in the motor IC task, and longer completion time in the verbal IC task.
Conclusions: Children with DCD have RI and IC difficulties in motor and verbal responses.

ARTICLE HISTORY
Received 1 September 2022
Revised 24 January 2023
Accepted 16 April 2023

Introduction

Evidence of Executive Function (EF) difficulties have been reported in neurodevelopmental disorders, such as Attention Deficit Hyperactivity Disorder (ADHD) (Willcutt et al., 2005), Autism Spectrum Disorder (ASD) (Demetriou et al., 2018), and Developmental Coordination Disorder (DCD) (Blank et al., 2019; P. H. Wilson et al., 2017). However, heterogeneity of performance on EF tasks has been noted both within and across these disorders (Leonard & Hill, 2015; Vaidya et al., 2020). The complexity of EF and the measurement challenges contribute to this heterogeneity. EF is a multifaceted construct consisting of separate domains which share underlying commonality (Miyake et al., 2000). Although different components have been described, the most commonly cited domains are Working Memory, Cognitive Flexibility, and Inhibition (Diamond, 2013).

EF has been examined less frequently in DCD compared to ADHD and ASD. However, individuals with DCD have themselves highlighted challenges with EF as a primary area of concern associated with difficulties in daily life, such as concentrating on tasks and managing household responsibilities (O'Dea & Connell, 2016). DCD is a condition affecting between 5% and 6% of children and is characterized by poor motor control and coordination which negatively impacts participation in everyday life (American Psychiatric Association APA, 2013). Research on EF in children with DCD has reported mixed findings, particularly on Working Memory and Cognitive Flexibility (Leonard & Hill, 2015).

There is less research on inhibition in children with DCD and the impact this may have on their motor control and coordination. Inhibition is the ability to override automatic but inappropriate or incorrect responses as well as the ability to resist interference which could cause distraction (Lui et al., 2015). Inhibition itself is a multifaceted construct, and researchers do not always agree on the classification of

CONTACT Teresa Joyce ab5590@coventry.ac.uk School of Nursing Midwifery and Health, Faculty of Health and Life Sciences, Coventry University, The Hudson School of Health, 350 Kennington Lane, Vauxhall SE11 5HY, London

domains (Miyake et al., 2000). It is widely acknowledged that there is a distinction between Response Inhibition (RI) and Interference Control (IC) (Laloi et al., 2017; Nigg, 2000) with further research confirming differing patterns of brain activation for these two components of Inhibition (Brydges et al., 2012; 2013). RI is the ability to override automatic but unhelpful responses, and IC is the ability to ignore distracting information (Laloi et al., 2017). These inhibition skills are required in everyday life; for example, a child would need to stop and/or adapt ongoing actions and ignore distractions to respond to signals or environmental changes when walking or playing in a busy environment.

A recent meta-analysis of research, although limited to studies from 2016 to 2021, does report evidence of inhibition difficulties in individuals with DCD. Group differences were found between inhibition components as well as across temporal and error/accuracy measures (Subara-Zukic et al., 2022). However, case–control research has often only considered one component of inhibition (RI or IC) and either a temporal or error measurement rather than both. It is important to consider both RI and IC as they are conceptually different. This will allow for a better understanding of inhibition performance in DCD and what type of targeted intervention would be most appropriate. A further limitation of previous studies was highlighted by Subara-Zukic et al. (2022), in that they did not apply the DSM-5 diagnostic criteria in participant selection, which affects the generalizability of results in the DCD population. Subara-Zukic et al. (2022) meta-analysis covered motor control, cognitive, and neural underpinnings of DCD. This broad scope has resulted in several limitations when considering the Inhibition findings specifically. These limitations include a lack of detail on the studies which studied inhibition, a lack of information regarding how the inhibition tasks were classified, limited reporting on the papers which considered the different classifications of inhibition, and the inclusion of a large age range spanning childhood and adulthood.

However, focusing on children specifically and also taking into account earlier studies not included in the above review by Subara-Zukic et al. (2022), it is possible to examine the inhibition skills of children with DCD in more detail. The most common RI task used with children with DCD is a Go/No-Go task which requires children to respond to a "Go" cue and withhold response to a "No-Go" cue (Mandich et al., 2003; Querne et al., 2008; Rahimi-Golkhandan et al., 2016; Ruddock et al., 2015; Sartori et al., 2020; Thornton et al., 2018).

Rahimi-Golkhandan et al. (2016) found that children with DCD aged 7–12 years made significantly more errors in a Go/No-Go task requiring a motor response when using happy faces as stimuli. However, Thornton et al. (2018) also used happy faces as stimuli on a motor Go/No-Go task and did not find a difference between participants with and without DCD aged 8–17 years. Other Go/No-Go versions used in DCD research differ in the type of response required, e.g., button press, peddle push, touch screen, as well as the stimuli used.

This can often change the task demands, for example, in Mandich et al. (2003) research where the stimulus moved around the screen and spatial cues were provided regarding the potential location. In Querne et al. (2008) research, children were required to respond to letters if they were presented in the correct order (e.g., c after b) but not respond to the letter X, this potentially placed children with DCD at a greater disadvantage as they have higher rates of language and reading impairments (Blank et al., 2019). Sartori et al. (2020) are the only researchers to use a Go/No-Go task which had motor and verbal response conditions. Using numbers as stimuli for children aged 8–9 years with and without DCD, Sartori et al. (2020) found that children performed more poorly under both verbal and motor response conditions.

Studies by Leonard et al. (2015) and Bernardi et al. (2016) used a RI task, the Verbal Inhibition Motor Task (VIMI) (Henry et al., 2012) that had a verbal and motor response. In their studies of children aged 7–11 years, they found that children with DCD had a higher error rate than those without DCD when a motor, but not a verbal, response was required. Bernardi et al. (2016) also found that children with DCD took longer to complete the RI task in motor condition, but not verbal one. The combined findings across this research may reflect the different response modalities required by the experimental tasks, which is an important consideration in a population of children with motor difficulty.

In contrast to RI tasks, IC tasks present a stimulus with two conflicting dimensions but only one is relevant to the task (Laloi et al., 2017). The most commonly used IC task is the Stroop task which requires the identification of one characteristic of a stimulus while ignoring another more prominent one (Killikelly & Szücs, 2010). Performance differences between motor and verbal response modalities have not been examined using IC tasks in children with DCD. Some studies have used a verbal response (Alesi et al., 2019; Pratt et al., 2014), while others used a motor response only (Koch et al., 2018; Mandich et al., 2002). Alesi et al. (2019) in children aged 3–6 years and Pratt et al. (2014) in children aged 6–14 years found that those with DCD had higher error rates on a verbal Stroop task. However, Koch et al. (2018) found no difference in error rates between children aged 8–12 years with and without DCD on a Stroop task when a motor response was required. These results suggest a potential difference in performance when a motor or verbal response is required. However, Alesi et al. (2019) and Pratt et al. (2014) used animals as stimuli, whereas Koch et al. (2018) used numbers, which might have influenced the results. It is therefore important to study the inhibition performance of children with DCD including both RI and IC using tasks that require both a motor and verbal response. This is because poorer motor skills in children with DCD could affect performance when a motor response is required but not when a verbal response is required.

