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Analysis of the relationships that body composition and muscular strength have with oxygen cost of walking in children with cerebral palsy☆

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ABSTRACT

Objective: To investigate whether body composition and lower extremity strength relate to oxygen cost of walking in children with cerebral palsy (CP), and to evaluate the relative contributions of these measures to explain variation in oxygen cost seen in this population.
Methods: A total of 116 children with spastic diplegic CP, Gross Motor Function Classification System levels I–III, aged 8–18 participated. Strength, body composition (body mass index (BMI) and percent body fat) and oxygen cost were recorded. Pearson correlations assessed relationships between variables of body composition and strength to oxygen cost. Forward stepwise linear regression analyzed variance explained by strength and body composition measures. Oxygen data were analyzed by weight status classifications using one-way analysis of variance with significance set at $p < 0.05$.
Results: Total strength ($r = -0.27$) and total extensor strength ($r = -0.27$) had fair inverse relationships with oxygen cost. Total extensor strength explained 7.5% ($r^2 = 0.075$, beta = -0.274, $p < 0.01$) of the variance in oxygen cost. Body composition did not explain significant variance in oxygen cost, however significant differences were found in oxygen consumption ($p = 0.003$) and walking velocity ($p = 0.042$) based on BMI weight classifications.
Conclusions: For ambulatory children with CP, oxygen cost during walking can be partially explained by total extensor strength and not body composition. However, those categorized as obese may adjust to a slower walking speed to keep their oxygen cost sustainable, which may further affect their ability to keep up with typically developing peers and possibly lead to greater fatigue.

1. Introduction

There is some evidence that many children with cerebral palsy (CP) expend greater energy during walking than their age and sex-matched typically developing (TD) peers [1]. This greater expenditure can be due to gait abnormalities caused by reduced selective motor control, abnormal muscle tone, muscle weakness and imbalance, and deficient equilibrium reactions [2,3]. A method commonly used to objectively quantify energy expense during walking is oxygen cost, a reliable measurement of gait efficiency [4]. Oxygen cost describes the amount of energy used to walk a certain distance, and is defined as the amount of oxygen consumed (ml) per kilogram body weight per meter walked (ml/kg/m) [4], where a lower oxygen cost reflects a more efficient gait. In TD children, energy expenditure at normal walking speed decreases with age, however energy expenditure increases as a child with CP approaches maturity, which can lead to walking less or a reliance on a wheelchair because of the greater physical exertion with age [2]. This greater physical exertion may be due to increases in body weight and size along with impaired motor control, spasticity, and impaired balance reactions to efficiently transport the added weight [5].

In children with CP, the prevalence of obesity as classified by body mass index (BMI) has significantly increased in a manner that

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parallels the trends documented in the general pediatric population [6]. Children classified as Gross Motor Function Classification System (GMFCS) levels I and II had the most significant increases [6]. Similarly, Hurvitz et al. [7] found that although nonambulatory children (GMFCS IV and V) also had high occurrences of obesity comparable to the general population, those who were ambulatory without assistive devices (GMFCS I and II) showed a trend for a higher prevalence of obesity compared to non-ambulatory children. Children classified within GMFCS level III also had high levels of obesity however results were viewed with caution due to low sample size. The prevalence of obesity in children with CP has been established; however, the effect of obesity on gait efficiency has received little attention. One study reported that a simulated 10% increase in body mass significantly impacted energy cost of walking in children with CP [8].

Muscle weakness is also a recognized problem in children with CP. Children with CP are weaker when compared to TD children [9], and research has shown walking ability is related to muscle strength as there are significant differences in muscle strength among GMFCS levels [10,11]. Moderate to high correlations between muscle strength and the Gross Motor Function Measure (GMFM) [12], a measure to classify gross motor function that includes walking, running and jumping dimensions, have also been reported with increased muscle strength being associated with higher scores on the GMFM [10,13]. With respect to walking efficiency, previous work has reported that stronger knee extensor muscles were modestly related to walking efficiency and gross motor ability in adolescents with CP [14].

