Reliability and validity of short-term performance tests for wheelchair-using children and adolescents with cerebral palsy

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ABBREVIATIONS

ADL	Activities of daily living
FMS	Functional Mobility Scale
LoA	Limits of Agreement
MPST	Muscle Power Sprint Test
WAnT	Wingate Anaerobic Test

AIM To investigate the test–retest reproducibility of the Muscle Power Sprint Test (MPST), the 10 × 5-m sprint test, and the arm-cranking Wingate Anaerobic Test (WAnT) in children and adolescents with cerebral palsy (CP). A secondary objective was to assess the construct validity of the MPST.

METHOD Twenty-three participants with spastic CP (mean age 13y 3mo, range 7-18y, SD 3.6y; 18 males, five females, two classified as having spastic unilateral CP, 21 as having spastic bilateral CP) using a manual wheelchair for at least part of the day were recruited and tested in different rehabilitation settings in the Netherlands. Participants were classified as in Gross Motor Function Classification System Expanded and Revised (GMFCS-E&R) levels III and IV.

RESULTS Intraclass correlation coefficients (range 0.93–0.99; 95% confidence interval 0.82–1.0) for all variables indicated highly acceptable reproducibility. Limits of agreement analysis revealed satisfactory levels of agreement. The MPST variables demonstrated very strong significant positive correlations for peak power and mean power from both tests (peak power: r=0.91, p<0.001; mean power: r=0.88, p<0.001).

INTERPRETATION The MPST, the 10 × 5-m sprint test, and the arm-cranking WAnT are reproducible tests for measuring anaerobic performance and agility in adolescents with spastic CP who self-propel a manual wheelchair. The MPST has been shown to be a valid test to measure anaerobic performance in this population.

Anaerobic performance and agility are important physiological factors that play a critical role in the ability of a child or adolescent with cerebral palsy (CP) to participate in daily activities.[1] This is especially true for children with CP who use a wheelchair for mobility, because most motor activities of daily living (ADL), including playing in the playground, moving around in the classroom, but also climbing a curb and ascending a ramp, are of short duration.[2] These short bouts of activity rely primarily on the energy produced by the ATP-PCr (or alactic) component of the anaerobic system and produce a relatively high physical stress on the individual.

Exercise testing over time can provide a quantitative assessment of the improvement or decline in the anaerobic performance of children and adolescents with CP and has the potential to be an important measurement tool in clinical practice as well as in research. For children with CP who are able to walk or run independently, running-based field tests, like the Muscle Power Sprint Test (MPST) and the 10 × 5-m sprint test, are currently used in clinical practice and are inexpensive measures that do not require special equipment or training.[3] The MPST has been developed with the specific goal of examining anaerobic performance,[3] while the 10 × 5-m sprint test is a marker of agility.[3] These tests, however, have not yet been examined in children and adolescents with CP who use wheelchairs.

Anaerobic performance in children with neuromuscular disorders such as CP is often assessed in the laboratory setting using the cycling Wingate Anaerobic Test (WAnT).[4] While much of the focus to date has revolved around lower-limb-based anaerobic performance in children with CP, the upper-body or arm-cranking WAnT has been used to predict functional anaerobic performance.[5] Tirosh et al.[6] reported that the arm-cranking WAnT was both feasible and reliable in a group of children with CP. This study, conducted over two decades ago, relied on the use of a mechanically braked ergometer with custom-made software calculating mechanical power based on the braking force applied as well as participant revolutions per minute, averaged over a 3- or 5-second interval. Today, the most commonly used and widely available ergometers are electro-magnetically braked, with the ability to calculate instantaneous mechanical power output with a higher frequency and precision. Given the potential utility of the arm-cranking WAnT in both clinical settings for patient follow-ups as well as outcome measure in clinical trials, an assessment of the reproducibility of this test in adolescents with CP using newly available and more commonly used technology seemed warranted.

