European Journal of Human Movement

OPEN ACCESS

Original Article

Attentional focus instruction on the hands during bimanual coordination in children with probable developmental coordination disorder

Marcela Ferraciola-Gama[1], Daniel Traina-Gama[2], Cynthia Yukiko-Hiraga[3], Ana Maria Pellegrini[3]

1 Institute of Physical Education and Sports, Federal University of Ceara, Fortaleza, Ceará, Brazil.
2 Faculty of Education, Federal University of Grande Dourados, Dourados, Mato Grosso do Sul, Brazil.
3 Bioscience Institute, Sao Paulo State University, Rio Claro, São Paulo, Brazil.

*Correspondence: (MFG) marcelaferracioli@ufc.br 0000-0003-1782-691X
Received: 17/11/2022; Accepted: 27/12/2023; Published: 31/12/2023

Abstract: Directing attention to one aspect of the bimanual coordination task improves performance. Few studies investigated the effect of attention on the coordination patterns of children with Developmental Coordination Disorder (DCD). Aims: To investigate the effect of attentional focus instructions on the hand on stabilizing bimanual coordination in children with probable DCD. Method: Twenty-eight 9-10 years old children participated in two groups matched by age and gender, based on the results of the Movement Assessment Battery for Children: probable DCD (pDCD) [n=14] and typically developing (TD). Children couple the horizontal movements of the hands in an in-phase coordination pattern, with the attentional focus instruction on the preferred hand, non-preferred hand, and free. Variability of the coupling between the hands and motor control variables were used to assess stability and control strategies adopted by children. Results: Both groups showed more variability concerning in-phase patterns when the attentional focus instruction was on the preferred hand than in other conditions. pDCD showed more variability than TD when the attentional focus instruction was on the non-preferred hand. pDCD performed faster, shorter movements and with more pressure than TD. Conclusion: Attentional focus affected the bimanual coordination patterns of groups, but children with pDCD use different control strategies than TD children. Practical applications: Attentional focus instruction strategies for performing motor tasks, especially tasks that are unfavorable to children with DCD, could help during the motor intervention of this population.

Keywords: Bimanual task; Internal focus of attention; Perception-action.

1. Introduction

Developmental Coordination Disorder (DCD) is not associated with any medical conditions but leads to impaired motor performance in daily activities (American Psychiatric Association - APA, 2013). The motor performance of children with DCD is consistently slower, less accurate, and more variable than that of typically developing (TD) children (Diz, Ferracioli, Hiraga, Oliveira, & Pellegrini, 2018; Ferracioli, Hiraga, & Pellegrini, 2014; Ferracioli-Gama & Tamplain, 2023; Golenia et al., 2018; Roche, Viswanathan, Clark, & Whitall, 2016; Volman & Geuze, 1998; Volman, Laroy, & Jongmans, 2006). Based on the dynamic systems approach, the underlying mechanisms of motor behavior in children with DCD rely on the assumption that motor behavior develops in a system of interactions. The study of the emergence and stability of rhythmic bimanual and interlimb coordination contributes to understanding how the parts of this system interact according to its intrinsic pre-dispositions and environmental demands (Kelso, 1984; Kelso, Fink, Delaplain, & Carson, 2001; Whitall & Clark, 2018). Thus, an atypical coordination pattern, like those of children with DCD, results from difficulties in interacting with their motor systems, the environment's specifications, and the task performed (Wade, Johnson, & Mally, 2005; Wilmut, Wang, & Barnett, 2022).

One of the strategies in the dynamic approach to explaining motor behavior is to observe the result of perturbation of the perceptual system on individual-environment interaction. Such a strategy seeks to capture information from the environment and then analyze how the motor system stabilizes rhythmic coordination patterns from this perturbation (Whitall & Clark, 2018). Studies that used the perturbation strategy with different oscillation frequencies of the limbs involved in bimanual (Whitall et al., 2008) and interlimb coordination patterns (Whitall et al., 2006), or the manipulation of sensory information (e.g., auditory and visual) during the execution of bimanual (Roche, Wilms-Floet, Clark, & Whitall, 2011) and interlimb (Mackenzie et al., 2008) coordination patterns, confirm that children with DCD showed more variable patterns than children without this disorder. An interpretation of these difficulties is that they result from the exploratory behavior of their motor system in an attempt to apply specific adjustments in response to the conditions/demands of the environment (Ferracioli et al., 2014; Golenia et al., 2018). Thus, if the child-environment integration is exploratory while performing a motor task, then the rhythmic coordination patterns of children with DCD are more variable than those of TD children.

Since attention has a fundamental role in the executive function and regulation of cognitive processes related to the planning and execution of motor tasks (Monno, Temprado, Zanone, & Laurent, 2002), it is essential to understand how children with DCD use their attentional capacity to perform a task. The performance of children with DCD has been associated with attentional deficits since they show impaired behavior when they need to respond quickly to a stimulus or to control the inhibition of motor response (Castelnau, Alabaret, Chaix, & Zanone, 2007; Chen, Wilson, & Wu, 2012; Tsai, Pand, Chang, Wang, & Tseng, 2010). Similarly, this occurs when the execution of two tasks competes for their limited attentional capacities (Cherng, Liang, Chen, & Chen, 2009; Laufer, Ashkenazi, & Josman, 2008). Furthermore, studies showed no benefit for children with DCD from the internal or external attentional focus instructions in a computer screening task (Jarus et al., 2015) and the internal or external attentional focus feedback in motor learning a 'slinger ball' throwing task (van Cappellen–van Maldegem, van Abswoude, Krajenbrink, & Steenbergen, 2018). Unlike those results, two studies showed the advantages of the external attentional focus instruction, compared to the internal, on postural stability and object control task (Li, Li, Chu, Pan, & Chen, 2019) and vertical jump task (Psotta, Abdollahipour, & Janura, 2020).

Studies indicate that directing or maintaining attention on one aspect of the execution of the bimanual coordination task improves performance (Hiraga, Summers, & Temprado, 2004; Lee, Blandin, & Proteau, 1996; Monno et al., 2002; Pellegrini, Andrade, & Teixeira, 2004; Poel, Peper, & Beek, 2006; Temprado, 2004; Temprado, Zanone, Monno, & Laurent, 1999; Zanone, Monno, Temprado, & Laurent, 2001). The premise is that attention resides with the dynamics of the system's self-organization, forming an inseparable part of such dynamics. The co-variation of the stability of the coordination pattern with attentional demands reflects a general principle that links the coordination dynamics to the central processing (Hiraga, Summers, & Temprado, 2005). In this view, the question raised concerns about the possibility of attention being "shaped" as an additional dynamic interacting with the dynamics inherent to the coordination system. Could the attentional focus during motor performance be manipulated to relevant aspects of the coordination patterns so that their stability would be maintained and the implementation of motor tasks improved?