Few studies have investigated physical factors of body composition and strength and their relationships to gait efficiency in children with CP. Clinical observation in children with CP has frequently revealed that increasing body mass challenges walking capacity of some patients with CP [8], however this relation has not been fully investigated. Greater energy utilization may affect daily-life functioning [15] and cause early onset of fatigue [16] which may perpetuate habits that lead to a sedentary lifestyle and to excessive weight gain in children. Muscle strength has been shown to be related to walking efficiency [14]; however, the study of the combination of both factors and their relationship to gait efficiency is limited. The purpose of this study was to investigate relationships that body composition and lower extremity strength have with oxygen cost in children with spastic diplegia CP. It is hypothesized that children with CP who are classified as obese will have higher oxygen cost and those who are stronger will have a lower oxygen cost. It is also hypothesized that body composition and strength parameters will explain a significant amount of the variance in oxygen cost seen among ambulatory individuals with CP.

2. Methods

These data are a part of a larger prospective multicenter project studying the combinations of strength, body composition, and strength to weight ratio that best explain variance with measures of activity and participation [17]. It was approved by the Institutional Review Boards of all participating sites. Patients were identified and recruited in outpatient clinics at three pediatric orthopedic outpatient facilities by local research coordinators (Shriners Hospitals for Children in Lexington, Northern California, and Salt Lake City). Written informed consent, assent and Health Insurance Portability and Accountability Act authorization were obtained from the parents or guardians of children who participated and assent from the child obtained, as appropriate. Inclusion criteria were: individuals between the ages of 8 to 18 years with a diagnosis of spastic diplegia CP (GMFCS levels I–III), ability to complete an approximately 10 min walking protocol, and, ability to follow simple commands. Patients were excluded if they had lower extremity orthopedic surgery within the prior year, botulinum toxin injections within the prior four months, or a currently implanted and operating baclofen pump.

Study personnel including research coordinators, physical therapists and kinesiologists, were trained prior to the start of the study on administration of all test measures and standard protocols used. Each assessment included evaluation to determine GMFCS level, recording of patient medical history, height, weight, oxygen cost, lower extremity muscle strength, percent body fat, and BMI.

Oxygen cost of walking was measured using a standard protocol. Each site used validated instruments including the Cosmed K4b^2 [18] (Cosmed, Rome, Italy), the Parvo Medics TrueMax 2400 [19] (ParvoMedics, Salt Lake City, UT), and the Carefusion Vmax Encore 29 [19] (Carefusion, San Diego, CA) which were calibrated before each patient use according to manufacturer's recommendations. Participants had not eaten for at least 4 h prior to testing. First, oxygen consumption (ml oxygen/kg/min) at rest was measured for 5 min while the participant sat quietly. Next, oxygen consumption was measured while the participants walked at a self-selected speed in their most typical walking condition (including aids and orthoses if applicable) until steady state was reached. Patients walked up to 10 min in order to obtain steady state, however if after 10 min steady state was not achieved, data collection continued until steady state was achieved. Steady state was defined as 3 min of oxygen consumption data collected with variation of less than 10%. The distance covered and elapsed time of the walking test was recorded to calculate an overall walking velocity. Gross oxygen cost (ml oxygen/kg/m), was calculated by dividing the gross oxygen consumption of walking by velocity (m/min).

Maximum isometric strength of hip flexors, extensors, abductors, and adductors, knee flexors and extensors (knee at 30 degrees of flexion), and ankle plantar flexors and dorsiflexors were obtained with a handheld dynamometer (JTECH PowertTrack II Commander, Salt Lake City, UT), using a standard protocol [9]. Handheld dynamometry is a reliable method to measure strength in children with CP [20]. At each site, there were at least two strength assessors who attended training sessions to maintain standard protocols. The maximum force from three trials for each muscle was normalized to body weight and used as the strength score for that muscle. This study examined knee extensor strength (defined as the sum of the maximum strength value for each knee extensor bilaterally) and two aggregate strength measures of total strength and total extensor strength. Total strength was calculated as the mean of the maximum strength values for all muscles bilaterally. Total extensor strength is the sum of the maximum strength values of the hip and knee extensors and ankle plantar flexors bilaterally. *z*-Scores were calculated by examiner, as recommended by the study statistician, to account for inter-examiner differences [21]. Strength data for all evaluators demonstrated good face validity (GMFCS level I participants were stronger than level II and level II were stronger than level III) and the distribution of strength seen by all evaluators was similar and included a range from very weak to very strong. By normalizing to *z*-scores relative strength was examined in the context of oxygen cost.

