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Accelerometry as an Estimate of Energy Expenditure in Healthy Children and Children with Cerebral Palsy During Self-Paced Ambulation

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Abstract
Oxygen consumption (VO_2) is the criterion standard for determining energy expenditure during activity. Newer technologies have resulted in the development of portable metabolic gas analyzers capable of measuring VO_2 during a wide range of physical activities in the field. Unfortunately, use of these devices is still limited due to the cost, availability and skill level required to utilize this newer technology. However, there is an instrument which may be utilized. Accelerometers are a type of physical activity monitor that provide estimates of energy expenditure and may potentially be of more practical use in the clinical setting. Purpose: This study was designed to compare estimates of energy expenditure using two different accelerometers to VO_2 during self-paced walking speeds in children with spastic diplegia cerebral palsy (CP) and in healthy children (HLT). Methods: Ten HLT children and five children with spastic diplegia CP participated in this pilot study (age range: 7.5-17.5 years). Subjects ambulated at self-paced speeds on a level surface wearing a Caltrac accelerometer and a BioTrainer-Pro accelerometer, while VO_2 was measured simultaneously with an AeroSport KB1-C portable metabolic gas analyzer. Results: Both accelerometers overestimated caloric expenditure in HLT children. In the children with spastic diplegia CP, we found no significant differences in the mean caloric expenditure estimated by the accelerometers and VO_2 ($p = 0.62$). Conclusions: Preliminary findings suggest accelerometers may have potential as a means of estimating energy expenditure during ambulation in children with spastic diplegia CP, which could be useful to clinicians evaluating therapeutic interventions. Further research is indicated.

Introduction

For children with spastic cerebral palsy (CP), the energy cost of ambulation is significantly greater than for healthy (HLT) children.[1, 2, 3] This increased energy expenditure, for children with spastic CP, has been attributed to a lower mechanical efficiency during ambulation as a result of a loss of selective motor control, impaired balance, abnormal tone, weakness, and loss of range of motion.[2,3,4,5] Evaluating changes of energy expenditure during ambulation has potentially important clinical ramifications in assessing the effectiveness of various interventions on improving gait economy.

The criterion standard used to assess energy expenditure during activity is the measurement of oxygen consumption (VO_2). Until recently, measuring VO_2 in the field setting was somewhat cumbersome, especially with children. However, use of newer technologies has resulted in the development of portable metabolic gas analyzers capable of accurately measuring VO_2 during functional activity.

Clinical use of this newer technology is not always feasible based on the therapeutic setting, availability of such devices, and cost, which may be prohibitive for many clinical facilities. On the other hand, use of accelerometers which are small, relatively inexpensive monitors that use advanced motion sensing technologies to record movement may offer an alternative, practical means of estimating energy expenditure in various settings.

With HLT children tested under laboratory conditions, various models of accelerometers have demonstrated relatively strong correlations (r= 0.61-0.93) to VO_2 during treadmill walking and jogging at various speeds on a level surface and have provided an objective estimate of energy expenditure.[6,7,8] Field studies with HLT children have demonstrated fair to moderate correlations (r= 0.42-0.60) in energy expenditure by accelerometry compared with physical acitivity.)[9,10,11] However, no studies were found using accelerometers to assess energy expenditure in children with spastic CP. This preliminary study may be the first to compare estimates of caloric expenditure by accelerometry with VO_2 caloric estimates of energy expenditure in children with spastic diplegia CP.

The purposes of this preliminary study were to: 1) assess the validity of accelerometer estimates of energy expenditure to VO_2 and, 2) compare the estimates of energy expenditure by accelerometry to VO_2 measurements of energy expenditure in HLT children and children with spastic diplegia CP during self-paced walking on a level surface. The information obtained using accelerometers during self-paced ambulation could potentially be of relevance to clinicians in assessing the energy expenditure of a child while walking at his or her preferred velocity and changes resulting from therapeutic interventions.

