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Timing abilities among children with developmental coordination disorders (DCD) in comparison to children with typical development

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ABSTRACT

Timing ability is essential for common everyday performance. The aim of the study was to compare timing abilities and temporal aspects of handwriting performance and relationships between these two components among children with Developmental Coordination Disorders (DCD) and a control group. Forty two children, 21 diagnosed as DCD and 21 with typical development, aged 7–12, were matched for age, gender and school performed 14 tasks of the interactive metronome (IM) and three functional handwriting tasks on an electronic tablet that was part of a computerized system (ComPET – computerized penmanship evaluation tool). The IM supplies response time, while on-paper and in-air time per written stroke is received from the ComPET. Results indicated significant differences between the groups for both IM and handwriting tasks (ComPET). Linear regression indicated that the mean IM response time explained 37% of variance of the in-air time per stroke during a paragraph-copying task. Furthermore, based on one discriminate function including two measures reflected timing ability, 81% of all participants were correctly classified into groups. Study results strongly recommend consideration of the IM as an evaluation and intervention tool for children with DCD who are faced with timing deficits in their everyday functioning.

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1. Introduction

Developmental coordination disorders (DCD) are prevalent among five to 9% of school-aged children (Cairney, Hay, Faught, & Hawes, 2005). Two features included in the definition of DCD at the DSM-IV (American Psychiatric Association, 1994) are difficulties in performing activities of daily living (ADL) and handwriting difficulties (Cantin, Polatajko, Thach, & Jaglal, 2007; May-Benson, Ingolias, & Koomar, 2002). What is common to these and other everyday functional activities is that they are expected to be completed with appropriate reaction time, within a reasonable time span, and continuous movement, while taking the spatial environment into consideration (Ben-Pazi, Kukke, & Sanger, 2007; Missiuna, Rivard, & Bartlett, 2003; Rao, Mayer, & Harrington, 2001). Such timing of actions is essential for developing skilled movements, and is crucial for many aspects of human performance as for the survival of living organisms (Buhusi & Meck, 2005; Johnston, Burns, Brauer, & Richardson, 2002; Rao et al., 2001). Timing abilities while performing various sequential motor tasks are dependent on the close interrelation of motor and cognitive development involving the cerebellum and dorsolateral prefrontal cortex (Diamond, 2000; Wassenberg et al., 2005). Hence, deficient timing abilities could be a manifestation of both cognitive and motor function deficits that co-occur in children with DCD (Hamilton, 2002; Kaplan, Dewey,Crawford, & Wilson, 2001; Mandich, Buckolz, & Polatajko, 2003; Pitcher, Piek, & Hay, 2003; Visser, 2003).

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The International Classification of Functioning, Disability and Health (ICF, 2001) would consider deficits in timing and its components as problems in body functions. According to the ICF, understanding both *body function* components and *activity* process performance features is relevant for understanding the participation limits of children with DCD. The question is: do children with DCD indeed exhibit timing deficiency? What are the characteristics of their temporal organization during activity performance (activity) and is their timing ability associated with their temporal organization during activity performance?

Findings indicate that children with DCD indeed have internal deficits in sense of time that affect their ability to perform precise, synchronized movements at a reasonable pace and that their movements are more temporally variable in comparison to controls (e.g., Ben-Pazi et al., 2007; Geuze & Kalverboer, 1987, 1994; Johnston, Burns, Brauer, & Richardson, 2002; Mackenzie et al., 2008). However, most previous studies were focused on discrete movements or on a sequential movement using one finger (such as finger-tapping) or specific limbs (Van Waelvelde et al., 2006) and did not address functional every day task. Functional, sequential, continuous everyday tasks involving timing ability are more demanding and require more cortical activation than discrete movements (Schaal, Sternad, Osu, & Kawato, 2004; Zelanznik, Spencer, & Ivry, 2002). Moreover, the requirements are dynamic and rapidly changing, as are the conditions in the environment.

Hence, further studies are needed including objective measures of the process of performing functional, dynamic everyday tasks, to enable decoding of the underlying timing mechanism among children with DCD.

In the current study, the Interactive Metronome® (IM) was implemented to evaluate timing abilities considered as *body functions* while temporal measures of handwriting *activity* were evaluated using the computerized penmanship evaluation tool (ComPET, Rosenblum, Parush, & Weiss, 2003). The Interactive Metronome® (IM)[1] is a computerized intervention tool designed to improve timing, sequencing and coordination through training (Bartscherer & Dole, 2005), which requires the participant to synchronize his or her movements with an auditory stimulus. Movement synchronization manifested in reaction time reflects timing abilities.