As a motor skill is learned, elements become automatized (Clark, 2015) allowing for attention to be directed elsewhere without affecting movement production (Schott et al., 2016). Evidence suggests that automatization deficits in children with DCD result in greater attentional resources being directed to motor production compared to those without DCD (Jolly & Gentaz, 2014). The theory of limited attention suggests that attentional resources are finite (Kahneman, 1973). Therefore, it is possible that children with DCD completing an inhibition task with a motor response use more attentional resources for motor production and have less available for the inhibition demand. Furthermore, debate exists regarding whether the inhibition of motor and verbal responses might be conceptually separate (Messer et al., 2018). This provides an additional justification to separate the two modalities when investigating EF in children with DCD and to explore more systematically how inhibition impacts on motor control and co-ordination. In a systematic review, Lachambre et al. (2021) found that Executive Function difficulties in children with DCD were more prevalent in tasks with motor response modalities compared to verbal response modalities. The majority of previous research examining Inhibition in children with DCD has used tasks with motor response modalities. To gain a comprehensive understanding of the Inhibition profile of children with DCD, it is important to use both motor and verbal response modalities in a sample of children with DCD. Therefore, the aim of the current study was to examine the inhibition performance of children with and without DCD using RI and IC tasks with motor and verbal responses. This helps build on previous research and enhance comparability of results by using adaptations of tasks previously used with children with DCD. Based on existing evidence, it was predicted that children with DCD would have poorer RI and IC performance compared to peers without DCD. The automatization deficits and limited attention capacity hypotheses suggest that greater deficits should be expected when a motor response was required, compared to a verbal response.

Material and methods

Participants

An a-priori power analysis for t tests found that a sample size of 24 children with DCD and 24 controls was the minimum needed to find a 1-tailed difference with a large effect size between each group (.8) with a power of 85% and an α of .05. Fifty children took part in the study, 25 with DCD aged 6–10 years and 25 typically developing (TD) controls matched on age (± 6 months) and sex. This is a narrower age range than the majority of previous research and is at the lower end of when experimental measures of RI and IC can be assessed within a group of children with DCD. At this age, inhibition emerges as a separate component of EF (Messer et al., 2018) but is still developing (Leon-Carrion et al., 2004).

DCD group

Children with DCD were recruited through a University participant database; all had a full diagnostic assessment in line with the International Guidelines (Blank et al., 2019) and DSM-5 criteria for DCD (American Psychiatric Association APA, 2013): (A) the presence of a significant motor difficulty was confirmed by a total test score at or below the 16th percentile on the Movement ABC-2 (MABC-2) Test (Henderson et al., 2007). This is in line with the International Guidelines for DCD (Blank et al., 2019)

(B) Motor difficulties were confirmed to have a significant impact on daily life as indicated by a score in the "significant movement difficultly"/"indication of DCD" range on parent/carer questionnaires, the MABC-2 Checklist (Henderson et al., 2007) and the Developmental Coordination Disorder Questionnaire (DCDQ; B. N. Wilson et al., 2009), respectively. (C) A parent/carer telephone interview confirmed onset of symptoms in early/middle childhood. (D) A parent/carer telephone interview confirmed the absence of a neurological or intellectual impairment or medical condition, which could better explain the motor difficulties, as well as adequate prior learning opportunities. The British Picture Vocabulary Scale 3rd edition (BPVS-3) (Dunn et al., 2009), a measure of receptive language, was used to provide a quick measure of verbal ability. Scores on the BPVS-3 were within two standard deviations from the mean. Children with co-occurring conditions were not part of the exclusion criteria due to the high prevalence within clinical samples of children with DCD (Blank et al., 2019) and the recommendation that research samples should be more reflective of this clinical presentation (Astle & Fletcher-Watson, 2020). In the DCD group, six children were reported by parent/carers to also have Autism Spectrum Disorder (ASD), one Attention Deficit Hyperactivity Disorder (ADHD), and one both ASD and ADHD.

Typically developing (TD) group

TD children were recruited through opportunity sampling within the first author's personal networks, schools, and recommendations from previous participants. A child was included in the TD group if they had a total standard score of >7 on the MABC-2 Test (above the 16th percentile) and a standard score of ≥70 on the BPVS-3. Children were excluded from the TD group if they were reported by the parent/carer to have a clinical diagnosis of intellectual disorder, visual impairment, DCD, ADHD, ASD, or any neurological condition.

Parents/carers of both the TD and DCD groups also completed the hyperactivity and inattention section of the Strengths and Difficulties Questionnaire (SDQ) (Goodman & Goodman, 2009) and a demographic information sheet. The results of these and the BPVS-3 are provided in Table 1. Taking both groups together, the proportion of White British children (80%) and Ethnic Minorities (20%) included in the study are in line with the 2011 Census (80.5%; 19.5%) (Office for National Statistics; National Records of Scotland; Northern Ireland Statistics and Research Agency, 2016). There were no significant differences between the groups on the BPVS-3, with both groups scoring very close to the mean (100). Children with DCD had higher rates of hyperactivity and inattention on the SDQ compared to TD peers. Using the SDQ UK population survey categories, the mean hyperactivity and inattention score for the TD group fell within the "average" range, whereas the mean hyperactivity and inattention score for the DCD group fell at the top boundary of the "slightly elevated" category. Out of the 25 children with DCD, 19 had "slightly elevated" or higher scores for hyperactivity and inattention, indicating potential difficulties in these areas. This indicates that the children in the DCD group not only had higher hyperactivity and inattention scores than the TD control group but that they also had higher scores compared to the wider UK population.

Table 1. Background Information for Children with DCD and the TD Control group.

		DCD	TD	p	Cohen's *d*
Gender	Male	23	23		
	Female	2	2		
Age	Mean (SD)	8;8 (1;3)	8;8 (1;2)		
(years; months)	Range	6;2–10;11	6;4–10;9		
Ethnicity	White – British	22	18		
	Asian – Pakistani, Bangladeshi, Chinese	2	4		
	Black -Caribbean, African, other	1	-		
	Other	-	3		
BPVS-3 Standard Score		103.52	*101.52*	*.62*	*.143*
SDQ Hyperactivity and Inattention Score		7.16	2.56	*< .001*	*1.89*

Measures

To measure RI, an adaptation of the Verbal Inhibition Motor Inhibition (VIMI) task (Henry et al., 2012) was used, which had both motor and verbal response conditions. The VIMI has previously been used with children with DCD (Bernardi et al., 2016; Leonard et al., 2015).

