Reference values for anaerobic performance and agility in ambulatory children and adolescents with cerebral palsy

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ABBREVIATIONS

GAMLSS	Generalized additive models for location, scale, and shape
MPST	Muscle Power Sprint Test

AIM The aim of this study was to provide reference values of anaerobic performance and agility in a group of children and adolescents with spastic cerebral palsy (CP).
METHOD A total of 300 children (184 males, 116 females) with spastic CP were recruited from 26 rehabilitation centres in six different countries. Of these, 215 were classified at GMFCS level I (mean age 11y 2mo, SD 3y, range 6–18y) and 85 were classified at GMFCS level II (mean age 11y; SD 3y 1mo, range 6–18y). The children performed the Muscle Power Sprint Test (MPST) and the 10×5m sprint test in a standardized manner. To establish reference values, reference curves were created using generalized additive models for location, scale, and shape.
RESULTS Height-related reference curves were created based on performance on the two tests.
INTERPRETATION This study provides height-related reference values for anaerobic performance and agility for children and adolescents with CP classified at GMFCS levels I and II. These curves are clinically relevant and provide a user-friendly method in the interpretation of anaerobic performance and agility for children with spastic CP.

Many daily childhood activities consist of short bursts of intense activity.[1] Performing these brief activities requires sufficient levels of muscle power and agility. Short-term muscle power is the ability of the neuromuscular system to perform work over a short time (anaerobic performance).[2] Agility is the ability to change the direction of the body in an efficient and effective manner. Impairment of anaerobic performance and agility means that certain activities cannot be performed at the same pace as can be achieved by typically developing children, or cannot be performed at all.

The progression of anaerobic performance and agility has been well established in healthy individuals without disabilities from childhood through to adolescence.[3] Anaerobic performance and agility increase with age, reaching a plateau around late adolescence.[4] Bar-Or[5] asserted that, in children with a neurodevelopmental disorder, anaerobic performance might be a better measure of gross motor capacity than aerobic capacity. Verschuren et al.[6] have demonstrated that *n* children and adolescents with cerebral palsy (CP) there is a moderate to strong relationship between short-burst running performance and gross motor capacity.

Sprinting is a particularly appropriate model for studying the development of anaerobic performance and agility in children because it is a natural exercise for children and is easy to test. The clinimetric properties of the Muscle Power Sprint Test (MPST) and the 10×5m sprint test have recently been used to assess anaerobic performance and agility in children and adolescents with CP at Gross Motor Function Classification System (GMFCS) levels I or II.[7] Both tests are non-threatening, inexpensive, and easy to administer in a non-research setting, and can be administered in a short timeframe. These aspects make both tests very suitable for most clinicians working with children with CP.

However, the lack of reference values regarding anaerobic performance and agility in children and adolescents with spastic CP hinders the clinical usefulness of these tests in this age group. Therefore, the aim of this study was to provide reference data for anaerobic performance and agility in children and adolescents with CP classified at GMFCS level I or II using the MPST and the 10×5m sprint test.

METHOD

Procedure and participants

The MPST and the 10×5m sprint test were implemented in 17 rehabilitation centres and schools for special education in the Netherlands from August 2008 to June 2009. The tests were also implemented in rehabilitation centres in Switzerland (3), Australia (3), Canada (2), and the USA (1). During the implementation process, the (paediatric) physical therapists and exercise physiologists received both theoretical and practical training in executing the tests. All therapists from the participating centres performed both tests under supervision of the developers, and were instructed to follow the test guidelines throughout the data collection period. Only trained therapists or exercise physiologists were asked to return the anonymous patient data obtained by testing children and adolescents with CP in their clinics using a standardized data sheet.

Data were included in this study if the children and adolescents, aged 6 to 20 years, were diagnosed with spastic CP and classified at GMFCS level I or II. All children were receiving physical therapy or were assessed as part of a check-up. Their cognitive ability was required to be such that they were able to follow simple commands. Children were excluded if they had undergone orthopaedic surgery or neurosurgery within the 6 months before study entry or if they had cardiac or respiratory conditions that could be negatively affected by exercise. Children who were considered athletes (i.e. who undertook more than 10h of formal exercise training per week) were also excluded. As well as test performance data, information regarding assessment dates, diagnosis, GMFCS level, date of birth, height, weight, and sex was collected. We obtained approval for the study from the local ethics committees of the participating rehabilitation centres. Informed consent was not obtained because the protocols did not include any activities that were outside the standard of care or usual clinical assessments.