Although a preliminary evaluation of the IM user is implemented before training, as far as we know, only one study by Kuhlman and Schweinhart (1999) examined the IM evaluation's reliability and validity. To address the need to establish the evaluation's reliability and validity further, internal reliability will be presented in the current study, as well as discriminant validity – meaning the ability to distinguish between children with and without DCD.

Further to the IM evaluation, handwriting as a sequential, continuous functional activity was evaluated, as it is an essential skill for school-aged children. For both children and adults, proficient handwriting means the ability to produce legible text in a reasonable amount of time (see Rosenblum, Weiss, & Parush, 2003 for more details).

In this context, understanding the relationships between timing abilities and temporal organization in sequential functional activity, while validating the preliminary evaluation of the IM, can contribute to future development of appropriate evidence-based evaluation tools and intervention methods that are necessary for children with DCD (e.g., Holsti, Grunau, & Whitfield, 2002).

Therefore, the aim of the study was to compare timing abilities and temporal aspects of handwriting performance and the relationships between these two components among children with DCD and those with TD. Through the study, the preliminary evaluation of the Interactive Metronome® for evaluation of timing ability among children with DCD was validated.

Therefore, the study hypotheses were as follows:

1. Significant differences will be found in timing abilities, as manifested by the IM scores, between children with DCD and those with TD.
2. Significant differences will be found in temporal measures of handwriting performance between children with DCD and those with TD.
3. Significant correlations will be found between timing abilities (the three categories of IM scores) and temporal measures of handwriting performance in each group (DCD versus TD).
4. Timing abilities, as supplied by the IM, will predict handwriting performance time among children with DCD.
5. Timing abilities as supplied by the IM with certain handwriting measures will best differentiate between groups (DCD versus TD).

2. Methods

2.1. Participants

Twenty-one children with DCD (eight girls, 13 boys), ranging in age from seven to 10 years, and 21 age- and gender-matched children in a control group participated in the study.

The mean age of the DCD group was nine years and nine months, SD = 1 month, and the mean age of the control group was nine years and eight months, SD = 1.3 months. No significant age differences were found between the two groups ($t(40) = .086$, $p = .93$).

The children with DCD were recruited from schools and clinical centers based on educators' or clinicians' reports about motor coordination problems interfering with ADL performance and handwriting deficiencies (based on the criteria of DSM-IV for DCD (American Psychiatric Association, 1994)). To verify their status as children with DCD, they were then tested with the Movement Assessment Battery for Children (M-ABC) (Henderson & Sugden, 1992). Children who scored below the 15th percentile for their age on the M-ABC were included in the DCD group.

The control group was recruited from the same local schools and clinical centers as the DCD group. The 21 controls had no symptoms of DCD, as indicated by the children's parents and teachers and by their M-ABC scores (Henderson & Sugden, 1992). Table 1 illustrates details of the M-ABC scores of both groups.

In each of the groups, most of the children (20) were right-handed and one was left-handed. No significant differences were found between the groups for mother's education level ($\chi^2 = .38$, $p = .76$).

Children with known neurotic/emotional disorders, autistic disorders, physical disabilities or neurological diseases were excluded from the study. All subjects were native Hebrew speakers, attended school, and reported no hearing or vision problems.

2.2. Instruments

2.2.1. Movement assessment battery for children (M-ABC) (Henderson & Sugden, 1992)

The M-ABC was developed as a clinical and research tool that provides an indication of motor functioning through fine and gross motor tasks for children 4–12 years old, in which there are four age-related item sets, which measure manual dexterity, ball skills, static balance, and dynamic balance. Each set consists of eight items, and scores range from 0 to 5 on each item, resulting in a total score of between 0 and 40 per set appropriate to each age group. The total scores can be transformed to percentile scores.

The M-ABC has acceptable validity and reliability (Henderson & Sugden, 1992) and was also validated among children in Israel (Engel-Yeger, Rosenblum, & Josman, 2010).

