Research in Developmental Disabilities 93 (2019) 103461

Contents lists available at ScienceDirect

Research in Developmental Disabilities

journal homepage: www.elsevier.com/locate/redevdis

Children's Repetitive and Intermittent Sprinting Performance (CRISP) Test: A new field-based test for assessing anaerobic power and repeated sprint performance in children with developmental coordination disorder

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ARTICLE INFO

Number of reviews completed is 2

Keywords:
Anaerobic fitness
Anaerobic power
Muscle endurance
Fatigue
Developmental coordination disorder
Children

ABSTRACT

Background: Evidence on anaerobic power and sprinting performance of children with Developmental Coordination Disorder (DCD) is limited.
Aims: The primary aim of this study was to investigate if the Children's Repetitive and Intermittent Sprinting Performance (CRISP) test could induce fatigue among participants. Secondly, the study examined the construct validity of the test in children with probable DCD (p-DCD) and typically developing (TD) peers.
Methods and procedures: The study was carried out in two phases. In phase 1, we compared performance of 25 children (7–12 years) on the CRISP test to their performance on the Muscle Power Sprint test (MPST). For phase 2, forty-six (n = 46) participants with p-DCD were matched with TD children (n = 46) on age, weight and sex. Anaerobic performance of participants was assessed using the CRISP test, 10 × 5 m sprints straight and slalom tests, side jumps, stepping on platform task and the ladder agility test.
Outcomes and results: Phase 1: The increase in running time on the CRISP test was greater than on the MPST, indicating that the CRISP test was more fatiguing than the MPST. Phase 2: Children with p-DCD had poorer anaerobic capacity (muscle power, muscle endurance) compared to their TD peers. However, fatigue was comparable between the two groups. The differences in performance between p-DCD and TD children were found to be greater for tests with more agility elements.
Conclusions and implications: The findings showed that CRISP test could induce fatigue in children. The CRISP test was also found to have positive construct (i.e. known-group) validity. The differences in muscle power and endurance between children with p-DCD and TD peers tend to widen when assessments are performed with tests having high agility components.

What this paper adds

Anaerobic power and sprinting are important for functional independence in childhood but research investigating these variables is limited, particularly among pediatric populations. The present study validated a newly developed anaerobic power test among

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https://doi.org/10.1016/j.ridd.2019.103461
Received 6 March 2019; Received in revised form 2 August 2019; Accepted 5 August 2019
Available online 19 August 2019

children with and without movement difficulties. Also, the study sought to determine if fatigue induced during testing would be different between children with p-DCD and TD peers. Results indicated that the CRISP test possesses good construct validity and may be suitable for measuring anaerobic power and estimating fatigue in children. Fatigue does not seem to explain the widely reported differences in anaerobic performance between children with DCD and TD children. It was also evident that motor coordination could confound anaerobic performance in children with p-DCD. The results demonstrate that sprint tests with little or no directional changes may be valid alternatives for measuring anaerobic power in children with DCD. Based on these findings, we do not recommend the use of tasks with high agility elements in assessing anaerobic performance in children with DCD.

1. Introduction

Anaerobic power has been emphasized as an important determinant of children's functional ability (Bailey et al., 1995; Bongers et al., 2015; Praagh, 2007). A child's daily activities usually consist of frequent short-duration high intensity movements (e.g. sprinting, jumping and throwing) (Bailey et al., 1995; Bongers et al., 2015). Yet, the assessment of anaerobic power and sprint ability has received little attention in children especially among those with developmental disabilities such as Developmental Coordination Disorder (DCD). DCD is a motor skill disorder characterized by impaired motor coordination that significantly affects daily activities and academic achievements and is unexplained by any intellectual disability or identifiable neurological disease (American Psychiatric Association, 2013; Blank, Smits-Engelsman, Polatajko, & Wilson, 2012). Consequently, children with DCD often experience difficulties with numerous tasks that most typically developing (TD) peers can easily perform (Caçola & Lage, 2019). In addition, children with DCD participate less in physical activity compared to TD children (Cairney et al., 2005; Rivilis et al., 2011). Along with decreased physical activity, impaired physical fitness has been documented in children with DCD (Aertssen, Ferguson, & Smits-Engelsman, 2016; Cairney, Hay, Faught, Flouris, & Klentrou, 2007; Cairney, Veldhuizen, King-Dowling, Faught, & Hay, 2017; Farhat et al., 2015; Ferguson, Aertssen, Rameckers, Jelsma, & Smits-Engelsman, 2014; King-Dowling, Rodriguez, Missiuna, Timmons, & Cairney, 2018; Li, Wu, Cairney, & Hsieh, 2011; O'Beirne, Larkin, & Cable, 1994; Raynor, 2001; Rivilis et al., 2011; Schott, Alof, Hultsch, & Meermann, 2007; Tsiotra, Nevill, Lane, & Koutedakis, 2009; Smits-Engelsman, Jelsma, & Ferguson, 2016; Wu, Lin, Li, Tsai, & Cairney, 2010). Cairney et al. (2007) demonstrated significant differences in cardiorespiratory fitness between children with and without DCD.