Materials and Methods

Participants

Subjects were recruited from the Omaha, Nebraska, area via newspaper advertisements, flyers, and personal contacts. Study inclusion criteria for the HLT children included verbal confirmation of good health by a parent or guardian and review of a health history questionnaire by the investigator. Additional criteria included: 1) no diagnosis of CP or other neuromuscular disorder; 2) 7 to <18 years of age; 3) no significant endurance impairments due to cardiovascular limitations; and 4) no surgery in the last year. Inclusion criteria for children with spastic diplegia CP included: 1) diagnosis of spastic diplegia CP; 2) 7 to <18 years of age; 3) able to ambulate continuously for six minutes, with or without assistive devices and/or orthotics; 4) no significant endurance impairments due to cardiovascular limitations based on subject's health history; and 5) no musculoskeletal or neuromuscular surgical procedures within the last year. Ten HLT children and five children with spastic diplegia CP participated in this pilot study (Table 1). Written assent and consent were obtained from the children and their parents or guardians. The study protocol and consent forms were reviewed and approved by the University of Nebraska Medical Center's Institutional Review Board. All testing and procedures were conducted in the Division of Physical Therapy Education's research laboratory (subject consent, orientation, and preparation) and in the adjacent hallways (ambulation course).

Each subject and parent or guardian received an orientation to the testing procedures and equipment by the investigator prior to any testing. Subjects were allowed as much time as needed to acclimate to the equipment being used to measure VO_2 as well as the accelerometers. The subjects were able to try on the face mask and handle the accelerometers to allow them to be comfortable with the equipment before it was placed on them by the investigator. This acclimation time averaged approximately 10-15 minutes among the subjects. During orientation each subject's height and weight were obtained using a calibrated clinical scale. Body mass index (body mass in kg / [height in cm]^2) was calculated for each child to compare the two groups of children.

Metabolic Gas Analysis

Each subject was fitted with a silicone face mask (Hans Rudolph, Inc., Kansas City, MO) that allowed the subjects to breathe through their nose and mouth during testing. A medium flow pneumotach was affixed to the face mask with a sampling line connecting it to the AeroSport Model KB1-C portable metabolic gas analyzer system. The absolute VO_2 (L/min) at rest and during ambulation was measured by indirect calorimetry with an AeroSport Model KB1-C unit which had been validated in a prior study that measured VO_2 during exercise.[12] The AeroSport KB1-C portable metabolic gas analyzer was gas and flow calibrated according to manufacturer specifications prior to testing each subject .

Physical Activity Monitors

Two different models of accelerometers, the Caltrac (Muscle Dynamics, Torrance, CA) and the BioTrainer-Pro (IM Systems, Baltimore, MD) were utilized to assess if one model was better than the other for use with children. The Caltrac accelerometer is a uni-axial (senses one axis) physical activity monitor that uses a piezoceramic cantilevered beam to produce a voltage in response to vertical accelerations and decelerations. Before use, the subjects' weight, height, age, and sex were entered into the Caltrac accelerometer, according to the product manual, which allowed the Caltrac to calculate kilocalories (kcal) expended during activity.

The BioTrainer-Pro accelerometer contains a piezoelectric sensor that is positioned at a 45-degree angle from vertical, allowing the unit to detect a portion of both vertical and horizontal accelerations of the body during physical activity. The kcals of expended energy obtained from the BioTrainer-Pro accelerometers were recorded. Both accelerometers are approximately the size of a pager (2.5"x 3.5"x 0.75"), are unobtrusive, and did not interfere with subjects' ability to ambulate or move.

Protocol

After each subject was familiarized with the equipment and verbally acknowledged their readiness to don the testing equipment, the walking protocol and course was reviewed with each subject by the investigator. Resting HR and VO_2 were recorded while the subject sat quietly at rest for seven minutes. The resting baseline HR and VO_2 were recorded as the average of minutes six and seven. The Caltrac and BioTrainer-Pro accelerometers were then zeroed, clipped to a waist belt, and worn simultaneously during testing.

