Immediate effect of maximal treadmill walking on muscle fatigue and postural stability in children with cerebral palsy

Walaa A. Abd El-Nabie[a], Maha A. Attia[b]

[a]Department of Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, Giza, [b]Department of Physical Therapy, Fevers Hospital, Benha, Qalyubia, Egypt

Correspondence to Walaa A. Abd El-Nabie, PhD, 7 Ahmed E lzayat Street, Doky, Giza, 12613, Egypt. Tel: +20 111 560 6185; fax:0237617693;
e-mail: dr.walaapt@yahoo.com

Received 2 November 2018
Accepted 25 March 2019

Bulletin of Faculty of Physical Therapy
2019, 24:79–84

Aim
Postural instability and muscle fatigue are from elementary causes of deteriorations in children with cerebral palsy (CP). The aim of this study was to investigate the immediate effect of maximal treadmill walking on muscle fatigue and postural stability in children with hemiplegic CP.

Patients and methods
Thirty (17 boys and 13 girls) children with hemiplegic CP of both sexes, aged from 5 to 11 years, participated in this study. Muscle fatigue and postural stability were assessed for every child by using isokinetic dynamometer and pediatric reaching test, respectively, before and after maximal treadmill walking at two separated sessions.

Results
The results showed that there were no significant differences in fatigue index (P=0.33 and 0.1), peak torque of quadriceps and hamstring muscles (P=0.52 and 0.14), and anterior and lateral reaching tests of postural stability (P=0.46 and 0.63) before and after maximal treadmill walking.

Conclusion
Maximal treadmill walking does not cause muscle fatigue or postural instability in children with hemiplegic CP.

Keywords:
cerebral palsy, hemiplegia, maximal treadmill walking, muscle fatigue, posture stability

Bulletin of Faculty of Physical Therapy 24:79–84

1110-6611

Introduction

Cerebral palsy (CP) describes group of developmental dysfunctions that deteriorate the control of movement. It is the most common cause of physical impairment in childhood, with a prevalence of two per 1000 live births [1]. Primary impairments associated with CP include muscle weakness, postural control deficit, and lowered cardiorespiratory fitness. These impairments restrict the ability of children with CP to perform activities of daily living [2]. Hemiplegia is a common clinical subtype of CP that is characterized by unilateral weakness or paralysis owing to damage of contralateral side of the brain [3]. Children with hemiplegia have multiple severities in postural control, perception, range of motion, and sensory function that deteriorate the quality of life and gross motor function [4].

Postural control is the maintenance of body position in space to achieve postural stability and orientation. Postural control deficit is an essential problem facing children with CP [5]. It is caused by brain damage, which leads to impairment of postural, motor, and perceptual networks causing postural instability [6]. Postural stability is essential for achieving daily life activities that require maintaining of the body in upright position [7]. It relies on integration between nervous and musculoskeletal systems. In children with hemiplegic CP, this integration is destroyed, which leads to postural control deficit and postural instability [8].

Muscle fatigue can be defined as exercise-related reduction in the maximum power of a muscle or muscle groups correlated to an increase in effort required to exert the desired power [9]. Children with CP are characterized by production of low muscle force, when they are compared with normal children [10]. Muscle weakness results in high levels of fatigue owing to recruitment of additional motor units and high frequency of excitation, which are essential to perform a specific task [11]. Muscle fatigue has an adverse effect on children with CP, in which it declines their walking ability, social communication, and participation of daily life activities [12]. Knee flexors and extensors muscles in children with neuromuscular disorders are vulnerable to muscle fatigue [13]. Hilberink *et al.* [14] reported that postural instability and muscle fatigue are common impairments experienced by children with CP, which may cause a decrease in their walking ability.