Although many previous works have investigated physical fitness among children with DCD, fewer studies have focused on anaerobic capacity (muscle power, muscle endurance) (Aertssen et al., 2016; Ferguson et al., 2014; Hands & Larkin, 2006; King-Dowling et al., 2018; O'Beirne et al., 1994; Raynor, 2001; Schott et al., 2007). Recently, King-Dowling et al. (2018) examined differences in health-related physical fitness between DCD and TD children aged 4–5 years (n = 592) using laboratory-based assessments. In their study, the Bruce protocol (a progressive treadmill test that increases in speed and grade) was used to measure aerobic fitness while muscle power was measured using the Wingate test. The authors found that young children with DCD and TD differ both in terms of aerobic and anaerobic capacity. Raynor (2001) who also used laboratory assessments to measure maximal strength and power produced similar results indicating that children with DCD are less powerful than TD peers. Further, earlier studies involving field-based assessments (e.g. the muscle power sprint test and 20-m sprint time) have reported decreased anaerobic power in children with DCD compared to those with typical development (Aertssen et al., 2016, Schott et al., 2007). Obviously, both young and older children with DCD are more likely to have lower anaerobic capacity than TD peers. It would also seem that the mode of assessment (field or laboratory-based) has little influence on children's anaerobic performance. Several factors may explain the observed differences (Ferguson et al., 2014). Notable among these could be differences in coordination, physical activity and fatigue between DCD and TD children (Cairney et al., 2007; King-Dowling et al., 2018; Raynor, 2001; Schott et al., 2007). Raynor (2001) posited that decreased muscle power seen in children with DCD might partly be explained by inefficient muscle activation, which could be a consequence of their limited movement experiences. Besides, poor motor coordination, low perception of adequacy in physical activity and fatigue (Cairney et al., 2005; Ferguson et al., 2014; Schott et al., 2007) may also explain why children with DCD are unable to generate maximum power outputs as compared to TD peers. King-Dowling et al. (2018) found that children with DCD produce lower muscle power and fatigue faster during a progressive aerobic endurance test and also when performing short-term anaerobic tests. This gives an indication that fatigue may be an important limiting factor for optimal anaerobic performance. To improve anaerobic performance, it is necessary to develop cost-effective, standardized tools to measure anaerobic power in DCD research. This may help us to better characterize children's anaerobic performance and to gain insight about the factors that may be associated with poor performance.

Fatigue can be defined as an exercise-induced decline in the capacity to generate maximal force or maximal power output (Girard, Mendez-Villanueva, & Bishop, 2011). Fatigue may be expressed as a reduction in speed or power, which can reduce one's ability to accomplish everyday tasks such as running (Girard et al., 2011; Vøllestad, 1997). Numerous assessment techniques can be used to measure fatigue (Girard et al., 2011; Vøllestad, 1997). However, in most field-based studies, fatigue is often estimated using Fatigue index (FI) (Girard et al., 2011). FI expresses the rate at which power declines and is considered to be an indirect indicator of an individual's ability to maintain power output over time. Thus, smaller FI represents an increased ability to resist fatigue (Girard et al., 2011).

Given the absence of validated field-based anaerobic tests and the limited evidence on the underlying mechanisms responsible for the low levels of anaerobic performance reported children with DCD, it was thought of interest to develop and validate a new test that can be used to assess anaerobic performance in this population. Currently, existing measures require a lot of coordination, which tends to contaminate results when used for children with DCD. Verschuren, Bongers, Obeid, Ruyten, and Takken (2013) developed the Muscle Power Sprint Test (MPST) to measure anaerobic performance and muscle function in children with cerebral palsy (CP).

Table 1
Ranking of anaerobic capacity tests (muscle power, muscle endurance) based on task constraints.

Test	Hypothesized coordinative tasks constraints (Ascending order)
1. 30 m straight sprint (First run CRISP)	Low
2. 10x5 m straight sprint with 9 turns	
3. 10X5 m slalom sprint (curvilinear trajectory) with 9 turns	
4. Ladder Agility Test (Running with 1 foot in each square with 1 turn)	
5. Jumping sideways for 15s	
6. Moving side ways on platforms for 20s	High

Though the authors chose an adequate distance (15 m) for their CP sample, this distance appears to be too short for children with mild movement difficulties. In one of our earlier works, we found that the average running time for the 15 m MPST was less than 5 s for both TD and DCD children (Aertssen, Bonney, Ferguson, & Smits-Engelsman, 2018). Further, we noticed no significant decrease in their running speed. It has also been suggested that different anaerobic performance tests require different levels of coordination. With this in mind, we decided to rank commonly used anaerobic performance tests to identify the most suitable test for children with low motor abilities (Table 1). Based on this, we found it prudent to examine the construct validity of the Children's Repetitive and Intermittent Sprinting Performance (CRISP) test. The CRISP test is a-six by 30 m discontinuous sprint test with brief recovery period. In this paper, we investigated the construct validity of the CRISP test and examined whether it could be administered to induce fatigue (as determined by a significant increase in running time over the six sprints). We were also interested in determining if the performance of children with DCD and TD would be different in terms of running time, increase in running time over repeated runs and changes in heart rate. Construct validity was assessed using a known-group comparison approach and factor analysis. Given that technique is an important determinant of sprinting efficiency, it was hypothesized that reduced motor proficiency in children with DCD would be associated with poor anaerobic performance and increased fatigue. Similarly, we expected wider gaps in performance between the two groups if tests required more coordination and agility. In summary, we conducted a two-pronged study to address the following four questions;

1 Can the CRISP test distance induce fatigue in children (as measured by an increase in running time over six sprints)?
2 Will participants' performance (as measured by running time and power, and heart rate over six runs) on the CRISP test differ between children with p-DCD and TD (known-group validity)?
3 Will the differences in anaerobic performance between children p-DCD and TD be larger if the coordinative task constraints are higher?
4 Do the anaerobic capacity tests used in this study measure a similar construct among children with p-DCD and TD peers?

2. Method

2.1. Study design and setting

This cross-sectional study involved participants with and without DCD attending mainstream elementary school in a low-income area of Cape Town, South Africa. Because of the limited resources and unsafe playgrounds in this area, physical education is less frequent in most schools. Thus, the children in this community have limited access to physical activity opportunities. The study was performed in two phases. Phase one involved the comparison of participants' performance on the MPST and CRISP test. This was intended to address the first research question. In phase two, we compared scores of children (p-DCD and TD) on the CRISP test and on five other tests to provide answers to the remaining questions.