Wuyts, Summers, Carson, Byblow, and Semjen (1996) and Pellegrini et al. (2004) showed that, although the attentional focus on the non-preferred hand in a bimanual coordination task improves the performance of this hand considerably, the general characteristics of coordination patterns do not change. If the information is significant only for the behavior that it changes, then the focus of attention should not be considered relevant information to the bimanual coordination pattern. However, although there are no changes in the collective variables of the requested patterns, the improvement observed in the performance of the non-preferred hand when it is attended to, suggests that this focus of attention can be considered relevant information for the movement control parameters (Oliveira & Ivry, 2008).

The interest of the present study is the difficulty of children with DCD to couple their hands in rhythmic coordination patterns. Thus, the analysis of coordination (relative phase between hands) and control (movement amplitude and pressure force) variables can help to identify strategies used by these children to execute a bimanual coordination pattern. This study aimed to investigate the effect of attentional focus instructions on stabilizing the bimanual coordination pattern in children with DCD. Specifically, the current study tests the following hypotheses: (i) attentional focus instruction to the non-preferred hand improves performance in a bimanual coordination task of children with and without DCD; (ii) the measures of stability of the coupling between the hands identify the quality of the coordination patterns showed by the children; and (iii) the variables of motor control of each hand identify the mechanisms underlying the strategies adopted by the children.

2. Materials and Methods

Participants - Twenty-eight children aged 9-10-year-old from the same elementary school participated in the study. Fourteen children (female = 8, male = 6; 117.3 ± 6.2 months) scored below the 16th percentile (six below the 16th and eleven at or below the 5th) for total score on the motor tests of Movement Assessment Battery for Children (MABC-2) (Henderson, Sugden, & Barnett, 2007) formed the probable Developmental Coordination Disorder group (pDCD). Another 14 children matched by age and gender (female = 8, male = 6; 113.9 ± 6.1 months) who scored at or above the 25th percentile (five at the 25th and nine above the 37th) for total score on the motor tests of MABC-2 constituted the typically developing group (TD). The term pDCD was adopted because identifying the children's motor competence was made through the results of one field test. This study did not evaluate all criteria for DCD described in the *Diagnostic and statistical manual of mental disorder* (APA, 2013). For instance, we were unable to determine if children's motor difficulties were affecting their daily living activities (Criterion B). According to Smits-Engelsman, Schoemaker, Delabastita, Hoskens, and Geuze (2015), a child identified with a movement difficulty but with one or more criteria for DCD not evaluated should be reported as with pDCD. The MABC is the most frequently applied field test in research and clinical practice related to DCD (Smits-Engelsman et al., 2015; Blank et al., 2019; Smits-Engelsman & Verbeque, 2022).

The experimental groups comprised only children who showed at least 70% of consistency in the use of one hand (Bryden, Pryde, & Roy, 2000), according to the Edinburgh Inventory (Oldfield, 1971) used to determine manual preference (pDCD = 14 right-hand; TD = 12 right-hand and two left-hand). According to the school's records, the participants had no neurological or intelligence deficits. The participants' parents provided written consent for the children's participation as required by the study protocol, which the Research Ethics Committee approved (5465 - Sao Paulo State University, n. 30268714.2.0000.5465). The study was conducted in accordance with the Declaration of Helsinki.

Experimental Procedures - For the experimental task, one graphics tablet - model Intuos2 from WACOM (30.4 X 45.7 cm), two pens that accompany the graphics tablet, one laptop equipped with the MovAlyser program (developed by NeuroScript Softwares), two school desks to support the tablet, and the computer, and one chair with backrest and height adjustment were used for data collection. After arriving at a ready room isolated from noise and interruptions, in which the experiment was carried out, the child received instructions about data collection procedures. First, the child sat comfortably in a chair adjusted for height so that the elbow joint was approximately 90º.

Each child performed bilateral trajectory movements with both hands (horizontal back-and-forth), with the pen tip on the tablet, with both hands in-phase (360°) coordination pattern. The instruction given to the child was to perform hand movements in a synchronized pattern, at the preferred frequency by the child, in the enclosed space for each hand (approximately 22 cm) and continuously for 15 seconds. Also, the researcher provided a demonstration trial of the task before the first experimental trial (Fig. 1).

Each child performed five trials of the task in three experimental conditions: (i) free attention direction, that is, the child was free to choose and direct the focus of attention; (ii) attentional focus to the preferred hand, that is, the child was instructed to pay attention to the preferred hand while performing the task and; (iii) attentional focus to the non-preferred hand, that is the child was instructed to pay attention to the non-preferred hand while performing the task.

The researcher encouraged the participants to visually monitor their hands during each trial (Pellegrini et al., 2004), considering that the instructions: "pay attention to the action of your dominant hand" for the focus of attention on the dominant hand condition and "pay attention to the action of your non-dominant hand" for the focus of attention to the non-dominant hand condition, could be superficial for children of this age. The free attention direction condition was always executed first by both groups so that performance in this condition could be used as an initial reference and as a reference for the child's spontaneous behavior (avoiding the practice effect and the attention focus instruction effect), while the order of execution of the other two conditions was counterbalanced. The free attention direction condition was always performed first. A 30-second rest was provided between trials.

Data reduction and dependent variables

- The signs of contact of the pens with the tablet were recorded at 100Hz for each pen. The data of the pens' displacements in the X-axis in the Cartesian coordinate system over time (1500 points for each pen, see Fig. 2) and the pressure on the tablet were recorded in an electronic spreadsheet.

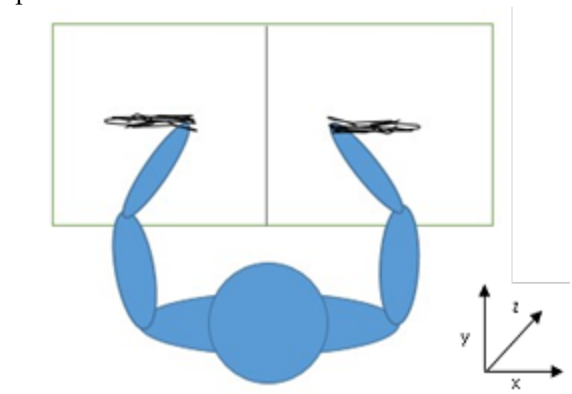

Fig. 1. Graphical representation of the experimental task of bilateral trajectory in-phase bimanual pattern.