While the arm-cranking WAnT may be considered the criterion standard for assessing anaerobic performance, it must be noted that the results of the arm-cranking WAnT are not solely a reflection of the ATP-PCr (alactic) system (primarily responsible for supporting short bouts of activity) but also the anaerobic lactic and aerobic systems, each of which have been estimated to contribute to 28%, 60%, and 11% respectively, in an upper body WAnT.[7] Furthermore, perhaps the greatest limitation of the arm-cranking WAnT is the fact that its application requires the use of sophisticated and costly technical equipment and software, ultimately rendering it impractical for use in a field setting. It is, however, equally important to note that while a field test may be more practical, there is a shortage of options for field exercise testing to specifically examine agility and/or anaerobic performance in adolescents with CP who rely on a manually propelled wheelchair for locomotion.[8] Ideally, this test should be safe, inexpensive, easy to administer in a non-academic setting, and relatively quick, allowing patients to be assessed in a short time-frame. Moreover, much like laboratory-based tests, reproducibility and validity of field exercise tests are important issues for clinical outcomes. Since the 10 × 5-m sprint test measures agility and not anaerobic performance, validity of this test cannot be examined using the arm-cranking WAnT.

Therefore, the objective of the present study was to investigate the test–retest reproducibility of (1) the MPST, (2) the 10 × 5-m sprint test, and (3) the arm-cranking WAnT in a sample of adolescents with CP who rely on a manually propelled wheelchair for locomotion. A secondary objective was to assess the construct validity of the MPST, where we hypothesised a significant positive correlation between MPST and arm-cranking WAnT power outcomes.

METHOD

Participants

This study focused on children with CP between the ages of 7 years and 18 years who were diagnosed with spastic CP and classified in Gross Motor Function Classification System Expanded and Revised (GMFCS-E&R)[9] levels III and IV. All participants were further required to self-propel a manual wheelchair for at least a part of the day and be capable of following simple instructions.

All participants were receiving rehabilitation services in the Netherlands at the time of participation. Participant characteristics are provided in Table I. A total of 23 children with CP and their parents provided informed consent for participation in this study, which was approved by the Institutional Ethics Committee of the University Medical Center, Utrecht.

What this paper adds

- Identifies two inexpensive and easy to administer short-term performance wheelchair tests.
- Describes a reproducible and valid anaerobic exercise test for On behalf of Olaf Verschuren (o.verschuren@dehoogstraat.nl) children and adolescents with CP who self-propel a wheelchair.

Procedures

All participants attended a total of three testing sessions. During the first two sessions, participants performed both the MPST and the 10 × 5-m sprint test. During a separate third session, participants performed the arm-cranking WAnT twice. In all sessions participants were given at least 15 minutes of rest between the two tests performed. Participants and assessors were blind to the child's performance on each of the tests. All tests were performed within a period of 2 weeks in four rehabilitation centres across the Netherlands.

Before testing, each participant's body mass was determined using an electronic scale (Stimag, Hoofddorp, the Netherlands), which was also used to determine the weight of the participant's wheelchair. Standing height was assessed, and arm span (fingertip to fingertip, with arms abducted 90° and elbow and wrists straight) was measured as a surrogate for standing height when the participant was unable to adopt a vertical position. Functional mobility was quantified using the Functional Mobility Scale (FMS).[14]

To assess the test–retest reliability of the MPST and the 10 × 5-m sprint test, the participant performed the same test at the same time of the day within 2 weeks, with both tests administered by the same two assessors. During each test, participants were verbally encouraged to propel the wheelchair as fast as they could.

Table I: Participant characteristics

Characteristic	Mean	SD
Age (y)	13.3	3.6
Height (cm)	149.6	14.3
Height-for-age SDS	−1.48	1.07
Body mass (kg)	42.3	13.1
Body mass-for-age SDS	1.05	1.03
BMI (kg/m^2)	18.5	4.0
BMI-for-age SDS	−0.47	1.96
GMFCS-E&R, level		*n*
III		3
IV		20
Spastic unilateral		2
Spastic bilateral		21

Age, body height, body mass, and BMI data were means SDs. BMI, Body Mass Index; GMFCS-E&R, Gross Motor Function Classification System Expanded and Revised; SDS, standard deviation score.[25]

Measures

GMFCS-E&R

A paediatric physical therapist (OV) experienced in using the GMFCS-E&R[9] used the translated Dutch version to classify the children and adolescents with CP according to their functional ability.