2.2. Participants

All children in grades 2–4, whose parents signed written informed consent were eligible for inclusion (n = 210). Children's motor coordination was measured using the Movement Assessment Battery for Children-2 (MABC-2 test) (Henderson, Sugden, & Barnett, 2007). Fifty-one (n = 51) children scored below the 16th percentile on the MABC-2 test but one child was expelled from the school after the first round of selection. We were able to match 46 children who scored below the 16th percentile on the MABC-2 test with 46 typically developing children (who scored above the 16th percentile on the MABC-2 test) (Geuze, Schoemaker, & Smits-Engelsman, 2015). Matching was based on age, sex and weight. None of the children showed signs of severe physical or cognitive problems. Because we could not confirm all the DSM-5 criteria, we have elected to refer to the group identified as having movement difficulties as probable DCD (p-DCD) (Geuze, Jongmans, Schoemaker, & Smits-Engelsman, 2001). Of the children who were not included in the matched sample, 25 TD children were randomly selected and their performance on the CRISP test was compared with scores on the MPST (Research question 1).

2.3. Procedure

The protocol received ethical approval from the Human Research Ethics Committee of the University of Cape Town (HREC #: 209/2018). Permission was also obtained from the principal of the school and designated education authorities in the Western Cape Province of South Africa. All the tests were performed by five trained assessors (physiotherapists and pediatric physiotherapy students) who were not involved in the data analysis. Each child received verbal instructions, demonstrations and practice trials before the actual test was performed.

2.3.1. Phase 1: comparison of scores on the MPST and CRISP test

The two sprint tests (MPST and CRISP test) were administered on the school's playground. During testing, participants were allowed a 10 s rest between runs for both tests. Participants' heart rates were measured during the resting interval using the Fitbit (Inspire HR, Fitbit Inc., San Francisco, CA). About half of the participants performed the MSPT on the first test day, while the rest started with the CRISP.

2.3.2. Phase 2: comparison of scores between p-DCD and TD groups

After the MABC-2 assessments (which were administered in a designated classroom), participants completed five sprints and agility tests within a period of 2 weeks. These tests were performed in a random order.

2.4. Measurements

2.4.1. Demographic and anthropometric characteristics

Demographic data including age, sex and grade were collected. Height was measured using a portable stadiometer and weight was assessed with an electronic scale. Height and weight values were used to calculate body mass index (BMI) by dividing participants' weight (in kilograms) by the height (in meters) squared.

2.4.2. Movement assessment battery for children test-2 (MABC-2 test)

All children completed the MABC-2 test (Henderson et al., 2007). The MABC-2 test is suitable for children aged 3–16years. It assesses eight motor tasks across three age bands (3–6, 7–10 and 11–16years). Age bands 2 and 3 were used in this study. The tests are divided into three components; manual dexterity, ball skills and balance tasks. Raw scores were converted to standardized scores and used for the analysis. The MABC-2 test is considered to have excellent psychometric properties (Henderson et al., 2007). Since there are no norms for African countries, we elected to use the Dutch Norms as was done in our earlier studies involving South African children (Bonney, Ferguson, & Smits-Engelsman, 2017; Ferguson et al., 2014).

2.4.3. Field-based assessments

2.4.3.1. The children's repetitive and intermittent sprinting performance (CRISP) test. The CRISP test was used to assess anaerobic fitness and fatigue. The test involves a series of six 30 m sprints at maximum speed with a short recovery period. Each child had to run as fast as possible from one line to the other and was instructed not to slow down before crossing the finishing line. The time taken to complete each run was measured (sprint time). Before executing the test, the child performed a 1-minute warm-up and the test was explained and also demonstrated (by the tester or by watching other children who were being tested) to ensure participants understood the requirements of the test. Children were provided with verbal encouragement throughout the testing period.

For the comparison between TD and DCD groups, additional outcomes, based on the sprint times, were calculated. Mean power (MP) was used as a measure of anaerobic capacity and was calculated using the sprint time of the six runs and the weight of each participant. Power was computed using the following formula; power = (body mass × distance^2)/sprint time^3 (Steenman, Verschuren, Rameckers, Douma-van Riet, & Takken, 2016). Mean and peak power (W), which is the average and highest power output of all six sprints, were determined. Greater MP indicates the ability to maintain power output over time and translates into better maintenance of anaerobic performance. Fatigue Index-Power was calculated using the peak and low power data points over the six runs. Fatigue was also measured as a percentage of the difference between the slowest and fastest running time [Fatigue Index-Time = (slowest running time − fastest running time/fastest running time) * 100].

2.4.3.2. The muscle power sprint test (MPST). During the MPST, each participant performed six runs at top speed over a 15 m course (Verschuren, Takken, Ketelaar, Gorter, & Helders, 2007). The time between consecutive runs was 10 s. The time taken to complete each run was measured. Test–retest reliability has been reported to be good with an ICC value 0.98 (Douma-van Riet et al., 2012).

2.4.3.3. Heart rate. In phase 1 of the study, Fitbit (Inspire HR, Fitbit Inc., San Francisco, CA) heart rate monitors were worn by participants (around the wrist). In the past years, several studies have been published on the most recent predecessor of this device, (Fitbitt Charge HR) and indicated mean biases between −2.5 bpm and −9.3 bpm (Cadmus-Bertram, Gangnon, Wirkus, Thraen-Borowski, & Gorzelitz-Liebhauser, 2017; Wallen, Gomersall, Keating, Wisløff, & Coombes, 2016). Heart rate was recorded 6 times at the end of each run during a 10 s interval.

In phase 2, Polar heart rate monitors (Polar S810 heart-rate monitor (HRM; Polar Electro OY, Kempele, Finland) were worn by participants (across the chest). The Polar S810 is thought to be an accurate measure of heart rate (Nunan et al., 2008). The protocol for phase 2 was slightly different than phase 1.

In phase 2, children sat down when they arrived on a chair for 1-min and their resting heart rate was taken. Heart rate was also recorded after runs 2, 4 and 6 (during a 15 s interval between runs) and again at the end of a 1-min rest after crossing the finishing line. The rest interval between runs for sprints 1, 3 and 5 was 10 s. We calculated the relative increase in heart rate (HR at end of run 6 - resting HR), and relative recovery heart rate (HR at end of run 6 - HR 1 min later).