BMI was calculated from each participant's standing height and weight. BMI percentile was calculated based on sex and age. Participants were placed into one of four Centers for Disease Control and Prevention (CDC) categories based on BMI age and sex matched percentiles [22]: (1) underweight ($<$5 percentile), (2) normal (5th–85th percentile), (3) overweight (85th–95th percentile), or (4) obese ($>$95th percentile). Percent body fat was measured using a Quadscan 4000 Bioelectric Impedance Analysis device (Bodystat Limited, British Isles). Percent body fat was measured twice bilaterally and averaged to obtain mean percent body fat.

Statistical analyses were performed using IBM SPSS Statistics v21 software. Pearson correlations were used to assess relationships between variables of body composition and strength to oxygen cost. Strength of relationships were interpreted as: 0.00–0.25 suggest little to no relationship; 0.25–0.50 suggest a fair degree of relationship; 0.50–0.75 suggest a moderate relationship; and values above 0.75 were considered excellent [21]. A sample of 116 subjects has 80% power to detect a correlation of 0.25 or larger at the 0.05 level of significance. Forward stepwise linear regression was used with oxygen cost as the dependent variable to examine variance explained by body composition and strength. Predictor variables were introduced into the model in a stepwise manner on the basis of an *F*-test, with $p < 0.05$, and were excluded from the model with $p > 0.10$. The amount of variance in oxygen cost explained by independent variables (BMI percentile, percent body fat, total strength, total extensor strength, and knee extensor strength) was assessed. One-way analysis of variance (ANOVA) was used to test for differences in oxygen data (oxygen consumption, oxygen cost and walking velocity) by factor of CDC obesity category. Significance was set at $p < 0.05$ a priori.

3. Results

Participant demographics are presented in Table 1. A total of 116 children with spastic diplegic CP participated in this study. There were no significant differences in age, weight, BMI, and percent body fat among GMFCS levels. Children classified within GMFCS III were significantly shorter than those classified within GMFCS levels I and II (ANOVA, $p < 0.05$). Classifications of obesity showed that out of the total cohort ($n = 116$), 10% of were underweight, 54% were normal, 21% were overweight, and 15% were obese, similar to previous study findings [6].

There were no significant correlations between body composition as measured by BMI or percent body fat and oxygen cost in children with CP. There were significant correlations found between strength and oxygen cost. Total strength ($r = -0.27$), and total extensor strength ($r = -0.27$), had inverse relationships of fair strength with oxygen cost (Table 2). Forward stepwise linear regression found that total extensor strength explained 7.5% ($r^2 = 0.075$, beta = -0.274, $p < 0.01$) of the variance in oxygen cost. Total strength, knee extensor strength, BMI and percent body fat did not explain significant variance in oxygen cost.

Significant differences were found in oxygen consumption ($p = 0.003$) and walking velocity ($p = 0.042$) during the oxygen test when body composition was classified by BMI percentile (Table 3) but not for oxygen cost. Post hoc tests revealed those in the obese category had significantly lower oxygen consumption rates than those in the normal category.

Table 2
Means and correlations between variables and oxygen cost.

Variables	Mean (SD)	Oxygen cost, *r* value
Total strength *z* score (SD)	−0.76 (1.02)	−0.27*
Total extensor strength *z* score (SD)	−0.09 (1.02)	−0.27*
Knee extensor strengh *z* score (SD)	−0.11 (1.00)	−0.17
BMI percentile (SD)	58 (35)	0.01
% body fat mean (SD)	26 (9)	0.03

* Significant correlation $p < 0.05$.