Functional Mobility Scale

The FMS, a reliable and valid instrument, is a 6-point ordinal scale that quantifies mobility according to the need for assistive devices at three specific distances: 5m, 50m, and 500m.[10] These distances represent home, school and community environments respectively. The FMS is administered by asking the child or parent a few questions to indicate if the child used a wheelchair (score 1) or was ambulatory with or without assistive devices (score 2–6) for every distance.

Muscle Power Sprint Test and 10 × 5-m sprint test

For both the MPST and 10 × 5-m sprint test, participants used their own wheelchair and back support, with no adjustments made to wheelchair configuration during the test period.

Muscle Power Sprint Test (anaerobic performance)

Peak power and mean power (Watts) were calculated and used as markers of anaerobic performance in the MPST, which was performed as previously described.[3] 'Mean power' refers to the ability of the neuromuscular system to produce the greatest possible impulse in a given time period. 'Peak power' was defined as the highest mechanical power that can be delivered during exercise of up to 30 seconds' duration.[11]

Before executing the test, each participant performed the test at a slow speed, which served as both a warm-up, as well as a habituation for the participant to ensure that he/she understood how to perform the test. The warm-up was followed by a 3-minute rest period. The participant was then asked to complete six 15m runs at maximum pace. The 15m distance was marked by two lines taped to the floor. Cones were placed at the end of each of the lines. The participant was instructed to propel the wheelchair as fast as possible from one line to the other, and to be sure to cross each line with all wheels of their chair. Between each run, the participant was given a 10-second period to turn around and prepare for the following sprint. Power output for each sprint was calculated using total mass (body mass and wheelchair weight) and propelling times, where:

$$\text{Power} = (\text{total mass} \times \text{distance}^2)/\text{time}^3.$$

Power was calculated for each of the six sprints. Peak power was defined as the highest calculated power, while mean power was defined as average power over the six sprints. The MPST was administered by two experienced researchers (OV and MZ).

The total exercise time in the arm-cranking WAnT is 30 seconds. We expected that total exercise time for the MPST would be greater than 30 seconds. After performing the MPST for all participants, the number of consecutive sprints that result in a mean total exercise time closest to 30 seconds was determined.

10 × 5-m sprint test (agility)

Previous investigations into the 10 × 5-m sprint test with typically developing children have demonstrated good reliability; however, it has yet to be examined in children with CP who self-propel a wheelchair.[12,13] The 10 × 5-m sprint test is a continuous sprint test whereby the participant is asked to perform nine fast turns upon completion of every 5m distance. The participant is not given the opportunity to rest between each turn. This may be a problematic and/or extremely difficult task for some children with CP who experience difficulty with movement coordination. Thus, this test is not designed to measure the muscle power; rather, the time taken to complete the 10 × 5-m sprints is a good indicator of participant agility.

All tests were performed in a gymnasium. Participants were provided with a practice session prior to test completion wherein they performed the test at a slow speed to ensure a proper understanding of the instructions. After a 3-minute rest period, participants were given the verbal cues of 'Ready? 3, 2, 1, go!' and were instructed to complete 10 runs of 5m at a maximum pace. The 5m distance was marked by two taped lines on the floor and by cones. The participant had to propel themselves as fast as possible to each line, had to place all wheels across each line, make a turn and sprint back as fast as possible, with no rest between the sprints. At the end of the 10th sprint, participants had to cross the finish line. The assessors recorded time to completion to a 10th of a second for the total 50m (10 × 5m) using a hand-held stopwatch.

The arm-cranking Wingate Anaerobic Test (anaerobic performance)

The arm-cranking WAnT was performed on an electromagnetically braked cycle ergometer (Lode Angio, Procare BV, Groningen, the Netherlands). The ergometer was fixed to the floor to prevent any ergometer movement during arm-cranking. Participants sat in a chair (also fixed to the floor) and were asked to remain seated throughout the test. Seat height and backrest angle were adjusted such that the elbow joint was almost in full extension (165–175°) and the shoulders were in line with the centre of the ergometers shaft when the participant's hands were grasping the handles (synchronously) with the crank horizontally positioned away from the body. A braking force of 0.26 Nm/kg was used primarily based on our pilot work, as well as previously published literature.[14,15] The lowest braking force recommended for leg cycling is 0.53 Nm/kg. Because less active muscle mass is involved in the arm-cranking WAnT compared with the cycling WAnT, braking force was reduced, with our pilot testing suggesting a reduction of 50% as most appropriate for our age range. The arm-cranking WAnT was administered by two experienced assessors (OV and MZ).