Measurements

Anthropometry

Participants' body mass and height were measured using standardized methods. Before testing, each child was weighed in underwear to the nearest 100g on the digital scales available (Seca, Hamburg, Germany; Soehnle, Nassau/Lahn, Germany; or Salter, Oak Brook, IL, USA) in the participating clinics. On the same day, height was measured to the nearest 0.5cm, using a stadiometer or wall-mounted measuring stick, while the child was standing against a wall. Body mass index (BMI) was calculated as weight in kilograms divided by height in metres squared.

GMFCS

The GMFCS was used by a paediatric physical therapist experienced in use of the scale to classify the children and adolescents with CP based on their functional mobility. Owing to the nature of the shuttle run tests, only children and adolescents who were classified at GMFCS level I (able to walk indoors and outdoors and climb stairs without limitation) or level II (able to walk indoors and outdoors and climb stairs holding on to a railing, but experiencing limitations in walking on uneven surfaces and inclines and in walking in crowds or confined spaces) were included. The original GMFCS has been reported to yield reliable and valid data for children aged 6 to 12 years.[8] Children over 12 years of age were classified using the expanded and revised version of the GMFCS (GMFCS – E & R).[9]

What this paper adds

- Insight into the development of anaerobic performance and agility in children with spastic CP
- Useful reference values for anaerobic performance
- Useful reference values for agility

Anaerobic performance

Anaerobic performance was measured as the mean power (watts) derived from the MPST. This test has been demonstrated to be reliable and valid in children with CP.[7] For the MPST, the participants were instructed to complete six 15m runs at a maximum pace. The 15m distance was marked by two lines taped on the floor. Cones were placed at each end of the lines. The participant had to run as fast as possible from one line to the other, and was instructed to cross the line. Between each run, participants were allowed to rest for 10 seconds before turning around to allow them to prepare for the following sprint.

For the first run, the participants were given the cues 'ready', 'three', 'two', 'one', and 'go'. For the second to sixth runs the assessors counted backwards from 10 to 1 and then gave the cue 'go'.

Power output for each sprint was calculated from the collected data using the following equations:[10]

$$\text{Velocity (m/s)} = \text{distance/time}$$
$$\text{Acceleration (m/s}^2) = \text{velocity/time}$$
$$\text{Force (kg/s}^2) = \text{mass} \times \text{acceleration}$$
$$\text{Power (W)} = \text{force} \times \text{velocity}$$

Mean power was defined as average power output during the six runs.

Agility

Agility was assessed by the 10×5m sprint test, which is a continuous sprint test. This test has been shown to be reliable in children with CP.[7] The participants were instructed to complete 10 runs of 5m at a maximum speed. The distance was marked by two taped lines on the floor and by cones. The participant had to run as fast as possible to each line, to place at least one foot on each line, then to make a turn and run back as fast as possible. On the next line the participant had to make a similar turn and run back to the previous line. This continued until at the end of the tenth run, when the participant had to cross the finish line.

All testing was performed in the gym or in a corridor at school or the rehabilitation centre; the children wore their usual clothing and shoes (and orthoses if applicable). Before undertaking each test, there was a preparatory session in which the child performed the test at walking speed to make sure he or she understood how to perform the test. After these practice sessions, the participants were allowed a rest period of 3 minutes to recover.[11]

Statistical analysis

Cross-sectional data analyses were performed using SPSS, version 15.0 (SPSS Inc., Chicago, IL, USA), and the R statistical program (R Foundation for Statistical Computing, Vienna, Austria)[12] by a registered statistician (CK).

Data from all participants (GMFCS levels I and II, and males and females together) were analysed using generalized additive models for location, scale, and shape (GAMLSS).[13] This method is similar to those used for the recently published World Health Organization growth standard.[14] This generalized additive modelling via GAMLSS extends the least mean square[15] method in several ways.[16] GAMLSS are (semi)parametric regression-type models in which various distribution functions can be compared to find the best distribution for the data. GAMLSS offer a choice of error distributions (rather than just one), handle quite general linear predictors for each moment parameter (rather than limited to a single covariate), and are flexible in the choice of link between predictor and outcome. Preliminary analyses demonstrated that height was the variable that best correlated with MPST and 10×5m sprint test performance. GMFCS level, sex, and height, and their interactions were therefore included as possible predictors. Model building was then performed for each test (dependent variable) to determine the significant predictor variables and their effect size; formulae were constructed from these models. All data were used for model building. The larger number of children classified at GMFCS level I increased the stability for the curves that were created for GMFCS level II. Separate graphs of the resulting models were made according to GMFCS level and sex (Figs 1–4).