DOI: 10.4103/bfpt.bfpt_26_18

Maximal treadmill walking is considered as a basic exercise test that is used for assessment of hemiplegic children [15]. It is the maximal aerobic capacity of a child which determines when he/she performs the objective and subjective criteria at end of the test. Heart rate (HR) more than 120 beats/min is the objective criterion, whereas signs of exhaustion (e.g. sweating, difficulty of breathing, and fatigue) and inability of the child to keep on the test are the subjective criteria [16]. There are several studies focused on maximal treadmill walking and different outcomes in children with CP, such as the study conducted by Hoofwijk *et al.* [17] and Lauglo *et al.* [18]. However, the studies that concentrate on the effect of maximal treadmill walking on muscle fatigue and postural stability are still limited. Therefore, this work aimed to evaluate the immediate effect of maximal treadmill walking on muscle fatigue and postural stability in children with hemiplegic CP. The authors hypothesized that children with hemiplegic CP would exhibit muscle fatigue and postural instability after maximal treadmill walking.

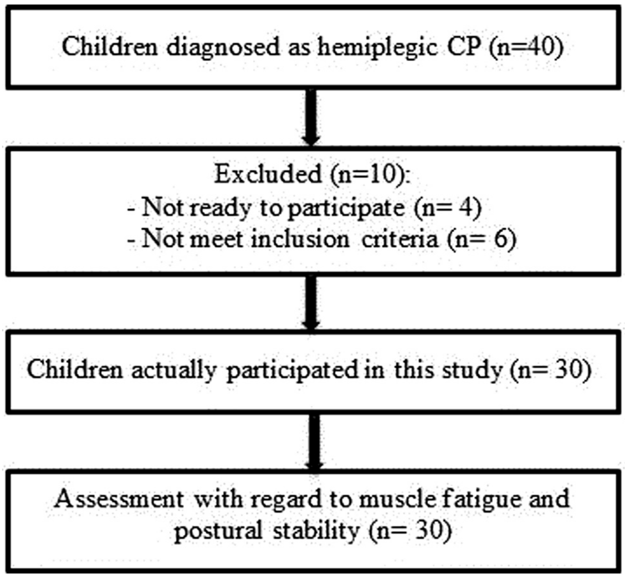
Patients and methods

Participants

This study was carried out in the isokinetic laboratory of the Faculty of Physical Therapy, Cairo University, from April 2017 to December 2017. At the beginning of this study, parents or legal guardians of all participants signed an informed consent that was approved by the Ethical Committee of the Faculty of Physical Therapy, Cairo University, regarding the participation of their children in this study (no: P.T. REC/012/001451).

Thirty children with right-side hemiplegia of both sexes with their ages ranged from 5 to 11 years were recruited from the Outpatient Clinic of the Faculty of Physical Therapy, Cairo University, with the following inclusion criteria: the children had a diagnosis of hemiplegia which was confirmed by pediatric neurologist, and they were selected at level I and II according to Gross Motor Function Classification System [19]. The degree of spasticity ranged from 1 to 1+ according to Modified Ashworth Scale [20]. The children were excluded if they had cognitive or behavioral impairment, cardiovascular disease, visual and auditory problems, application of botulinum toxin in lower extremities for at least 6 months before the current study, and/or fixed deformity of both upper and lower limbs. The flow chart of participants is illustrated in Fig. 1.

Figure 1



Flow chart for patient selection.

Study design

This study had a quasi-experimental design (pre–post design).

In this study, the children were invited for two visits of evaluation. One visit for the assessment of muscle fatigue (fatigue index and peak torque) of quadriceps and hamstring muscles by using isokinetic dynamometer before and after maximal treadmill walking, whereas the second visit for the assessment of postural stability by pediatric reaching test (anterior and lateral reaching tests).

Materials of evaluation

Isokinetic dynamometer

Isokinetic dynamometer has been used for the objective assessment of muscle strength and muscle injury [21]. It is commonly used in the rehabilitation centers as it provides unique insights on the evaluation of muscle function for human performance [22]. Moreover, it is a valid and reliable method used to assess the muscle fatigue of hamstring and quadriceps muscles in children with CP [23].

Pediatric reaching test

Pediatric reaching test is a reliable and valid test used for measuring of postural stability from anterior and lateral directions in children with CP [24–26]. This test is easy to be applied in clinical sitting, and it measures the distance that the child is able to reach forward and laterally from standing position without loss of his/her balance [24].

