Physical strain: a new perspective on walking in cerebral palsy

Balemans ACJ, Bolster EAM, Brehm MA, Dallmeijer AJ
ABSTRACT

OBJECTIVES: To describe (1) physical strain of walking, (2) the proportion of participants walking above the anaerobic threshold, and (3) 4 phenotypes of physical strain of walking on the basis of deviations in aerobic capacity and walking energy cost (EC) in children and adolescents with cerebral palsy (CP).

DESIGN: Cohort study.

SETTING: Academic medical center.

PARTICIPANTS: A sample (n = 57) of participants (n = 37; mean age, 13.5 ± 4.0 y) with CP (Gross Motor Function Classification System [GMFCS] levels I [n = 13], II [n = 17], and III [n = 7]) and typically developing (TD) participants (n = 20; mean age, 11.8 ± 3.5 y).

INTERVENTIONS: Not applicable.

MAIN OUTCOME MEASURES: Oxygen consumption (VO_{2walk}), speed, and EC were determined during walking at a comfortable speed. Peak oxygen consumption (VO_{2peak}) and anaerobic threshold were measured during a maximal cycling exercise test. Aerobic capacity was reduced if lower than the 10th percentile, and EC was increased if higher than 3SD. Physical strain was defined as follows: (VO_{2walk} / VO_{2peak}) x 100.

RESULTS: Participants with CP had a higher physical strain (GMFCS level I, 55% ± 12%; GMFCS level II, 62% ± 17%; GMFCS level III, 78% ± 14%) than did TD participants (40% ± 11%) (p < 0.001). Forty-three percent of participants with CP showed a VO_{2walk} at or above their anaerobic threshold as compared with 10% of TD participants (p = 0.007). Phenotypes showed that a reduced VO_{2peak} (n = 9) or an increased EC (n = 9) lead to an 18% to 20% higher physical strain, whereas a combination (n = 12) leads to a 40% increase.

CONCLUSIONS: Children and adolescents with CP walk at a high physical strain, approximating intense exercise and a considerable proportion walks close to or above their anaerobic threshold, probably explaining fatigue and reduced walking distance. Both an increased EC and a reduced VO_{2peak} contribute to high physical strain in children or adolescents with CP. The different causes of high physical strain in individuals with CP require different intervention strategies.
INTRODUCTION

Several studies show that the energy cost (EC) of walking (energy consumption normalized for speed) at a comfortable speed can be extremely elevated in children and adolescents with cerebral palsy (CP) as compared with their typically developing (TD) peers\(^1\)\(^-\)\(^3\) and can even be up to 3 times higher with more severe motor involvement.\(^2\)\(^,\)\(^4\) Especially for these individuals, walking can be a strenuous activity and may therefore be less integrated in activities of daily living.\(^5\)

Aerobic capacity, defined as the maximal amount of oxygen that a person is able to use for physical activities (peak oxygen consumption \([\text{VO}_{\text{peak}}]\), has been shown to be significantly lower in children with CP.\(^6\) In addition, children with CP have a lower absolute anaerobic threshold than do TD children.\(^6\) The anaerobic threshold is the point above which energy production is supplemented by anaerobic glycolysis.\(^7\) At intensities above the anaerobic threshold, as a result of intracellular accumulation of lactate and acidosis, one becomes exhausted and muscles become sore and painful. Because of the increased energy demands of walking and the reduced aerobic capacity, it is likely that children and adolescents with CP have an oxygen consumption during walking \([\text{VO}_{\text{walk}}]\) that is close to or above the anaerobic threshold, which accordingly may induce fatigue complaints. This is, however, not yet investigated.