RESULTS

Data for 300 participants (the Netherlands, 166; Switzerland, 39; Australia, 68; Canada, 13; and the USA, 14) were used to establish reference values for the MPST. A total of 215 participants (184 males, 116 females) were classified at GMFCS level I and 85 at GMFCS level II. The demographic characteristics of the participants are presented in Table I. The demographic characteristics of males and females classified at GMFCS level I were not significantly different. The demographic characteristics of males and females classified at GMFCS level II were similar except for height, with males being significantly taller than females.

Data for 290 participants were used to establish reference values for the 10×5m sprint test. A total of 207 participants (178 males, 112 females) were classified at GMFCS level I and 83 at GMFCS level II. The demographic characteristics of the participants are presented in Table II. The demographic characteristics of males and females classified at GMFCS level I were not significantly different. The demographic characteristics of males and females classified at GMFCS level II were similar, except for height; the males were significantly taller than the females. Figures 1 and 2 show the height-related centile curves (3rd, 25th, 50th, 75th, and 97th centiles) for the MPST for both sexes and both GMFCS levels, calculated using a gamma distribution. Figures 3 and 4 demonstrate the height-related centile curves (3rd, 25th, 50th, 75th, and 97th centiles) for the 10×5m sprint test for both sexes and both GMFCS levels, calculated using a gamma distribution.

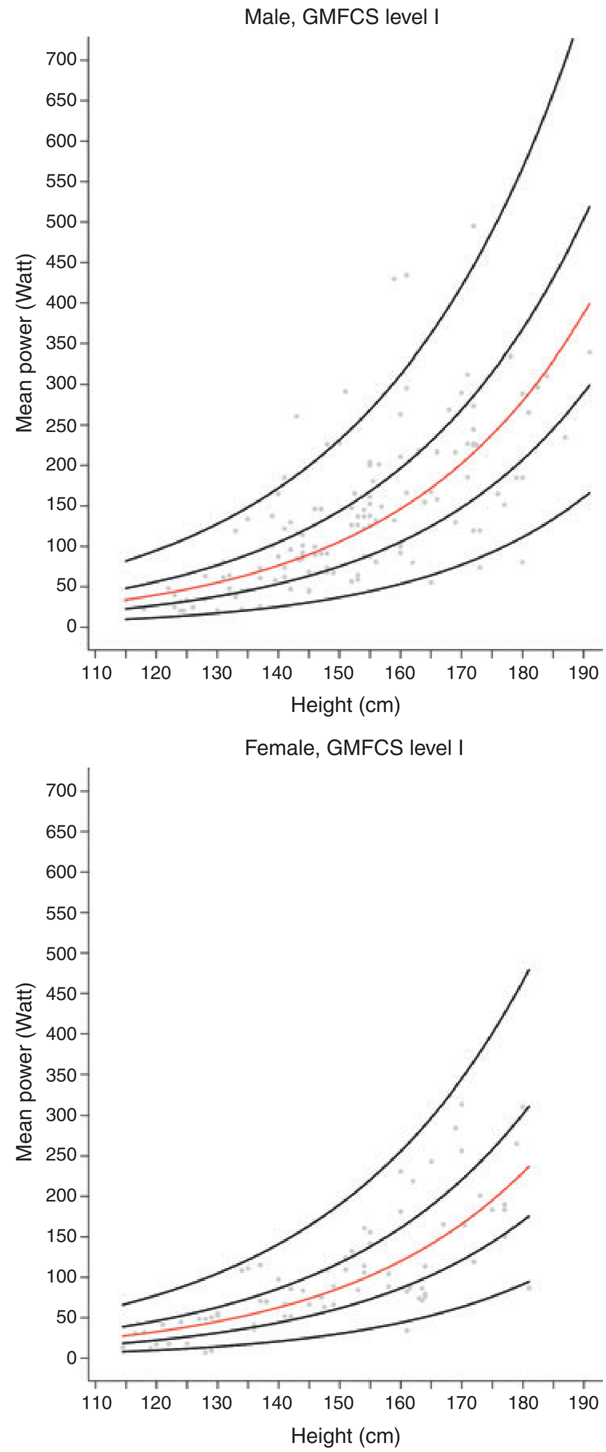

Figure 1: Reference centile curves for the Muscle Power Sprint Test for males and females classified at Gross Motor Function Classification System (GMFCS) level I.