Estimated maximum heart rate was calculated using the equation; Estimated maximum Heart rate (HRmax) = 206 − (0.88 × age) (Gulati et al., 2010). The percentage of the estimated maximum HR reached during the test was also computed.

2.4.4. Additional field-based tests used in phase 2

2.4.4.1. 10 × 5 m straight sprint test. The 10 x 5 m straight sprint test was chosen to assess anaerobic fitness. Participants were instructed to perform ten sprints at maximum speed over a 5 m trajectory with no breaks. To complete the test, each participant was required to execute nine 180 degrees changes in direction without any precision stepping. The time taken to complete ten laps was recorded and used for the analysis. This test is reported to be reliable in children with an ICC ranging between 0.81-0.92 (Aertssen et al., 2018).

2.4.4.2. 10 × 5 m slalom sprint test. This test resembles the 10 × 5 m straight sprint test described above except that it requires the individual to perform quick sprints through a curved trajectory at maximum speed without breaks. The total time taken to complete 10 laps was recorded and used for the analysis. The test is considered to be a valid and reliable measure in children with ICC reported to be greater than 0.70 (Aertssen et al., 2018).

The 10 × 5 m sprinting tests were used to assess general anaerobic capacity. Both the 10 × 5 m straight and slalom tests require high levels of agility, as the child is expected to apply deceleration, change direction, and to accelerate efficiently within a very short time.

2.4.4.3. Side jump test. Participants completed a dynamic balance test item from the Körper Koordinationstest für Kinder test (Kiphard & Schilling, 2007). This side jump test involves jumping side-ways over a wooden plank (60 cm long × 4 cm wide × 2 cm high) for 15 s. Each participant was instructed to jump over the plank as fast as possible without any mistakes. Two trials were given, and correctly executed jumps were summed up and used for the analysis. Test-retest reliability coefficients for the raw score are reported to be r = 0.95 (Kiphard & Schilling, 2007). The side jump was selected to measure anaerobic capacity with high levels of dynamic balance.

2.4.4.4. Platform test. The platform test is one of the items of the Körper Koordinationstest für Kinder test (Kiphard & Schilling, 2007). The child starts standing with both feet on one platform (25 cm × 25 cm × 2 cm, supported on 3.7 cm high stoppers). The child places the second platform alongside the first and steps onto it. Then the first platform is placed alongside the second and the child steps onto it as fast as possible in a sequential manner. This sequence continues for 20 s. This item with repetitive movements of bending down and picking up and moving the platforms, was selected as a measure of muscle endurance with high coordination load (dynamic balance). Two trials were given, and the correctly executed platforms moves, and steps were summed up and used for the analysis. Test-retest reliability coefficients for the raw score are reported to be r = 0.94 (Kiphard & Schilling, 2007).

2.4.4.5. The ladder agility test. The Ladder Agility Test (LAT) is an agility test involving running over a ladder with specified dimensions (3.5 m + 0.5 m for the turn) (Smits-Engelsman, Aertssen, & Bonney, 2019). The LAT consists of 4 items (running and stepping in a normal ladder and running and stepping in an accuracy ladder). The running item in the normal ladder was used for this study. Participants were instructed to step into each square as quickly as possible, make a 180-degree turn around a pylon at the other end and run back to the starting position. Participants began with both feet behind the cross bar of the first square and completed the test when they returned to the starting point with two feet on the floor. Upon hearing a go signal, the participant was required to run forward, turn at the designated turning point and return to the starting point by following the appropriate running pattern. The total running time (0.01 s) and number of mistakes (stepping on the bars) were measured. The LAT is viewed as a valid and reliable test in children with an ICC of 0.94 (Smits-Engelsman et al., 2019). The LAT was selected to measure anaerobic capacity with high levels of agility.

2.5. Data analysis

Data were checked for normality using the Kolmogorov-Smirnov test and appropriate analyses are reported. Mean and standard deviation (SD) are reported for age, height, weight, BMI, and values on the MABC-2 test for the different groups.

To test the effect of the tests (i.e. MPST/CRISP), two repeated measures ANOVA with the runs (6), or HR values (6 readings) as within subject factors were performed (phase 1).

Next, for phase 2, descriptive analyses including comparisons between the two groups (i.e. TD and p-DCD) on anthropometric measures and anaerobic fitness tests were performed using independent t-tests and Cohen's *d* for effect size. Groups were also used as between subject factor in two repeated measures ANOVA for the CRISP time (6 runs), mean power (6) and HR values (5 readings), which were further fitted using polynomial contrasts.

In order to explore the possible underlying construct in the various measures for the two groups, a factor analysis (principal components analysis with varimax rotation) was carried out on the test scores (CRISP, 10 × 5 m straight, 10 × 5 m slalom, Side

Table 2
Characteristics of participants in phase 1 (TD n = 25) and phase 2 of the study (TD n = 46 and DCD = 46).

Variables	TD Mean (n = 25)	SD	TD Mean (n = 46)	SD	p-DCD Mean (n = 46)	SD
Age (years)	9.6	1.5	9.5	1.3	9.5	1.2
Weight (kg)	32.3	8.9	32.1	8.6	34.8	14.2
Height (cm)	139.5	12.1	137.0	9.1	138.0	11.3
BMI (kgm^{-2})	16.3	2.1	16.8	3.0	17.8	4.8
MABC-2 (TSS)	10.9	2.1	9.4	1.2	4.5**	1.6
Boys/Girls	12/13		22/24		22/24	

Abbreviation: BMI-Body mass index, MABC-2 test -Movement Assessment Battery for Children test, second edition, TSS-Total Standard Score, SD-Standard deviation, TD-Typically developing children, p-DCD-probable Developmental Coordination Disorder.
** Independent *t*-test showed statistically significant differences between TD and p-DCD group at p = 0.001.

jumps, Platforms, Ladder agility test, MABC-2). Tests that clustered together were hypothesized to measure the same construct. Varimax rotation was used to maximize the loading of each item onto one of the extracted factors while minimizing the loading on all other factors. The factor structure was achieved by looking for items that correlated highly with other items (loading > 0.40) but did not correlate with other items outside that group.