2.2.2. The Interactive Metronome® (IM)

The Interactive Metronome® (IM) is a computer-based version of a traditional music metronome used to improve timing accuracy in musicians (Bartscherer & Dole, 2005). The system includes a software program, movement-sensing triggers for the hands and feet and two stereo headphones. The triggers are plugged into the computer's serial port. The stereo headphones are connected to a splitter and then to the computer and allow the participant to hear the metronome beat and feedback sounds (Bartscherer & Dole, 2005). The computer program produces a fixed auditory reference beat. The number of beats per minute can be set up. The participant is required to synchronize his/her movements with the rhythm dictated by the computer, while performing various tasks, such as clapping hands, tapping both toes or heels on the footpad or tapping the right or left toe or heel on the footpad. When the participant claps his/her hands or taps his/her feet, the attached trigger sends a signal to the program.

Different discriminative sounds that are tailored to guide the participant's performance are received through the headphones. Each sound is a representation of when the movement occurred in relation to the beat. For example, if a movement is made before the beat, a low pitch tone is heard in the left ear. If the movement follows the beat, a higher pitch tone is generated in the right ear.

The objective is for the participant to move his or her limbs in time with the metronome, namely, patting or tapping his/her hand or foot at the exact moment of the beat. The software analyze the timing relationships between the participant's movements and the beat in milliseconds (Libkuman, Otani, & Steger, 2002) and provides an outcome measure for each task. The participant's timing score is the difference in milliseconds between the moment the beat sounds and the participant's motor response, with longer response time indicating lower time management ability.

In the study by Kuhlman and Schweinhart (1999), internal reliability between the Metronome's diagnostic items was found to be .89. The distinguishing validation for the age factor was found to be $F = 34.13$, $p = <.001$, and the concurrent validity for the school performance test was $r = .264$, $p = .001$.

In the current study, the preliminary assessment for the IM user was implemented. The assessment comprised 14 tasks that involved movements of both hands and both feet, on a scale of increasing difficulty. The outcome measures are based on the mean of response time in milliseconds for each of the 14 tasks.

According to the IM manual, following the response times of the 14 tasks, scores are calculated for seven categories; hands, feet, both hands, both feet, left and right sides of the body and bilateral performance. However, some of the tasks are included in more than one category. Hence, in the current study, only the three categories of tasks for which there was no repetition of the same tasks were analyzed. Those three categories were: hands – tasks 1, 2, 3 and 14, feet – tasks 4–9, 12 and 13 and bilateral – tasks 10 and 11. The Cronbach's alpha analysis performed in the current study yielded high values of reliability for each of the following three categories: hands – .87, feet – .92, and bilateral – .81. The reliability for all 14 tasks was .95.

2.2.3. Computerized penmanship evaluation tool (ComPET – previously referred to as POET; Rosenblum, Parush, et al., 2003; Rosenblum, Weiss, et al., 2003):

This standardized, validated handwriting assessment utilizes a digitizing tablet and on-line data collection and analysis software. It was developed for collecting objective measures of the handwriting process (see Rosenblum, Parush, et al., 2003 for more details) (see Fig. 1). In the current study, three functional handwriting tasks were performed: writing one's name, writing the alphabet sequence and copying a paragraph. Writing one's name is a familiar trained task, and should be performed automatically at age eight. The letters of the alphabet are the building blocks required for writing, and paragraph copying is the kind of task required in the classroom and for preparing homework.

Fig. 1. Computerized penmanship evaluation tool (ComPET) – including a digitizing tablet and on-line data collection and analysis software.

The tasks were performed on A4-size lined paper affixed to the surface of a WACOM Intuos II *x–y* digitizing tablet (404 mm × 306 mm × 10 mm), using a wireless electronic pen with a pressure-sensitive tip (Model GP-110). This pen is similar in size and weight to regular pens commonly used by children and therefore does not require them to change the grip they would ordinarily use or otherwise affect their handwriting performance (see Fig. 1).

Displacement, pressure and pen tip angle were sampled at 100 Hz via a 1300 MHz Pentium (R) M laptop computer. The ComPET system analyze spatial, temporal and pressure measures for each writing stroke, as well as for the entire task. The temporal outcome measures used in the current study were the mean on-paper time and in-air time (i.e., the time during the writing task in which the pen is not in contact with the writing surface) (Rosenblum, Parush, et al., 2003) per writing stroke. In fact, the in-air time + on-paper time constitutes part of the total time required for each written stroke. To document the handwriting process, the description of in-air, on-paper and total time per stroke was supplied.