Procedures of evaluation

For muscle fatigue

After familiarization of children with the equipment, he/she was allowed to sit on the chair of dynamometer with the tested hip and knee in a position of 90° flexion. Proper stabilization for each child was provided via straps around trunk and thigh during the sitting position. The rotational axis of the knee joint (lateral femoral epicondyle) was aligned with the axis of the lever arm of isokinetic, and the resistance pad was attached ~three centimeters above the medial malleolus. Additional back support was added when necessary to ensure the biomechanical alignment between the rotational axis of both knee and dynamometer [23]. A brief demonstration through pictures and verbal instructions about the movement to be performed was given to each child after he/she was positioned at the chair of dynamometer, then the child was asked to perform a reciprocal maximal concentric contraction of quadriceps and hamstring muscles through 90° range of motion and at angular velocity of 60/s [27]. During this test, each child was verbally encouraged to extend and flex his/her knee as forcefully as possible during each contraction.

For postural stability

Before testing, the task was clarified to each child and he/she was attached by a sheet of paper to the floor, to trace his/her foot position without socks and shoes. The test was repeated if the child either touched the wall or examiner or if he/she took a step [24]. For anterior reaching test, each child was asked to stand near a wall with his tested arm maintained at 90° of shoulder flexion with extended elbow and neutral position of the wrist. The child was asked to hold this starting position for three seconds. During this position, the examiner who stood next to the child recorded the initial reading from the level of child's acromion to the tip of middle finger by using a measuring tape. Then the child was asked to reach forward as far as he can toward a motivating object and to hold his position for three seconds. The final reading was taken at this ending position in the same way as in starting one. The reaching distance was measured by finding the difference between two positions. For lateral reaching test, the starting position of the tested shoulder was maintained at 90° of abduction, with the elbow extended and neutral position of the wrist. Then the child was asked to reach laterally as far as he can. Measurement of distance at starting and ending positions, and the difference in measurement between them were the same as in anterior reaching test. Three trials were allowed for every child for each test, and their means were taken according to Bartlett and Birmingham [24].

Protocol of treadmill walking

Bruce treadmill protocol was the protocol of treadmill walking in this study. It is a valid and reliable graded maximal exercise test that can be used in children and adult population [28]. It consists of seven stages, during them the inclination and speed of treadmill increase every three minutes as illustrated in Table 1 [29]. The children had been instructed to avoid heavy physical activity in the day of evaluation and the day before to avoid exhaustion and to have the ability to do test. Before testing, proper and clear explanation of the protocol and its objectives were allowed to every child [30]. It was settled to use the 'half Bruce' protocol in this study that was started from stage 1 to 3, as it was recognized that children with CP can adapt to smaller steps of the Bruce protocol [31]. Each child was started on a speed of 2.7 km/h and 10° of inclination. The speed, inclination, and time were increased gradually to reach to the third stage (half) of Bruce protocol. HR was monitored during the treadmill walking by using HR monitor (Garmin Forerunner 310XT or Polar WearLink RS400, Garmin international, Inc., Kansas city). Evaluator stood behind each child during treadmill walking to protect him from falling. The test was ended when the child was unable to complete or he/she appeared exhausted or the HR reached above 150 beats/min [32]. At the end of the test speed, time and inclination were lowered gradually on treadmill for each child to prevent the pooling of the blood in dilated vessels.

Statistical analysis

Descriptive statistics in form of mean, SD, minimum, maximum and range values were conducted for the age, weight, height, and foot length of hemiplegic children. Paired *t*-test was conducted for comparison between pre-maximal and post-maximal treadmill walking mean values of fatigue index, peak torque, and anterior and lateral reaching of the hemiplegic children. The level of significance for all statistical tests was set at *P* value less than 0.05. All statistical measures were performed through the statistical package for the social sciences (SPSS, IBM SPSS, Chicago, IL, USA) version 19 for Windows.