DISCUSSION

This study provides an objective characterization of anaerobic performance and agility in relation to the height of children and adolescents with CP from various geographic regions, using GAMLSS to construct centile curves. These centile

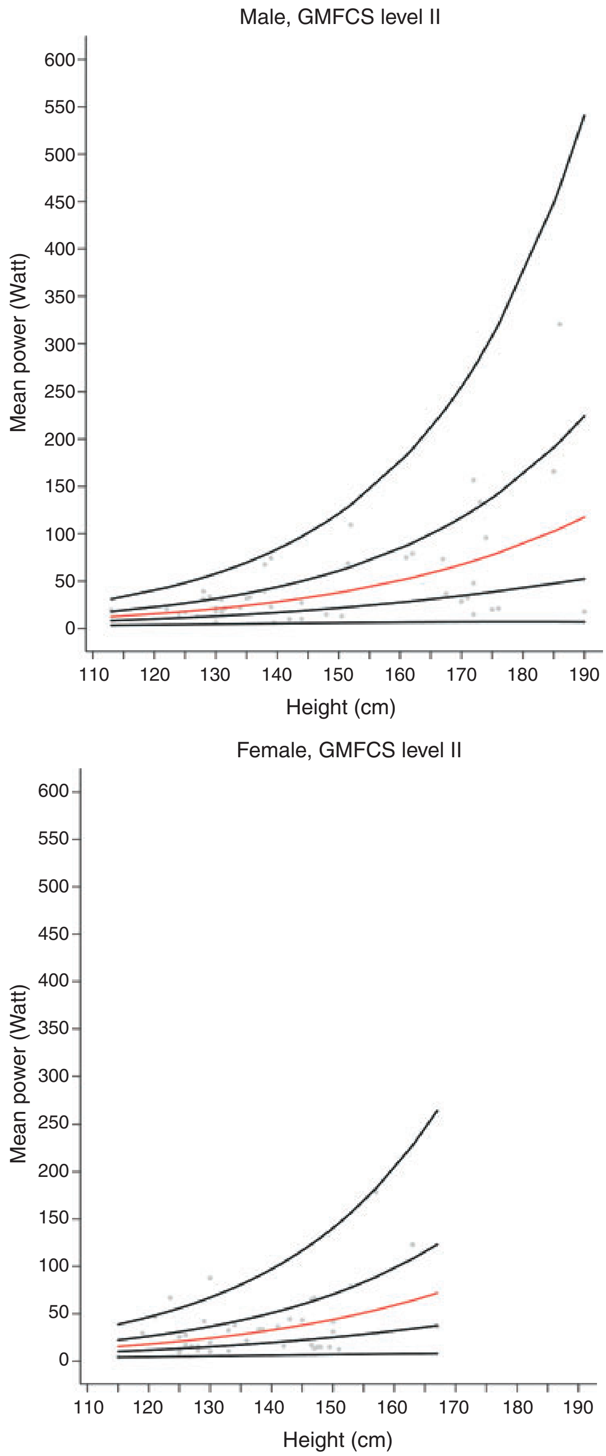

Figure 2: Reference centile curves for the Muscle Power Sprint Test for males and females classified at Gross Motor Function Classification System (GMFCS) level II.