The ComPET demonstrates good validity and reliability. Four occupational therapy experts confirmed the face validity and suitability of the ComPET paragraph-copying task for handwriting performance evaluation. Furthermore, the discriminant validity of the ComPET system was determined by finding significant differences between the performance of children with poor and proficient handwriting for the system's spatial and temporal measures (Rosenblum, Parush, et al., 2003; Rosenblum, Weiss, et al., 2003).

Test–retest reliability of this system was determined by the author on a sample of 30 typical adults aged 20–40 by demonstrating that no significant differences existed between their first and second handwriting performance via the objective measures of the ComPET. For example, no significant differences were found in total performance time ($t = 1.39$, $p = .18$); total length of pen excursion ($t = .61$, $p = .54$); number of writing segments ($t = .41$, $p = .68$); or writing velocity ($t = .28$, $p = .77$). (See Rosenblum, 2008 for more details.)

2.3. Procedure

The study was carried out with the permission of the Ethics Institutional Review Board at the University of Haifa and the Ministry of Education.

A preliminary screening of the school children to identify those with DCD was conducted with the help of the school counselor. Letters were sent to the parents, as well as a consent form for their child's participation in the study. After receiving the signed consent form, the researcher conducted the M-ABC test to confirm the DCD diagnosis. After identifying 21 children who exhibited the DCD criteria and 21 children matched for the control group, their parents were requested to fill in the demographic questionnaire.

The preliminary IM evaluation, as well as the handwriting evaluation, was administered to the children under similar conditions in a quiet room in their school or in the clinic, under environmental conditions similar to those that the child would normally experience. Each subject was tested individually during the morning hours.

2.4. Data analysis

Descriptive statistics (means, standard deviation, percentages) were used to describe the study participants and main variables.

To Compare the DCD and TD groups in their M-ABC, a MANOVA for each of the three subscales (Manual dexterity, ball and balance) and a *t*-test for the final score were applied.

Internal reliability of the three IM categories and the entire scale was analyzed using Cronbach's alpha.

To examine whether the children in the DCD and TD groups differed with respect to timing abilities, a MANOVA for each of the three IM categories was applied.

Furthermore, the differences between the groups for the final mean response time of the IM 14 tasks was analyzed using a t-test.

MANOVA was applied also, to study differences between groups for each of the two ComPET temporal measures: on-paper and in-air time, across the three handwriting tasks (writing one's own name, alphabet sequence and paragraph copying).

Pearson correlations were calculated to investigate associations between the IM mean response time for each of the three categories (Hands, feet and bilateral tasks) and the temporal measures of the handwriting tasks.

Series of linear regression were conducted to determine whether timing ability as manifested through total mean IM response time predicts performance time per stroke on-paper and in-air for all the three handwriting tasks.

3. Results

3.1. Background characteristics – M-ABC scores

The MANOVA analyses applied to test for group differences (DCD vs. TD) across the three subscales of the M-ABC (e.g., fine motor, ball skills and balance), yielded significant difference between the groups (F (3,38) = 17.10; $p < .0001$ $\eta^2 = .57$).

To test for group differences for each of the three subscales, the data were subjected to a series of one-way MANOVAs. The results, shown in Table 1, indicated significant differences between the groups for each of the three M-ABC subscales.

Hypothesis 1. Significant differences will be found in timing abilities, as manifested by the IM scores, between children with DCD and those with TD.

The MANOVA analyses applied to test for group differences (DCD vs. TD) across the three categories of the IM (e.g., hands, feet and bilateral tasks), yielded significant differences between the groups (F (3,38) = 9.11; $p < .0001$ $\eta^2 = .42$).

To test for group differences (children with DCD versus children with TD) for each of the three categories of the Interactive Metronome (e.g., hands, feet and bilateral tasks), the data were subjected to a series of one-way MANOVAs.

The MANOVA yielded significant group differences for each category: hands (F(3,38) = 14.02 $p = .001$ ES-$\eta^2 = .26$), feet: (F(3, 38) = 28.24 $p < .0001$ ES-$\eta^2 = 41$) and Bilateral (F(3,38) = 15.71 $p = <.0001$ ES-$\eta^2 = .28$). The mean response time of each task, as well as the mean response time for the tasks in each of the three categories shown in Table 2, indicated that the response time of children with DCD was significantly longer compared to that of the children with TD.