The arm-cranking WanT protocol consisted of three parts: (1) warm-up – the child had to cycle at a comfortable pace for 2 minutes without a braking force; (2) arm-cranking WAnT – participants were given a 5-second countdown before the braking force was applied and were instructed to crank the handles as fast as possible over a 30-second period. All participants were verbally encouraged to maintain the highest possible cadence throughout the arm-cranking WAnT. The braking force was applied immediately at the start of the test (default: 0.26 × body weight in Nm); (3) recovery – once the arm-cranking WAnT was completed, participants were given a chance to cycle at their own pace for as long as they desired with a braking force of 20W.

There are two primary markers of performance on the arm-cranking WAnT: peak power and mean power. With the fully computerized Lode Ergometry Manager Software (LEM; Procare BV, Groningen, the Netherlands), instantaneous power values can be obtained. Specifically, peak power is defined as the highest mechanical power (Watts) achieved at any stage of the test; it represents the explosive characteristics of muscle power and is closest to a person's 'real' maximal mechanical power. Mean power represents the average local muscle endurance over the entire 30 seconds of the arm-cranking WAnT.

Data analysis

The sample size for this study was determined by the most demanding hypothesis to examine the reproducibility for the MPST and the 10 × 5-m sprint test. Sample size was calculated based on data from children with CP in GMFCS level III who had performed the 7.5-m shuttle run test,[16] with a β of 0.9 and an α of 0.05. This resulted in a required sample size of 23 participants. Based on Donner and Eliasziw,[17] with 23 participants, we had a power value of >0.80 to detect an intraclass correlation coefficient (ICC) >0.80, with statistical significance of 0.05.

Reproducibility

Reproducibility encompasses both reliability and agreement.[18] For reliability the ICCs (two-way mixed) were used. An ICC >0.80 reflects excellent reliability, while ICCs from 0.70 to 0.79 reflect good reliability.[19] The recommended minimum for the lower bound of the 95% CI was 0.85.[20] The Bland–Altman procedure was used to check for heteroscedasticity of the test and retest of the MPST, the 10 × 5-m sprint test, and the arm-cranking WAnT.[21] Furthermore, the consistency of measurements was verified graphically using the method of Bland and Altman.[21] This method plots differences between two measurements against the average of the two measurements. Size and range of differences, scoring distribution and possible measurement bias can be visually assessed. The Bland and Altman Limits of Agreement (LoA)[21] were used to evaluate the level of agreement between test and retest. The LoA define the limits within which 95% of the differences are expected to fall (mean 1.96SD of the differences).

Construct validity

The association between the results of the MPST and the arm-cranking WAnT was tested using Pearson's correlation coefficients. An α of <0.05 (two-tailed) was considered as statistically significant.[19]

RESULTS

A total of 18 males and five females (mean age of 13y 3mo, range 7-18 y, SD 3.6y) completed all tests without complications. Twenty-one children were bimanually functional and two children used one arm to propel and one arm to steer their wheelchair using a steering wheel. The FMS data show that 11, 14, and 23 children used their wheelchair at home, school and community environments respectively. Mean total exercise time for the MPST was 72.7 seconds (SD 40.5s). The number of sprints completed within approximately 30 seconds was three (mean exercise time 36.4s, SD 30.6s). Therefore, the MPST for children who self-propel a wheelchair consists of three sprints of 15m.

There were no significant differences between both subgroups (males vs females, GMFCS levels and age). As such, the following results include both sexes and GMFCS levels combined. The physiological variables measured on both exercise tests are provided in Table II.