When using more energy for walking together with a reduced aerobic capacity, the physical strain of walking can consequently be high. Physical strain is defined as \([\text{VO}_{\text{walk}}]\) expressed as a percentage of \([\text{VO}_{\text{peak}}]\). The physical strain is an important measure because it reflects the relative intensity of walking. In children with mild CP, the physical strain was shown to be higher than that in TD children.\(^8\) The physical strain of walking in children and adolescents with CP having severe motor impairment is yet unknown. Presumably, because of the higher energy demands of walking in these individuals, the physical strain may be even higher. A high physical strain, especially when walking at an intensity above the anaerobic threshold, may lead to faster exhaustion during activities of daily living, which is often a complaint of individuals with CP who consult a physician.\(^9\)

Reducing the physical strain may be a promising way to reduce fatigue-related walking problems in individuals with CP. To establish this, better insight into the causes of increased levels of physical strain of walking in individuals with CP with different Gross Motor Function Classification System (GMFCS) levels is required. By definition, \([\text{VO}_{\text{walk}}]\) and aerobic capacity determine the physical strain. It is unknown what the contribution of a reduced aerobic capacity and an increased EC of walking is to physical strain. Also,
walking speed is often lower in children with higher GMFCS levels, which reduces the oxygen consumption and consequently the physical strain. However, for individuals with severe motor impairment, physical strain may be even higher at lower walking speeds because of low walking economy (i.e., high EC). To gain more insight into fatigue-related walking problems in children and adolescents with CP, it is important to investigate whether the high physical strain levels are caused by an increased EC or a reduced aerobic capacity or by both. With this knowledge, treatment can focus on intervention strategies that reduce the physical strain in children and adolescents with CP, leading to less rapid exhaustion during activities of daily living. The aims of this study were (1) to compare physical strain of walking in children and adolescents with CP with that of TD participants; (2) to describe the proportion of participants with CP walking above the anaerobic threshold; and (3) to describe 4 phenotypes of physical strain of walking on the basis of deviations in aerobic capacity and EC in children and adolescents with CP.

METHODS

Participants

Children and adolescents with CP who were referred for exercise testing in a university medical center as part of their clinical assessment in the period of May 27, 2010 to November 5, 2015 were included in the cross-sectional study. Twenty TD participants in the same age range as the CP participants were recruited as a control group through primary and secondary schools and through employees of the outpatient clinic and university. Indication criteria for referral for exercise testing were (1) complaints of reduced walking duration and/or distance or fatigue during walking-related activities; (2) diagnosed with spastic CP; (3) aged 6 to 24 years; and (4) classified as GMFCS level I, II, or III. Exclusion criteria were contraindications to perform maximal exercise, such as unstable seizures, cardiac arrhythmia, mitochondrial defects, hip dysplasia, and severe musculoskeletal complaints of the lower extremities. The study was approved by the medical ethics board at the VU University Medical Center in Amsterdam, and parents and participants of the control group older than 12 years signed an informed consent before participation.

Procedure and measurements

Participants visited the outpatient clinic for exercise testing. Participants were given specific instructions not to eat or drink (except for water) 1.5 hours before the measure-
ments and not to perform intensive exercises before the measurements. Anthropometric data were collected. Height (cm) was measured with a wall-fixed measure in the standing position (DGI 250D, KERN DE version 3.3 10/2004), and weight (kg) was measured with an electronic scale (DGI 250D, KERN DE version 3.3 10/2004).

**Walking test**

Oxygen consumption per unit time (VO₂), carbon dioxide output (VCO₂), and minute ventilation were measured breath by breath with a portable system (METAMAX 3B). Before the measurement, air pressure was calibrated, volume was calibrated with a 3-L syringe, and the oxygen and carbon dioxide analyzers were calibrated using ambient air and a reference gas of known concentration. Heart rate was monitored continuously during the tests with a heart rate monitor (Polar Vantage XL). Participants wore a face mask, which was carefully inspected for leakage. Participants watched a movie for 5 minutes in the supine position to get used to the gas analysis equipment, after which participants performed a walk test for 6 minutes at their own comfortable speed on an oval track. Participants wore their daily walking gear as well as their orthosis and used a walking aid, if applicable. The distance walked in 6 minutes was measured to calculate walking speed (m·min⁻¹). EC can be reliably determined in children and adolescents with CP using this protocol.³

