



Original Article

## The relationship between the physical cost index and knee extensor strength in children with hemiplegic cerebral palsy

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**Abstract.** [Purpose] Lower extremity strength is a contributing factor to energy efficiency of gait. However, this contribution has not previously been evaluated in children with hemiplegic cerebral palsy (CP). The aim of this study was to evaluate the association between energy consumption, measured by the physical cost index (PCI), and strength of lower extremity, measured by the maximum knee extensor strength (MKES), in children with hemiplegic CP. [Subjects and Methods] Subjects were 10 children (4 males and 6 females; age, 7–17 years) with hemiplegic CP, but no history of orthopedic intervention or botulinum toxin treatment over the 1 year prior to the assessment. The PCI was measured during a 6-min walk test, and MKES using hand-held dynamometry, with the highest of two measures used for analysis. [Results] A negative correlation was identified between the PCI and MKES (R-value,  $-0.81$  (affected) and  $-0.83$  (unaffected) lower limb). [Conclusion] Higher lower extremity strength was associated with lower fatigability during a 6-min walk test in children with hemiplegic CP, providing evidence for the inclusion of strengthening exercises for both the affected and unaffected extremities in the rehabilitation of these children.

**Key words:** Cerebral palsy, Physical cost index, Knee extensor strength

(This article was submitted Jun. 13, 2017, and was accepted Jul. 7, 2017)

### INTRODUCTION

The development of gross motor function in children with cerebral palsy (CP) often plateaus at around the age of 8 to 10 years<sup>1)</sup>. Limitation in the energy efficiency of walking may be an important limiting factor to the continued development of gross motor function in children with CP. As an example, Rose et al.<sup>2)</sup> reported a significantly higher energy consumption during walking for children with CP than for age-matched children with no impairments. As a result of this higher energy demand, children with CP tend to fatigue easily, which limits their activity participation and lowers their overall quality of life (QOL). Different methods are available to assess energy efficiency, such as the physical working capacity and oxygen cost at 75% of the maximum heart rate. However, these techniques require specialized equipment and are not practical for use with children. Therefore, in our study, we used the physical cost index (PCI), which quantified the energy demand of a physical activity by the change in heart rate (HR) from resting baseline to post-activity. The PCI has previously been used to assess the energy requirement of walking in children with CP having movement impairments<sup>3,4)</sup>.

Decreased strength may be an important limiting factor of energy efficiency among children with CP. Previous studies have reported on the benefits of a program of functional strengthening in improving the energy efficiency of walking in children with diplegic CP<sup>3,4)</sup>. Based on these findings, it is likely that lower extremity strength is a contributing factor to energy efficiency, although this association has not previously been evaluated in children with hemiplegic CP. A relationship between lower extremity strength and the energy efficiency of walking has been reported for adults with hemiplegia<sup>5)</sup>, with

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general strengthening typically being included in the physical rehabilitation of adults post-stroke. However, the movement limitations of adults with a hemiplegic stroke and children with hemiplegic CP is very different, as adults have prior knowledge of normal movement while children acquire their motor function within the context of their hemiplegia. Therefore, it is not apparent that the association between lower extremity strength and energy efficiency would be comparable for adult and pediatric patients with a hemiplegia. Accordingly, the aim of our study was to evaluate the association between energy consumption, measured by the physical cost index (PCI), and strength of lower extremity, measured by the maximum knee extensor strength (MKES), in children with hemiplegic cerebral palsy (CP). Clarification of the association between lower extremity strength and energy efficiency for motor function in this clinical population would be important to inform physical therapy intervention.

## SUBJECTS AND METHODS

This was a cross-section study, including 10 children (4 males, 6 females, with a mean age of 11.7 years, range, 7–17 years) with a diagnosis of hemiplegic CP, who attended the orthopedic department at our hospital for either consultation or rehabilitation, between August 2015 and February 2016. All subjects had sufficient cognitive capacity to provide consent and to safely and effectively complete the experimental task and measures. None of the subjects had a history of orthopedic intervention or botulinum toxin treatment over the 1 year prior to the assessment. To ensure a representative pulse rate was used in the calculation of the PCI, we excluded patients who were attending a first visit and those with poor physical fitness. Energy efficiency was assessed using the PCI, calculated as the difference between the average heart rate at rest, measured over a 5-min period in quiet sitting, and the heart rate after a 6-min walk test. The PCI was normalized to walking speed for between-subject comparison.

The MKES was assessed using a standardized method, with subjects in a seated position, without arm support, and the knee in 90° flexion. Resistance was applied to the anterior surface of the lower tibia, approximately 5 cm proximal to the lateral malleolus. Resistance was gradually applied using a hand-held dynamometer over a 3-s period, allowing subjects to adjust to the applied force and to recruit the maximum number of muscle fibers. Subjects were instructed to exert their maximal force against the applied resistance. Two trials were completed for each leg, with the average maximal force calculated and used in the analysis.

The normality of the distribution of the PCI and MKES scores was assessed using the Shapiro-Wilk test. The MKES was compared between the unaffected and the affected lower extremity using a paired t-test. The Spearman's rank correlation coefficient between the PCI and the MKES was calculated independently for the unaffected and affected lower extremity. All analyses were performed using SPSS (version 24.0 for Windows), with a p-value <0.05 considered statistically significant.