Table 1
Comparison of MABC mean scores between groups.

	DCD (n = 21) M (SD)	TD (n = 21) M (SD)	F/t	η^2
Mean of manual dexterity total score	2.62 (1.24)	1.08 (1.22)	$F = 16.46^{***}$	.29
Mean of ball skills total score	2.17 (1.30)	.38 (.48)	$F = 35.16^{***}$	.47
Mean of balance total score	1.46 (1.08)	.32 (.43)	$F = 19.85^{***}$	.33
Mean of total MABC score	2.07 (.78)	.62 (.57)	$t(40) = 6.87^{***}$	

*** $p \leq .001$

Table 2
Mean (SD) of the Response Time (RT) for all tasks in the three Interactive Metronome categories between the groups (DCD versus TD) in milliseconds.

DCD (n = 21) (Mean ± SD)	TD (n = 21) (Mean ± SD)	F(3,38) t(40)	p	η^2	
Hands					
1. Both hands	171.80 (101.55)	127.80 (74.42)			
2. Right hand	162.52 (103.24)	73.85 (36.50)			
3. Left hand	176.57 (110.38)	75.52 (43.95)			
14. Repeat both hands	203.57 (81.07)	121.42 (82.08)			
Hands mean total RT	178.66 (85.79)	99.80 (44.15)	14.02	.001	.26
Feet					
4. Both toes	194.27 (107.56)	141.43 (130.06)			
5. Right toe	210.36 (112.85)	91.62 (58.98)			
6. Left toe	198.90 (87.90)	87.56 (52.44)			
7. Both heels	210.72 (88.82)	12.06 (90.37)			
8. Right heel	225.72 (97.72)	95.25 (80.79)			
9. Left heel	232. 09 (141.79)	134.81 (97.03)			
12. Balance right foot	219.00 (117.10)	103.00 (55.02)			
13. Balance left foot	201.63 (117.12)	103.18 (78.37)			
Feet mean RT	223.90 (8.49)	110.62 (53.84)	28.24	<.0001	.41
Bilateral					
10. Right hand/left toe	246.50 (117.77)	173.52 (120.74)			
11. Left hand/right toe	248.80 (139.13)	108.28 (69.94)			
Bilateral mean RT	246.52 (119.17)	127.81 (68.06)	15.71	<.0001	.28
Final mean IM tasks RT	213.38 (77.95)	111.90 (46.39)	5.12	.013	

Furthermore, a *t*-test indicated significant differences between groups for the IM mean total response time mean (DCD M = 213.38 ± 77.95; TD: 111.90 ± 46.39 T (40) = 5.12 *p* = .013).

Hypothesis 2. Significant differences will be found in temporal measures of handwriting performance between children with DCD and those with TD.

To test for group differences for the temporal measures of each of the handwriting tasks (e.g., mean on-paper and in-air time per stroke), the data were subjected to a series of one-way MANOVAs. To examine the source of significance for the task measures, the data were subjected to univariate ANOVAs and results are presented in Table 3.

The MANOVA for the on-paper per stroke yielded no significant result across the three handwriting tasks ($F(3,38) = 2.76$, $p = .055$ ES-$\eta^2 = .18$). The results, shown in Table 3, indicated that a significant difference was found in on-paper time per stroke for the paragraph copying task.

However, the MANOVA for the in-air per stroke yielded significant results across the three handwriting tasks ($F(3, 38) = 6.61$, $p = .001$ ES-$\eta^2 = .34$). The results, shown in Table 3, indicated that significant differences were found for mean in-air time per stroke for all three tasks.

Table 3
Mean (SD) of the temporal measures (on-paper and in-air time per stroke) across the three handwriting tasks (writing one's own name, alphabet sequence and paragraph copying) between the groups (DCD versus TD).

Task	Variables	DCD (*n* = 21) (Mean ± SD)	TD (*n* = 21) (Mean ± SD)	*F*	*P*	Partial Eta squared
On-paper time per stroke (s')	Writing own name	.43 (.20)	.32 (.15)	3.59	NS	.082
	Alphabet sequence	.49 (.21)	.38 (.17)	3.70	NS	.085
	Paragraph copying	.39 (.15)	.28 (.07)	8.71	.005	.179
In-air time per stroke (s')	Writing own name	.67 (.54)	.38 (.20)	16.48	<.001	.292
	Alphabet sequence	1.34 (.76)	.64 (.19)	5.26	.027	.116
	Paragraph copying	1.24 (.67)	.59 (.24)	16.51	<.001	.292

Hypothesis 3. Significant correlations will be found between timing abilities (the three categories of IM scores) and temporal measures of handwriting performance in each group (DCD versus TD).