**Maximal exercise test**

The maximal exercise test was performed on a cycle ergometer (Corival V2) after 5- to 10-minute rest, depending on the needs of the participant. The exercise test started with a warm-up cycling period (2 – 3 min). Then, a submaximal exercise bout (3 – 5 min) was performed to get used to the cycling frequency and to determine the initial load of the maximal exercise test. The initial load of the submaximal exercise bout was based on height and GMFCS level.⁶ After 1-minute rest, the maximal test commenced and the participants had to cycle until exhaustion. Verbal encouragement was given. Every minute the load increased with a work rate, which was dependent on the participant’s height and GMFCS level. Maximal exercise was considered achieved and used in the analyses if 2 of the following 3 were achieved: (1) heart rate > 180 beats·min⁻¹;¹¹ (2) respiratory exchange ratio > 1; and/or (3) subjective signs of exhaustion, such as sweating, out of breath, and fatigued. More information on this protocol can be found elsewhere.⁶ The test-retest reliability of VO₂peak assessments in children with CP using this protocol was excellent.¹²
Data analysis

Oxygen consumption during walking (ml·kg\(^{-1}\)·min\(^{-1}\)) and heart rate (beats·min\(^{-1}\)) were averaged over the last 2 minutes of the test in which a steady state was reached. Steady state was controlled for by checking whether walking speed, VO\(_2\), and VCO\(_2\) were stable (minimal fluctuation) and respiratory exchange ratio was < 1.0. Energy consumption (J·kg\(^{-1}\)·min\(^{-1}\)) was calculated using the following formula: \(VO_{walk} (\text{ml·kg}^{-1}·\text{min}^{-1}) \times (4.960 \times \frac{VCO_{walk} (\text{ml·min}^{-1})}{VO_{walk} (\text{ml·min}^{-1})} + 16.040)\).\(^{13}\)

EC (J·kg\(^{-1}\)·m\(^{-1}\)) was calculated using the following formula: energy consumption/speed.

\(VO_{peak} (\text{ml·kg}^{-1}·\text{min}^{-1})\) was determined by selecting the highest 30-second value of the last 2 minutes before the recovery phase. Peak heart rate was determined as the highest measured heart rate. The anaerobic threshold was determined over the maximal exercise test data. The anaerobic threshold is the point at which the CO\(_2\) production increases relatively faster than the O\(_2\) consumption, indicating that energy production is supplemented by anaerobic glycolysis. This was determined by 2 independent raters using the V-slope method: VCO\(_2\) is plotted against VO\(_2\), and it is determined where the slope exceeds 1.0.\(^{7}\) In case of disagreement between the 2 raters, a third rater was consulted (needed in 2 cases). For each participant, it was determined whether VO\(_{walk}\) was higher or lower than their anaerobic threshold. First, 10% of the anaerobic threshold of reference values was calculated.\(^{14}\) A VO\(_{walk}\) higher than the anaerobic threshold was defined as VO\(_{walk}\) greater than the anaerobic threshold with a difference between VO\(_{walk}\) and anaerobic threshold of more than 10%. Previous studies have shown that 10% was valid for showing a deviation from normal gait parameters.\(^{15}\)

Physical strain of walking was denoted as VO\(_{walk}\) (ml·kg\(^{-1}\)·min\(^{-1}\)) and expressed as a percentage of VO\(_{peak}\) (ml·kg\(^{-1}\)·min\(^{-1}\)).

