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Brief Report: Response inhibition and processing speed in children with motor difficulties and developmental coordination disorder

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Abstract

A previous study reported that children with poor motor skills, classified as having motor difficulties (MD) or Developmental Coordination Disorder (DCD), produced more errors in a motor response inhibition task compared to typically-developing (TD) children, but did not differ in verbal inhibition errors. The present study investigated whether these groups differed in the length of time they took to respond in order to achieve these levels of accuracy, and whether any differences in response speed could be explained by generally slow information processing in children with poor motor skills. Timing data from the Verbal Inhibition Motor Inhibition test were analyzed to identify differences in performance between the groups on verbal and motor inhibition, as well as on processing speed measures from standardized batteries. Although children with MD and DCD produced more errors in the motor inhibition task than TD children, the current analyses found that they did not take longer to complete the task. Children with DCD were slower at inhibiting verbal responses than TD children, while the MD group seemed to perform at an intermediate level between the other groups in terms of verbal inhibition speed. Slow processing speed did not account for these group differences. Results extended previous research into response inhibition in children with poor motor skills by explicitly comparing motor and verbal responses, and suggesting that slow performance, even when accurate, may be attributable to an inefficient way of inhibiting responses, rather than slow information processing speed *per se*.

KEYWORDS: Response inhibition, processing speed, motor difficulties, Developmental Coordination Disorder, executive functioning

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Developmental Coordination Disorder (DCD) occurs in between 1.8-6% of the population (Lingam, Hunt, Golding, Jongmans, & Emond, 2009; American Psychiatric Association: APA, 2013). It is defined by motor impairment that has an impact on activities of daily living and academic achievement that is not better explained by intellectual disability or an underlying neurological condition (APA, 2013).

Executive functions (EFs) have been investigated as possible neurocognitive mechanisms underlying the difficulties experienced by individuals with DCD. EF encompasses a cluster of higher order cognitive skills including *response inhibition* (RI), which refers to the ability to intentionally suppress dominant, automatic, prepotent responses to successfully complete a task (Nigg, 2000). Previous studies on RI in children with DCD have reported that even when accuracy of performance is typical, the speed of task completion is slower in children with DCD compared to typically-developing (TD) controls (Mandich, Buckolz, & Polatajko, 2002; Piek, Dyck, Francis, & Conwell, 2007; Querne et al., 2008). However, these studies have used measures of RI that involve a degree of motor demand (e.g., pressing a button), which may influence performance in individuals with impaired motor skills.

Leonard, Bernardi, Hill, and Henry (in press) assessed children screened for motor difficulties (MD), children with DCD, and TD peers on five different EF domains, including RI. The MD group were included to provide a 'purer' group of children with motor impairments, without the higher rate of co-occurring conditions or symptoms of other disorders that are often reported in clinical samples of individuals with DCD (Bishop, 2002;

Wilmut, 2010). The inclusion of both the DCD and MD groups within one study also addressed the issue of comparing results across studies using different sampling procedures. To investigate RI in equivalent tasks with varying levels of motor demands, Leonard et al. (in press) used the total number of errors in the Verbal Inhibition Motor Inhibition test (VIMI; Henry, Messer, & Nash, 2012) as a measure of RI. They reported significantly higher errors on the motor task by the DCD and MD groups compared to TD children, but no differences on the verbal task. However, it remains possible that children with impaired motor skills demonstrate poorer RI in terms of *time taken to respond*, despite producing similar numbers of errors. The first aim of the current study was to investigate speed of performance in motor and verbal RI tasks in children with DCD and MD, with the hypothesis that both groups would take longer to inhibit responses compared to TD children.

Studies reporting slower inhibition performance in children with DCD often observe longer reaction times on trials in which the inhibition of a response is not required (e.g., Go trials on the Go-NoGo task; Querne et al., 2008), and other studies of simple reaction time have reported prolonged latency in children with DCD (Henderson, Rose, & Henderson, 1992; Piek & Skinner, 1999). This may indicate a processing speed deficit, suggesting that longer completion times on RI tasks reflect general inability to process information at an adequate speed, rather than inhibition impairments. The second aim of the current study was to determine the impact of processing speed on completion times in RI tasks in children with DCD and MD. It was expected that children with DCD would be slower than TD children at processing information, while the investigation of processing speed in the MD group was exploratory.

Method

The data presented here are drawn from a larger study of EF in children with MD and DCD, and full details of the participants, measures and procedures used in the original study are provided in Leonard et al. (in press).