3. Results

3.1. Characteristics of participants

Twenty-five (n = 25) children participated in phase one of this study (mean age: 9.6 ± 1.5 years; mean BMI 16.3 ± 2.1 kg/m^2; 48% boys and 52% girls). Ninety-two (n = 92) children participated in phase two of the study (mean age: 9.4 ± 1.2 years; mean BMI 17.3 ± 4.0 kg/m^2; 50% boys and 50% girls) (Comparison of TD- and p-DCD groups). Of these, fifteen (n = 15) were classified as “at risk of DCD” (all scored below the 10th percentile on the MABC-2 test) and thirty-one (n = 31) had scores denoting “definite motor impairments” (had scores at or below the 5th on the MABC-2 test). With the exception of motor coordination scores, no significant differences were found between the groups on any variable. The characteristics of participants per group are shown in Table 2.

3.2. Phase 1: comparison of scores on the MPST and CRISP test

Repeated measures ANOVA showed a main effect of Test [$F(1,23) = 1141.00$; $p < 0.0001$, eta 0.98], and Run [$F(1,23) = 11.11$; $p < 0.0001$, eta 0.33] confirming longer running times on the CRISP test than MPST, and an increase in running time over repeated runs. Importantly, Test x Run interaction [$F(1,23) = 11.56$; $p < 0.0001$, eta 0.33] was significant, indicating the increase in time was caused by the CRISP test not the MPST (See Fig. 1).

There was an increase in the 6 readings of HR over repeated runs. This was confirmed by a main effect [$F(5,19) = 25.14$; $p < 0.0001$, eta 0.87]. The main effect of Test [$F(1,23) = 3.17$; $p < 0.88$] and the Test x Run interaction were not significant [$F(5,19) = 1.06$; $p < 0.41$] (See Fig. 2).

3.3. Phase 2: differences in performance between p-DCD and TD children during the CRISP test (known-group validity)

3.3.1. Comparison of running time and power between p-DCD and TD children during the CRISP test

Repeated measures ANOVA showed a main effect of group, indicating poorer performance among the p-DCD group in running time [$F(1.90) = 14.24$; $p < 0.0001$, eta 0.14] (Fig. 3a) and power [$F(1.90) = 14.24$; $p < 0.017$, eta 0.06] (Fig. 3b). Also, a large main effect of runs was found on running time [Main effect $F(5.450) = 29.61$ $p < 0.0001$, eta 0.25; polynomial higher order effect F

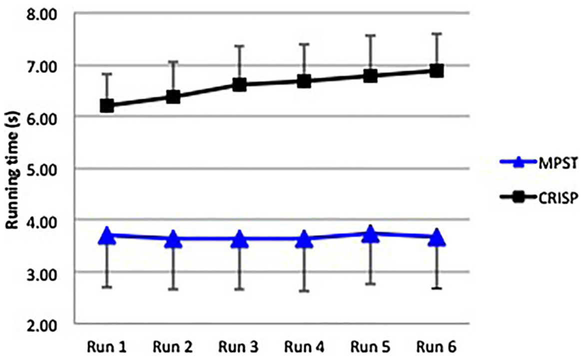

Fig. 1. Mean time for each of the 6 sprints of the MPST and CRISP test.

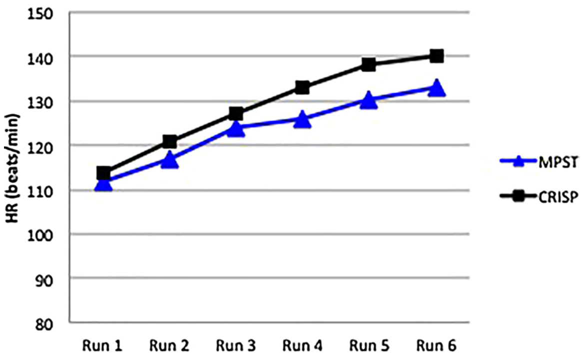

Fig. 2. Mean heart rate during MPST and CRISP test over 6 runs.

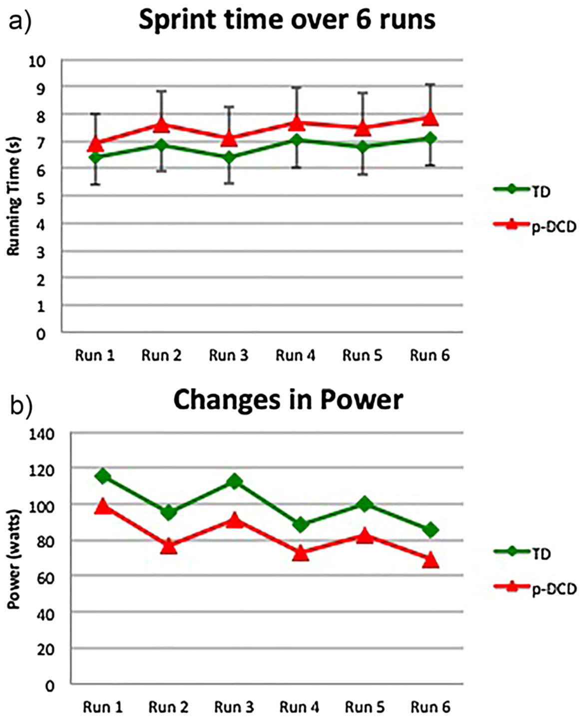

Fig. 3. 3a. Mean time and 3b. Mean power for each of the 6 sprints of the CRISP test for TD children and children with p-DCD.