To describe which components determine the high physical strain in participants with CP, 4 phenotypes were identified on the basis of cutoffs for reduced VO\(_{peak}\) and increased EC. A low VO\(_{peak}\) was defined as a VO\(_{peak}\) lower than the 10\(^{th}\) percentile of age- and sex-matched reference values of TD children,\(^{14}\) and a high EC was defined as higher than 3SD from age-matched reference values (Appendices 3.1 and 3.2). A VO\(_{peak}\) lower than the 10\(^{th}\) percentile can discriminate children and adolescents being at risk of having metabolic syndrome.\(^{36}\) Phenotype 1 was characterized by a normal VO\(_{peak}\) and a normal EC; phenotype 2 was characterized by a low VO\(_{peak}\) and a normal EC; phenotype 3 was characterized by a normal VO\(_{peak}\) and a high EC; and phenotype 4 was characterized by a low VO\(_{peak}\) and a high EC. Physiological variables and walking speed were determined for different phenotypes.
Statistics

It was checked whether data followed a normal distribution through inspection of mean values, SDs, and ranges and through visual inspection of the histogram and normal Q-Q plot. Because the data were distributed normally, parametric tests were used. The differences in physiological parameters (and walking speed) between TD individuals and those with different GMFCS levels were analyzed using 1-way analysis of variance with a Bonferroni correction. Confounding of height and age was checked by determining whether mean differences of the physiological parameters between groups changed > 10% when adding height or age as a covariate. The proportion of participants who were walking above their anaerobic threshold was determined and compared between TD and different GMFCS levels using a Fisher-Freeman-Halton exact test. Analyses were performed using SPSS version 22.0. A p-value of < 0.05 was considered statistically significant.

RESULTS

Participants

Forty-three participants with CP were referred for both a walking test and a maximal exercise test in the period from May 2010 to November 2015. Six of these participants did not meet the criteria for maximal exercise. Therefore, the data of 37 participants with CP were analyzed in this study. Twenty TD participants served as a control group. Participant characteristics are presented in Table 3.1. All children were used to cycling.

Table 3.1  Participant characteristics

<table>
<thead>
<tr>
<th></th>
<th>TD (N = 20)</th>
<th>GMFCS I (N = 13)</th>
<th>GMFCS II (N = 17)</th>
<th>GMFCS III (N = 7)</th>
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<tr>
<td>Gender [boy/girl]</td>
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<td>7/6</td>
<td>7/10</td>
<td>4/3</td>
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<td>Age [y mo]</td>
<td>11y8mo (3y5mo)</td>
<td>11y4mo (3y1mo)</td>
<td>13y11mo (3y7mo)</td>
<td>16y4mo (4y11mo)</td>
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<td>Height [cm]</td>
<td>152.4 (16.8)</td>
<td>144.0 (12.8)</td>
<td>154.5 (14.3)</td>
<td>158.4 (11.6)</td>
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<tr>
<td>Weight [kg]</td>
<td>43.2 (20.3)</td>
<td>39.9 (12.3)</td>
<td>46.9 (11.9)</td>
<td>52.7 (11.2)</td>
</tr>
<tr>
<td>Type CP [uni/bi]</td>
<td>NA</td>
<td>6/7</td>
<td>0/17</td>
<td>0/7</td>
</tr>
<tr>
<td>Walking aid [no/stiff sole inlays/ort/aid + ort]</td>
<td>20/0/0/0</td>
<td>7/3/3/0</td>
<td>6/3/7/1</td>
<td>0/0/0/7</td>
</tr>
</tbody>
</table>

Values are presented as mean (SD) or n. TD, typically developing; CP, cerebral palsy; GMFCS, gross motor function classification system; ort: orthosis, aid: walking aid; NA, not applicable; uni, unilateral; bi, bilateral.
<table>
<thead>
<tr>
<th>Table 3.2 Descriptives of physiological parameters</th>
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<tr>
<td></td>
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<tr>
<td>-----------------------------------------------</td>
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<tr>
<td>6-minute walking test</td>
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<tr>
<td>VO$_{2\text{walk}}$ [ml·kg$^{-1}$·m$^{-1}$]</td>
</tr>
<tr>
<td>Energy cost [J·kg$^{-1}$·m$^{-1}$]</td>
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<tr>
<td>Walking speed [m·min$^{-1}$]</td>
</tr>
<tr>
<td>HR$_{\text{walk}}$ [beats·min$^{-1}$]</td>
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<tr>
<td>Maximal exercise test</td>
</tr>
<tr>
<td>VO$_{2\text{peak}}$ [ml·kg$^{-1}$·m$^{-1}$]</td>
</tr>
<tr>
<td>HR$_{\text{peak}}$ [beats·min$^{-1}$]</td>
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<tr>
<td>RER$_{\text{peak}}$</td>
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<tr>
<td>Anaerobic threshold [ml·kg$^{-1}$·m$^{-1}$]</td>
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<td>Physical strain</td>
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<tr>
<td>%VO$_2$</td>
</tr>
<tr>
<td>VO$_{2\text{walk}}$ (number of participants walking below / above their anaerobic threshold)</td>
</tr>
</tbody>
</table>