Reproducibility

The test–retest reliability statistics of the MPST, the 10 × 5-m sprint test and the arm-cranking WAnT are presented in Table III. As can be appreciated from the Bland–Altman plots (Figs 1–3), there were some obvious outliers. These outliers are included in the calculations. For the anaerobic performance tests, ICC values for mean power and peak power were 0.99 for both the MPST and arm-cranking WAnT. For the agility test (10 × 5-m sprint test) ICC values were 0.93.

Construct validity of the Muscle Power Sprint Test

The MPST variables were significantly lower than the arm-cranking WAnT scores, but demonstrated very strong

Table II: Results of the Muscle Power Sprint Test, the arm-cranking Wingate Anaerobic Test, and the 10 × 5-m sprint test

Variable	Mean	SD	Range
Anaerobic performance			
MPST PP (W)	21.8	20.8	0.3–64.6
MPST MP (W)	19.7	19.4	0.3–62.0
WAnT PP (W)	85.6	56.9	15.2–206.2
WAnT MP (W)	43.8	36.8	3.3–115.7
Agility			
10 × 5-m sprint test (s)	74.0	38.1	39.8–186.5

MPST, Muscle Power Sprint Test; WAnT, arm-cranking Wingate Anaerobic Test; PP, peak power; MP, mean power.

Table III: Test–retest reliability statistics

Test	ICC	LoA	95% CI of ICC
Anaerobic performance			
MPST PP (W)	0.99	−39.9 to 59.7	0.98–1.0
MPST MP (W)	0.99	−7.1 to 6.4	0.98–1.0
WAnT PP (W)	0.99	−15.0 to 18.4	0.99–1.0
WAnT MP (W)	0.99	−11.3 to 10.7	0.99–1.0
Agility			
10 × 5-m sprint test (s)	0.93	−8.0 to 9.2	0.82–0.97

ICC, intraclass correlation coefficient; LoA, limits of agreement; CI, confidence interval; MPST, Muscle Power Sprint Test; WAnT, arm-cranking Wingate Anaerobic Test; PP, peak power; MP, mean power.

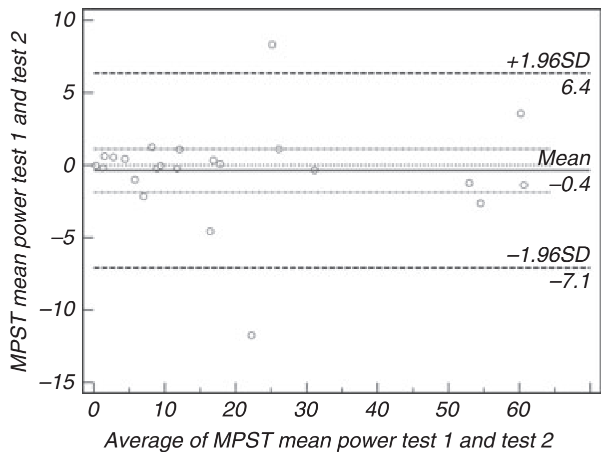

Figure 1: Bland–Altman plot of mean power on test and retest on the Muscle Power Sprint Test (MPST).

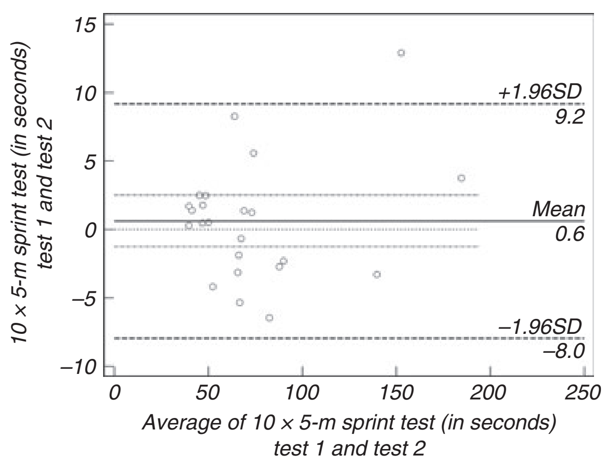

Figure 2: Bland–Altman plot of exercise time on test and retest on the 10 × 5-m sprint test.

significant positive correlations for peak power and mean power from both tests (peak power: r=0.91, p<0.05; mean power: r=0.88, p<0.05, Fig. 4).