Adaptions were made to increase the sensitivity by shortening the length of the task, providing uniformity to the stimuli presentation, and recording timings for individual trials. Since a well-established IC task including both motor and verbal response conditions was not available, adaptations of separate verbal IC and motor IC tasks were used. It is important to note that speech is also a motor process; however, no difficulties with speech and language were reported for children in either group. Ho and Wilmut (2010), in a study of the motor control of speech, did not find a difference between children with DCD and TD children in the production time of single words. Therefore, all verbal tasks required a single-word answer to minimize the influence of the motor requirements of speech on the results. All four measures are described below.

Verbal and motor ri inhibition task: AdVIMI

The Verbal Inhibition Motor Inhibition "VIMI" task is an experimental task designed by Henry et al. (2012) to assess RI in children aged 6–14 years and has also been used to investigate RI in children with DCD (Bernardi et al., 2016; Leonard et al., 2015). The VIMI was adapted to increase the sensitivity and control of potential confounding variables such as attention and presentation style (see supplementary material). The presentation and scoring format was finalized following extensive trialing and piloting. The Adapted VIMI (AdVIMI) took approximately 10 min to complete and had one copy (congruent) and one inhibit (incongruent) block each with 20 trials for both the verbal (target words: "car" and "doll") (see Supplementary Figure 1) and the motor (target actions: point finger and make fist) (see Supplementary Figure 2) tasks. Prior to starting each block, children practiced responding to each stimulus once to confirm understanding of the instructions. Presentation of the stimuli was via Microsoft PowerPoint on a 14 inch computer monitor approximately 60 cm distance from the child with the timing controlled manually by the researcher. In contrast to the original VIMI, the AdVIMI mode of presentation enabled the children to always respond to a visual stimulus (e.g., picture of a hand gesture and picture of a doll/car), thus enhancing the comparability of the results from the verbal and motor tasks. Children were instructed to "say the word" or "move" as quickly as possible for the verbal and motor tasks, respectively. Children's performance was audio and video recorded, and scoring was completed offline. Verbal performance was measured using the mean trial Reaction Time (RT, in msec) and total error rate. Motor performance was measured using mean trial RT (in msec), mean trial Movement Time (MT) (in msec), and total error rate. Errors were marked zero for a correct response, one for a self-corrected response, or two for an incorrect response.

Motor IC task: AdFlanker

An adaptation of the NIH Toolbox Flanker task (Gershon et al., 2009) was created using the software PsychoPy. The NIH Toolbox Flanker task has been reported to have excellent test–retest reliability (ICC=.92) and moderate-to-good correlations with tasks assessing similar constructs. However, it does not allow access to raw scores and lacks consistency in stimuli presentation. The Adapted Flanker (AdFlanker) task was presented on a touch screen; children were shown five fish in a line and instructed to press the arrow which corresponded to the direction of the middle fish as quickly as they could. In the congruent condition, all the fish pointed the same way, while in the incongruent condition, the middle fish pointed in the opposite direction. Children had four practice trials (two congruent and two incongruent) for which they received feedback. Following successful completion of the practice items, children completed two blocks of 25 trials, each with 16 congruent and nine incongruent trials. There was a 1-min break between the two blocks. The AdFlanker had one to three congruent trials preceding each incongruent trial. RT for each trial (measured in msec) and total error rate were measured for the congruent and incongruent trials as well as RT and later the error rate difference between the congruent and incongruent conditions was also calculated.

Verbal IC task: AdAC

To measure verbal IC, the *Animal Colors* task from the Intelligence and Development Scales for Children and Adolescents – 2nd Edition (IDS-2) (Grob & Hagmann von Arx, 2017) was adapted. The original *Animal Colors* task has three conditions: in the first, animals are presented in the correct color (e.g., a blue dolphin), in the second, animals are presented in gray, and in the third condition, animals are presented in the incorrect color (e.g., red dolphin). The task is always to say the correct color of the animal as quickly as possible, irrespective of the presenting color. Each condition involves the presentation of 36 images, consisting of four animals (dolphin, frog, chick, and ladybird) in a non-sequential order that is fixed for all participants. Scoring for the Adapted Animal Color (AdAC) task focused on the first condition (correct colors) as the congruent control condition and the third condition (incorrect colors) as the incongruent condition, to measure verbal IC. Time taken (in sec) to complete each condition plus the number of non-self-corrected errors in the incongruent condition was recorded.

Procedures

The study was approved by the Institutional University Research Ethics Committee. Parents gave written consent, while children provided verbal assent. A standard script was used to administer each task. Children were assessed individually and completed all experimental tasks in the same testing session.

Statistical analysis

This study is part of a PhD project (Joyce, 2021). For the study reported here, all comparisons were planned a priori, and all conditions and comparisons run on these tasks are reported. The widely cited work of Althouse's (2016) (Bingham et al., 2019; Martin-Willett et al., 2020) recommendations for multiple comparisons are used rather than using statistical corrections. These are to (1) clearly define the methodology used, (2) report effect sizes, confidence intervals, and p values, and (3) allow the reader to use their own judgment regarding the weight of the conclusions. Effect sizes, confidence intervals, and p values are included in supplementary material. There were many significant correlations between the inhibition measures, and it has been recommended that Althouse's method for multiple comparisons is used rather than statistical corrections, particularly when variables are highly related (Armstrong, 2014).

Jamovi version 0.9 was used for statistical analyses. If the data met the assumptions of normality and equal variance, then parametric tests were conducted, otherwise non-parametric alternatives were used. Effect sizes are reported for all analyses, and cutoffs of .10–<.30 for a small effect, .30–<.50 for a medium effect, and ≥.50 for a large effect were used (Cohen, 1988). Group differences were examined across congruent and incongruent conditions, with incongruent conditions taken as a measure of inhibition in line with previous research (Bernardi et al., 2016; Sartori et al., 2020). T-tests and the non-parametric alternative Mann-Whitney U tests were used to examine the differences between mean values on all measures of inhibition. This facilitates comparison of the results to previous research.

To reduce the risk of type 1 error when running multiple comparisions, only when significant group differences were found on **both** the congruent and incongruent conditions were the difference between conditions also considered across groups. This was to assess if the additional Inhibition demand effected children in the DCD group more than those in the TD group. This approach was taken due to the non-parametric nature of the data. Furthermore, running comparisons only in these circumstances helped to reduce the overall number of comparisons made and the family-wise error rate.