4. Discussion

This study hypothesized that body composition and strength of children with CP would have significant relationships with oxygen cost of walking and would subsequently explain a significant amount of variance in gait efficiency. This study found that at a self-selected walking speed, total extensor strength explained a small significant amount of variance in oxygen cost of walking, while measures of body composition did not. Children with CP who are obese walked slower with significantly lower oxygen consumption rates per minute than their normal weight peers which may help to keep oxygen cost at a sustainable level.

The data from the study did not support the first hypothesis, that children classified as obese will have higher oxygen cost. However, ANOVA analyses by CDC weight status category revealed significant differences in walking speed and oxygen consumption which could have made oxygen cost similar among body composition classifications. This is similar to results seen in typically developing children where, as a consequence of excess fat mass, overweight children have a slower walking pattern [23]. Plasschaert et al. [8] reported that with a simulated 10% increase in body weight, children with CP tended to reduce walking speed whereas unimpaired children were able to maintain their pre-loaded speed. Children with CP work at a higher percentage (52% versus 36%) of their maximal aerobic capacity than typically developing children [24] when walking, so further increases in oxygen consumption may not be attainable. Walking slower may help to decrease oxygen consumption to keep oxygen cost low. Other orthopedic complications of being overweight, such as increased musculoskeletal discomfort or lower extremity mis-alignment that have been reported in overweight TD children and

Table 1
Patient demographics of study sample.

	Total	GMFCS I	GMFCS II	GMFCS III	*p*-Value
CP type					
Diplegia, *n*	116	27	62	27	
Sex					
Female, *n* (%)	38 (33)	7 (26)	19 (31)	12 (44)	
Male, *n* (%)	78 (67)	20 (74)	43 (69)	15 (56)	
Descriptive variables					
Age, yrs; mean (SD)	13 (3)	14 (3)	13 (3)	12 (3)	0.150
Height, cm; mean (SD)	148 (15)	151 (15)	149 (14)	141 (14)[a]	0.025
Weight, kg; mean (SD)	46 (16)	47 (17)	46 (16)	44 (14)	0.814
BMI mean (SD)	21 (5)	20 (4)	20 (5)	22 (5)	0.309
BMI percentile (SD)	58 (35)	54 (35)	56 (35)	67 (32)	0.324
% body fat mean (SD)	26 (9)	25 (6)	26 (10)	29 (11)	0.190
CDC weight classifications					
BMI: underweight, *n* (%)	12 (10)	3 (11)	8 (13)	1 (4)	
BMI: normal, *n* (%)	63 (54)	16 (59)	35 (57)	12 (44)	
BMI: overweight, *n* (%)	24 (21)	7 (26)	10 (16)	7 (26)	
BMI: obese, *n* (%)	17 (15)	1 (4)	9 (15)	7 (26)	

CP, cerebral palsy; SD, standard deviation; BMI, body mass index; CDC, centers for disease control and prevention.
[a] Reflects significant difference from GMFCS I and II.

Table 3
Oxygen data by CDC weight status category.

	Total mean (SD)	Underweight mean (SD)	Normal mean (SD)	Overweight mean (SD)	Obese mean (SD)	*p*-Value
Gross oxygen cost (ml oxygen/kg/m)	0.43 (0.20)	0.37 (0.14)	0.43 (0.20)	0.46 (0.23)	0.44 (0.20)	0.729
Oxygen consumption (ml oxygen/kg/min)	16.4 (3.9)	16.8 (4.5)	17.5 (4.2)	15.4 (2.5)	**13.9 (3.0)**[a]	**0.003**
Velocity during oxygen test (m/min)	42.6 (14.1)	46.6 (11.4)	44.9 (13.9)	39.3 (14.9)	35.7 (12.8)	**0.042**

CDC, centers for disease control and prevention.
Bolded *p* value for velocity reflects significant difference among CDC weight status category.
[a] Reflects significant difference from normal.

adolescents [25], could also affect walking speed but were not accounted for in this study.