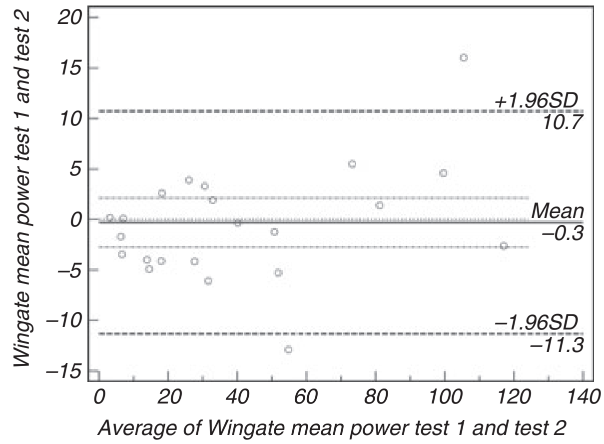

Figure 3: Bland–Altman plot of mean power on test and retest on the arm-cranking Wingate Anaerobic Test.

DISCUSSION

The purpose of this study was to determine the two aspects of reproducibility (reliability and agreement) of the arm-cranking WAnT, MPST and 10 × 5-m sprint test in children and adolescents with CP who self-propel a manual wheelchair. Reliability of the arm-cranking WAnT and MPST can be considered excellent, with ICCs of 0.99 (with 95% CI between 0.98 and 1.0). Agreement was good, as reflected by the narrow LoA. The ICCs for the MPST and 10 × 5-m sprint test are similar to those previously reported for both tests in the literature, ranging from 0.97 to 0.99 for ambulatory children with CP and with ICCs for mean power and peak power on the MPST, of 0.98 for typically developing children.[3,22] Moreover, significant correlations between the performance on the arm-cranking WAnT and MPST were found, indicating that the MPST is a valid test for the assessment of anaerobic performance in children with CP who self-propel a manual wheelchair.

The MPST and the 10 × 5-m sprint test are inexpensive, safe, easy to administer, and are closely related to wheelchair-based ADL. Neither test requires any special equipment or training, making them available for use by a variety of professionals working with children and adolescents with CP. The choice of the instrument depends on the goal of the intervention. The MPST measures the ability to exert muscular strength quickly. Therefore, when treatment is focused on muscle strength and high-intensity exercise, the MPST is probably the most appropriate outcome measure. When the intervention is more focused on functional outcomes, such as the ability to change direction of the wheelchair abruptly, the 10 × 5-m sprint test may be more suitable.

When power outputs (peak power and mean power) from both tests were compared, we found that MPST values were significantly lower than those of the arm-cranking WAnT. This difference may be explained by the fact that

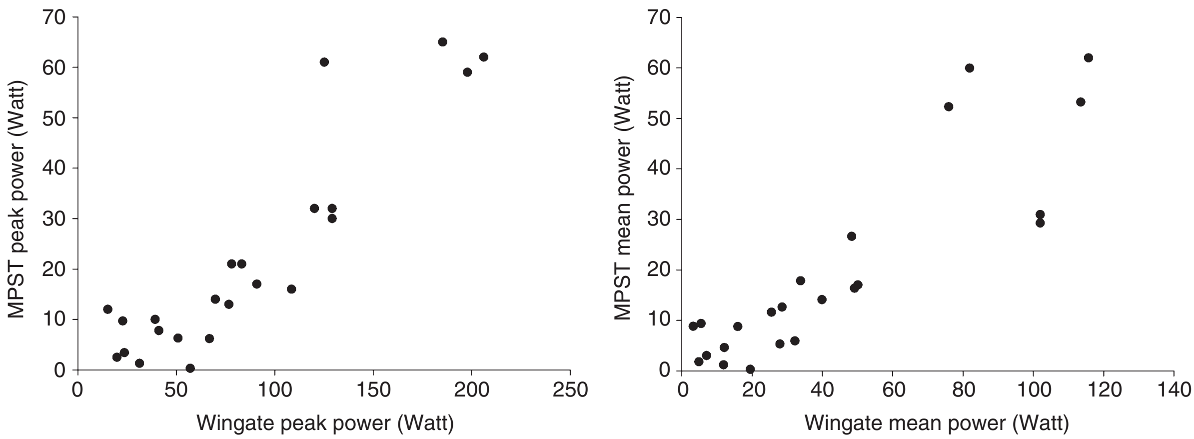

Figure 4: Scatterplot showing the relationship between peak power and mean power on arm-cranking Wingate Anaerobic Test and Muscle Power Sprint Test (MPST).