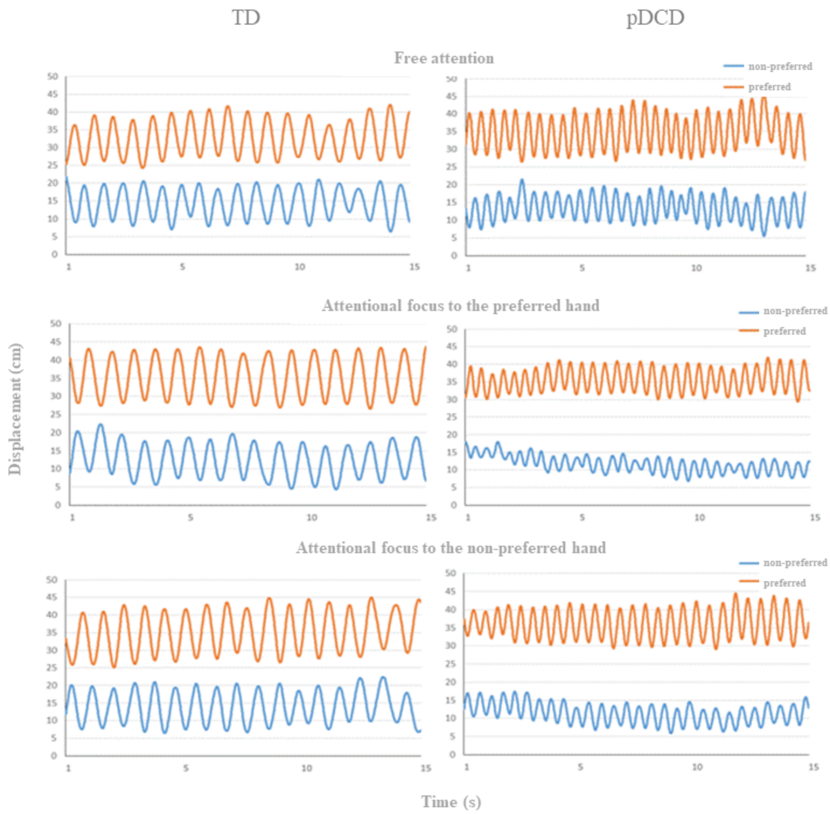

Fig. 2. Typical examples of the displacements of the pens in the tablet in the X-axis coordinate during 15-s, in the three experimental conditions performed by a child of pDCD group and a child of TD group.

The first two trials of each experimental condition were considered familiarization trials and were not analyzed. The three remaining trials of each child in each condition were analyzed according to the variables of interest in the present study. With these data, the variables related to bimanual coupling and its stability (continuous relative phase and variability of the continuous relative phase) and kinematics and kinetics of each hand (cycles, movement amplitude, variability of movement amplitude, pressure force, and variability of pressure force) were calculated. The MATLAB software (The Math Works Inc. - version 7) was used for data treatment.

Continuous Relative Phase (RP): obtained based on the calculation of the temporal difference between the displacement of the preferred hand and that of the non-preferred hand, following the model: $\phi = (t1 - t2)$, where t1 is the preferred hand phase and t2 is the non-preferred hand phase (Wheat & Glazier, 2006). To calculate RP (ϕ), the "hilbert" function of the MATLAB software was used to transform the discrete data into continuous ones. The "angle" function was used to calculate the phase space in radians, and data were multiplied by 180/pi to transform them from radians to degrees. Subsequently, the subtraction between the preferred hand's phase space and the non-preferred hand's phase space was performed, point to point. This variable indicates the point of advance of an oscillatory signal (i.e., hand) about the other signal within the same cycle (Semjen, Summers, & Cattaert, 1995), and it is given in degrees.

Variability of relative phase (VRP): The standard deviation of relative phase (SD) was obtained from the measure of RP variability within a preferred/non-preferred hands cycle of a trial, which was calculated as follows: $SD = \sqrt{(\sum ((xi - x)^2 / n - 1))}$, where xi is the RP of a bimanual cycle, x is the mean of RP in a trial, and n is the number of RP observations in a trial. The VRP indicates the variability of task components synchronization (both hands) (Whitall et al., 2006), and it is given in degrees.

Cycles: identified by the "diff" function of MATLAB software which calculates the time interval between the beginning and the end of the hand trajectory when it returns to the original point. This variable identifies the number of times each hand made a back-and-forth motion during the trial.

Movement amplitude: identified by calculating the difference between the maximum and minimum displacement of the pens in the X coordinate, obtained through the "peaks" function of MATLAB software. This variable indicates the mean of the spatial amplitude of the cycles of each hand during the task, and it is given in centimeters.

Variability of movement amplitude (VMA): obtained by calculating the standard deviation of the location of the endpoints of each displacement, which was calculated as follows: $SD = \sqrt{(\sum ((xi - x)^2 / n - 1))}$, where xi is the location of an endpoint of a displacement, x is the mean of displacements of the areas of the endpoints, and n is the number of displacements in a trial. This variable indicates the spatial amplitude variability of the cycles of each hand during the task, and it is given in centimeters.

Pressure force: obtained through the values converted into grams by calibrating the force exerted with the pen on the tablet, proposed by the developers of the MovAlyzer software. Subsequently, the formula Force = Mass (grams) X Acceleration ($9.8 m/s^2$) was used to obtain the pressure values in Newtons. This variable indicates the force exerted with the pen tip on the tablet during the task.

Variability of pressure force (VPF): obtained by calculating the standard deviation of the pressure force of each hand in the trials, which was calculated as follows: SD = $\sqrt{(\sum ((xi - x)^2 / n - 1))}$, where xi is the endpoint of pressure, x is the mean of the endpoints of pressures, and n is the number of pressure forces in a trial. This variable indicates the variability of the force exerted by the hand with the pen tip on the tablet during the task, which is given in Newtons.

Statistical analysis - SPSS for Windows (version 20.0) was used for statistical analysis. The distribution of RP, VRP, VMA, Pressure force, and VPF proved not normal (Shapiro-Wilk test for normality, $p < 0.05$). Then cycles and movement amplitude were normally distributed (Shapiro-Wilk test for normality, $p > 0.05$). For non-parametric analysis, the group effect (pDCD and TD) was examined using the Mann-Whitney U-test. The condition effect (free attention direction, attention to the preferred hand, and the non-preferred hand) was analyzed using the Friedman test with multiple comparisons. Also, the Friedman test was performed to examine the within-group differences among the conditions. A Mann-Whitney U-test was performed for VMA, pressure force, and VPF to identify the hand (preferred and non-preferred) effect. For parametric analysis, repeated measures ANOVAs 2(Group) X 3(Condition) X 2(Hand) were employed for cycles and movement amplitude. A conventional alpha level of 0.05 was adopted in all analyses. With a power of 0.95 and a two-tailed $\alpha = 0.05$, the sample size used in the current study (n = 14 in each group) is sufficient to detect medium effects (f = 0.50) in a repeated measure ANOVA of within-between interaction.

3. Results

Coupling and stability of bimanual coordination

Results from RP showed no significant group effect in the three conditions (Table 1), no significant condition effect [$X^2(2) = 2.643$, $p = 0.26$], and no within-group significant differences for pDCD [$X^2(2) = 0.571$, $p = 0.75$] and TD [$X^2(2) = 5.571$, $p = 0.06$]. TD children showed bimanual coordination (mean of RP = 359.1°) closer to that requested in in-phase coordination patterns than the pDCD (mean of RP = 402.4°).