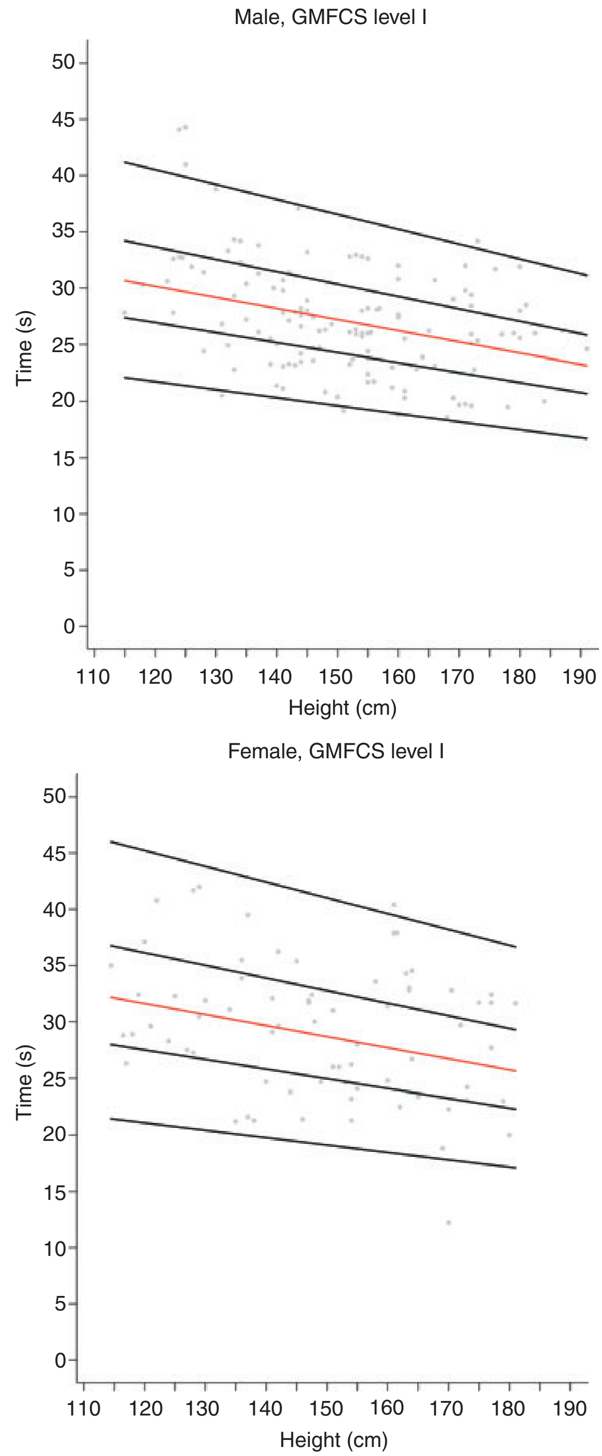

Figure 3: Reference centile curves for the 10×5m sprint test for males and females classified at Gross Motor Function Classification System (GMFCS) level I.

curves are clinically relevant and provide a user-friendly method of predicting anaerobic performance and agility.

Several studies in typically developing children have described the effect of growth on anaerobic performance:[17–19] most were cross-sectional studies. All investigations reported a significant increase in anaerobic performance with chronological age or maturity.[3] In the present study, short-term muscle power and agility increased more in males than in females. This suggests not only that growth affects anaerobic performance, but also that sex affects the resulting anaerobic and