Table 1 shows significant group differences in hyperactivity and inattention on the SDQ. This result is supported by previous research suggesting that higher hyperactivity and inattention scores are not independent of group membership (Crane et al., 2017). To control for the effect of co-occurring conditions, the tests were repeated excluding children with co-occurring conditions. This was not found to substantially change the results, and so these are included as supplementary material.

Results

RI – motor response

Table 2 displays the mean and standard deviations (SD) for each group on the AdVIMI Motor task, with levels of statistical significance and effect sizes for group differences. Significant group differences were found for error rate and Movement Time (MT) for both the congruent and incongruent conditions. Children with DCD made more errors than those without DCD and took longer to move into position. There were no significant group differences in Reaction Time (RT) for either condition.

As significant group differences were found for Error Rate and MT across both the congruent and incongruent conditions, a further analysis was conducted to examine whether the conditions affected each group in the same manner. Mann–Whitney U tests highlighted a significant group difference for error rate, representing a large effect ($d = .60$) in the increase in error between congruent and incongruent conditions ($U = 208$, $p = .043$). Children with DCD had a larger increase across the conditions ($M = 7.80$, SD = 6.83) than the TD control group ($M = 4.52$, SD = 3.55). There was also a significant difference between the groups for the increase in MT between the congruent and incongruent conditions (U = 204, $p = .035$) representing a large effect size ($d = .66$). Children with DCD had a larger increase in MT across the conditions ($M = .31$, SD =.17) compared to TD controls ($M = .22$, SD =.12).

Table 2. Mean (SD) AdVIMI Motor Scores for the DCD and TD groups.

Measure	DCD (n = 25) Mean (SD)	TD (n = 25) Mean (SD)	p	Cohen's d
Congruent Error rate[1]	6.24 (2.13)	4.88 (3.26)	**	.49
Congruent RT[1] (msec)	350 (120)	330 (110)	ns	.17
Congruent MT (msec)	640 (110)	560 (90)	**	.73
Incongruent Error rate	14.00 (6.21)	9.40 (4.97)	**	.83
Incongruent RT (msec)	470 (200)	430 (180)	ns	.21
Incongruent MT[1] (msec)	950 (190)	780 (170)	***	.96

Note: ***≤.001; ** ≤.01; *≤ .05 RT - mean trial RT.
MT – mean trial MT.
1 Mann–Whitney U.

Table 3. A Comparison of Mean (SD) AdVIMI Verbal scores for the DCD and TD groups.

Measure	DCD (*n* = 25) Mean (SD)	TD (*n* = 25) Mean (SD)	*p*	Cohen's *d*
Congruent Error	1.28 (1.57)	.96 (1.06)		.24
Congruent RT (msec)	730 (140)	660 (80)		.59
Incongruent Error rate	4.76 (8.54)	.20 (.50)	***	.75
Incongruent RT (msec)	850 (230)	770 (160)		.43

Note: ***≤.001 RT – Mean trial RT.

RI – verbal response

Table 3 displays the means and SD for each group on the AdVIMI verbal task, with levels of statistical significance and effect sizes for group differences also shown. A significant difference, representing a medium effect size, was found for the error rate for the incongruent condition. Children with DCD made more errors compared to their TD peers. There were no significant group differences in error rate for the congruent condition or in RT for either condition.

IC – motor response

Table 4 displays the means and SD for each group on the AdFlanker task, together with the results of Mann–Whitney U tests to investigate group differences. Significant group differences representing large effects were found for RT for both the congruent and incongruent conditions, with children with DCD reacting more slowly than their TD peers in both conditions. There were no significant group differences in error rate for either condition. Mean error rate scores for both groups in each condition fell below one indicating a low rate for both groups. There was no significant difference between the groups for the increase in RT between the congruent and incongruent conditions ($U = 260$, $p = .316$).

IC – verbal response

Table 5 displays the means and SD for each group on the AdAC task for completion time for the congruent and incongruent conditions and error rate for the incongruent condition. Table 5 also shows the statistical significance and effect sizes of group differences. A significant group difference, representing a large effect size, was found for completion time in the incongruent and congruent conditions. Children with DCD performed more slowly than their TD peers. There were no significant group

Table 4. A Comparison of mean (SD) AdFlanker Scores for the DCD and TD groups.

Measure	*DCD (n = 25) Mean (SD)*	*TD (n = 25) Mean (SD)*	*p*	*Cohen's d*
AdFlanker Congruent Error rate	.76 (2.01)	.12 (.33)	ns	.45
AdFlanker Congruent RT (sec)	2.74 (.54)	2.31 (.15)	**	1.07
AdFlanker Incongruent Error rate	.56 (1.04)	.20 (.05)	ns	.44
AdFlanker Incongruent RT (sec)	2.54 (.46)	2.26 (.18)	*	.82

Note*** ≤.001; ** ≤.01; *≤ .05 RT – mean trial RT.

Table 5. Mean (SD) AdAC Scores for the DCD and TD groups.

Measure	DCD (*n* =25) Mean (SD)	TD (*n* = 25) Mean (SD)	*p*	Cohen's *d*
AdAC Congruent Completion Time	43.80 (13.60)	38.10 (10.20)	*	.51
AdAC Incongruent Error Rate	1.20 (2.23)	.24 (.66)	ns	.56
AdAC Incongruent Completion Time (sec)	82.30 (26.10)	63.80 (21.70)	**	.76

Note: **≤.01.

differences for error rate in the incongruent condition. Data were not collected on the error rate for the congruent condition. The mean error rates for both groups were low (DCD $M = 1.20$; TD $M = .24$), indicating that neither group made many errors.

As significant group differences were found for completion time across both the congruent and incongruent conditions, a further analysis was conducted to examine whether the conditions affected each group in the same manner. Mann–Whitney U tests highlighted a significant group difference, representing a large effect ($d = .75$) in the increase in time between congruent and incongruent conditions ($U = 106$, $p = .003$). Children with DCD had a larger increase across the conditions ($M = 38.58$, SD = 17.39) than the TD control group ($M = 25.76$, SD = 16.85).

Discussion

EF has been highlighted as an area of difficulty which impacts everyday life for those with DCD (O'Dea & Connell, 2016). Inhibition is a fundamental component of EF, and inhibition-specific difficulties have been reported in individuals with DCD (Subara-Zukic et al., 2022). However, the results have been inconsistent and previous studies have not fully examined the two sub-components of inhibition, IC and RI, using tasks that require verbal and motor responses. Response modality is an important consideration in a population of children with motor difficulties. As IC and RI are conceptually separate (Nigg, 2000), different intervention approaches are likely to be needed for each. It is, therefore, important to understand the inhibition skills of children with DCD more fully to gain a complete understanding of their difficulties and because of the impact inhibition may have on motor performance.