Results from VRP showed a significant group effect only in the attention to the non-preferred hand condition (Table 1), indicating that pDCD children were less stable than TD children. Also, the Friedman test showed a significant attention effect [$X^2(2) = 8.357$; $p = 0.01$], indicating that participants were less stable under the condition of attention to the preferred hand than the free attention ($p < 0.01$) and the non-preferred hand ($p = 0.04$) conditions. No within-group significant difference was observed for pDCD [$X^2(2) = 4.429$, $p = 0.10$] and TD [$X^2(2) = 4.000$, $p = 0.13$].

Motor Control parameters of bimanual coordination patterns

Anova results from Cycles showed significant group and condition effects, $F(1, 52) = 4.517$, $p < 0.05$ and $F(2, 104) = 73.979$, $p < 0.01$, respectively. These results indicate that pDCD children did more cycles with their hands (mean = 29.2 cycles) than TD children (mean = 25.8 cycles). Also, participants from both groups did more cycles with the hands under the condition of attention to the preferred hand (mean = 30.0 cycles) than they did under the free attention (mean = 25.1 cycles) and the non-preferred hand (mean = 27.5 cycles) conditions.

Table 1. Relative phase and standard deviation of relative phase median, mean and standard deviation of bimanual coordination pattern children groups comparisons by experimental conditions.

Condition	Relative Phase					Standard Deviation of Relative Phase				
	pDCD		TD			pDCD		TD		
	Median	Mean (SD)	Median	Mean (SD)	*p*	Median	Mean (SD)	Median	Mean (SD)	*p*
Free	357.6	370.7 (78.3)	360.8	347.8 (24.0)	0.55	60.4	86.2 (100.1)	19.3	29.0 (22.8)	0.08
Preferred hand	354.3	419.3 (243.4)	354.2	363.2 (107.0)	0.58	53.0	159.5 (243.9)	45.0	83.7 (122.7)	0.24
Non-preferred hand	358.4	417.1 (174.4)	360.7	366.1 (48.8)	0.60	55.8	153.5 (227.1)	17.5	32.1 (25.4)	0.03

pDCD – probable developmental coordination disorder; TD – typically developing; SD – standard deviation; *p* – p-value of Mann-Whitney U Test.

Anova results from Movement Amplitude showed significant condition effect and significant group and condition interaction, $F(2, 104) = 53.324$, $p < 0.01$, and $F(2, 104) = 3.212$, $p < 0.05$, respectively. Also, a marginally significant group effect was observed, $F(1, 52) = 3.934$, $p = 0.05$. These results indicate that pDCD children showed smaller movement amplitude of cycles (mean = 5.4 cm) than TD children (mean = 6.0 cm). Figure 3A shows that participants produced smaller movement amplitude of cycles under the condition of attention to the preferred hand (mean = 5.2 cm) than they did to the non-preferred hand (mean = 5.7 cm) and the free attention (mean = 6.2 cm).

Results from VMA showed no significant group effect for each condition of attention: free attention direction [U = 372.000, $p = 0.74$], preferred hand [U = 367.000, $p = 0.68$], and non-preferred hand [U = 335.500, $p = 0.35$] conditions. No significant condition effect [$X^2(2) = 5.370$, $p = 0.07$], no significant hand effect in the free attention [U = 325.500, $p = 0.27$], preferred hand [U = 312.500, $p = 0.19$], and non-preferred hand [U = 342.500, $p = 0.41$] conditions, and no within-group significant differences for pDCD [$X^2(2) = 1.099$, $p = 0.57$] and TD [$X^2(2) = 5.019$, $p = 0.08$]. Although there was no significant hand effect, the movement amplitude of participants' non-preferred hand (mean = 0.48 cm) is more variable than the movement amplitude of their preferred hand (mean = 0.42 cm) in all attention conditions (Fig. 3B).

Results from Pressure showed a significant group effect in each condition (free attention direction U = 238.500, $p = 0.01$; to the preferred hand U = 263.500, $p = 0.03$; non-preferred hand U = 260.500, $p = 0.03$), indicating that pDCD children produced more pressure force on the pens during all experimental conditions than TD children (Fig. 4A). Results showed no significant condition effect [$X^2(2) = 2.240$, $p = 0.32$], no significant hand effect under the free attention direction [U = 374.500, $p = 0.77$], attention to the preferred hand [U = 364.000, $p = 0.64$], and the non-preferred hand [U = 379.000, $p = 0.83$] conditions, and no within-group significant differences for pDCD [$X^2(2) = 4.019$, $p = 0.13$] and TD [$X^2(2) = 0.514$, $p = 0.77$].

Results from VPF showed only a significant hand effect. Regardless of the group, the non-preferred hand was more variable than the preferred hand in all three attention conditions (free attention U = 243.500, $p = 0.01$; to the preferred hand U = 237.000, $p = 0.01$; to the non-preferred hand U = 227.500 $p < 0.01$) (Fig. 4B).

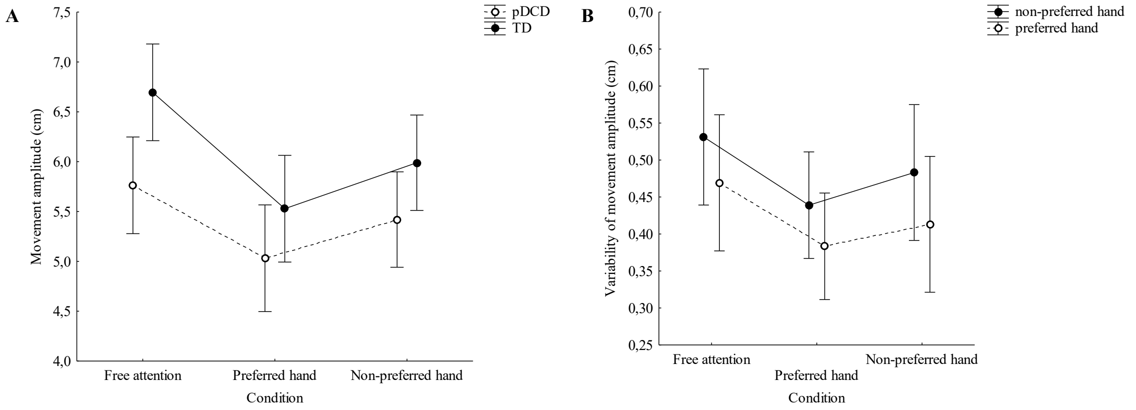

Fig. 3. Mean and standard deviation of (A) movement amplitude of cycles (cm) showed by children in the pDCD and TD groups, and of (B) the variability of movement amplitude of cycles (cm) performed by non-preferred and preferred hands under the three conditions.