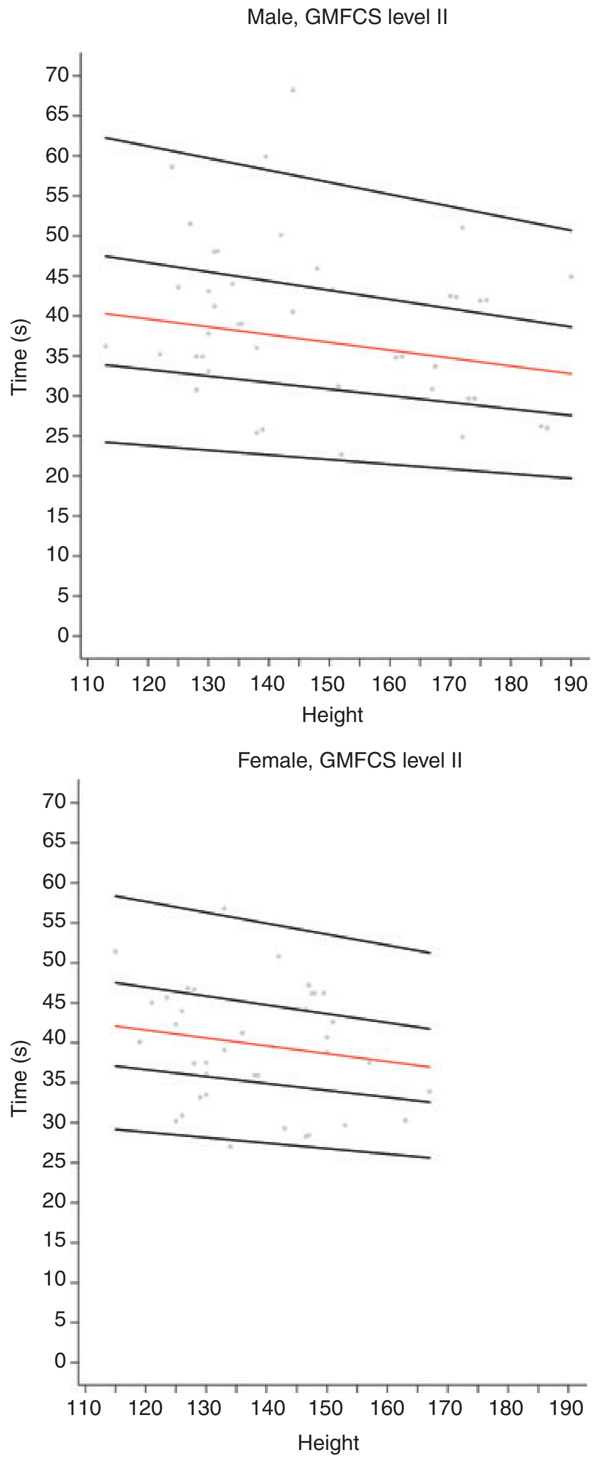

Figure 4: Reference centile curves for the 10×5m sprint test for males and females classified at Gross Motor Function Classification System (GMFCS) level II.

agility measures. Interestingly, the MPST score and performance on the 10×5m sprint test did not level off with increasing height in either females and males, indicating that anaerobic performance and agility continue to develop in adolescents. Future studies should investigate the relationship of anaerobic performance and agility to (biological) age in adolescents and young adults with CP who have reached their full height.

Height was used instead of age for the construction of these standard reference curves because, among all anthropometric factors that have been proven to have a significant correlation with the MPST and the 10×5m sprint test, height was the most discriminative variable with the highest correlation with performance. Height is one of the anthropometric parameters that is routinely recorded in all medical records in paediatric clinics. In addition, height is a more robust parameter than age, because individuals of the same age can differ substantially in height, especially in the case of those from different backgrounds. Using height-specific curves could reduce such ethnic group variation, but further studies involving participants from other ethnic groups will be needed for formal comparison.[20] Moreover, an individual with a greater stride length is generally thought to have an advantage in sprint performance by being able to produce greater forward propulsion.

Exercise tests such as the MPST and the 10×5m sprint test can add variety to a training programme. Test results can also be used to satisfy the children's competitive urge. Testing children with CP using both tests and the reference values can have some additional benefits. First, the results of the tests can be used to indicate relative weaknesses – a lower score on one or both tests indicates relative weakness in this area compared with same-sex peers of the same GMFCS level. However, a clinician cannot, based on centile values alone, determine whether or not training is indicated, as it has been shown that anaerobic capacity is lower in children with CP (between two and four standard deviations below the expected values) than in typically developing children.[21] Second, these tests can measure improvement over time with adjustment for natural development – in children and adolescents, morphological parameters and physiological functions develop with increasing age and body size. Furthermore, physical fitness changes with growth and maturation.[17] Variations in growth and maturation can have profound effects on aspects of physical fitness, such as anaerobic performance and agility. The reference values provided in this study will be useful in determining whether an intervention programme (without a control group) has been effective or whether any changes observed simply reflect normal development. Third, these tests enable clinicians to assess the success of a training programme aimed at improving anaerobic performance or agility by using the reference values. The clinician can readily determine whether a child or adolescent is achieving a higher score (centile) than his or her peers with the same diagnosis and functional limitations related to that diagnosis. Fourth, the tests enable clinicians to place a child or adolescent in an appropriate training group by forming training groups based on baseline centile scores of anaerobic performance and agility. Finally, the results of the MPST and the 10×5m sprint test can, over time, be used to measure progression and motivate the child to continue training.