The correlations between the three IM categories (hands, feet, bilateral) and the final IM score and the temporal measures of the three handwriting tasks for each of the study groups (DCD versus TD) are presented in Table 4.

As presented in Table 4, significant moderate correlations were found among the DCD group for the hands category score of the IM and on-paper time of the alphabet sequence task ($r = .48$, $p < .05$). Among the TD group, significant moderate correlations (*r* ranged .48–.67) were found between the three IM category scores (hands, feet and bilateral) and on-paper and in-air time per stroke for the three handwriting tasks.

Table 4
Pearson correlations between the Interactive Metronome response time (the three categories and total) and the temporal measures of the handwriting tasks in each of the two groups (DCD; TD).

	Bilateral		Feet		Hands		Total mean response time (14 tasks)	
	DCD	TD	DCD	TD	DCD	TD	DCD	TD
On-paper time per stroke								
Writing own name		.48*		.53*		.67**		.612**
Alphabet sequence	.48*	.45*						
Paragraph copying		.48*		.54*		.50*		.490*
In-air time per stroke								
Writing own name				.58**				
Alphabet sequence		.47*						.556**
Paragraph copying				.48*				.460*

* $p \leq .05$.
** $p \leq .01$.

Hypothesis 4. Timing abilities, as supplied by the IM, will predict handwriting performance time among children with DCD.

Following the above decrypted results, the purpose was to find whether total mean response time of the IM predicts the handwriting performance time (both on-paper and in-air time per stroke) in the three handwriting tasks (own name, alphabet and paragraph copy), beyond group differentiation (as DCD or TD).

Results of the linear regressions presented in Table 5 indicated that, indeed, mean total response time of the IM predicts the variance percentile of both on-paper and in-air measures of all the three handwriting tasks. The highest level of prediction of on-paper time per stroke achieved for the paragraph copy task – 27% ($F(2,39) = 7.17$ $p = .03$ $\beta = .384$). For the same task, a prediction of 37% was found for the in-air time per stroke ($F(2,39) = 11.65$ $p < .0001$ $\beta = .368$).

Table 5A
Predicting handwriting performance time (on paper per stroke) across tasks, by the IM mean final response time.

Variable	Model 1			Model 2		
	B	SE B	*β*	*B*	SE B	*β*
One's own name						
Group	−1.08	.056	−.29	.013	.066	.036
IM mean RT				.001	.00	.52**
R^2		.085			.247	
F for change in R^2		3.70			8.44**	
Alphabet task						
Group	−.114	.060	−.287	−.007	.073	−.017
IM mean RT				.001	.000	.43*
R^2		.082			.194	
F for change in R^2		3.59			5.39*	
Paragraph copy						
Group	−.113	.038	−.423	−.048	.047	−.180
IM mean RT				.001	.000	.386*
R^2		.179			.269	
F for change in R^2		8.715**			.480*	

* $p \leq .05$.
** $p \leq .01$.

Table 5B
Predicting handwriting performance time (in air time per stroke) across tasks, by the IM mean final response time.

Variable	Model 1			Model 2		
	B	SE B	*β*	*B*	SE B	*β*
One's own name						
Group	−.289	.126	−.341*	−.092	.157	−.108
IM mean RT				.002	.001	−.369*
R^2		.116			.199	
F for change in R^2		5.26			4.01*	
Alphabet task						
Group	−.703	.173	−.543***	−.403	.212	−.310
IM mean RT				.003	.001	.366*
R^2		.292			.372	
F for change in R^2		16.48***			5.014*	
Paragraph copy						
Group	−.641	.158	−.540***	−.366	.193	−.309
IM mean RT				.003	.001	.368*
R^2		.292			.374	
F for change in R^2		16.50***			5.10*	

* $p \leq .05$.
*** $p \leq .001$.

In both cases, longer response time for the metronome tasks was associated with longer performance time required for handwriting performance.

Hypothesis 5. Timing abilities as supplied by the IM with certain handwriting measures will best differentiate between groups (DCD versus TD).