The Caltrac was positioned in the anterior axillary line on the subject's right side as recommended in the product manual. The BioTrainer-Pro was positioned just medial to the Caltrac as the accuracy of the BioTrainer-Pro had previously been found not to be as sensitive to positioning.[13] Each subject used whatever assistive device(s) he or she typically utilized during gait and was encouraged to walk at his or her comfortable, everyday speed for six minutes continuously. All subjects walked in the same series of connecting hallways, forming a continuous 50-meter oval pathway. The average self-paced ambulation velocity was calculated and recorded as meters/minute.

Corry et al have previously reported that steady state HR and VO_2 are obtained after three minutes of low level activity in children.[14] For this study, HR and VO_2 data obtained over minutes four and five was averaged for data analysis.

Data Analysis

Descriptive statistics were used to compile demographic data and t-tests were used for comparisons between the two groups of children. One-way analysis of variance tests were performed for comparing the estimated caloric expenditures measured by the two accelerometers and the activity specific VO_2 obtained with the AeroSport KB1-C portable metabolic gas analyzer. For purposes of comparing kcals expended across all three devices, the activity specific VO_2 (L/min) was multiplied by 5 kcal/L to calculate kcal expended.[15] For all tests the level of significance was set at $P < 0.05$.

Results

There were no significant differences between the two groups of children tested with regard to age, weight, height, BMI, or resting VO_2 (Table 1). There was a significant difference in the mean self-paced velocities between the HLT children and the children with spastic diplegia CP (Table 1).

Table 1. Comparison of Group Characteristics (Mean ± SD)

	Healthy Children	Children with Spastic Diplegia CP	P-value
Age (yrs)	12.6 ± 2.8	13.7 ± 3.6	0.52
Weight (kg)	52.0 ± 15.0	48.0 ± 13.9	0.62
Height (cm)	159.3 ± 14.7	154.4 ± 15.3	0.56
Body Mass Index	20.3 ± 4.7	19.8 ± 3.7	0.83
Mean Velocity (m/min)	68.3 ± 8.5	40.8 ± 8.3	< 0.001
Gender Distribution	6F; 4M	3F; 2M	----

All subjects were able to complete the six minutes of continuous walking without stopping or pausing. The activity specific VO_2 associated with self-paced ambulation was calculated as the total VO_2 during ambulation minus the resting VO_2. Based on the data collected from the two accelerometers, comparisons of the energy expenditure for HLT children, in kilocalories, during self-paced ambulation, showed no significant difference ($p = 0.32$); however estimates of energy expenditure from both accelerometers were significantly different ($p < 0.002$) from the VO_2 estimated calories expended (Table 2).

Table 2. Energy Expenditure During Self-paced Walking (Mean ± SEM)

Energy Expenditure During Self-paced Walking	Healthy Children N= 10	Children with Spastic Diplegia CP N= 5
BioTrainer-Pro (kcal)	22.2 ± 4.1*	11.0 ± 2.6
Caltrac (kcal)	18.3 ± 1.9*	9.6 ± 2.9
AeroSport (kcal)	5.6 ± 1.1	14.6 ± 5.1

* Significantly different from AeroSport kilocalories (p < 0.002) for HLT children

Both accelerometers over-estimated the caloric expenditure in HLT children during self-paced ambulation compared to VO_2 estimates. However, for the children with spastic diplegia CP, no significant differences were noted between the estimated kcal of the two accelerometers or the VO_2 estimated caloric expenditure (p= 0.62) during self-paced ambulation (Table 2).