Values are presented as mean (SD) or otherwise as indicated. TD, typically developing; GMFCS, Gross Motor Function Classification System; VO$_{2\text{walk}}$, oxygen uptake during walking; %VO$_2$, physical strain; HR, heart rate; RER, respiratory exchange ratio; NA, not applicable; VO$_{2\text{peak}}$, peak oxygen uptake. * Fisher Freeman Halton exact test.
Outcome measures

Oxygen consumption during walking was not different between participants with GMFCS level I, II, III, and TD. Walking speed was lower in participants with GMFCS levels I, II, and III than in TD ($p < 0.001$) and lower in participants with GMFCS levels II and III than in participants with GMFCS level I. EC was higher in participants with GMFCS levels II and III than in TD and higher in participants with GMFCS level III than in participants with GMFCS levels I and II (Table 3.2).

$VO_{peak}$ was lower in all GMFCS levels than in TD ($p < 0.001$) but not different among GMFCS levels ($p < 0.001$). Participants with CP had a higher physical strain than did TD participants, and physical strain was higher in GMFCS level III than in GMFCS level I ($p < 0.001$).

Forty-three percent of participants with CP (GMFCS level I, 23%; GMFCS level II, 47%; GMFCS level III, 71%) showed a $VO_{walk}$ that was higher than their anaerobic threshold, while this was the case in 10% of TD participants ($p = 0.007$) (see Table 3.2).

The distribution of participants with CP over the different walking phenotypes was as follows: 7 participants could be identified in phenotype 1 (normal $VO_{peak}$ and normal EC), 9 participants in phenotype 2 (low $VO_{peak}$ and normal EC), 9 participants in phenotype 3 (normal $VO_{peak}$ and high EC), and 12 participants in phenotype 4 (low $VO_{peak}$ and high EC).

Participants with CP who had either a low $VO_{peak}$ (phenotype 2) or a high EC (phenotype 3) had an 18% to 20% higher physical strain ($60\% \pm 10\%; p < 0.028$ and $58\% \pm 13\%; p < 0.076$, respectively) than did participants with CP showing both components within normal ranges ($43\% \pm 7\%$). Participants with both a reduced $VO_{peak}$ and an increased EC had a 40% higher physical strain ($79\% \pm 12\%; p < 0.003$) than did those showing both components within normal ranges (Figure 3.1). The analysis showed that there was no confounding of age or height.

DISCUSSION

The results of our study show that the physical strain of walking was higher in children and adolescents with CP classified as GMFCS levels I, II, and III who report walking complaints than in TD peers. A considerable proportion of children and adolescents with CP have a $VO_{walk}$ that was higher than their anaerobic threshold. Furthermore, most individuals have a reduced aerobic capacity or an increased EC.
Figure 3.1  Physiological characteristics of the different phenotypes of children and adolescents with CP.

\( a: p < 0.05; \)  \( b: p < 0.1. \)

\( \text{VO}_2\text{walk} \), oxygen uptake during walking; \( \text{VO}_2\text{peak} \), peak oxygen uptake.
Our study was the first to examine this perspective on physical strain of walking. The high levels of physical strain of walking at a comfortable speed found in all GMFCS levels lie, as compared to training guidelines, within the moderate (GMFCS levels I and II) and vigorous (GMFCS level III) intensity exercise zones. Walking at intensities of 60% to 80% of VO\textsubscript{2peak} and higher is fatiguing and may not be sustained for a long period. It is therefore not surprising that fatigue during walking is an often reported complaint in individuals with CP.