Table 1 Bruce treadmill protocol

Time (min)	0	3	6	9	12	15	18
Speed (km/h)	2.7	4.0	5.5	6.8	8.0	8.8	9.6
Tilt (%)	10	12	14	16	18	20	22

Results

The mean±SD of ages, weights, heights, and foot length of participants were shown in Table 2. The sex distribution of the hemiplegic children revealed that there were 13 girls, with reported of 45%, whereas the number of boys was 17 with reported percentage of 55%.

The results showed that there were no significant differences in fatigue index and peak torque of quadriceps and hamstring muscles between pre-maximal and post-maximal treadmill walking values. Moreover, there were no significant differences in the anterior and lateral reaching tests between pre-maximal and post-maximal treadmill walking values ($P>0.05$).

Table 3 showed the results of pre-maximal and post-maximal treadmill walking mean value of quadriceps and hamstring muscles fatigue index of children with hemiplegic CP. These analysis showed that there was no significant difference in the fatigue index of quadriceps muscle between pre-maximal and post-maximal treadmill walking values ($P=0.33$). In addition, there was no significant difference in the fatigue index of hamstring muscle between pre-maximal and post-maximal treadmill walking values ($P=0.1$).

Table 4 demonstrated the results of pre-maximal and post-maximal treadmill walking mean value of quadriceps and hamstring muscles peak torque of children with hemiplegic CP. This analysis showed that there was no significant difference in the peak torque of quadriceps muscle between pre-maximal and post-maximal treadmill walking ($P=0.52$). Moreover, there was no significant difference the peak torque of hamstring muscle between pre-maximal and post-maximal treadmill walking ($P=0.14$).

Furthermore, pre-maximal and post-maximal treadmill walking mean values of anterior and lateral reaching of children with hemiplegic CP were demonstrated in Table 3. The results indicated that there was no significant difference in the anterior reaching test between pre-maximal and post-maximal treadmill walking ($P=0.46$). Moreover, there was no significant difference in the lateral reaching test between pre-maximal and post-maximal treadmill walking values ($P=0.63$).

Discussion

To our knowledge, there are limited studies that investigated the immediate effect of maximal treadmill walking on muscle fatigue and postural stability in children with CP. Therefore, the current study was conducted to investigate the immediate effect of maximal treadmill walking on muscle fatigue and postural stability in children with hemiplegic CP. The major results of this study indicated that children with hemiplegic CP performed maximal walking on the treadmill without muscle fatigue and postural instability.

The nonsignificant differences in fatigue index and peak torque before and after treadmill walking may be owing to fatigue resistance in children with CP. This is

Table 2 Demographic characteristics of hemiplegic children

Variables	Mean±SD	Minimum	Maximum	Range
Age (years)	8.25±1.77	5	11	6
Weight (kg)	26.83±5.77	20	45	25
Height (cm)	118.13±7.45	104	137	33
Foot length (cm)	17.6±1.86	13	22	9

Table 3 Paired *t*-test for comparison between pre-treadmill and post-treadmill walking mean values of anterior and lateral reaching tests, quadriceps muscles fatigue index, and hamstring muscles fatigue index of hemiplegic children

Variables	Pre-exercise (mean±SD)	Post-exercise (mean±SD)	Mean difference	Percentage of change	*t* value	*P* value	Significance
Anterior reaching test (cm)	0.85±0.53	0.96±0.6	−0.11	12.94	−0.73	0.46	NS
Lateral reaching test (cm)	0.82±0.43	0.86±0.38	−0.04	4.87	−0.47	0.63	NS
Quadriceps muscle fatigue index (%)	18.59±5.36	19.2±4.71	−0.61	3.28	−0.98	0.33	NS
Hamstring muscle fatigue index (%)	24.31±6.23	26.91±5.92	−2.6	10.69	−1.65	0.1	NS

Table 4 Paired *t*-test for comparison between pre-treadmill and post-treadmill walking mean values of quadriceps and hamstring peak torque of the hemiplegic children

Peak torque (Nm)	Pre-exercise (mean ±SD)	Post-exercise (mean ±SD)	Mean difference	Percentage of change	*t* value	*P* value	Significance
Quadriceps	24.51±6.53	25.1±7.46	−0.59	2.4	−0.64	0.52	NS
Hamstring	10.82±3.57	11.21±3.9	−0.39	3.6	−1.49	0.14	NS

illustrated by Ratel *et al.* [33] and Peterson *et al.* [34] who reported that children with CP may have greater resistance to fatigue in the laboratory setting than typically developing children. Additionally, Riner and Sellhorst [35] reported that children with disability in contrast to adult individual experience less fatigue during activities.