The absolute VO_2 (L/min) measured was converted to relative VO_2 (mlO_2/kg/min) for assessing the energy expenditure of the subjects. The activity specific increase in VO_2 between the two groups of children during self-paced ambulation showed a significantly greater increase in energy expenditure for the children with spastic diplegia CP compared to HLT children ($p < 0.03$). The mean relative VO_2 increase over the resting VO_2, associated with self-paced walking for the children with spastic diplegia CP was 0.49 ml O_2/kg/min and for the HLT children 0.19 ml O_2/kg/min.

Discussion

For children with spastic diplegia CP, altered gross motor abilities secondary to musculoskeletal, neuromuscular and biomechanical changes may directly impact walking efficiency and therefore energy expenditure.16 Measuring oxygen uptake by indirect calorimetry is the best method of quantifying gait efficiency during functional walking, though it is not always practical or feasible to obtain in various therapeutic and field settings (e.g., clinics, schools, home, and community environments).[17] Nonetheless, collecting and interpreting measures of energy expenditure utilizing other methods for children during ambulation can be an important aspect of the clinical decision making process in evaluating efficacy of various interventions and energy economy.

In this study, caloric expenditures obtained from the Caltrac and the BioTrainer-Pro accelerometers were compared to VO_2 caloric expenditure during self-paced walking in HLT children and children with spastic diplegia CP.

Prior studies conducted with healthy adults under field conditions have reported that accelerometers were fair to moderately correlated with overall energy expenditure, although they did tend to overestimate energy expenditure during walking compared to indirect calorimetry measures.[13,18,19] The findings of this study support the prior studies in that accelerometers overestimated energy expenditure in HLT children walking at self-paced ambulation.

However, for the group of children with spastic diplegia CP, the caloric values recorded using accelerometers showed no significant difference from those values calculated from VO_2 measures. Our finding that energy expenditure during self-paced ambulation in children with spastic diplegia CP was significantly greater than in HLT children is consistent with the findings of other investigators.[1,2,3] This increased energy expenditure during self-paced ambulation in children with spastic diplegia CP is most likely reflective of the lower mechanical efficiency of walking in children with spastic CP. Based on our results, measuring caloric output using either the Caltrac or the BioTrainer-Pro accelerometer may provide for a reasonable means of estimating energy expenditure during self-paced ambulation as well as changes in energy expenditure due to therapeutic interventions in children with spastic diplegia CP.

The findings of this study are encouraging and appear to support the use of accelerometers to estimate energy expenditure in children with spastic diplegia CP walking at self-paced speeds; however, the results should be viewed as preliminary and interpreted with caution. The primary purpose of this pilot study was to assess if the estimates of energy expenditure by accelerometry were reflective of the caloric expenditure estimated from the “gold” standard of measuring VO_2 obtained by indirect calorimetry in HLT children and children with spastic diplegia CP under field conditions (comparable to clinic or school settings). Accelerometers significantly overestimated, by two to three fold, the energy expenditure in the HLT children in this study raising concern as to the validity and value of accelerometer use for estimating caloric expenditure in HLT children ambulating at self-paced velocities. However, for children with spastic diplegia CP, the caloric estimates of energy expenditure by accelerometry were more consistent with that of VO_2 caloric estimates and may have potential use as a clinical tool with this population.

The inherent limitations of this pilot study include a small sample size and the inclusion of children with spastic diplegia CP who were able to ambulate continuously for six minutes, which may limit the generalization of the findings to the population of children with spastic diplegia CP as a whole. Also, limitations of reliance on parental or guardian report for inclusion in study versus medical reports or specific testing of movement limitations, tone/strength, contractures, alignment, or postural control should be considered when designing future studies. In addition, the applicability of our findings to individuals younger or older than those tested needs further investigation. The findings of this pilot study suggest that further investigation into the use of accelerometers to estimate energy expenditure for children with spastic diplegia CP is warranted. Future studies assessing the validity and reliability of using accelerometers to evaluate changes in energy expenditure during self-paced ambulation as a result of therapeutic interventions could be valuable to clinicians in their clinical decision making process.

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