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Energy cost of walking in children with spastic cerebral palsy: Relationship with age, body composition and mobility capacity

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ABSTRACT

The energy cost (EC) of walking is different for typically developing (TD) and children with cerebral palsy (CP). The associated factors of EC are not fully understood in children with CP. We assessed the relationship between EC and age, body surface area (BSA), and gross motor function measure (GMFM). We retrospectively examined data collected between 2003 and 2011 on 276 children aged 4–18 years who were classified as Gross Motor Function Classification System level I, $n = 79$; II, $n = 123$; and III, $n = 74$. Energy cost was assessed while children walked 6–8 min at a comfortable, self-selected speed using their typical walking aids and/or orthoses as part of a clinical gait analysis. During the test, participants wore a breath-by-breath portable gas analysis system, measuring oxygen consumption. To calculate EC (J/kg/m), oxygen consumption was converted to J/kg/min and divided by walking speed. Data were analyzed using linear regression model. Energy cost correlated inversely with age ($\beta = -0.16$, $R^2 = 0.02$, $P = 0.01$), BSA ($\beta = -3.35$, $R^2 = 0.11$, $P < 0.0001$), and GMFM ($\beta = -0.12$, $R^2 = 0.42$, $P < 0.0001$). In the multiple linear regression model, GMFM was the most potent correlate of EC, BSA explained another 10% of the variance ($R^2 = 0.53$), and age was a marginally significant correlate of EC ($P = 0.08$). In summary, in children with CP in our study, EC decreased as GMFM and BSA increased, and GMFM was the most potent correlate of EC.

1. Introduction

Cerebral palsy (CP) is an umbrella term, encompassing a "group of non-progressive disorders of motor coordination secondary to lesions of the brain arising in utero or during the very early stages of development" [1]. It occurs in every 2/1000–2.5/1000 live births [1]. Although these brain 'lesions' are described as static, the outcomes of these conditions lead to many different forms of motor impairment, such as weakness of muscles (paretic muscles) and spasticity [1]. Specifically, children with CP tend to exhibit a defect in the development of the gross motor function, thus implying reduced mobility [1,2]. One of the results of impairments in motor function in children with CP is increased energy expenditure during walking, relative to typically developing (TD) children [2–5], resulting in a lower economy of walking.

Energy expenditure covers the energy consumption (energy used per unit of time) as well as the energy cost (EC), defined as the energy consumed per meter. It can be calculated as the energy consumption divided by speed. The EC has been reported to be higher (about 40%) in children and adolescents with CP compared with TD children, which implies lower economy of walking [6]. Such high energy costs of walking can lead to limited participation in activities and even to the loss of walking mobility when excessively high EC makes gait impractical. Knowledge of the factors associated with EC is necessary for appropriate care planning for children and youth with CP.

Some studies already investigate the relationship between EC and the Gross Motor Function Classification System (GMFCS), a five-level classification system developed to classify the severity of the gross motor function in children with CP. They demonstrate that EC increases with an increase of GMFCS-level [7–9] or with a lower score on dimensions D and E of the Gross motor function measure (GMFM) [10]. These inverse correlations between oxygen cost and GMFM are recently confirmed by the prospective studies of Sullivan et al. and Kerr et al. [9,11]. They studied age-related trends in the economy of walking in children with CP and showed that the relationship between oxygen cost and age was best described by a quadratic model, with the lowest point of the curve occurring at age 12 years, suggesting that gait is least efficient at this age [7]. Bowen et al. studied the body surface area (BSA) and its relation with oxygen

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cost in a population of TD children [12]. This study established an inverse linear relationship between BSA and oxygen cost, suggesting that regardless of the changes with age, as a child's body size becomes bigger, oxygen cost declines. To our knowledge, there are no studies that investigated this relationship in children with CP. Since children grow during a period of rehabilitation, the relation between EC and BSA would be relevant when evaluating the outcome of therapy on economy of walking. The aim of this current study was to simultaneously assess the relationship of EC with age, BSA, and GMFM of children and youth with CP.

2. Methods

After an Institutional Review Board (IRB) approval from the relevant institutions, we conducted a retrospective cohort study to assess factors related with EC in children diagnosed with CP, who were followed at a pediatric orthopedic specialty hospital for their condition.

2.1. Patients

Children and youth with spastic (unilateral or bilateral) CP at GMFCS levels I, II, or III (able to walk with or without walking aids) who underwent clinical gait analysis between 2003 and early 2011 were considered for this study. Those children who performed oxygen consumption testing during walking were reviewed for inclusion in this retrospective study.

To be included in this study, patients were between 4 and 18 years of age, able to cooperate with the test, able to walk independently with or without walking devices (GMFCS I, II, or III), and able to walk for at least 6 min in a steady-state condition at a comfortable walking speed of at least 20 m/min. Potential participants were excluded if they underwent orthopedic or neurosurgical treatment within six months or received botulinum toxin A within three months before the assessment.