Moreover, these results are supported by Stackhouse *et al.* [10] who quantified the fatigue of quadriceps muscle during maximal isometric contraction in children with CP and normal children. They found that in children with CP, the fatigue of quadriceps muscle was less than in normal children.

The mechanism of muscle fatigue resistance in children with CP is the alteration in muscle fiber type (increase in type I or atrophy of type II muscle fibers); this alteration may be caused by chronic stimulation of a muscle as an outcome of spasticity, by which muscle cells transform into slower and more fatigue resistant phenotype [36].

Increased muscle stiffness and excessive cell collagen accumulation are considered from the other causes of fatigue resistance in children with CP. It was suggested that increased muscle stiffness may compensate weakness, thereby allowing better usage of elastic energy during different activities such as walking [37,38].

On the contrary, the current result regarding muscle fatigue does not come in agreement with the finding of Stephenson *et al.* [39] who illustrated that muscle fatigue develops during high-intensity or maximal exercise, which may be owing to failure in the cycle of muscle contractility and excitation-contraction.

The current results explained that, there were nonsignificant differences in anterior and lateral reaching tests of postural stability before and after treadmill walking, which may be owing to the immediate effect of treadmill walking. This result indirectly clarified that, maximal treadmill walking did not cause postural instability.

Long-term effect of treadmill training improves postural stability through regular repetitions of walking steps. This is in consistent with Grecco *et al.* [40] who stated that walking on a treadmill contributes to postural control and postural stability by allowing several repetitions of steps of the walking cycle in a regular pattern, thus improving coordination between agonist and antagonist muscles.

Treadmill walking improves postural control and muscle strength of lower extremity by improving neural adaptability, which in turn improves neuromuscular capacity in children with disability [41]. Moreover, it provides prolonged weight bearing on lower extremity which in turn improves standing balance and stability [42].

Walking on a treadmill stimulates central pattern generators in the spinal cord [43]. Central pattern generators lead to rhythmical strides and allow the training of gait cycle, postural control, and stability [44].

Limitation of the study

This study was limited to children with hemiplegic CP with the age group from 5 to 11 years. The lack of power analysis is considered another limitation in this work. So, similar research studies are recommended on other types of CP with sample size calculation. We assessed only the muscle fatigue of knee flexors and extensors before and after maximal treadmill walking, so it is recommended for future studies to evaluate the fatigue of other muscle groups in lower extremities under similar condition.

Conclusion

From the obtained results of this study, it could be concluded that, maximal treadmill walking is well tolerated, and does not cause muscle fatigue or postural instability. Moreover, it may be helpful in the evaluation of children with CP and may provide valuable guidelines for their treatment protocols.

Acknowledgements

The authors wish to acknowledge our gratitude to the children, parents, and our volunteered colleagues.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Novak I, Mcintyre S, Morgan C, Campbell L, Dark L, Morton N, *et al.* A systematic review of interventions for children with cerebral palsy: state of the evidence. Dev Med Child Neurol 2013; 55:885–910.

2 Nooijen C, Slaman J, van der Slot W, Stam HJ, Roebroeck ME, van den Berg-Emons R, *et al.* Health-related physical fitness of ambulatory

adolescents and young adults with spastic cerebral palsy. J Rehabil Med 2014; 46:642–647.

3 Kulak W, Sobaniec W. Comparisons of right and left hemiparetic cerebral palsy. Pediatr Neurol 2004; 31:101–108.

4 Rosenbaum P, Paneth N, Leviton A, Goldstein M, Bax M, Damiano D, *et al.* A report: the definition and classification of cerebral palsyApril 2006. Dev Med Child Neurol Suppl 2007; 109:8–14.