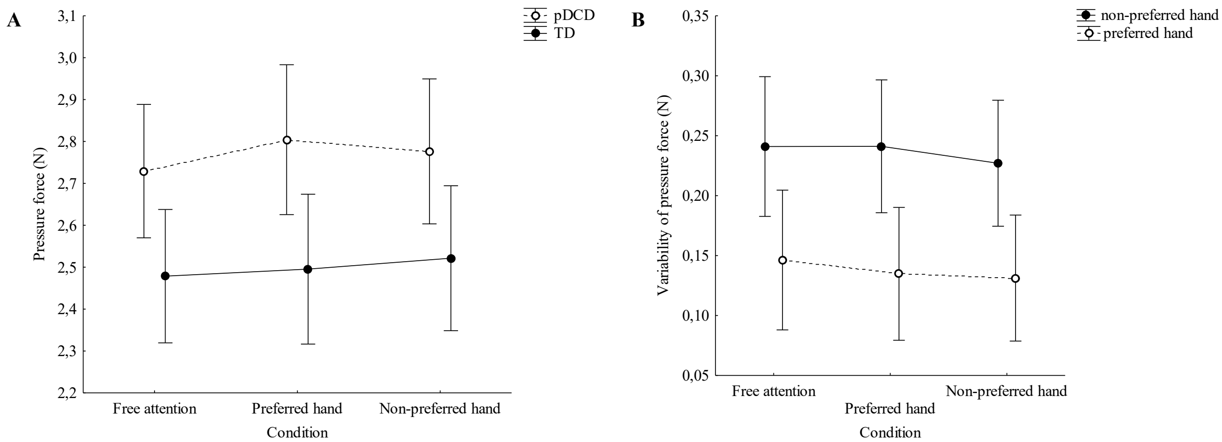

Fig. 4. Mean and standard deviation of (A) pressure force (N) performed by children in the pDCD and TD groups, and of (B) variability of pressure force (N) performed by non-preferred and preferred participants' hands under the three conditions.

Results showed no significant group effect (free attention U = 390.000, $p = 0.97$; the preferred hand U = 347.000, $p = 0.46$; the non-preferred hand U = 392.000, $p = 0.99$), no significant condition effect [$X^2(2) = 0.180$, $p = 0.91$], and no within-group significant differences for pDCD [$X^2(2) = 0.396$, $p = 0.82$] and TD [$X^2(2) = 0.990$, $p = 0.60$].

4. Discussion

The present results indicated that the instruction to focus on the preferred hand led to inferior performance of the bimanual coordination task by the children of both groups compared to the instruction to focus on the non-preferred hand or with free attention direction. However, children with pDCD showed a less stable bimanual coordination pattern when compared to children with TD.

Stability of bimanual coordination patterns - Regardless of the experimental conditions, children in both groups showed similar in-phase coordination patterns, evidenced by the absence of significant RP differences. These results are similar to findings from other studies, where children with DCD exhibited an in-phase coordination pattern similar to that of children with TD in tasks involving jumping and clapping simultaneously (Ferracioli et al., 2014), finger oscillation (Volman & Geuze, 1998), tapping between hands and feet (Volman et al., 2006), and walking and clapping simultaneously (Whitall et al., 2006). However, when comparing the relative phase variability between the groups, it was observed that children with pDCD were more variable than children with TD. This difference was statistically significant in attentional focus instruction to the non-preferred hand.

Research on human bimanual rhythmic patterns has shown that the in-phase coordination pattern is often more accurate and stable (Hiraga et al., 2004; Swinnen, Dounskaia, Walter, & Serrien, 1997), requiring fewer control adjustments (Schoner & Kelso, 1988) and less attentional demand (Temprado et al., 1999) compared to the anti-phase coordination pattern. Regarding the control adjustments, it is known that the changes in the control parameter (e.g., increased speed, differences in trajectory amplitude, increased activation of non-homologous muscles) lead to changes (or fluctuations) in the relative phase between two oscillators and that these changes are reduced when adopting in-phase coordination patterns. Regarding the attentional influence of performing motor tasks, Temprado et al. (1999) showed that the in-phase bimanual coordination pattern was easier to stable in all conditions (with different attentional demands) than the anti-phase pattern, given the persistent influence of the stable states of the coordination dynamics. Therefore, they concluded that the in-phase coordination pattern requires little attention to be executed and maintained. Based on this evidence about the stability of the in-phase coordination pattern, it is suggested that the difficulties shown by children with pDCD in bimanual and interlimb coordination patterns (Ferracioli et al., 2014; MacKenzie et al., 2008; Volman & Geuze, 1998; Volman et al., 2006; Whitall et al., 2008; Whitall et al., 2006; Wilmut et al., 2022) would be associated with the difficulties adjusting control mechanisms and attentional focus during the task.

The children participating in the present study showed significantly more coordination pattern variability in the preferred hand condition compared to the other experimental conditions. These results suggest that attentional focus on the preferred hand in the bimanual coordination task increases the difficulty in coupling the hands. According to Oliveira and Ivry (2008), this may have occurred because manipulating the attentional focus increases the degree of independence between the hands instead of stabilizing the task. Some studies could observe such behavior using attentional focus during a bimanual coordination task. Wuyts et al. (1996) showed that when the non-preferred hand was the focus of attention in drawing circles in a bimanual task, the participants' movements were more circular, and the temporal variability decreased. On the other side, the movements of the preferred hand were not affected by the attentional focus. Pellegrini et al. (2004) showed that children aged 5-12 years performing an in-phase bimanual tapping task reduced the movement time and the number of errors when their attentional focus was the non-preferred hand.

Thus, the result of the present study partially corroborates with the results mentioned above, as there was no evidence of an improvement in the coupling between the hands when attention was directed to the non-preferred hand (having as initial reference the performance in the free attention condition). However, there was an increase in the variability of coupling between the hands when the attentional focus instruction was to the preferred hand. The preferred hand probably requires less attention because its performance is inherently superior to the non-preferred hand (considering learning, genetics, and the interactions between these factors that determine manual preference) (Wuyst et al., 1996). Then, attentional focus on the preferred hand leads to redundancy of information in the action system, not satisfying the perceptual needs of coupling the oscillators (information about the "weakest" motor hand). According to Poel et al. (2006), coupling between the limbs is asymmetrical, with the non-preferred limb being more influenced by the preferred limb than vice versa. Therefore, the attentional focus on the non-preferred hand would facilitate stability between the hands.

The fact that there was no significant difference in the variability of the relative phase of the participants' coordination patterns between free attention (initial reference) and the attentional focus on the non-preferred hand conditions may have occurred because in the free attention condition, children were not instructed to concentrate on any specific information and, thus, they were free to "pay attention" to the necessary information that would satisfy the demands of their intrinsic dynamic. Similar results were found by Swinnen, Jardin, and Meulenbroek (1996). The authors argued that the participants should spontaneously pay attention to the non-preferred hand movements in the free condition. Therefore, their performance in this condition was similar to that in which the attention was experimentally focused on the non-preferred hand. Despite this, it was precisely when the attentional focus instruction was to the non-preferred hand that a significant group effect was observed in the variability of the coordination patterns, indicating that children with pDCD showed more variable patterns than TD children in this condition. It is suggested that, although no within-group effect was observed through the conditions, children with pDCD may not use the same attentional focus strategy as TD children, showing more difficulty in attending and keeping the intrinsic dynamics of their motor system stable.