The current study built on and extended previous work by examining the inhibition skills of children with and without DCD using IC and RI tasks requiring both motor and verbal response modalities. It was predicted that children with DCD would perform more poorly on tasks which required a motor response compared to typically developing (TD) children. Children with DCD were found to make significantly more errors on the incongruent condition of the motor RI task and have slower movement time as well as slower RT on the incongruent condition of the motor IC task. Children with DCD were also found to make more errors compared to TD peers on the incongruent condition of the verbal RI task and take longer time to complete the incongruent condition of the verbal IC task. This has shown that inhibition difficulties in children with DCD are present both when a motor and verbal response are required.

RI – Motor response

Children with DCD were found to have a higher Movement Time (MT) and error rate in both the congruent condition (not involving a RI demand) and in the incongruent condition (which did have a RI demand). These results suggest that children with DCD perform more slowly and less accurately in tasks that require a motor response (in this case, a hand gesture) than TD peers. This is not surprising as children with DCD are widely known to show slow and inaccurate movement, and this is often a difficulty which impacts their ability to effectively perform everyday motor tasks (Blank et al., 2019). Using the original VIMI task, Leonard et al. (2015) also found that children with DCD made more RI errors compared to TD peers. However, unlike the current study, which reported congruent and incongruent error rates separately, Leonard et al. (2015) used the total number of errors made across conditions as their measurement of RI, thus affecting the ability to isolate the inhibition demand.

Leonard et al. (2015) also did not consider MT. However, Bernardi et al. (2016) did consider completion time on the VIMI with the same sample of children and found no difference between children with and without DCD in the motor condition. However, completion time for a whole block is a less sensitive measure than mean trial MT.

Further analysis in the current study showed that children with DCD had a greater increase in error rate and MT between the congruent and the incongruent conditions compared to TD controls. This suggests that the higher error rate and slower MT of children with DCD in the incongruent condition relates not just to their motor difficulties but also to the RI demand. No significant group difference was found for RT in the motor condition of the AdVIMI. RT has not previously been examined using the VIMI task, and results considering RT across other RI tasks requiring a motor response have been inconsistent (Ruddock et al., 2015; Thornton et al., 2018). This inconsistency across the literature could relate to the range of motor responses used (e.g., key press, touch screen, and foot pedal).

RI – verbal response

The DCD group had significantly higher error rates than TD controls in the AdVIMI verbal incongruent condition, but not in the congruent condition. This result contrasts with Leonard et al. (2015) who found that children with DCD and TD controls did not differ in error rate on the VIMI verbal task. However, as stated above, there were substantial differences in how the error rate was calculated in Leonard et al. (2015) research compared to the current study.

Furthermore, Leonard et al. (2015) considered only correct and incorrect responses, while the present study included “corrected” responses where a child may initially respond incorrectly and then self-correct to provide the accurate response. This increased sensitivity in measurement in the present study could explain the difference in findings. No significant group differences were found for RT in the verbal condition of the AdVIMI. No previous research has considered RT in a verbal RI task.

IC – Motor response

No significant group difference was found for the error rate on the AdFlanker, the IC task with a motor response. This finding contrasts with Michel et al. (2018) who found that children with motor difficulties made more errors on a Flanker task compared to TD peers. There are several possible explanations for this discrepancy in findings. Participants in Michel et al. (2018) study were younger (4–6 years) than those in the current study (6–10 years). Therefore, it is possible that accuracy on the AdFlanker is impaired for younger children with motor difficulties but not for older children with DCD. Another possibility is that the two versions of the task have different cognitive demands. The Flanker task used by Michel et al. (2018) had both a “standard” condition and a “switch” condition where the rules were switched and children responded to the direction of the flanking fish. Michel et al. (2018) error rate in the standard flanker conditions was much higher than in the AdFlanker used in the present research. However, the addition of the “switch” condition could have affected performance on the standard condition of Michel et al. (2018) task due to the increased working memory load of the rule change.

Children with DCD were found to have a longer RT in both the congruent and incongruent conditions of the AdFlanker in the present study. However, no significant group difference was found in the increase in RT between the congruent and incongruent conditions. This demonstrates that children with DCD were slower at reacting to this task regardless of the IC demand. Children with DCD have been found to have poorer visual perception skills (Subara-Zukic et al., 2022). Therefore, it is possible that the slower RT of children with DCD in the AdFlanker task is the result of poorer visual perception, which is required to quickly locate the target fish and interpret its direction, rather than poorer IC skills when a motor response is required.

IC – Verbal response

No significant group differences were found for the error rate on the AdAC, the IC task with a verbal response. Similarly, to the AdFlanker task, there was a low error rate across both groups, so it is possible that it was too easy to elicit differences between the groups. This finding is in line with Alesi et al. (2019) and Pratt et al. (2014) who did not find a group difference in error rate, but it is in contrast to Michel et al. (2011) who did report a difference between children with and without motor difficulties. While there was no difference in error rate in the present study, children with DCD were found to take significantly longer to complete the task in both the congruent and incongruent conditions compared to the TD peers. Further analysis showed that children with DCD had a significantly greater increase in completion time between the congruent and incongruent conditions compared to TD controls. This suggests that the Inhibition demand added in the incongruent condition slowed down children with DCD more than TD peers. This suggests that children with DCD took longer to complete the task when they were required to inhibit distracting information and produce a correct response. Similarly, to the AdFlanker task, the poorer visual perception skills of children with DCD could contribute to the differences found in both conditions (Subara-Zukic et al., 2022).

Theoretical implications, limitations, and directions for future research

The results from the current study suggest that skill automation deficits and limited attention capacity hypotheses cannot singularly account for the motor difficulties central to DCD, as inhibition problems may also negatively impact performance. These results are in line with a recent meta-analysis which found that individuals with DCD had poorer inhibition skills (Subara-Zukic et al., 2022). Inhibition is required to focus on task relevant stimuli and inhibit automatic responses, thus enabling people to respond appropriately to task and environmental cues which are necessary for completing or mastering many motor activities. Navigating a busy environment, for example, requires the ability to maintain focus on task relevant information and adapt actions (such as stopping or moving out of the way) based on changing environmental conditions. Inhibition is also important in adapting actions in sports and playground games based on continually changing environmental circumstances (e.g., a moving football), and therefore, inhibition difficulties could contribute to reduced mastery of and participation in these activities, limiting socializing and physical activity opportunities.