5 Duarte M, Freitas SM. Revision of posturography based on force plate for balance evaluation. Braz J Phys Ther 2010; 14:183–192.

6 Hadders-Algra M, Carlberg EB. Postural control: a key issue in developmental disorders. London: Mac Keith; 2008.

7 Näslund A, Sundelin G, Hirschfeld H. Reach performance and postural adjustments during standing in children with severe spastic diplegia using dynamic ankle-foot orthoses. J Rehabil Med 2008; 39:715–723.

8 Kenis-Coskun O, Giray E, Eren B, Ozkok O, Karadag-Saygi E. Evaluation of postural stability in children with hemiplegic cerebral palsy. J Phys Ther Sci 2016; 28:1398–1402.

9 Leunkeu A, Keefer D, Ahmaidi S. Electromyographic (EMG) analysis of quadriceps muscle fatigue in children with cerebral palsy during a sustained isometric contraction. J Child Neurol 2010; 25:287–293.

10 Stackhouse SK, Binder Macleod SA, Lee SC. Voluntary muscle activation, contractile properties, and fatigability in children with and without cerebral palsy. Muscle Nerve 2005; 31:594–601.

11 Lindström B, Lexell J, Gerdle B, Downham D. Skeletal muscle fatigue and endurance in young and old men and women. J Gerontol A Biol Sci Med Sci 1997; 52:B59–B66.

12 Van der Dussen L, Nieuwstraten W, Roebroeck M, Stam H. Functional level of young adults with cerebral palsy. Clin Rehabil 2001; 15:84–91.

13 Jahnsen R, Villien L, Stanghelle JK, Holm I. Fatigue in adults with cerebral palsy in Norway compared with the general population. Dev Med Child Neurol 2003; 45:296–303.

14 Hilberink SR, Roebroeck ME, Nieuwstraten W, Jalink L, Verheijden J, Stam HJ. Health issues in young adults with cerebral palsy: towards a life-span perspective. J Rehabil Med 2007; 39:605–611.

15 Verschuren O, Ketelaar M, Keefer D, Wright V, Butler J, Ada L, *et al.* Identification of a core set of exercise tests for children and adolescents with cerebral palsy: a Delphi survey of researchers and clinicians. Dev Med Child Neurol 2011; 53:449–456.

16 Armstrong N, Welsman JR. Aerobic fitness: what are we measuring. Med Sport Sci 2007; 50:5–25.

17 Hoofwijk M, Unnithan V, Bar-Or O. Maximal treadmill performance of children with cerebral palsy. Pediatr Exerc Sci 1995; 7:305–313.

18 Lauglo R, Vik T, Lamvik T, Stensvold D, *et al.* High-intensity interval training to improve fitness in children with cerebral palsy. BMJ Open Sport Exerc Med 2016; 2:1–6.

19 Paulson A, Vargus-Adams J. Overview of four functional classification systems commonly used in cerebral palsy. Children 2017; 4:30–40.

20 Yam WKL, Leung MSM. Interrater reliability of Modified Ashworth Scale and Modified Tardieu Scale in children with spastic cerebral palsy. J Child Neurol 2006; 21:1031–1035.

21 Hong WH, Chen HC, Shen IH, Chen CY, Chen CL, Chung CY. Knee muscle strength at varying angular velocities and associations with gross motor function in ambulatory children with cerebral palsy. Res Dev Disabil 2012; 33:2308–2316.

22 Carusoa J, Brownb L, Tufanob J. The reproducibility of isokineti dynamometry data. Isokinet Exerc Sci 2012; 20:239–253.

23 Moreau N, Li L, Damiano DL. A feasible and reliable muscle fatigue assessment protocol for individuals with cerebral palsy. Pediatr Phys Ther 2008; 20:59–65.