Kinematics and kinetics variables during bimanual coordination pattern - Regarding variables of motor control of the hands, the results showed that children with pDCD had more hand cycles during the 15 seconds, smaller movement amplitude of the pen displacement on the tablet, and greater pressure force in controlling the pen than TD children. These results generally point to different motor control strategies between the groups in executing the experimental task. Children with motor difficulties made faster, shorter, and more pressure back-and-forth movements.

Some studies have suggested that the differences in the performance between children with pDCD and TD are due to motor control differences. Huh, Williams, and Burke (1998), for example, examined the performance characteristics and neuromuscular measures (EMG) of pointing movements with children's unilateral and bilateral arms. They showed that children with pDCD prolong the agonist muscle activity and delay the antagonist muscle activity, which contributes to an inability to produce stable and accurate movements. Other studies that analyzed muscle activity also showed increased co-activation and co-contraction activity in children with DCD (Raynor, 2001; Geuze, 2003). Another result related to the force control strategies of children with DCD showed that they produced excessive gripping when lifting objects, despite having adapted these forces in response to different object surfaces (Pereira, Landgren, Gillberg, & Forssberg, 2001). The authors suggested that the motor difficulties were more associated with deficits in the implementation stage of motor control responses and less related to task constraints or functional limitations in adapting to environmental constraints. Also, children with DCD showed more significant variability and less accuracy in controlling force by the fingers due to their inability to explore the dimensionality of motor response (Oliveira, Loss, & Petersen, 2005; Diz et al., 2018). These children's inability results in a more predictable motor response, typical of younger children, characterizing a developmental delay in children with DCD (Oliveira et al., 2005), even if they can improve finger force control with practice (Diz et al., 2018).

The results presented in the studies cited above (Huh et al., 1998; Pereira et al., 2001; Oliveira et al., 2005; Diz et al., 2018) are relevant to understanding the production of rhythmic coordination patterns by children with motor difficulties, as they indicate the mechanisms underlying these difficulties. Although the present study did not measure the children's muscular activity during the task, the increase in the pressure force of the pen tip on the tablet and the decrease in the movement amplitude showed by the pDCD group, when compared with the TD group, may be associated with co-contraction or co-activation of the musculature involved in the control of hand movements in the experimental task. Based on these results, it is suggested that there are essential differences in the strategies of the motor control system of children with pDCD to organize bimanual responses compared to the responses of TD children.

Another result concerns the attentional focus on experimental conditions. Regardless of the experimental group, the children showed more hand cycles and less movement amplitude when the attentional focus instruction was the preferred hand. These control parameters results are similar to coordination measures in which children perform differently in the condition in which attentional focus instruction was the preferred hand compared to the other experimental conditions. In general, studies that analyzed the attentional focus for one hand in a bimanual task suggest that the coordination patterns, defined by the intrinsic dynamics, do not change due to the focused hand. It has been shown that the attentional focus on the non-preferred hand improves performance about motor control parameters (e.g., accuracy and movement amplitude, and movement time) (Pellegrini et al., 2004; Poel et al., 2006; Swinnen et al., 1996; Wuyts et al., 1996). This prediction was partially observed in the present study, not because the attentional focus on the non-preferred hand improved performance but because the hands had different control strategies (faster and shorter back-and-forth movements) when the attentional focus instruction was on the preferred hand. It is noteworthy that this may have occurred because the attentional focus instruction to the preferred hand leads to redundancy of information to the action system, not satisfying the perceptual needs of the task of coupling the oscillators (information about the "weakest" hand). Since the action of the non-preferred hand is more influenced by the action of the preferred hand than vice versa, the children's motor control system adopted the strategy of making movements faster and shorter when the information (due to the focus of attention) was redundant to the system (about the preferred hand).

In the present study, the asymmetry in motor control between the hands was shown by the variability of pressure force results. Regardless of the experimental condition, the non-preferred hand varied the pressure force more than the preferred hand, indicating, once again, a possible intrinsic disadvantage of this oscillating system (Pellegrini et al., 2004) and, thus, a possible attempt to adjust to the task demands of coupling between hands.

The present study has advanced in understanding the cognitive aspects involved in perception-action coupling. It leads to the discussion that attention, as a cognitive function, resides with the intrinsic dynamics of coordination, influencing the stability of the bimanual coordination pattern and the control parameters of movements. However, some limitations need to be mentioned. Children without a diagnosed DCD, encompassing all DCD criteria, were included in the sample, potentially introducing bias. The sample size poses a limitation for generalizing the results. Additionally, we did not control for the co-occurrence of Autism Spectrum Disorder (ASD) and Attention-Deficit/Hyperactivity Disorder (ADHD) with DCD, representing another limitation. It is suggested that further studies emphasize the neuromuscular responses of children with DCD during motor tasks to identify prominent deficits in motor control associated with DCD and control of the sample for ADHD and ASD.

5. Practical Applications

Attentional focus instruction strategies for performing motor tasks, especially tasks that are unfavorable to children with DCD, can help during the motor intervention of this population. For example, during a motor intervention session, the professional can encourage or instruct the child to pay attention to their non-dominant hand while performing a bimanual or interlimb coordination task. This strategy can favor the stability of the adopted coordination pattern and, thus, improve performance.

6. Conclusions

This study investigated the effect of the attentional focus instruction on the hands' stabilizing bimanual coordination patterns in children with and without pDCD. As found in other studies, the children showed motor behavior that presents the relationship between manual preference and attention direction in a bimanual task. However, children with pDCD showed a less stable bimanual coordination pattern than TD children, especially when the attentional focus instruction was the non-preferred hand, indicating different motor control strategies adopted by the two groups of children. In particular, it was shown that the attentional focus on the non-preferred hand favors motor performance in a bimanual coordination task because this hand is less motor developed and thus requires more attention. The attentional focus on the preferred hand may lead to redundancy of information in the system, leading to increased coupling variability between hands. The main differences between the two groups of children are related to motor control strategies to organize the system and respond to the task demands.

Funding: This study did not receive any funding.

Acknowledgments: Non- declared

Conflicts of Interest: The authors declare no conflict of interest.

References

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorder* (5th ed.), Washington, DC.