2.2. Procedure

Each metabolic walking test consisted of a 5-min resting phase, followed by a 6–8-min walking phase, and completed by another 5 min of resting. Children were required not to eat or drink for 2 h prior to the test.

Before the children started testing, several characteristics were recorded including age, height, weight, and diagnosis. Body surface area (BSA) was calculated using a validated method for children and young adults reported by Lam et al. [20]. Motor function was registered using dimension D of the 88-item GMFM (GMFM-88). A GMFCS classification [13] was assigned either at the time of the test or retrospectively by a single experienced clinician through a standardized procedure. All measurements and registrations were performed by the physiotherapists in the gait lab. After completing this registration, patients were seated in a chair, the equipment was put on, and a mask was fixed on their faces. This mask was then checked carefully for any air leakage. During the resting test, the participants sat quietly for 5 min, supported on a chair with a backrest. This test was followed by a walking test over ground in the hallway of the hospital for 6–8 min, walking at comfortable, self-selected speed using their typical walking aids and/or orthoses. The test was completed by another 5 min of supported sitting, until the resting values of heart rate (HR in beats/min) and oxygen uptake (volume of oxygen: VO_2 in ml/min) were achieved. The distance covered during the walking test was also assessed to calculate average walking speed.

2.3. Equipment

During the tests, breath-by-breath oxygen uptake (VO_2 in ml/min), carbon dioxide output (VCO_2 in ml/min), minute ventilation (VE in l/min), and HR were registered by a breath-by-breath portable gas-analysis system (Cosmed K4b^2, Cosmed, Rome, Italy) [14]. The Cosmed K4b^2 system consists of a portable unit that contains O_2 and CO_2 analysers and is placed on the chest for the storage of data, which were uploaded on the computer after the test was completed; a silicon-mask, which was fitted on the face covering mouth and nose, with a flow-rate turbine; and a battery pack located on the back. Prior to testing, the instrument was calibrated.

To measure the HR, a Polar HR monitor (Polar Electro, New York, USA) was placed around the chest.

2.4. Measurements

Oxygen consumption was assessed during sub-maximal effort (walking at a comfortable speed). To calculate EC, which is expressed as the amount of energy consumed per meter, children had to walk in a steady-state condition. The method described by Schwartz [15] was used to determine whether there was a steady state. This method uses a floating 180-s window to identify respiratory steady-state portions. We then calculated the mean values over all the steady-state periods during this 6–8-min walking interval. In addition, the respiratory exchange ratio (RER, the ratio between VCO_2 and VO_2) had to be lower than 1.0 during the defined steady-state intervals. The oxygen cost (OC) was calculated by dividing the oxygen consumption (VO_2 in ml/kg/min) by average speed (m/min) of walking. Then, OC was converted to EC_{gross} following the equation below [6]:

$$EC_{gross}\ (\mathrm{J/kg/m}) = ((4.960 * \mathrm{RER} + 16.040) * \mathrm{OC(ml/kg/m)})$$

2.5. Statistical analysis

Normality tests were performed to assess the continuous variables for shape and distribution, implying skewness and kurtosis. To summarize the continuous variables, mean and standard deviation were used for normally distributed variables, whereas median and interquartile range (IQR) were used for non-normal variables. Categorical data were summarized using frequencies and percentages.

To describe the variability in EC by GMFCS level, a Kruskal–Wallis one-way analysis of variance (ANOVA), which is a non-parametric equivalent of ANOVA, was applied. In assessing the influence of the potential correlates GMFM, BSA, and age on EC, a univariate analysis was done first, with EC as the dependent variable and GMFM, BSA, and age as independent variables. Since data were not normally distributed, a robust linear regression model was used for the analyses, implying that the violation of normality does not necessarily negate the results in a simple or multivariate linear model [16]. Secondly, a multivariate model was built, including GMFM, BSA, and age as independent variables with EC as a dependent variable, using a forward selection procedure (adding most significant correlates first).

All tests were two-tailed, with $P < 0.05$ as the significance level. The analyses were performed using STATA, version 11.0 (STATA, College Station, TX, USA).

3. Results

Of the 276 children who met our inclusion criteria of RER, HR, walking velocity, and steady state conditions, 167 (60.5%) were boys and 109 (39.5%) were girls. There were 79 children who were GMFCS level I (28.6%), 123 children who were level II (44.6%), and 74 children who were level III (26.8%). There were 59 (21.4%) children with a unilateral, and 217 (78.6%) children with a bilateral form of spastic CP. Participants walked with a speed varying from 20.8 to 76.5 m/min with a median of 54.7 (16.9 IQR) The median and IQR of EC, OC, VO_2, walking speed, RER, age, height, weight, BSA, and GMFM stratified by GMFCS level I–III are all described in Table 1.