To select proper treatment, it is important to determine whether an increased EC and/or a reduced VO\textsubscript{2peak} is responsible for the high levels of physical strain in participants with CP. Our finding of an equal distribution over the different phenotypes shows that either an increased EC, a reduced VO\textsubscript{2peak}, or an increased EC combined with a reduced VO\textsubscript{2peak} can cause high physical strain. Likely, increased EC is associated with motor impairments in CP (e.g., spasticity, uncontrolled movements, muscle weakness, and poor balance) and the related gait deviations, whereas reduced VO\textsubscript{2peak} also depends on the level of physical activity. It appeared that a VO\textsubscript{2peak} lower than the 10\textsuperscript{th} percentile or an EC higher than 3SD of reference values contributed to an 18% to 20% higher physical strain. Having both a deviated VO\textsubscript{2peak} and a higher EC resulted in a 40% higher physical strain, meaning that those children walk at 80% of their maximal capacity. Addressing increased EC and reduced VO\textsubscript{2peak} requires different treatment strategies for lowering physical strain. To increase VO\textsubscript{2peak}, physical fitness training may be indicated, whereas orthoses and orthopedic surgery have the potential to reduce the EC, especially in children with more severe motor involvement and thus higher EC.22 Appropriate treatment of physical strain may lead to a reduction of fatigue, enabling a more physically active and healthy lifestyle and helping individuals with CP to participate with peers.

Our results imply that a considerable proportion of children and adolescents with CP, especially those with severe motor involvement (GMFCS levels), walk at intensities where metabolism is supplemented by anaerobic metabolism. This cannot be continued for a prolonged period because muscles can become sore, fatigued, and painful. In daily life, this hampers walking for longer distances. In young adults with CP, physical fitness training can lead to an increase in the anaerobic threshold. On the basis of this finding, we hypothesize that fitness training can also be an effective intervention to lower the number of youth with CP walking close to or above their anaerobic threshold, which might lower fatigue issues in this group. However, whether lowering the anaerobic threshold and/or increasing the VO\textsubscript{2peak} leads to less fatigue during walking is yet to be determined.
From our results it can be concluded that walking may be a moderate or even vigorous activity for individuals with CP. This indicates that walking on a regular basis can be a type of physical fitness training for this group. However, as can be seen from our results, $VO_{peak}$ is often reduced in children and adolescents with CP. It could be that those individuals do not walk long enough\textsuperscript{24} to provide an overload with concomitant improvement in $VO_{peak}$\textsuperscript{17}. The other condition for improvement in $VO_{peak}$ is a sufficient recovery of 24 to 36 hours after vigorous exercise\textsuperscript{17}. If recovery is not warranted, for instance, when individuals with CP walk several times a day at a high intensity, overtraining can occur with accompanying issues such as ineffectiveness of training, soreness, and fatigue. However, no previous study has investigated the possibility of overtraining in CP. Future research should reveal whether meeting training and recovery guidelines and/or decreasing EC leads to a lower physical strain of walking and reduction of fatigue complaints.

A higher physical strain was previously found in a study\textsuperscript{8} in children with mild (GMFCS level I) CP than in TD peers. Physical strain values in this study in which $VO_{peak}$ values were obtained using a shuttle run test (36\% for TD and 52\% for CP) correspond to our findings (40\% and 55\%, respectively). The high physical strain in our study was detected during walking at a comfortable speed, which was lower in all participants with CP than in TD peers. In the previously mentioned study, walking speed was not different in participants with CP as compared with controls and comparable (75.7 m·min$^{-1}$) to what we found in GMFCS level I (71.6 m·min$^{-1}$). Another study that evaluated physical strain in adults (mean age, 36 ± 6 y) showed a lower physical strain (GMFCS level I, 37\%; GMFCS level II, 58\%; GMFCS level III, 54\%). The lower walking speeds (GMFCS level I, 52 m·min$^{-1}$; GMFCS level II, 47 m·min$^{-1}$; GMFCS level III, 40 m·min$^{-1}$) probably explain these lower strain levels because $VO_{walk}$ is speed dependent.