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

Bryden, P. J., Pryde, K. M., & Roy, E. A. (2000). A performance measure of the degree of hand preference. *Brain and Cognition, 44*(3), 402-414. https://doi.org/10.1006/brcg.1999.1201

Castelnau, P., Alabaret, J. M., Chaix, Y., & Zanone, P. G. (2007). Developmental coordination disorder pertains to a deficit in perceptuo-motor synchronization independent of attentional capacities. *Human Movement Science, 26*(3), 477-490. https://doi.org/10.1016/j.humov.2007.03.001

Chen, W. Y., Wilson, P. H., & Wu, S. K. (2012). Deficits in the covert orienting of attention in children with Developmental Coordination Disorder: Does severity of DCD count? *Research in Developmental Disabilities, 33*(5), 1516-1522. https://doi.org/10.1016/j.ridd.2012.03.005

Cherng, R. J., Liang, L. Y., Chen, Y. J., & Chen, J. Y. (2009). The effects of a motor and a cognitive concurrent task on walking in children with developmental coordination disorder. *Gait & Posture, 29*(2), 204-207. https://doi.org/10.1016/j.gaitpost.2008.08.003

Diz, M. A. R., Ferracioli, M. C., Hiraga, C. Y., Oliveira, M. A., & Pellegrini, A. M. (2018). Effects of practice on visual finger-force control in children at risk of developmental coordination disorder. *Brazilian Journal of Physical Therapy, 22*(6), 467-473. https://doi.org/10.1016/j.bjpt.2018.04.002

Ferracioli, M. C., Hiraga, C. Y., & Pellegrini, A. M. (2014). Emergence and stability of interlimb coordination patterns in children with developmental coordination disorder. *Research in Developmental Disabilities, 35*(2), 348-356. https://doi.org/10.1016/j.ridd.2013.11.002

Ferracioli-Gama, M. C., & Tamplain, P. (2023). Infographic: Developmental coordination disorder (part I) - characteristics, diagnosis, and consequences. *Brazilian Journal of Motor Behavior, 17*(4), 73–74. https://doi.org/10.20338/bjmb.v17i4.349

Geuze, R. H. (2003). Static balance and developmental coordination disorder. *Human Movement Science, 22*(4-5), 527-548. https://doi.org/10.1016/j.humov.2003.09.008

Golenia, L., Bongers, R. M., Van Hoorn, J. F., Otten, E., Mouton, L. J., &Schoemaker, M. M. Variability in coordination patterns in children with developmental coordination disorder (DCD). *Human Movement Science, 60*, 202-213. https://doi.org/10.1016/j.humov.2018.06.009

Henderson, S. E., Sugden, D. A., & Barnett, A. L. (2007). *Movement assessment battery for children-2*. Harcourt Assessment.

Hiraga, C. Y., Summers, J. J., &Temprado, J. J. (2004). Attentional costs of coordinating homologous and non-homologous limbs. *Human Movement Science, 23*(3-4), 415-430. https://doi.org/10.1016/j.humov.2004.08.015

Hiraga, C. Y., Summers, J. J., &Temprado, J. J. (2005). Effects of attentional prioritization on the temporal and spatial components of an interlimb circle-drawing task. *Human Movement Science, 24*(5–6), 815-832. https://doi.org/10.1016/j.humov.2005.10.010

Huh, J., Williams, H. G., & Burke, J. R. (1998). Development of bilateral motor control in children with developmental coordination disorders. *Developmental Medicine and Child Neurology, 40*(7), 474-484. https://doi.org/10.1111/j.1469-8749.1998.tb15398.x

Jarus, T., Ghanouni, P., Abel, R. L., Fomenoff, S. L., Lundberg, J., Davidson, S., & Zwicker, J. G. (2015). Effect of internal versus external focus of attention on implicit motor learning in children with developmental coordination disorder. *Research in Developmental Disabilities, 37*, 119-126. https://doi.org/10.1016/j.ridd.2014.11.009

Kelso, J. A. S. (1984). Phase transitions and critical behavior in human bimanual coordination. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology, 246*(6), 1000-1004. https://doi.org/10.1152/ajpregu.1984.246.6.R1000

Kelso, J. A. S., Fink, P. W., Delaplain, C. R., & Carson, R. G. (2001). Haptic information stabilizes and destabilizes coordination dynamics. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 268*(1472), 1207-1213. https://doi.org/10.1098/rspb.2001.1620

Laufer, Y., Ashkenazi, T., & Josman, N. (2008). The effects of a concurrent cognitive task on the postural control of young children with and without developmental coordination disorder. *Gait & Posture, 27*(2), 347-351. https://doi.org/10.1016/j.gaitpost.2007.04.013

Lee, T., Blandin, Y., & Proteau, L. (1996). Effects of task instructions and oscillation frequency on bimanual coordination. *Psychological Research, 59*(2), 100-106. https://doi.org/10.1007/BF01792431

Li, L. L., Li, Y. C., Chu, C. H., Pan, C. Y., & Chen, F. C. (2019). External focus of attention concurrently elicits optimal performance of suprapostural pole-holding task and postural stability in children with developmental coordination disorder. *Neuroscience Letters, 703*(11), 32-37. https://doi.org/10.1016/j.neulet.2019.03.011

Mackenzie, S. J., Getchell, N., Deutsch, K., Wilms-Floet, A., Clark, J. E., & Whitall, J. (2008). Multi-limb coordination and rhythmic variability under varying sensory availability conditions in children with DCD. *Human Movement Science, 27*(2), 256-69. https://doi.org/10.1016/j.humov.2008.02.010

Monno, A., Temprado, J. J., Zanone, P. G., & Laurent, M. (2002). The interplay of attention and bimanual coordination dynamics. *Acta Psychologica, 110*(2–3), 187-211. https://doi.org/10.1016/S0001-6918(02)00033-1

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*(1), 97-113. https://doi.org/10.1016/0028-3932(71)90067-4

Oliveira, F. T. P., & Ivry, R. B. (2008). The representation of action: insights from bimanual coordination. *Current Directions in Psychological Science, 17*(2), 130-135. https://doi.org/10.1111/j.1467-8721.2008.00562.x

Oliveira, M. A., Loss, J. F., & Petersen, R. D. S. (2005). Controle de força e torque isométrico em crianças com DCD. *Revista Brasileira de Educação Física e Esporte, 19*(2), 89-103. https://doi.org/10.1590/S1807-55092005000200001

Pellegrini, A. M., Andrade, E. C., & Teixeira, L. A. (2004). Attending to the non-preferred hand improves bimanual coordination in children. *Human Movement Science, 23*(3–4), 447-460. https://doi.org/10.1016/j.humov.2004.08.017

Pereira, H. S., Landgren, M., Gillberg, C., & Forssberg, H. (2001). Parametric control of fingertip forces during precision grip lifts in children with DCD (developmental coordination disorder) and DAMP (deficits in attention motor control and perception).