This study was approved by the Ethics Review Board (Authorization Number: 006) of the Minamitama Orthopedic Hospital. All subjects, and their parent(s), provided informed consent. This study was supported by a research grant from the Tokyo Metropolitan Physical Therapy Association. The authors have no conflicts of interest to declare.

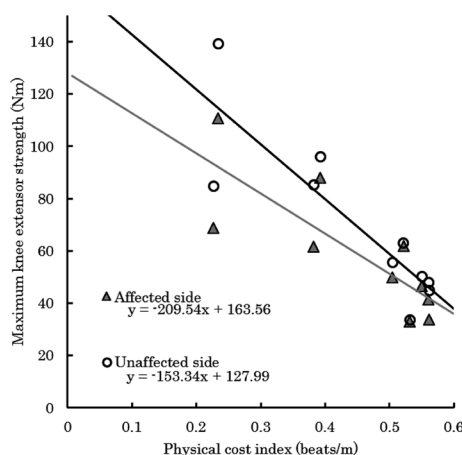
## RESULTS

The mean  $\pm$  standard deviation of the PCI was  $0.45 \pm 0.12$  beats/m. There was a significant difference in the MKES score between the affected ( $59.5 \pm 24.7$  Nm) and unaffected ( $70.0 \pm 31.6$  Nm) lower extremity ( $p < 0.01$ ). A significant negative correlation between MKES and PCI was identified for both the affected (R-value,  $-0.81$ ; power ( $1-\beta$ ),  $0.94$ ) and unaffected (R-value,  $-0.83$ ; power ( $1-\beta$ ),  $0.96$ ) lower extremities (Fig. 1,  $p < 0.01$ ).

## DISCUSSION

Using a 6-min walk test, we identified a significant negative association between MKES measured at rest and the PCI, indicative that a decrease in lower extremity strength is associated with greater fatigability during walking and, therefore, might be a limiting factor to the gross motor function of children with hemiplegic CP. Functional strengthening has been shown to improve the GMFM score among children with diplegic CP<sup>3</sup>. An increase in lower extremity strength after the intervention was deemed to be the principal factor contributing to the increase in GMFM score, increasing the stability of the lower extremity and strength during the stance phase of gait, with a decrease in the crouched position in standing, and other gross motor function tasks<sup>6</sup>. Therefore, knee extension strength improves the smoothness of walking and, therefore, the energy efficiency of walking. In fact, in our study, greater MKES was associated with a lower PCI, indicative of a lower difference between resting heart rate and the heart rate after the 6-min walk. Our findings are in agreement with previous studies that have reported a correlation between the MKES of the affected lower extremity and walking speed and distance among adult stroke patients<sup>7-9</sup>.

Of note, we identified a significant correlation between the PCI and MKES of both the affected and unaffected lower extremities, which is contrary to findings for adult stroke patients for whom energy efficiency during walking correlates specifically with the extensor strength of the affected lower extremity<sup>7, 9</sup>. This likely reflects the implicit difference of a hemiplegia sustained during child development compared to adults. In adults, energy efficiency is susceptible to the unilateral



**Fig. 1.** Spearman's rank correlation between the PCI and the maximum knee extensor strength for the affected (R-value.  $-0.81$ ; power  $(1-\beta)$ ,  $0.94$ ;  $p < 0.01$ ) and unaffected (R-value.  $-0.83$ ; power  $(1-\beta)$ ,  $0.96$ ;  $p < 0.01$ ) lower limbs.

decline in motor function and strength of the hemiplegic side. However, children with hemiplegic CP have acquired their motor function and strength in the presence of the hemiplegia-related asymmetry, which likely explains the association between energy efficiency and the strength of both lower extremities. Therefore, in children with hemiplegic CP, there is an indication to increase the strength of both the affected and unaffected lower extremities for improving energy efficiency. However, as we only included children with hemiplegic CP, it is unclear if identified association between MKES and PCI for walking would be comparable in children with other types of CP.

Previous studies have reported the PCI to typically range between 0.34 and 0.49 in healthy children<sup>10, 11</sup>). In this study, the PCI was usually around 0.4. The energy efficiency of children with a  $PCI \leq 0.4$  was considered to be comparable to the efficiency of healthy age-matched children. Therefore, exercise experience and activity level in daily life may have a greater influence over the development of energy efficiency than motor function itself. In future research, we will evaluate the association between the PCI and exercise experience and activity level, in addition to MKES measurements. As the PCI is sensitive to the pulse rate, it is important to consider that stress associated with the testing session might have influenced our results. Inclusion of a self-report of stress might be important to include in future studies as well.

In conclusion, higher lower extremity strength was associated with lower fatigability during a 6-min walk test in children with hemiplegic CP, providing evidence for the inclusion of strengthening exercises for both the affected and unaffected in the habilitation of these children.

## ACKNOWLEDGEMENTS

This study was supported by Tokyo Metropolitan Physical Therapy Association. We thank patients and their family for their participation.

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