One discriminant function was found for group classification of all participants (Wilks' Lambda = .553, $p < .0001$) based on the mean total response time of the IM tasks and in-air per stroke for the paragraph copy task. The IM response time made the greatest contribution to group membership (loading = .90) while the in-air time measures was loaded .71. Based on this function, 81% of the participants overall, 76% of the children with DCD, and 86% of the typically developed children were correctly classified. A Kappa value of .62 ($p < .0001$) was calculated, demonstrating that the group classification did not occur by chance.

4. Discussion

Although findings have positively linked timing abilities to scholastic achievements and gross motor abilities among children (e.g., Greenspan, 2002), studies on this topic among children with DCD are scarce. The aim of the current study was to find out whether children with DCD differed from those with TD in movement synchronization manifested in reaction time, as measured by the IM and by temporal measures of handwriting performance. A further aim was to find out whether deficits in movement synchronization would predict performance of a functional everyday task such as handwriting.

As expected, the response time for 11 out of 14 IM tasks was significantly longer for the DCD group compared to controls. There is evidence in the literature that children with DCD require a longer time to respond to visual signals (Johnston et al., 2002; Wilson & McKenzie, 1998). The current results exhibit their difficulty also when they were required to respond and synchronize their movements using auditory signals. The children in the DCD group had difficulty adapting their movement to the given sound and to perform planned motion with appropriate coordination. These results support previous findings by several authors, who found difficulties among children with DCD in adapting their movements to auditory stimuli (e.g., Whitall et al., 2006; Volman, Laory, & jongmans, 2006), which was explained as caused by deficits in auditory processing (Whitall et al., 2006).

As presented in Table 2, considerable gaps were found between the groups in response time for the 11 IM tasks. The question arising from such results is whether such gaps in movement synchronization are indicators of the performance mechanism of varied activities routinely required of children with DCD in their everyday life tasks.

Indeed, the results of the current study indicated that timing deficits in children with DCD compared to those with TD were manifested not just in their performance of the IM tasks, but also in the temporal measures of their handwriting performance.

When including three functional graded writing tasks, such as writing one's own name, the alphabet sequence and paragraph copying at the MANOVA, no significant difference was found for on-paper time per stroke. However, similar to our previous findings (Rosenblum & Livneh-Zirinsky, 2008), a significant difference was found for on-paper per stroke of the paragraph copying task (Table 2). Furthermore, in accordance with our previous results (Rosenblum & Livneh-Zirinsky, 2008), significant differences were found in the current study for mean in-air time per stroke for all three handwriting tasks, from the simple one–writing one's own name, through writing the alphabet sequence, to continuous paragraph copying. These results support the DSM4 criteria for the diagnosis of DCD among school-aged children indicating deficits in handwriting performance, but also add a clue about the source of their difficulty.

In our previous studies, we found that the in-air measure might be a manifestation of the perceptual aspects of the actual performance (e.g., Werner, Rosenblum, Bar-On, Heinik, & Korczyn, 2006). In fact, the longer in-air time required might be caused by perceptual deficits previously mentioned among children with DCD, such as deficits in speed of kinesthetic information processing (Smyth & Mason, 1997), visual memory (Dwyer & McKenzie, 1994), motor programming and motor imagery (Wilson, Maruff, Ives, & Currie, 2001) or visual spatial organization (Piek & Dyck, 2004).

In fact, the same trend of a slower performance was found for the Metronome and for handwriting performance. These results are compatible with previous findings about deficits among children with DCD in relation to timing, duration and sequencing of movement (Barnhart, Davenport, Epps, & Nordquist, 2003; Mackenzie et al., 2008; Missiuna et al., 2003), as well as those on the ''slowness in movement'' among this population (Henderson, Rose, & Henderson, 1992; Van der Meulen, Denier Van der Gon, Gielen, Gooskens, & Willemse, 1991). It seems that the temporal processing deficit is inherent and is not dependent on the kind of task that the child with DCD performs.

The significant medium correlations between on-paper time of the alphabet task and the IM hands category in both the DCD (.48) and the TD group (.45) show that the IM performance does indicate handwriting abilities. These findings add that not only reading, but also handwriting performance, is related to visual temporal processing abilities (Boden & Brodeur, 1999).