(1.90) = 49.36.; $p < 0.0001$, eta 0.35] and power [Main effect F (5.450) = 5.97 $p < 0.017$, eta 0.24; polynomial higher order effect F (1.90) = 51.88.; $p < 0.0001$, eta 0.37]. It is important to note that the fact that we had to extend the interval between runs 2 and 3, and between 4 and 5 to 15 s to be able to measure HR, caused this higher order effect in the changes observed in running time and power. After the extra 5 s rest, children performed the next run faster. As shown in Fig. 3, the pattern of response to the 10 s intervals (after runs 1, 3, 5) or 15 s intervals (after runs 2, 4, 6) was comparable between TD and p-DCD children. There was no interaction between runs and group (F (5.450) = 0.478; p = 0.79).

3.3.2. Comparison of changes in heart rate between p-DCD and TD groups

There was a change in HR during the CRISP test, confirmed by a main effect of time of measurement [F (4,360) = 813.94; $p < 0.0001$ eta 0.90], the interaction with group was also significant [F (4,360) 3.52 p = 0.008 eta 0.038)]; and the polynomial analysis showed a quadratic effect [F (1,90) = 7.49; $p < 0.007$, eta 0.077)]. As can be seen in the inverted U-shape of the change over the measurements (Fig. 4), the resting HR was higher in the p-DCD group (p = 0.005) and the increase in HR was less (p = 0.004). There was a tendency for the p-DCD children to demonstrate less recovery in the first minute of rest (p = 0.058) compared to TD peers (Table 3). The HR below the estimated maximum HR was not different between the two groups (p = 0.21; TD 16.2 and p-DCD 19.7 beats/min).

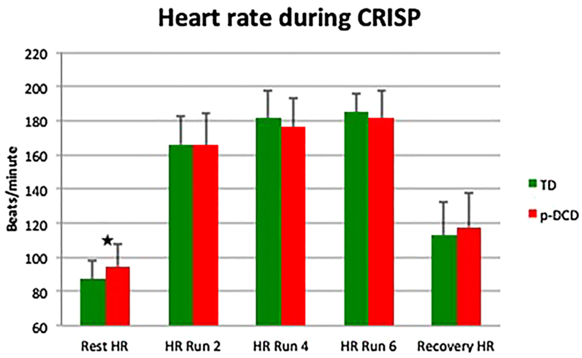

Fig. 4. Mean heart rate during the CRISP test for TD children and children with p-DCD.

Table 3
Mean (SD) Sprint time, Power, and HR on the CRISP test for TD and p-DCD groups and statistics.

Descriptives and Statistics	TD (n = 46)		DCD (n = 46)			
CRISP Test	Mean	SD	Mean	SD	t-value	p-value
Mean Time Run 1–6	6.77	0.64	7.45	1.00	−3.774	0.001
Time 1 (s)	6.40	0.70	6.93	1.08	−2.758	0.007
Time 2 (s)	6.89	0.81	7.63	1.18	−3.522	0.001
Time 3 (s)	6.42	0.69	7.12	1.14	−3.532	0.001
Time 4 (s)	7.03	0.85	7.70	1.23	−3.052	0.003
Time 5 (s)	6.77	0.94	7.47	1.29	−2.934	0.004
Time 6 (s)	7.11	0.80	7.87	1.20	−3.562	0.001
Time Best run (s)	6.08	0.56	6.67	0.91	−3.723	0.001
Mean Power (Watts)	99.6	35.8	81.9	33.4	2.443	0.017
Peak Power (Watts)	132.3	44.8	109.4	44.9	2.339	0.017
Fatigue Index Time (%) (Worst-best time)/best time*100)	24.3	11.8	26.3	11.3	0.814	0.418
Fatigue Index Power (%) (High-lowest power)/high*100)	45.5	13.4	48.2	12.2	−1.029	0.306
Resting HR (bpm)	87.3	11.0	94.6	13.4	−2.880	0.005
HR after Run 2 (bpm)	166.0	17.0	165.5	18.6	0.117	0.907
HR after Run 4 (bpm)	181.6	15.9	176.1	17.0	1.581	0.117
HR after Run 6 (bpm)	185.3	10.9	181.7	15.5	1.257	0.212
Recovery HR (bpm)	112.6	20.0	117.3	19.8	−1.205	0.232
Increase in HR (From resting till end Run 6) (bpm)	98.0	12.9	87.2	21.6	2.915	0.004
Decrease in HR after 1-min Rest (bpm)	72.6	17.7	64.1	24.4	1.919	0.058

Abbreviation: TD-Typically developing children, p-DCD-probable Developmental Coordination Disorder, CRISP- Children's Repetitive and Intermittent Sprinting Performance, HR-Heart Rate, bpm-beats per minute.

3.3.3. Comparison of fatigue between p-DCD and TD groups during the CRISP test

Although the differences in sprinting time for consecutive runs were significant between the TD and p-DCD groups ($p < 0.01$ for all runs), the overall decrease in speed and power over repeated runs was not. No differences were found between the percentage of increase in sprinting time (FI-time) and decrease in power (FI power) between the two groups (Means, SD and *t*-test statistics) are shown in Table 3.

3.4. Comparison of the influence of coordination on anaerobic performance between p-DCD and TD groups

To check whether differences in anaerobic performance between children with p-DCD and TD were larger if the coordinative task constraints were higher, we tested the effect size of the differences between the TD group and the p-DCD group. Since children were primarily selected based on their level of motor coordination, we expected that tests with the highest coordination load would produce the highest effect size. Most of our predictions were confirmed; higher agility requirements increased the differences between groups (Fig. 5). Also, we observed some unexpected results. Just running straight for 30 m was the least different but for the agility ladder. From a physiological perspective, these are both very short tasks (approximately 7 s), but given the fact that children had to run inside the squares of the ladder (adding some spatial constraints to the task), we expected this task to be harder for the children with poor coordination. Moreover, not many mistakes were made by the p-DCD children. The children with p-DCD did not step on the bars frequently while running in the agility ladder; they were only slower [7.45 s (1.00)] than the TD children [6.77 s (0.64)].