while both the MPST and arm-cranking WAnT measure power output of the upper limbs, the MPST uses intermittent propelling of the wheelchair instead of the continuous pushing and pulling used in arm cranking. Moreover, the outcomes of the MPST are based on averages over three 15m distances or roughly 30 seconds, while the arm-cranking WAnT outcomes are measured instantaneously (<1s). In spite of these differences, our results indicate that like the arm-cranking WAnT, the MPST can be used to measure the anaerobic performance of the arms. From a rehabilitation medicine perspective, this finding is very promising because of the minimal cost associated with performing the MPST, its easy application, and its similarity, and therefore relevance, to children's ADL.

Field tests that rely on manual wheelchair propulsion performance are affected by many factors beyond motor limitations. Vanlandewijck et al.[23] have shown that the type of wheelchair (i.e. basketball/tennis wheelchair vs ADL wheelchair) affects field test performance. Also minimal changes to wheelchair configuration, such as the presence or absence of a caster wheel (a fifth wheel at the back of the wheelchair for stability), may also alter field test performance significantly. Therefore, field tests, such as the MPST and the 10 × 5-m sprint test for wheelchair users should primarily be used to assess the individual progress of a child. Furthermore, the use of a standardized wheelchair should be discouraged due to the lack of individual adjustments that may impact, and potentially hamper, performance.[24]

Anaerobic testing has some intrinsic methodological limitations.[8] The arm-cranking WAnT and the MPST are largely dependent on participant motivation. Currently, there are no objective physiological criteria that can be used to establish a 'true' maximal anaerobic effort. Therefore, the researcher or the clinician must rely on the cooperation of the individual performing the exercise. Encouragement and a friendly environment are also important to ensure the participants perform the test to the best of their ability.

Our findings must be interpreted in light of certain limitations. First, this study included only children and adolescents with spastic CP. Whether our results are generalizable to other clinical types of CP and other medical conditions requires further investigation. Second, the participants in this study represented a convenience sample of children and adolescents with CP who were receiving physical therapy. This selection procedure may have led to some degree of selection bias, because it is unknown whether or not these participants differ from children and adolescents who are not receiving treatment in a rehabilitation centre or special education school. Third, we have selected a braking force of 0.26 Nm/kg for all children (and did not alter this for age or sex). This was primarily based on the fact that youths with CP may have different arm-ability that is not related to age or sex (e.g. spasticity, strength, mobility), but might influence the arm-cranking strength. The optimal braking force for males and females with CP of different age groups or between those with varying diagnoses remains to be investigated. Fourth, the large SDs in all tests suggests that there is large inter-individual variability in anaerobic performance in this group. This is probably the result of the large age-range and different classification levels of the participants. Fifth, our sample size was inadequate to compare the validity and reproducibility of specific subsets of the sample as grouped by age, sex or GMFCS level. Sixth, the degree to which the use of a static start in the MPST and a rolling start for the arm-cranking WAnT may have affected our findings remains to be determined. Future studies should seek to assess these differences, or make use of only one of the two starting techniques.

CONCLUSION

The MPST, the arm-cranking WAnT and the 10 × 5-m sprint test are reproducible tests for measuring anaerobic performance and agility in children and adolescents with CP who self-propel a manual wheelchair. Moreover, the

MPST has shown to be a valid test to measure anaerobic performance. The MPST and 10 × 5-m sprint test are easy to administer and inexpensive. Clinicians using both tests do not need special equipment or training, which makes both tests available for a variety of professionals working with children and adolescents with CP.

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