Participants were 91 children aged 7-11 years, split into three groups based on clinical diagnoses and their performance on the Movement Assessment Battery for Children (MABC-2; Henderson, Sugden, & Barnett, 2007), a standardized measure of motor ability. The MABC-2 provides a Total Score, which can be converted to a standard score (*M*=10, *SD*=3) and a percentile. Participants in the DCD group had a diagnosis from a qualified professional, corroborated by the research team, and all scored at or below the 16th percentile on the MABC-2. This cut-off was also used to classify children in the MD group, who were screened for motor impairments but had no diagnosis of DCD. Children were classified as having typical motor skills if they scored at or above the 25th percentile on the MABC-2.

Children with diagnoses of any neurodevelopmental disorder were not included in the MD and TD groups, and no additional diagnoses were present in the DCD group (including Attention Deficit-Hyperactivity Disorder (ADHD), which often co-occurs with DCD (Pitcher, Piek & Hay, 2003), and could have impacted RI performance in the current study). However, the DCD group had poorer reading scores and were reported to have increased levels of inattention / hyperactivity symptoms in comparison to their peers. These variables were, therefore, controlled in the analyses. All participants completed a large battery of EF tasks and a number of standardized background measures, and parents completed questionnaires relating to their children. Tasks were completed over one or two visits to the university or at their own home (DCD group), while MD and TD groups were tested over several sessions in a quiet room in the child's school.

Hierarchical multiple regression analyses, using group comparisons as dummy variables, were conducted to explore group differences on the tasks of interest. Predictors included in Step 1 of each regression model were chronological age, IQ (British Abilities Scales: BAS-3; Elliot & Smith, 2011), reading ability (Test of Word Reading Efficiency: TOWRE; Torgensen, Wagner, & Rashotte, 1999), and parent-reported hyperactivity/attentional difficulties (Strengths and Difficulties Questionnaire: SDQ; Goodman, 1997). Group comparisons (MD *vs.* TD, DCD *vs.* TD) were included in Step 2. The dependent variables were total completion times or mean latencies of tasks measuring *verbal and nonverbal response inhibition* (verbal and motor VIMI tasks, respectively), and *processing speed*, using the Motor Screening (MScr) and Big Circle Little Circle (BLC) tasks (Cambridge Neuropsychological Test Automated Battery: CANTAB; Cambridge Cognition, 2006), and Visual Scanning (VS) and Motor Speed (MSp) tasks (Trail-Making; Delis-Kaplan Executive Function System: D-KEFS; Delis, Kaplan, & Kramer, 2001).

In the VIMI, the experimenter produced one of two hand gestures (a pointed finger/fist: motor task), or one of two words ("car"/"doll": verbal task), and the participant was required to copy the gesture/word, or produce the alternative one, depending on whether the block included 'copy' or 'inhibit' trials. Twenty copy trials were followed by 20 inhibit trials, with the sequence repeated such that a total of 80 trials was administered. These 80 trials were then repeated with a second set of gestures/words (hand facing the experimenter / facing the table, or "bus"/"drum"). Each block of 20 trials was timed, and the sum of these times for the verbal task and the motor task were recorded separately, providing the Total

Time measure for each task. Children were instructed to respond as quickly as possible, but to prioritize accuracy over speed.

In the processing speed tasks, participants were required to respond as quickly as possible to a number of different stimuli: the MScr task required them to touch the center of a cross appearing at different positions on a touchscreen; the BLC task required them to touch either a big or a small circle presented next to each other in the center of the screen; the VS task required them to find and cross out the 24 examples of the number '3' presented amongst a visual array of 54 numbers and letters on an A3 piece of paper; the MSp tasks required them to draw a trail over a dotted line on the paper. Mean latencies of response times were calculated and scored by the computer program for the touchscreen tasks, while the total time taken to complete each of the paper tasks was recorded by hand. Descriptive data for all measures are presented in Table 1.

---Table 1 about here---

Results and Discussion

Since some of the timing measures providing the dependent variables for the analyses were not normally distributed, bootstrapping was performed on the data (see Leonard et al., in press, for details). The six hierarchical regression models met all other assumptions, and Bonferroni corrections were applied to the final models (p<.008). Multiple regressions are reported in Table 2.

---Table 2 about here ---

While there were no significant group differences in completion times on the *motor VIMI* task, the final regression model was significant, $F(6,80)=7.99$, $p<.001$. It accounted for 33% of the variance, with only age and IQ emerging as significant predictors. Given the difficulties that children with both DCD and MD demonstrated in performing accurately on this motor RI task (Leonard et al., in press) it was unexpected that they did not take significantly longer than their TD peers to complete the task. One explanation may be that the considerable motor demands of the task discouraged these children from attempting to perform well, and they did not take the extra time that they may have required to successfully inhibit the motor response.