**Study limitations**

Physical strain in participants who were not able to reach maximal exercise on the cycle ergometer was not determined. Peak $VO_2$ was determined on a cycle ergometer so that all participants, including those with severe balance problems, could be tested in the same way. In general, a higher $VO_{peak}$ and anaerobic threshold can be achieved with running tests. Therefore, the physical strain of walking in both CP and TD groups could have slightly been overestimated in this study. The literature shows that anaerobic threshold occurs at around 55\% to 64\% in boys and at 57\% to 66\% in girls determined by cycle ergometry\textsuperscript{14}, whereas during treadmill testing values varied from 61\% to 74\% in boys and from 54\% to 69\% in girls\textsuperscript{25}. However, a previous study\textsuperscript{8} investigating physical strain in
children with CP classified as GMFCS level I, with VO_{peak} determined using a shuttle run test, showed comparable physical strain values, so a possible overestimation of the physical strain due to cycle ergometry is not likely. TD children in this study tended to walk faster (81.7 m·min^{-1} in literature) than previously reported (70 – 73 m·min^{-1}). Therefore, VO_{peak} (20.0 ml·kg^{-1}·min^{-1} in this study vs 12.9 – 15.3 ml·kg^{-1}·min^{-1} in literature) was higher and thus physical strain in TD participants and the proportion of TD children walking above the anaerobic threshold in daily life may have been overestimated. Nevertheless, the anaerobic threshold in TD participants was in line with previous studies using cycle ergometry (25.5 ml·kg^{-1}·min^{-1} vs 23.0 – 28.1 ml·kg^{-1}·min^{-1}). All included participants with CP in this study had walking complaints; therefore, the results cannot be generalized to individuals with CP without walking complaints.

**Conclusions**

Compared with TD peers, children and adolescents with CP walk at a high physical strain, approximating intense exercise. A considerable proportion of children and adolescents with CP walk at oxygen consumption levels above their anaerobic threshold while walking at a significantly lower speed as compared with TD peers. Walking at intensities of > 60% of VO_{peak} is fatiguing and cannot be sustained for a long period. It is therefore not surprising that fatigue during walking is an often reported complaint in this group. Both an increased EC and a reduced VO_{peak} can determine the high physical strain in individuals with CP. Based on exercise test results, treatment should be targeted at decreasing EC and/or increasing VO_{peak} to lower the physical strain of walking in individuals with CP.

**Acknowledgments**

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REFERENCES


### Appendix 3.1  Cut-off values for the gross energy cost (J·kg⁻¹·min⁻¹) during walking

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<th>Age Group</th>
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<th>SD</th>
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<th>+3SD</th>
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<tbody>
<tr>
<td>6 – &lt; 9 year</td>
<td>54</td>
<td>4.98</td>
<td>0.77</td>
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<td>9 – &lt; 12 year</td>
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<td>12 – &lt; 15 year</td>
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<td>4.10</td>
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<td>≥ 15 year</td>
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<td>3.67</td>
<td>0.49</td>
<td>4.65</td>
<td>5.14</td>
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</table>

These reference values are retrieved from the database of the gait laboratory from the VU University Medical Center, Amsterdam, NL and from the Gillette Children’s Specialty Healthcare, Center for Gait and Motion Analysis, St Paul, USA (unpublished data).

### Appendix 3.2  Cut-off values for the aerobic capacity (VO₂peak, expressed in ml·kg⁻¹·min⁻¹)

<table>
<thead>
<tr>
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<th>P25</th>
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<td>&lt; 8 year</td>
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Physical strain