24 Bartlett D, Birmingham T. Validity and reliability of a pediatric reach test. Pediatr Phys Ther 2003; 15:84–92.

25 Volkman KG, Stergiou N, Stuberg W, Blanke D, Stoner J. Methods to improve the reliability of the functional reach test in children and adolescents with typical development. Pediatr Phys Ther 2007; 19:20–27.

26 Deshmukh AA, Ganesan S, Tedla JS. Normal values of functional reach and lateral reach tests in Indian school children. Pediatr Phys Ther 2011; 23:23–30.

27 Eken MM, Dallmeijer AJ, Houdijk H, Doorenbosch C. Muscle fatigue during repetitive voluntary contractions: a comparison between children with cerebral palsy, typically developing children and young healthy adults. Gait Posture 2013; 38:962–967.

28 Van der Cammen-van MH, IJsselstijn H, Takken T, Willemsen SP, Tibboel D, Stam HJ, *et al.* Exercise testing of pre-school children using the Bruce treadmill protocol: new reference values. Eur J Appl physiol 2010; 108:393–399.

29 Gumming GR, Everatt D, Hastman L. Bruce treadmill test in children: normal values in a clinic population. Am J Cardiol 1978; 41:69–75.

30 Bruno Messmer B, Bernuth G. Results of the Bruce treadmill test in children after arterial switch operation for simple transposition of the great arteries. Am J Cardiol 1998; 81:56–60.

31 Gorter H, Holty L, Rameckers EE, Elvers HJ, Oostendorp RA. Changes in endurance and walking ability through functional physical training in children with cerebral palsy. Pediatr Phys Ther 2009; 21:31–37.

32 Armstrong N, van Mechelen W. Paediatric exercise science and medicine. 2nd ed. New York: Oxford University Press; 2008.

33 Ratel S, Duché P, Williams CA. Muscle fatigue during high-intensity exercise in children. Sports Med 2006; 36:1031–1065.

34 Peterson MD, Gordon PM, Hurvitz EA, Burant CF. Secondary muscle pathology and metabolic dysregulation in adults with cerebral palsy. Am J Physiol Endocrinol Metab 2012; 303:E1085–E1093.

35 Riner WF, Sellhorst SH. Physical activity and exercise in children with chronic health conditions. J Sport Health Sci 2013; 2:12–20.

36 Smith LR, Lee KS, Ward SR, Chambers HG, Lieber RL. Hamstring contractures in children with spastic cerebral palsy result from a stiffer extracellular matrix and increased in vivo sarcomere length. J Physiol 2011; 589:2625–2639.

37 Booth CM, Cortina-Borja M, Theologis T. Collagen accumulation in muscles of children with cerebral palsy and correlation with severity of spasticity. Dev Med Child Neurol 2001; 43:314–320.

38 Fridén J, Lieber R. Spastic muscle cells are shorter and stiffer than normal cells. Muscle Nerve 2003; 27:157–164.

39 Stephenson DG, Lamb GD, Stephenson GM. Events of the excitation-contraction-relaxation (E-C-R) cycle in fast- and slow-twitch mammalian muscle fibres relevant to muscle fatigue. Acta Physiol Scand 1998; 162:229–245.

40 Grecco LA, Tomita SM, Christovão TC, Pasini H, Sampaio LM, Oliveira CS. Effect of treadmill gait training on static and functional balance in children with cerebral palsy: a randomized controlled trial. Braz J Phys Ther 2013; 17:17–23.

41 Damiano DL, Alter KE, Chambers H. New clinical and research trends in lower extremity management for ambulatory children with cerebral palsy. Phys Med Rehabil Clin N Am 2009; 20:469–491.

42 Smith GV, Forrester LW, Silver KH, *et al.* Effect of treadmill training on translational balance perturbation response in chronic hemiparetic stroke patients. J Stroke Cerebrovasc Dis 2000; 9:238–245.

43 Dimitrijevic MR, Gerasimenko Y, Pinter MM. Evidence for a spinal central pattern generator in humans. Ann N Y Acad Sci 1998; 860:360–376.

44 Silva MS, Daltrário SM. Cerebral palsy: functional performance after gait training treadmill. Fisioter Mov 2008; 21:109–115.