In the *verbal VIMI* task, the final regression model predicted more than 40% of the variance in performance, $F(6,80)=11.92$, $p<.001$, and children with DCD took significantly longer than TD children to complete the task ($p=.002$), despite similar accuracy between groups (see Leonard et al., in press). This result is consistent with previous research measuring RI which reported slower response times in children with DCD than TD children, even when responses were as accurate (Piek et al., 2007; Querne et al., 2008). It is possible that children with DCD were slower to respond in the verbal task because the effort of producing a word requires some level of motor control. However, a previous study reported that DCD and TD children did not differ in the duration of movements for single syllable words, such as those used in the current study (Ho & Wilmut, 2010), and thus this is an unlikely explanation for the current results. In the MD group, verbal completion times were not significantly different from the TD group, although a trend was identified ($p=.054$). It may be that the MD group was performing at an intermediate level between the TD and DCD groups. However, this will need to be investigated further with larger samples in order to understand whether this is the case, or whether the non-significant trend in the MD group is due to a lack of power.

Children with DCD may take longer to execute most tasks, regardless of the skills required, because they are slower at processing information. In order to understand the relationships between processing speed and completion time on RI tasks, further regressions assessing group differences were conducted on each of the four processing speed measures. The final regression models for three of these measures, MScr, MSp and BLC, were not significant (*p*s>.05), providing no evidence for group differences[1]. For the VS task, the final regression model predicted 25% of the variance in performance, $F(6,80)=5.81$, $p<.001$. Age was a significant predictor ($p=.001$), and the DCD group took significantly longer to complete the VS task compared to the TD group ($p=.007$).

What might differentiate the VS task from the other processing speed measures? The VS task involves considerable visuo-spatial demands, and children with DCD may be slower at completing the task because of difficulties in processing visuo-spatial information; such problems are often observed in this group (Wilson & McKenzie, 1998). The result is also consistent with previous research reporting slower visual inspection time in children with DCD (Piek et al., 2007). It remains possible, therefore, that group differences in RI time on the VIMI verbal task could be accounted for by slower processing speed. To account for the group differences in VS, an exploratory regression analysis of verbal RI times was conducted, which included VS completion time as an additional control variable in Step 1. The regression model was significant, $F(7,79)=10.58$, $p<.001$, accounting for 48% of the variance. Importantly, children with DCD remained significantly slower than TD children at completing the verbal RI task ($B=37.28$, $SE\ B=8.40$, $p=.002$). These results suggest that group differences in processing speed cannot fully explain slower performance in the verbal

RI task in children with DCD.

To conclude, children with DCD were as accurate as TD children in completing a verbal RI task, yet took significantly longer to do so. Individuals with MD, but no clinical diagnosis, did not demonstrate any significant difference from TD children although they seemed to respond at an intermediate time between the TD and DCD groups on this task. Therefore, the ability of children with MD to inhibit verbal responses needs to be further investigated in future studies with larger samples. In the DCD group, it seems likely that the verbal RI ‘slowing’ reflects inefficiency with the process of inhibiting a response, such that typical levels of accuracy can only be obtained at the expense of very slow and careful responding. This hypothesis is consistent with neuroimaging evidence reporting differences between children with and without DCD in the neural network pathways underlying RI (Querne et al., 2008), with a more effortful response suggested in DCD. It may be that these different and more effortful neural responses contribute to the slower RI seen in the current verbal task in children with DCD.

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Table 1

Mean, (standard deviation) and *range* for total errors and completion times for the Verbal Inhibition Motor Inhibition test (VIMI), completion times for Visual Scanning and Motor Speed, and latencies for Motor Screening and Big Circle, Little Circle. Descriptives are also provided for the chronological age and Movement ABC-2 (MABC-2) total standard scores for each group, as well as scores on the measures used as predictors in the analyses, namely the British Abilities Scales (BAS-3), the Test of Word Reading Efficiency (TOWRE), and the Hyperactivity/Inattention scale on the Strengths and Difficulties Questionnaire (SDQ).

Measure	**TD Group** (*N*=38)	**MD group** (*N*=30)	**DCD group** (*N*=23)
Chronological Age (Months)	111.61 (12.51) *86-133*	107.03 (14.14) *85-136*	120 (13.46) *97-143*
MABC-2 Total Standard Score	10.34 (2.13) *8-16*	4.70 (1.26) *2-7*	4.39 (1.83) *1-7*
BAS3 General Conceptual Ability Score	103.87 (12.46) *78-138*	95.9 (15.62) *71-138*	101.35 (19.55) *71-151*
TOWRE Reading Efficiency Standard Score	111.87 (13.72) *83-135*	107.6 (15.75) *73-131*	100.52 (12.34) *74-119*
SDQ Hyperactivity and Attentional Difficulties	2.46 (2.34) *0-8*	2.86 (2.69) *0-8*	7.18 (1.89) *2-10*
VIMI Motor Task Total Errors	31.68 (13.85) *3-60*	48.77 (14.00) *20-72*	50.74 (15.02) *21-76*
VIMI Verbal Task Total Errors	9.61 (5.90) *0-23*	13.10 (7.23) *5-31*	16.09 (10.17) *4-36*