Therefore, inhibition difficulties could underpin or exacerbate the motor difficulties experienced in DCD. Children with DCD are reported to participate in fewer sporting activities and have higher rates of sedentary behavior in comparison to TD peers (Steenbergen et al., 2020). While this could be due to motor difficulties, this avoidance of activities that use and develop inhibition skills could also explain why such skills in children with DCD are poorer than in their TD peers.

In line with Lachambre et al. (2021) systematic review, this research found that children with DCD had poorer Inhibition skills in tasks that required both motor and verbal responses. Currently, little is known about the mechanisms of verbal and motor inhibition and whether these are conceptually different or the same. Future research could use functional brain imaging to consider if motor and verbal inhibition use similar neural networks.

The results of this study need to be considered in light of their limitations. In the RI motor task, children with DCD were found to make significantly more errors in the incongruent condition than in the congruent condition. However, in the IC motor task, children with DCD were not found to make significantly more errors in the incongruent condition compared to the congruent condition. While this could be because the tasks assessed different inhibition components, the difference in results could also be explained by differences in the complexity of the motor demand required for the two tasks. The motor response of pressing a button in IC tasks is arguably less complex than making a fist and pointing a finger which was the required response in the motor RI task. Future research should aim to explore this further by examining the effect of motor complexity on inhibition performance for children with DCD in both RI and IC tasks using comparable response modalities.

All of the experimental tasks used in this study were specifically designed or chosen to be entertaining to children and to limit the influence of other variables on performance, such as a lack of attention to the task. However, balancing the engagement of the child and the sensitivity of the task is challenging and may have resulted in a low error rate in some of the tasks. While using fewer trials in tasks, compared to adult versions, helps reduce the impact of confounding variables, Rouder et al. (2019) suggest that having fewer trials affects the reliability of results. They highlight that performance on inhibition measures is subject to large measurement error and variance across trials and advocate for the use of a large number of trials to minimize this error. However, this is not practical with young children.

Another challenge of this field of work is the number of potential confounding variables such as levels of hyperactivity and inattention and co-occurring conditions. In line with findings from Lachambre et al. (2021) systematic review, excluding children with co-occurring conditions from the current study, was not found to impact the results.

Unfortunately, as the majority of the data in the current study were non-parametric, it was not possible to control for higher levels of hyperactivity and inattention. Therefore, it is possible that the higher levels of hyperactivity and inattention for children with DCD could explain the group differences.

Children with DCD have previously been found to have higher levels of hyperactivity and inattention (Crane et al., 2017). In the current study, 76% of children in the DCD group had "slightly raised" or higher scores on the SDQ. This suggests that higher levels of hyperactivity and inattention are not independent of a DCD diagnosis, and therefore, it may not be appropriate to partial out the effect. A fundamental difficulty when measuring EF is the issue of task impurity (Burgess, 1997). EF tasks, even when aiming to isolate individual components, rely on a range of other processes not directly under investigations such as the motor or language skills needed to respond to or understand task instructions. In comparison to the original VIMI, the AdVIMI limited the demands of working memory by including practice trials and limited attentional demands by reducing the number of trials by 75%. However, it is not possible to completely isolate Inhibition from all other cognitive processes, and this must be considered when interpreting the effect sizes of the results. Furthermore, whilst building on the range of tasks used in previous research, this study still used only one measure for each inhibition construct (RI and IC) separated by a response modality (verbal and motor). Therefore, it was not possible to consider in detail the potential influence of task impurity on the results. Future research could consider using several tasks for each construct (e.g., the RI tasks with a motor response), and latent variable analysis could be applied to account for task impurity difficulties.

Finally, the strength of the current work compared to some previous studies is the combination of a larger sample size (Alesi et al., 2019; Rahimi-Golkhandan et al., 2016) and full diagnostic assessment of DCD participants. The present study sample reflects the commonly reported increased incidence of DCD in males compared to females (Kadesjö & Gillberg, 1998; Lingam et al., 2009). As explanations for this gender imbalance are lacking, it may be appropriate to attempt to achieve more balanced samples in the future work on EFs in DCD.

Conclusion

Inhibition difficulties are reported to impact the daily life of individuals with DCD (O'Dea & Connell, 2016) and have been highlighted as an area of difficulty in a recent meta-analysis (Subara-Zukic et al., 2022). The present study added to our understanding by examining inhibition using specially adapted RI and IC tasks requiring motor and verbal responses in a group of children with a narrower age range than previous research. In line with previous investigations, this study found that, overall, children with DCD experience greater difficulties with inhibition. While these were not found across all measures, poorer performance was found across measures of both RI and IC when a motor and verbal response was required. This suggests that skill automatization deficits and limited attention capacity hypotheses cannot singularly account for the motor difficulties central to DCD and that EF limitations could partly contribute to the motor difficulties experienced.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The work was supported by the Hogrefe Ltd.

ORCID

Teresa Joyce http://orcid.org/0000-0003-1752-5391

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Alesi, M., Pecoraro, D., & Pepi, A. (2019). Executive functions in kindergarten children at risk for developmental coordination disorder. *European Journal of Special Needs Education*, *34*(3), 285–296. https://doi.org/10.1080/08856257.2018.1468635

Althouse, A. D. (2016). Adjust for multiple comparisons? It's not that simple. *The Annals of Thoracic Surgery*, *101*(5), 1644–1645. https://doi.org/10.1016/j.athoracsur.2015.11.024

American Psychiatric Association (APA). (2013). Diagnostic and statistical manual of mental disorders. 5th.

Armstrong, R. A. (2014). When to use the Bonferroni correction. *Ophthalmic & Physiological Optics : The Journal of the British College of Ophthalmic Opticians (Optometrists)*, *34*(5), 502–508. https://doi.org/10.1111/opo.12131

Astle, D. E., & Fletcher-Watson, S. (2020). Beyond the core-deficit hypothesis in developmental disorders. *Current Directions in Psychological Science*, *29*(5), 431–437. https://doi.org/10.1177/0963721420925518

Bernardi, M., Leonard, H. C., Hill, E. L., & Henry, L. A. (2016). Brief report: Response inhibition and processing speed in children with motor difficulties and developmental coordination disorder. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *22*(5), 627–634. https://doi.org/10.1080/09297049.2015.1014898

Bingham, B., Moniruzzaman, A., Patterson, M., Sareen, J., Distasio, J., O'Neil, J., & Somers, J. M. (2019). Gender differences among indigenous Canadians experiencing homelessness and mental illness. *BMC Psychology*, *7*(1), 57. https://doi.org/10.1186/s40359-019-0331-y

Blank, R., Barnett, A. L., Cairney, J., Green, D., Kirby, A., Polatajko, H., Rosenblum, S., Smits-Engelsman, B., Sugden, D., Wilson, P., & Vinçon, S. (2019). International clinical practice recommendations on the definition, diagnosis, assessment, intervention, and psychosocial aspects of developmental coordination disorder. *Developmental Medicine and Child Neurology*, *61*(3), 242–285. https://doi.org/10.1111/dmcn.14132

Burgess, P. W. (1997). Theory and methodology in executive function research. In P. Rabbitt (Ed.), *Methodology of Frontal and Executive Function* (pp. 81–116). Psychology Press.