Further support was received from the regression, which indicates that the IM mean final response time indeed explained the varied percentile of variance of both on-paper and in-air time per stroke–in all of the three handwriting tasks. The highest level of prediction was found for the paragraph copy task while 27% of the variance of the on-paper time per stroke and 37% of the variance of in-air time per stroke were explained by the IM response time. In fact, the IM mean response time reflects not only hands response time, which may be related to handwriting performance, but also foot performance tasks. Evidence of a more general deficit concerning hands and feet among children with DCD was previously presented by Volman et al. (2006). They found that children with DCD had difficulty producing stable rhythmic hand-foot coordination patterns compared to children in the control group.

The results of both performances in the IM tasks (hands, feet, bilateral), as well as handwriting performance as reflected through the regression and the discriminate analysis, support previous findings about general timing deficits among DCD; a kind of deficit in the internal sense of time, within the systems that maintain synchrony between the brain's neurochemistry and environments available to the individual (e.g., Dawson, 2004; Geuze & Kalverboer, 1987, 1994; Johnston et al., 2002; Mackenzie et al., 2008) and a kind of deficit concerning the close interrelation of motor and cognitive development (Diamond, 2000; Wassenberg et al., 2005). More response time required for the IM task performance, as well as more in-air time in handwriting performance indicates deficits in skill learning and autoimmunization, as previously mentioned as being associated with the cerebellum (e.g., Doyon et al., 1997; Kandel, Schwartz, & Jessell, 2000; Visser, 2003). These play an important role in representing sensory and motor timing (Ivry & Keele, 1989; Jueptner et al., 1995; Rao et al., 2001).

As previously mentioned, regarding the in-air measure, evidence from other studies might link this timing deficit to several sensory deficits found in children with DCD (e.g., Piek & Dyck, 2004), as well as to deficits in processing various kinds of stimuli (visual, auditory, tactile) found among this population (Mackenzie et al., 2008; Pitcher et al., 2003).

The current study results suggest that it might be worthwhile to conduct further studies of the possible contribution of the IM for improving internal sense of rhythm related to timing abilities (Koomar et al., 2001) among children with DCD toward improving their handwriting and overall functional abilities. In practice, children need to learn how to write automatically. The relationships between motor regulation and attention as part of executive functions have lead to the assumption that strengthening motor planning, sequencing, timing and rhthmicity will lead to improved attention and learning abilities (Greenspan, 2002).

Indeed, previous studies reported improvement in performance following the IM training in various areas, such as movement accuracy and timing abilities (Cosper, Lee, Peters, & Bishop, 2009; Stemmer, 1996) playing golf (Libkuman et al., 2002), attentiveness and motor coordination (Bartscherer & Dole, 2005), and in academic performance (Kuhlman and Schweinhart, 1999; Stemmer, 1996; Taub, McGrew, & Keith, 2007). Specifically, improvement in attention abilities (Kelly, 2001; Shaffer et al., 2001), motor skills, reading abilities, and some cognitive skills were found among children with ADHD (Shaffer et al., 2001), a population which is known to have high co morbidity with DCD (Deway, Kaplan, Crawford, & Wilson, 2002).

The alphabet represents the building blocks of reading and writing materials. Following the current results and evidence that audiovisual training improves reading skills (Kujala et al., 2001), it would be interesting to study whether combining auditory feedback when the alphabet is taught visually to children with DCD might enhance letter internalization, and as a result, improve these children's writing performance time.

There are three main advantages to implementing the IM for evaluation and intervention among children with DCD. First, it is a dynamic system in which the performance emanates from the individual's internal factors, the task being presented and the performance environment. All these factors, as well as the received feedback and the changing challenges, might contribute to behavioral organization (Koomar et al., 2001) and improvement in movement accuracy and performance time, which is necessary among children with DCD in particular (Missiuna et al., 2003).

Second, the training protocol can be adapted for each individual's level and needs. This is an important benefit in light of the current knowledge about the heterogeneity among children with DCD and the fact that their movement characteristics are diverse (Van Waelvelde et al., 2006).

Further studies are required to evaluate whether including auditory and visual inputs while training the children to perform everyday tasks (Niemeijer, Smits-Engelsman, Reynders, & Schoemaker, 2003) will indeed improve their performance.

The results of the current study add another stepping stone on the way to understanding the nature and mechanism underlying the coordination deficits among children with DCD (Cantin et al., 2007). Further studies with larger samples are required to find out whether auditory feedback and training with the IM might improve global everyday functioning and specifically academic functioning, such as handwriting, among children with DCD.

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