VIMI Motor Task	297.18 (30.73)	311.63 (27.60)	322.78 (39.80)
Total Completion Time (s)	*257-411*	*256-362*	*264-422*
VIMI Verbal Task	214.21 (25.89)	239.90 (38.11)	247.17 (31.18)
Total Completion Time (s)	*172-322*	*194-371*	*199-328*
D-KEFS	28.92 (8.46)	32.70 (8.21)	38.61 (12.95)
Visual Scanning Task (s)	*18-54*	*17-48*	*20-65*
D-KEFS	37.29 (14.51)	45.03 (19.62)	42.0 (17.23)
Motor Speed Task (s)	*17-81*	*17-87*	*21-92*
CANTAB Motor	752.66 (186.78)	855.72 (191.96)	767.91 (125.67)
Screening Task (ms)	*503.0-1339.3*	*543.0-1285.0*	*586.78-1277.18*
CANTAB Big /Little	715.25 (127.53)	770.36 (165.73)	789.79 (168.68)
Circle Task (ms)	*521.45-1088.15*	*531.72-1325.91*	*586.78-1277.18*

Note. TD=Typically-Developing, MD=Motor Difficulties, DCD=Developmental Coordination Disorder, CANTAB=Cambridge Neuropsychological Test Automated Battery, D-KEFS=Delis-Kaplan Executive Function System.

Table 2

Summary details of Step 2 of the hierarchical multiple regression analyses predicting speed of performance in the response inhibition and processing speed measures. Standardized beta values, *unstandardized coefficients* and *(standard errors)* are reported for each predictor variable. The total amount of variance predicted by the final model is also presented, along with the change in R^2 in Step 2 of the model (significant changes indicate an effect of the group comparisons after key background variables have been taken into account). Significant values are indicated where relevant.

	Details of Step 2 for each regression							
Measure	Final Model Adj. R^2	*Age*	*IQ*	*Reading Ability*	*SDQ H/I Scale*	*TD Vs. MD*	*TD Vs. DCD*	ΔR^2 Step 2
Response Inhibition Time								
VIMI Motor Task	**.33***** 	-.43** *-1.05* *(.23)*	-.27* *-.59* *(.23)*	-.06 *-.14* *(.26)*	.15 *1.66* *(1.81)*	.03 *2.18* *(7.10)*	.26 *20.21* *(12.06)*	.04
VIMI Verbal Task	**.43*****	-.49** *-1.19* *(.23)*	-.17 *-.38* *(.28)*	-.09 *-.19* *(.23)*	-.02 *-.22* *(1.08)*	.17† *12.25* *(6.33)*	.54** *41.37* *(8.55)*	.15***
Processing Speed								
D-KEFS Visual Scanning	**.25*****	-.32** *-.24* *(.07)*	-.14 *-.09* *(.06)*	-.09 *-.06* *(.09)*	.10 *.33* *(.35)*	.04 *.86* *(2.04)*	.41** *9.73* *(2.98)*	.09**

D-KEFS	.02	-.23*	-.11	.03	.03	.10	.17	.02
Motor		*-.28*	*-.12*	*.04*	*.14*	*3.55*	*6.50*	
Speed		*(.12)*	*(.15)*	*(.14)*	*(.69)*	*(4.09)*	*(5.95)*	
CANTAB	.02	-.08	.07	-.04	.10	.28*	-.02	.07†
Motor		*-.99*	*.76*	*-.51*	*5.66*	*105.46*	*-8.54*	
Screening		*(1.82)*	*(1.33)*	*(1.38)*	*(9.13)*	*(49.33)*	*(50.63)*	
CANTAB	.08†	-.04	-.29*	-.05	-.11	.08	.26*	.03
Big/Little		*-.39*	*-2.87*	*-.48*	*-5.60*	*27.44*	*90.78*	
Circle		*(1.45)*	*(1.13)*	*(1.25)*	*(6.41)*	*(36.85)*	*(45.27)*	

Note TD=Typically-Developing, MD=Motor Difficulties, DCD=Developmental Coordination, VIMI=Verbal Inhibition Motor Inhibition test, CANTAB=Cambridge Neuropsychological Test Automated Battery, D-KEFS=Delis-Kaplan Executive Function System, SDQ H/I=Strengths and Difficulties Questionnaire Hyperactivity/Inattention symptoms. Four children did not provide SDQ scores (TD: N=1; MD: N=2; DCD, N=1), and the regression analyses were therefore conducted with 87 participants.

*$p<.05$; **$p<.01$; ***$p<.001$; † $p<.06$ non-significant trend.

Footnotes

[1]Note that the significant group comparison between the TD and MD groups on the Motor Screening task, and between the TD and DCD groups on the Big/Little Circle task, cannot be interpreted because the overall regression model was non-significant.