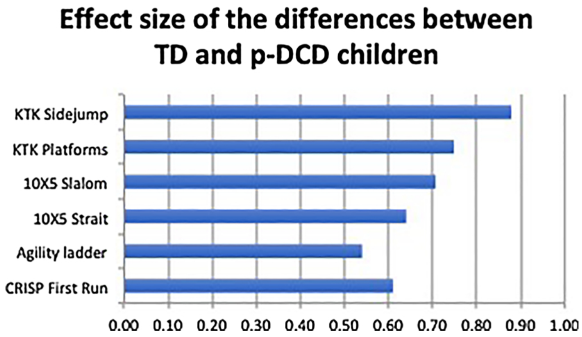

Fig. 5. Effect sizes (Cohen's *d*) of the differences between TD and DCD children.

3.5. Comparison of the construct underlying anaerobic capacity between p-DCD and TD groups

Lastly, to investigate if anaerobic capacity (muscle power, muscle endurance) tests measured a similar construct among children with p-DCD and typically developing peers, we looked at the factor analysis and its structure in the two groups separately. The solution for the TD comprised of three factors explaining 78% of the variance. It is clear from Table 4 that the pattern in TD was according to our predictions; an anaerobic performance test factor or running speed (CRISP test, 10 x 5 m sprint tests and Side jumps) and an agility performance component (Platform and Ladder agility tests), while the MABC-2 test emerged as an isolated factor that did not influence any of the other test results. In the p-DCD group, only 1 factor emerged with an Eigen value of 3.62, explaining 52% of variance in participants' performance on the tests (Table 4).

In summary the CRISP test, the 10 × 5 m straight and slalom tasks are the tests that end up in the running speed factor and may be measuring anaerobic performance in TD children. As expected, the platform and agility ladder tests seem to be measuring agility in TD children. In children with movement difficulties, it appears that all the sprint and agility tests also measure some degree of coordination.

4. Discussion

While the body of knowledge examining various aspects of physical fitness in children with DCD has increased, less is understood about anaerobic performance and repeated sprinting ability. To our knowledge, few studies have explored the relationship between motor coordination and anaerobic performance (Aertssen et al., 2016; O'Beirne et al., 1994; Raynor, 2001; Schott et al., 2007) and the influence of fatigue on performance in children with DCD (King-Dowling et al., 2018). In the current study, four important questions were answered. First, our results confirmed that the CRISP test distance leads to a significant increase in running time, suggesting it may be an appropriate distance that can be used to induce fatigue among children with DCD. Secondly, it was found that children with p-DCD achieve significantly poorer results on anaerobic performance tests than TD peers. Children with p-DCD have been observed to run more slowly, however, the increase in running time over the six runs and decrease in power (indicators of fatigue) were not different between the groups. Next, the hypothesis that anaerobic capacity tests with the largest coordination and agility demands would produce the most significant differences was confirmed; the 30-meter straight run, the 50-meter runs over a 5-meter trajectory and 8-meter running using a 4-meter agility ladder yielded the least differences between children with p-DCD and TD. Lastly, we found that the tests examined measure different constructs in children with p-DCD and TD children. The anaerobic performance tests load on one factor including coordination in children with DCD, on three factors in TD children. Importantly, the

Table 4
Factor solutions for the sprint tests in the TD and p-DCD groups.

Rotated Component Matrix	Components TD (n = 46)			Component DCD (n = 46)
	Speed	Agility	Coordination	Speed and coordination
CRISP (s)	**0.852**	0.098	0.209	**0.732**
10 × 5 m straight (s)	**0.825**	0.268	−0.208	**0.868**
10 × 5 m slalom (s)	**0.755**	0.223	−0.306	**0.732**
Side jump (#)	**−0.773**	−0.127	−0.257	**−0.809**
Platform (#)	−0.072	**−0.912**	−0.049	**−0.656**
Agility run (s)	0.368	**0.787**	−0.028	**0.568**
MABC-2 test (TSS)	0.032	0.029	**0.922**	**−0.573**
Extraction Method: Principal Component Analysis.				
Rotation Method: Varimax with Kaiser Normalization.				

Abbreviation: TD-Typically developing children, p-DCD-probable Developmental Coordination Disorder, MABC-2-Movement Assessment Battery for children, second edition, TSS-Total Standard Score, CRISP- Children's Repetitive and Intermittent Sprinting Performance Test. Values above 0.40 are bold.

MABC-2 test remains an isolated factor in the TD group, which is not the case in children with DCD. The 30-meter straight run of the CRISP test, 10 × 5 m straight and slalom sprint tests were found to be the least contaminated by agility and coordination components in TD children. Importantly, anaerobic performance was more influenced by agility and coordination elements among children with p-DCD. The CRISP test has an additional value as it may provide information about fatigue.

The importance of the exact timing of recovery periods, when testing repeated sprint performance, was also confirmed in the present study. The difference within the recovery periods of 5 s (10 s or 15 s rest) between runs clearly impacted on the time needed for the next run. Since, children are reported to recover faster than adults when performing repeated bouts of high-intensity tasks, we selected short recovery periods, which were expected to induce less recovery of phosphagen and aerobic contribution than longer recovery periods. Thus, maximizing the appearance of fatigue and increasing the contribution of glycolysis to the total energy output (Falk & Dotan, 2006; Hebestreit, Mimura, & Bar-Or, 1993; Zafeiridis et al., 2005). Due to logistical challenges, we tested the metabolic impact of the additional 5 s rest. The impact, however, was similar for children with and without movement difficulties. For future use of the CRISP test, we advise the use of a strict recovery interval (i.e. 10 s) between the runs.