Clark, D. J. (2015). Automaticity of walking: Functional significance, mechanisms, measurement and rehabilitation strategies. *Frontiers in Human Neuroscience*, *9*, 246. https://doi.org/10.3389/fnhum.2015.00246

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Lawrence Earlbaum Associates.

Crane, L., Sumner, E., & Hill, E. L. (2017). Emotional and behavioural problems in children with developmental coordination disorder: Exploring parent and teacher reports. *Research in Developmental Disabilities*, *70*(2017), 67–74. https://doi.org/10.1016/j.ridd.2017.08.001

Demetriou, E. A., Lampit, A., Quintana, D. S., Naismith, S. L., Song, Y. J. C., Pye, J. E., Hickie, I., & Guastella, A. J. (2018). Autism spectrum disorders: A meta-analysis of executive function. *Molecular Psychiatry*, *23*(5), 1198–1204. https://doi.org/10.1038/mp.2017.75

Diamond, A. (2013). Executive functions. *Annual Review of Psychology*, *64*(1), 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Dunn, L., Dunn, D., Styles, B., & Sewell, J. (2009). *The British Picture Vocabulary Scale* (3rd ed.). GL Assessment.

Gershon, R. C., Cella, D., Fox, N. A., Havlik, R. J., Hendrie, H. C., & M, W. (2009). Assessment of neurological and behavioural function: The NIH Toolbox. *Lancet Neurological*, *9*(2), 138–139. https://doi.org/10.1016/S1474-4422(09)70335-7

Goodman, A., & Goodman, R. (2009). Strengths and difficulties questionnaire as a dimensional measure of child mental health. *Journal of the American Academy of Child and Adolescent Psychiatry*, *48*(4), 400–403. https://doi.org/10.1097/CHI.0b013e3181985068

Grob, A., & Hagmann von Arx, P. (2017). *Intelligence and Development Scales for Children and Adolescents*. Hogrefe, Ltd.

Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2007). *Movement Assessment Battery for Children* (2nd ed.). Harcourt Assessment.

Henry, L. A., Messer, D. J., & Nash, G. (2012). Executive functioning in children with specific language impairment. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *53*(1), 37–45. https://doi.org/10.1111/j.1469-7610.2011.02430.x

Ho, A. K., & Wilmut, K. (2010). Speech and oro-motor function in children with developmental coordination disorder: A pilot study. *Human Movement Science*, *29*(4), 605–614. https://doi.org/10.1016/j.humov.2010.01.007

Jolly, C., & Gentaz, E. (2014). Analysis of cursive letters, syllables, and words handwriting in a French second-grade child with developmental coordination disorder and comparison with typically developing children. *Frontiers in Psychology*, *4*, 1022. https://doi.org/10.3389/fpsyg.2013.01022

Joyce, T. (2021). Executive Function in Children With and Without Developmental Coordination Disorder. [Doctoral dissertation, Oxford Brookes University London]. https://radar.brookes.ac.uk/radar/items/625ba5d2-08eb-408a-825c-c3ad6a591475/1/

Kadesjö, B., & Gillberg, C. (1998). Attention deficits and clumsiness in Swedish 7-year-old children. *Developmental Medicine and Child Neurology*, *40*(12), 796–804. https://doi.org/10.1111/j.1469-8749.1998.tb12356.x

Kahneman, D. (1973). *Attention and Effort*. Prentice-Hall.

Killikelly, C., & Szücs, D. (2010). The development of interference control: A pilot study using the manual colour word stroop paradigm. *Procedia - Social and Behavioral Sciences*, *2*(2), 4842–4847. https://doi.org/10.1016/j.sbspro.2010.03.781

Koch, J., Miguel, H., & Smiley-Oyen, A. L. (2018). Prefrontal activation during Stroop and Wisconsin card sort tasks in children with developmental coordination disorder: A NIRS study. *Experimental Brain Research*, *236*(11), 3053–3064. https://doi.org/10.1007/s00221-018-5358-4

Lachambre, C., Proteau Lemieux, M., Lepage, J. F., Bussières, E. L., Lippé, S., & Rodríguez, C. (2021). Attentional and executive functions in children and adolescents with developmental coordination disorder and the influence of comorbid disorders: A systematic review of the literature. *PloS One*, *16*(6), e0252043. https://doi.org/10.1371/journal.pone.0252043

Laloi, A., Jong, J., & Baker, A. (2017). Can executive functioning contribute to the diagnosis of SLI in bilingual children? A study on response inhibition. *Linguistic Approaches to Bilingualism*, *7*(4), 431–459. https://doi.org/10.1075/lab.15020.lal

Leonard, H. C., Bernardi, M., Hill, E. L., & Henry, L. A. (2015). Executive functioning, motor difficulties, and developmental coordination disorder. *Developmental Neuropsychology*, *40*(4), 201–215. https://doi.org/10.1080/87565641.2014.997933

Leonard, H. C., & Hill, E. L. (2015). Executive difficulties in developmental coordination disorder: methodological issues and future directions. *Current Developmental Disorders Reports*, *2*(2), 141–149. https://doi.org/10.1007/s40474-015-0044-8

Leon-Carrion, J., García-Orza, J., & Pérez-Santamaría, F. J. (2004). Development of the inhibitory component of the executive functions in children and adolescents. *The International Journal of Neuroscience*, *114*(10), 1291–1311. https://doi.org/10.1080/00207450490476066

Lingam, R., Hunt, L., Golding, J., Jongmans, M., & Emond, A. (2009). Prevalence of developmental coordination disorder using the DSM-IV at 7 years of age: A UK population-based study. *Pediatrics*, *123*(4), 693–700. https://doi.org/10.1542/peds.2008-1770

Liu, Q., Zhu, X., Ziegler, A., & Shi, J. (2015). The effects of inhibitory control training for preschoolers on reasoning ability and neural activity. *Scientific Reports*, *5*, 14200. https://doi.org/10.1038/srep14200

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*(1), 150–162. https://doi.org/10.1016/S0278-2626(02)00020-9