Table I: Participant characteristics for Muscle Power Sprint Test (*n*=300)

Variable	GMFCS level I				GMFCS level II			
	Mean	SD	Median	Range	Mean	SD	Median	Range
Males	(*n*=138)				(*n*=46)			
Age (y:mo)	11:3	2:8	11:0	6–18	10:9	3:1	11:0	6–18
Height (cm)	151.4	16.6	152	115–191	148.6	20.4	143.0	113–190
Weight (kg)	44.5	15.8	41.0	18.0–92.0	42.4	16.1	40.5	23.0–88.0
BMI (kg/m^2)	18.8	3.8	18.1	12.7–30.9	18.6	3.3	18.3	14.2–26.5
Females	(*n*=77)				(*n*=39)			
Age (y:mo)	10:9	3:2	11:0	6–18	11:0	3:0	11:0	6–17
Height (cm)	149.3	18.3	151	115–181	138.2	12.5	138.0	115–167
Weight (kg)	45.8	17.8	44.0	16.0–85.0	35.9	10.3	33.5	20.0–72.0
BMI (kg/m^2)	19.7	4.1	19.4	12.2–30.5	18.6	4.0	17.3	13.0–30.5

GMFCS, Gross Motor Function Classification System; BMI, body mass index.

Table II: Participant characteristics for 10×5m sprint test (*n*=290)

Variable	GMFCS level I				GMFCS level II			
	Mean	SD	Median	Range	Mean	SD	Median	Range
Males	(*n*=133)				(*n*=45)			
Age (y:mo)	11:4	2:10	11:0	6–18	10:11	3:2	10:6	6–18
Height (cm)	151.3	16.8	152.0	115–191	148.1	20.3	142.0	113–190
Weight (kg)	44.7	16.0	41.0	18.0–92.0	41.8	15.6	40.0	23.0–88.0
BMI (kg/m^2)	18.9	3.8	18.2	12.7–30.9	18.4	3.2	18.3	14.2–26.5
Females	(*n*=74)				(*n*=38)			
Age (y:mo)	10:11	3:2	11:0	6–18	10:11	3:0	10:6	6–17
Height (cm)	149.3	18.4	150.0	115–181	138.0	12.6	137.0	115–167
Weight (kg)	46.1	17.9	44.0	16.0–85.0	35.7	10.3	33.3	20–72
BMI (kg/m^2)	19.8	4.0	19.4	12.2–30.5	18.6	4.0	17.3	13.0–30.5

GMFCS, gross motor function classification system; BMI, body mass index.

LIMITATIONS

One important limitation of this study is its cross-sectional design. This should be addressed in future research, and a longitudinal study in a smaller cohort is required to confirm the current height-related increase in performance on both measures.

The study included only children and adolescents with spastic CP. Whether our results are generalizable to other clinical types of CP needs to be investigated in future research.

Reliable direct measure of height is difficult in children with severe CP because of contractures, scoliosis, and/or the inability to stand erect.[22] In the present study, we considered children and adolescents classified at GMFCS level I and II as having mild CP. Therefore, we did not use alternative means of measuring height in our sample. However, a possible limitation of our method of measuring height is that participants may have been standing against a wall and may have been undetectably crouching while doing so. This was not addressed in this study.

Moreover, the children and adolescents who constituted the participants in this study were 'open-source' convenience sample of children and adolescents with CP who were receiving physical therapy or were assessed as part of a check-up. Tests were mostly performed during physical therapy sessions in rehabilitation centres or special education schools, where most of the therapists, who received training in conducting the tests, worked. This may have led to selection bias, as data from children and adolescents who are not receiving treatment in a rehabilitation centre or special education school were excluded. The children with CP who do not attend a school of special education or a rehabilitation facility might be the children with the best exercise performance. This might affect the generalizability of the presented reference values to the clinical CP population.

Caution should also be taken when applying our centile curves to individuals who fall outside the characteristics of our cohort, such as those younger than 6 years and older than 19 years. The performance of young adults classified at GMFCS level III has not yet been investigated, nor has the performance of children with CP at GMFCS level III.

CONCLUSION

In conclusion, this study provides reference values for anaerobic performance and agility in relation to the height of children and adolescents aged 6 to 18 years with spastic CP and classified at GMFCS level I or II. These centile curves are clinically relevant and provide a user-friendly method of predicting anaerobic performance and agility in children with spastic CP.

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