4.1. Validity of running tests in children with p-DCD

The sprinting tests used in the present study assessed both coordination and physical fitness elements simultaneously. To determine whether coordination is an important factor in physical fitness, we used various anaerobic capacity (muscle power, muscle endurance) tests, each containing tasks with different coordination requirements. Since most of these tests required a certain amount of agility, we hypothesized that larger differences (effect sizes) would be observed between TD and p-DCD groups for tests requiring more coordination (e.g. side jump) and smaller differences in simpler tasks (e.g. 10 × 5 m straight run). This was confirmed in the present study and the findings revealed that differences between test scores were associated with motor coordination. There are important differences between the various running and agility tests and these differences should be considered when testing children with motor coordination difficulties. Our data show that straight running tests may be potentially useful and valid measures for assessing anaerobic performance in children with DCD. The groups reached similar peak heart rates and percentage of fatigue during the CRISP test. Our analysis showed that the single straight sprinting tasks (i.e. either the 30 m or 10 × 5 m sprints) are the tests with the least coordination demands. Any of these measures can be used to measure anaerobic power and can be considered to be cost-effective and/or time-efficient. Moreover, it is important to realize that the tasks with higher coordination load are closer to everyday playground activities and should therefore be part of the pediatric assessment toolbox, but not be used to measure anaerobic fitness in children with DCD.

Two previous studies have investigated running kinematics in children with DCD. Chia, Reid, Licari, and Guelfi (2013) found no differences in kinematic and kinetic trajectories between children with and without DCD, although the DCD group displayed lower speed than TD children (mean 4.5 m/s TD and 4.1 m/s DCD), which was close to the speed reported by Diamond, Downs, and Morris (2014) (3.47 m/s). According to Diamond et al. (2014), children with DCD demonstrated a lower propulsion strategy compared to TD children. This strategy in children with DCD was characterized by poor use of ankle plantar flexor and compensatory hip flexor power at push off (Diamond et al., 2014). Although this was not specifically measured in the current study, the impairment of power generation at the ankle in children with DCD could be attributed to muscle weakness. In our earlier study involving children with similar characteristics (Ferguson et al., 2014), we did show that there was no loss in isometric force but some children still demonstrated loss of lower extremity (functional) strength. Deficits in power generation in children with DCD may therefore represent poor motor planning and/or less experience with running leading to immature skill performance. A possible explanation for the unpredicted smaller difference (effect size) for the ladder test between TD and p-DCD groups could be that running in the agility ladder (steps of 40 cm) is closer to the “normal” running pattern of children with DCD. As mentioned they have been described to make the smaller steps than TD children, more hip flexion/leg lifting (pull off) and less propulsion or forward push off (Diamond et al., 2014). Running in the agility ladder is therefore different from the normal running pattern in TD children. There is a need for further studies to examine the kinematics of sprinting in children with poor motor coordination as data are currently missing. Data from jogging or slow running (8 km per hour) give some indication of the inefficiencies in running, but higher speeds may well exacerbate the difference between children with and without DCD. When running velocity increases, increased power for propulsion needs to be met by the generation of greater power in both ankle and hip flexors. Ankle plantar flexors typically dominate joint power generation at the end of stance to propel the center of mass forwards in push-off. Children with DCD may not be able to manage the optimal center of mass trajectory under the given circumstances.

4.2. Known-group validity

Our findings show that children with p-DCD perform differently compared to TD children on tests of anaerobic fitness. These differences are larger in tasks that require more coordination skills. Hence, the hypothesis that children with low MABC-2 test scores would show lower levels of peak and mean power in comparison to those with high MABC-2 test scores was confirmed. However, our data also show that only comparing groups that are known for differences in an outcome for construct validity can lead to misleading results. Anaerobic performance assessments, mostly running or jumping tests, also require certain level of agility and technique. In our case, the side jump showed larger differences between the known groups, but it was clear from factor analysis that these large differences were partly caused by the coordination component of the task and not just by poor anaerobic fitness. It appears that anaerobic fitness testing in children with DCD can be confounded by their motor ability. Our results suggest that children’s performance on anaerobic tests is largely dependent on the constraints of the task used in the assessment. Normal running efficiency cannot be assumed for individuals with DCD. The longer running times observed in children with DCD on the sprint tests could be attributed to inefficient running mechanics and not solely explained by lower anaerobic fitness. It seems that children with DCD do not only lack the anaerobic fitness required to run fast but have deficiencies in coordinating these activities, especially if the agility component becomes larger. Our comprehensive assessment pointed out that coordination ability could clearly be isolated from anaerobic performance in TD, which was less the case in children with DCD. Improving anaerobic fitness in children with DCD may require functional training focusing on improving running technique and functional strength.

4.3. Study limitations, future directions and conclusions

The principal finding of this study is the apparent coordination-related superiority in anaerobic performance observed in children with TD children compared to those with p-DCD. Further, there was no observable difference in children's ability to resist fatigue between the two groups. However, the children in this study live in socioeconomically disadvantaged circumstances and experience disproportionally limited opportunities to develop fundamental and sport related motor skills, which may limit the generalizability of our findings. Also, children were not checked on all the DCD criteria. Although it is often not practical to obtain laboratory measurements in many situations, validation by studying physiological factors, kinematic and kinetic parameters of running at higher speed (12–16 km per hour) is clearly needed. Running tests in children with motor control problems still need to be compared to the most relevant maximal anaerobic power 'gold standard' test (such as the Wingate test and Biodex) (King-Dowling et al., 2018; Raynor, 2001), which should take the coordination constraints into account. The CRISP test can be used to evaluate anaerobic performance, to estimate fatigue and to monitor changes in performance among children with DCD. However, further research is needed to explain the physiological mechanisms that may be associated with optimal anaerobic performance. More studies should be conducted to evaluate other psychometric properties of the CRISP test (e.g. criterion validity, sensitivity to change, and measurement error) in pediatric populations. Lastly our findings indicate that the underlying construct of tests needs to be checked in the relevant population before applying such tests to the target group.

Funding

This project received partial financial support from the USHEPiA doctoral grant awarded to the second author (EB).

Declaration of Competing Interest

The authors declare no conflict of interests.

Acknowledgments

The authors acknowledge the contributions of the physiotherapists and students who assisted with data collection. We also acknowledge the support of the principal, teachers and support staff at the school as well as the parents and children who participated in the study.

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