Neuropsychologia, 39(5), 478-488. https://doi.org/10.1016/S0028-3932(00)00132-9

Poel, H. J., Peper, C. L., & Beek, P. J. (2006). Intentional switches between bimanual coordination patterns are primarily effectuated by the nondominant hand. *Motor Control, 10*(1), 7-23. https://doi.org/10.1123/mcj.10.1.7

Psotta, R., Abdollahipour, R., & Janura, M. (2020). The effects of attentional focus instruction on the performance of a whole-body coordination task in children with developmental coordination disorder. *Research in Developmental Disabilities, 101*, 103654. https://doi.org/10.1016/j.ridd.2020.103654

Raynor, A. J. (2001). Strength, power, and coactivation in children with developmental coordination disorder. *Developmental Medicine & Child Neurology, 43*(10), 676-684. https://doi.org/10.1111/j.1469-8749.2001.tb00141.x

Roche, R., Viswanathan, P., Clark, J. E., & Whitall, J. (2016). Children with developmental coordination disorder (DCD) can adapt to perceptible and subliminal rhythm changes but are more variable. *Human Movement Science, 50*, 19-29. https://doi.org/10.1016/j.humov.2016.09.003

Roche, R., Wilms-Floet, A. M., Clark, J. E., & Whitall, J. (2011). Auditory and visual information do not affect self-paced bilateral finger tapping in children with DCD. *Human Movement Science, 30*(3), 658-671. https://doi.org/10.1016/j.humov.2010.11.008

Schoner, G., & Kelso, J. A. S. (1988). Dynamic pattern generation in behavioral and neural systems. *Science, 239*(4847), 1513-1520. https://doi.org/10.1126/science.3281253

Semjen, A., Summers, J. J., & Cattaert, D. (1995). Hand coordination in bimanual circle drawing. *Journal of Experimental Psychology: Human Perception and Performance, 21*(5), 1139-1157. https://doi.org/10.1037/0096-1523.21.5.1139

Smits-Engelsman, B., Schoemaker, M., Delabastita, T., Hoskens, J., & Geuze, R. (2015). Diagnostic criteria for DCD: Past and future. *Human Movement Science, 42*, 293-306. https://doi.org/10.1016/j.humov.2015.03.010

Smits-Engelsman, B., & Verbecque, E. (2022). Pediatric care for children with developmental coordination disorder, can we do better?. *Biomedical Journal, 45*(2), 250-264. https://doi.org/10.1016/j.bj.2021.08.008

Swinnen, S. P., Dounskaia, N., Walter, C. B., & Serrien, D. J. (1997). Preferred and induced coordination modes during the acquisition of bimanual movements with a 2:1 frequency ratio. *Journal of Experimental Psychology: Human Perception and Performance, 23*(4), 1087-1110. https://doi.org/10.1037/0096-1523.23.4.1087

Swinnen, S. P., Jardin, K., & Meulenbroek, R. (1996). Between-limb asynchronies during bimanual coordination: Effects of manual dominance and attentional cueing. *Neuropsychologia, 34*(12), 1203-1213. https://doi.org/10.1016/0028-3932(96)00047-4

Temprado, J. J. (2004). A dynamical approach to the interplay of attention and bimanual coordination. In V. K. Jirsa, & J. A. S. Kelso (Eds.), *Coordination Dynamics: Issues and Trends*. (21-39). Berlin, Germany: Springer.

Temprado, J. J., Zanone, P. G., Monno, A., & Laurent, M. (1999). Attentional load associated with performing and stabilizing preferred bimanual patterns. *Journal of Experimental Psychology-Human Perception and Performance, 25*(6), 1579-1594. https://doi.org/10.1037/0096-1523.25.6.1579

Tsai, C. L., Pand, C. Y., Chang, Y. K., Wang, C. H., & Tseng, K. D. (2010). Deficits of visuospatial attention with reflexive orienting induced by eye-gazed cues in children with developmental coordination disorder in the lower extremities: An event-related potential study. *Research in Developmental Disabilities, 31*(3), 642-655. https://doi.org/10.1016/j.ridd.2010.01.003

Van Cappellen–Van Maldegem, S. J., Van Abswoude, F., Krajenbrink, H., & Steenbergen, B. (2018). Motor learning in children with developmental coordination disorder: The role of focus of attention and working memory. *Human Movement Science, 62*, 211-220. https://doi.org/10.1016/j.humov.2018.11.001

Volman, M. J., & Geuze, R. H. (1998). Relative phase stability of bimanual and visuomanual rhythmic coordination patterns in children with a Developmental Coordination Disorder. *Human Movement Science, 17*(4-5), 541-572. https://doi.org/10.1016/S0167-9457(98)00013-X

Volman, M. J., Laroy, M. E., & Jongmans, M. J. (2006). Rhythmic coordination of hand and foot in children with Developmental Coordination Disorder. *Child: Care, Health and Development, 32*(6), 693-702. https://doi.org/10.1111/j.1365-2214.2006.00679.x

Wade, M. G., Johnson, D., & Mally, K. (2005). A dynamical system perspective of developmental coordination disorder. In D. Sugden, & M. E. Chambers (Eds.), *Children with developmental coordination disorder*. (72-92). Whurr Publishers.

Wheat, J. S., & Glazier, P. S. (2006). Measuring coordination and variability in coordination. In K. B. Davids, & K. M. Newell (Eds.), *Movement system variability*. (167-181). Human Kinetics.

Whitall, J., Chang, T. Y., Horn, C. L., Jung-Potter, J., McMenamin, S., Wilms-Floet, A., & Clark, J. E. (2008). Auditory-motor coupling of bilateral finger tapping in children with and without DCD compared to adults. *Human Movement Science, 27*(6), 914-931. https://doi.org/10.1016/j.humov.2007.11.007

Whitall, J., Getchell, N., McMenamin, S., Horn, C., Wilms-Floet, A., & Clark, J. E. (2006). Perception-action coupling in children with and without DCD: frequency locking between task-relevant auditory signals and motor responses in a dual-motor task. *Child: Care, Health and Development, 32*(6), 679-692. https://doi.org/10.1111/j.1365-2214.2006.00676.x

Whitall, J., & Clark, J. E. (2018). A perception–action approach to understanding typical and atypical motor development. *Advances in Child Development and Behavior, 55*, 245-272. https://doi.org/10.1016/bs.acdb.2018.04.004

Wilmut, K., Wang, S., & Barnett, A. L. (2022). Inter-limb coordination in a novel pedalo task: A comparison of children with and without developmental coordination disorder. *Human Movement Science*, 82, 102932. https://doi.org/10.1016/j.humov.2022.102932

Wuyts, I. J., Summers, J. J., Carson, R. G., Byblow, W. D., & Semjen, A. (1996). Attention as a mediating variable in the dynamics of bimanual coordination. *Human Movement Science, 15*(6), 877-897. https://doi.org/10.1016/S0167-9457(96)00033-4

Zanone, P. G., Monno, A., Temprado, J. J., & Laurent, M. (2001). Shared dynamics of attentional cost and pattern stability. *Human Movement Science, 20*(6), 765-789. https://doi.org/10.1016/S0167-9457(01)00055-0