Mandich, A., Buckolz, E., & Polatajko, H. (2003). Children with developmental coordination disorder (DCD) and their ability to disengage ongoing attentional focus: More on inhibitory function. *Brain and Cognition*, *51*(3), 346–356. https://doi.org/10.1016/S0278-2626(03)00039-3

Martin-Willett, R., Helmuth, T., Abraha, M., Bryan, A. D., Hitchcock, L., Lee, K., & Bidwell, L. C. (2020). Validation of a multisubstance online timeline followback assessment. *Brain and Behavior*, *10*(1), e01486. https://doi.org/10.1002/brb3.1486

Messer, D., Bernardi, M., Botting, N., Hill, E. L., Nash, G., Leonard, H. C., & Henry, L. A. (2018). An exploration of the factor structure of executive functioning in children. *Frontiers in Psychology*, *9*(13), 1179. https://doi.org/10.3389/fpsyg.2018.01179

Michel, E., Molitor, S., & Schneider, W. (2018). Differential changes in the development of motor coordination and executive functions in children with motor coordination impairments. *Child Neuropsychology: A Journal on Normal* *and Abnormal Development in Childhood and Adolescence*, *24*(1), 20–45. https://doi.org/10.1080/09297049.2016.1223282

Michel, E., Roethlisberger, M., Neuenschwander, R., & Roebers, C. M. (2011). Development of cognitive skills in children with motor coordination impairments at 12-month follow-up. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence*, *17*(2), 151–172. https://doi.org/10.1080/09297049.2010.525501

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex '"frontal lobe"' tasks: a latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin*, *126*(2), 220–246. https://doi.org/10.1037/0033-2909.126.2.220

O'Dea, Á., & Connell, A. (2016). Performance difficulties, activity limitations and participation restrictions of adolescents with developmental coordination disorder (DCD). *The British Journal of Occupational Therapy*, *79*(9), 540–549. https://doi.org/10.1177/0308022616643100

Office for National Statistics ; National Records of Scotland ; Northern Ireland Statistics and Research Agency. (2016). *2011 Census aggregate data*. UK Data Service. https://doi.org/10.5257/census/aggregate-2011-1

Pratt, M. L., Leonard, H. C., Adeyinka, H., & Hill, E. L. (2014). The effect of motor load on planning and inhibition in developmental coordination disorder. *Research in Developmental Disabilities*, *35*(7), 1579–1587. https://doi.org/10.1016/j.ridd.2014.04.008

Querne, L., Berquin, P., Vernier-Hauvette, M. P., Fall, S., Deltour, L., Meyer, M. E., & de Marco, G. (2008). Dysfunction of the attentional brain network in children with developmental coordination disorder: A fMRI study. *Brain Research*, *1244*, 89–102. https://doi.org/10.1016/j.brainres.2008.07.066

Rahimi-Golkhandan, S., Steenbergen, B., Piek, J. P., Caeyenberghs, K., & Wilson, P. H. (2016). Revealing hot executive function in children with motor coordination problems: What's the go? *Brain and Cognition*, *106*, 55–64. https://doi.org/10.1016/j.bandc.2016.04.010

Rouder, J., Kumar, A., & Haaf, J. M. (2019). Individual differences in cognitive tasks 3 why most studies of individual differences with inhibition tasks are bound to fail. *PsyArXiv*. https://doi.org/10.31234/osf.io/3cjr5

Ruddock, S., Piek, J., Sugden, D., Morris, S., Hyde, C., Caeyenberghs, K., & Wilson, P. (2015). Coupling online control and inhibitory systems in children with developmental coordination disorder: Goal-directed reaching. *Research in Developmental Disabilities*, *36*, 244–255. https://doi.org/10.1016/j.ridd.2014.10.013

Sartori, R. F., Valentini, N. C., & Fonseca, R. P. (2020). Executive function in children with and without developmental coordination disorder: A comparative study. *Child: Care, Health and Development*, *46*(3), 294–302. https://doi.org/10.1111/cch.12734

Schott, N., El-Rajab, I., & Klotzbier, T. (2016). Cognitive-motor interference during fine and gross motor tasks in children with Developmental Coordination Disorder (DCD). *Research in Developmental Disabilities*, *57*, 136–148. https://doi.org/10.1016/j.ridd.2016.07.003

Steenbergen, B., Bekhuis, H., & van Abswoude, F. (2020). Promoting participation in DCD: Physical activity levels and the social network. *Current Developmental Disorders Reports*, *7*(2), 43–47. https://doi.org/10.1007/s40474-020-00193-y

Subara-Zukic, E., Cole, M. H., McGuckian, T. B., Steenbergen, B., Green, D., Smits- Engelsman, B. C. M., Lust, J. M., Abdollahipour, R., Domellöf, E., Deconinck, F. J. A., Blank, R., & Wilson, P. H. (2022). Behavioral and neuroimaging research on developmental coordination disorder (DCD): A combined systematic review and meta-analysis of recent findings. *Frontiers in Psychology*, *13*, 1–28. https://doi.org/10.3389/fpsyg.2022.809455

Thornton, S., Bray, S., Langevin, L. M., & Dewey, D. (2018). Functional brain correlates of motor response inhibition in children with developmental coordination disorder and attention deficit/hyperactivity disorder. *Human Movement Science*, *59*, 134–142. https://doi.org/10.1016/j.humov.2018.03.018

Vaidya, C. J., You, X., Mostofsky, S., Pereira, F., Berl, M. M., & Kenworthy, L. (2020). Data-driven identification of subtypes of executive function across typical development, attention deficit hyperactivity disorder, and autism spectrum disorders. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *61*(1), 51–61. https://doi.org/10.1111/jcpp.13114

Willcutt, E. G., Doyle, A. E., Nigg, J. T., Faraone, S. V., & Pennington, B. F. (2005). Validity of the executive function theory of attention-deficit/hyperactivity disorder: A meta-analytic review. Biological psychiatry, 57(11), 1336–1346. https://doi.org/10.1016/j.biopsych.2005.02.006

Wilson, B. N., Crawford, S. G., Green, D., Roberts, G., Aylott, A., & Kaplan, B. J. (2009). Psychometric properties of the revised developmental coordination disorder questionnaire. *Physical & Occupational Therapy in Pediatrics*, *29*(2), 182–202. https://doi.org/10.1080/01942630902784761

Wilson, P. H., Smits-Engelsman, B., Caeyenberghs, K., Steenbergen, B., Sugden, D., Clark, J., Mumford, N., & Blank, R. (2017). Cognitive and neuroimaging findings in developmental coordination disorder: New insights from a systematic review of recent research. *Developmental Medicine and Child Neurology*, *59*(11), 1117–1129. https://doi.org/10.1111/dmcn.13530