A decrease in walking speed as a result of obesity may affect children with CP functionally out in the community. Children with CP only walk 57% of normal walking speed [5], and this study suggests that being obese may cause an additional decrease in speed. Recent cross-sectional data demonstrate that overweight/obese adolescents with CP have a higher prevalence of fatigue than age and weight matched individuals without CP [26]. Increased fatigue may be due to the greater energy expenditure needed to keep up with typically developing peers and the energy needed to transport extra weight. The current study found no significant differences in oxygen cost among weight status classifications, however this was based on the child's self-selected walking speed. When a child with CP is in the community with peers, they may walk faster than their preferred pace which could decrease gait efficiency, resulting in greater fatigue.

The results did support the second hypothesis of this study, that stronger children with CP had lower oxygen cost of walking. Individuals had a lower oxygen cost with greater total strength and greater total extensors strength at the hip, knee and ankle. However, the third hypothesis of this study, that both strength and body composition would explain significant variance in oxygen cost of walking in children with CP at their self-selected speed, was not supported. Total extensor strength was found to explain a small amount of the variation in oxygen cost seen in children with CP. Previous studies reported that knee extensors were modestly related to walking efficiency [14]. Evidence to support increased muscle strength improving oxygen cost is variable as some studies report increased gait efficiency and others reporting there is no change [27–29].

It is well documented that mechanistic causes of elevated oxygen cost are multifactorial and factors such as increased muscle tone, spasticity, or co-contraction [3] and mechanical power differences [30] affect oxygen cost. Strength may aid in efficient ambulation, however it explained little variance in oxygen cost across GMFCS levels suggesting strength is not one of the primary factors affecting oxygen cost. Strength should continue to be addressed clinically as research shows its relationship to motor function in children with CP [29]. Body composition does not explain significant variance in oxygen cost. Perhaps stronger relationships between strength, body composition and oxygen cost would be seen with maximal aerobic capacity, endurance or high intensity activities, and these activities warrant further investigation. Nonetheless, excess weight should be managed in children with CP as this study suggests obesity may affect walking speed. Surgical outcomes may also be compromised as rehabilitation following orthopaedic surgery may be more challenging for a child who is obese which may prolong rehabilitation and have a negative effect on overall surgical and functional outcome [6].

5. Study limitations

The large sample size in this study allowed for regression analyses to be used, however it was not large enough to stratify by GMFCS levels. In order to investigate the study hypotheses and assess strength and body composition across all levels of functioning, GMFCS level was not included as an independent variable. There were also only 27 subjects in GMFCS level III. In terms of body composition, the majority of the study cohort was classified as normal. Stratifying by GMFCS level would decrease sample sizes of those with obese or overweight classification. Future work with larger samples of children who are overweight and obese could help to investigate whether different relationships exist based on GMFCS levels. Each participating site administered a standard oxygen consumption protocol but the differences in laboratory configuration of the walking area and the equipment used could have increased the variability in the oxygen data. A site bias analysis, however found no significant difference in oxygen cost among the sites included in this study. Handheld dynamometry has limitations when compared to isokinetic dynamometers due to inter-assessor variability, so evaluator bias was addressed by converting strength values to *z*-scores which precludes strength data from being comparable to previous work.

6. Conclusions

Clinically it is often assumed that children who are obese with underlying weakness require increased cardiorespiratory effort to move a larger body mass. This study found that those with less overall strength and total extensor strength may have a greater oxygen cost. Additionally, total extensor strength explains a small significant percentage of variance to oxygen cost in children with diplegia. It is important for families to realize that strength is important for ambulation. Although BMI or percent body fat was not shown to be related to oxygen cost in this study, this study suggests those who are obese may adjust to a slower walking speed to keep oxygen cost sustainable. This may further affect their child's ability to keep up with their typically developing peers and may affect functional walking ability and participation. These findings can help clinicians modify treatment protocols to optimize walking ability, improve gait efficiency and endurance.

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Conflict of interest statement

No authors have any financial and personal relationships with other people or organizations that could inappropriately influence or bias their work.

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