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Mechanical efficiency and balance in adolescents and young adults with cerebral palsy

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ABSTRACT

Mechanical efficiency (ME) during stair-climbing measures ambulation ability. This study investigated the relationship between ME and age, anthropometric, functional walking, and balance parameters in 52 adolescents with cerebral palsy (CP), age 13.5–23.3 yrs, who participated in an intervention study to improve walking. Measurements included ME, 6-min and 10-m walk tests and the Berg balance scale (BBS). Walk test measures correlated significantly with ME, as expected, as did BBS ($r = 0.68$) and age ($r = 0.51$). The multiple correlation coefficient with both age and BBS increased to 0.80. The measurements were divided into two groups of low (<40, $n = 19$) and high (>40, $n = 33$) BBS scores. Repeating regression analyses, demonstrated that in the low BBS group ME was significantly related to BBS, but not age, in contrast to opposite results in the high BBS group. Regressions were calculated for each of the 14 items of the BBS with ME. For the whole group, 12 items correlated significantly, but only three in the high BBS group (one leg standing, reach while standing and tandem standing). In the low BBS group 10 of the items correlated significantly, with the former three ranking near the top. Balance is an important component of ambulation in children with CP. Mobility in those scoring >40 is related to age, but in those more deficient in balance (<40) mobility is more closely associated with balance than age. Effective therapy to improve walking in younger children might incorporate more balance-focused exercises, similar to those related to BBS items strongly associated with ME.

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1. Introduction

Mechanical efficiency (ME) defines the amount of energy expended to perform a measured amount of external work. ME of the human body in task execution represents the efficiency of all the body systems in transforming biochemical energy into external work. Efficiency is specific to the task and the age, health, muscle properties and limb coordination. One of several attributes of reduced ME is the cost of multi-segment limb coordination in locomotor displacement. It has been estimated that ME in human locomotion (i.e., walking, running and cycling) ranges between 20 and 30% [1,2]. However, there is large variability among individuals in economies of movement and speed at which tasks are performed.

There is an apparent improvement in metabolic economy from childhood to adulthood. Anatomical, biomechanical, physiological and psychological variables have been suggested to contribute [3]. Frost et al. have shown that it is possible to explain 62% of the variation in treadmill locomotion efficiency in children by analyzing a combination of mechanical power, co-contraction, stride length and age [4]. Age was the best single predictor of efficiency, as measured by dividing mechanical work by net submaximal oxygen consumption.

One major contributor to poor walking ability of children and adolescents with cerebral palsy (CP) is poor balance control. Children with CP experience difficulties with muscle coordination and the organization of sensory information and are affected by increased muscle tone. Balance strategies of children with CP differ from those of neurologically intact children. They demonstrate increased co-contractions of distal and proximal muscles and do not have a smooth distal-to-proximal muscle activation pattern [5]. Nashner et al. found that, unlike typically developing children, those with CP demonstrate a reversed order of activation of distal and proximal muscle synergies in response to a moving platform [6]. Roncesvalles et al. reported that one contributing factor to the

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smaller limits of stability of children with spastic diplegia, compared with typically developing children, is a reduced ability to increase muscle response amplitude when balance threats increase [7]. They found that typically developing children increased response magnitude with the level of difficulty of balance threats, whereas children with spastic diplegia were unable to do so.

The stair-climbing test can measure ME during ambulation in motor-challenged adults and children with CP [8]. Stair climbing requires balance control and the coordination of body segments to complete the task. ME is significantly lower in children with CP (2–5%) compared to typically developed children (~20%). An increase in ME has been found following interventions in children with CP that involved a motor learning approach and allowed a process of practice, tuning and optimization of motor functions to continue after the intervention ended [9].

Presently, there is little conclusive information about the neuromotor factors that determine or influence ME in general, and in individuals with CP in particular. Because most research has been reported in younger children with CP, the objective of this study was to investigate the relationship between ME and age, anthropometric, functional walking, and balance parameters in 52 adolescents and young adults with CP and determine whether balance is as an important component of ME, and whether this relationship varies with age.

2. Methods

This multicenter study is based on baseline data obtained from participants included in a matched controlled trial to determine the effects of two technical walking interventions in adolescents with CP in four Middle East countries. The participants were recruited from special schools and clinics.

2.1. Inclusion criteria

(a) Diagnosis of CP, predominantly spastic, with a distribution of diplegia/tetraplegia.
(b) Age range from 13 to 23 yrs.
(c) Gross motor function classification system (GMFCS) at levels II and III.
(d) Cognitive level sufficient to comprehend and cooperate with treatment and testing.
(e) No orthopedic surgery or other tone reduction intervention in last 6 months and not a candidate for such.

Institutional Ethics Committees in each country approved the study. All participants or their guardians gave written informed consent.

2.2. Functional measures

Functional mobility levels were categorized by the GMFCS [10,11], which describes the participant's current gross motor function abilities and limitations. The GMFCS scale is extensively used in CP research to categorize subjects who function at similar mobility levels. The scale consists of five distinct motor levels: level I – "Walks without limitations", level II – "Walks with limitations", level III – "Walks using a hand-held mobility device", level IV – "Self-mobility with limitations, may use powered mobility": and level V – "Transported in a manual wheelchair".

2.3. Other functional measurements included

(a) 6 min walk test (6minWT) [12]. This test measures the self-paced distance walked in meters in 6 min on a flat, firm surface. The self-paced 6minWT assesses the sub-maximal level of functional capacity where most activities of daily living are performed and therefore reflects the effort required for daily physical activities.
(b) 10-m walk test (10mWT): This test measures gait speed, important for safe community mobility (e.g., crossing streets according to signals). The 10mWT speed is measured by the time required to walk 10 m. The 10mWT is a short and convenient test that can be applied to any subject able to ambulate that distance [13].
(c) Berg balance scale (BBS): This 14-item scale measures static and dynamic balance abilities. The BBS was designed to assess balance and risk for falls in older community-dwelling adults and stroke patients by direct observation of performance tasks [14]. The BBS has been identified as the most common assessment tool across the continuum from acute to community-based care of elderly adults and is also used for children with CP [15,16].
(d) Net mechanical efficiency (ME) during stair-climbing: This is a quantitative physiological measure of coordination, strength and endurance. As described previously [8], in this test subjects climb special stairs for 4–5 min while heart rate (HR) is monitored continuously. The external work is calculated from the product of vertical body displacement during the stair-climbing, body weight and number of ascents in a measured time interval. ME is the resulting ratio of external work/energy cost (minus resting metabolic rate) as a percentage expressed in equivalent units. The metabolic rate during climbing was predicted from an equation determined from a previous study [17], from measurements of the increase in steady state HR above resting and the body weight. A number of studies have demonstrated improved ME after training and motor learning [9,18,19].

2.4. Statistical analysis

Single and multiple least squares linear regressions were used to analyze associations between variables. Partial correlation coefficients were obtained by the formula:

$$r_{yx1\cdot x2} = [r_{yx1} - (r_{yx2})(r_{x1x2})]/[(\sqrt{(1 - r_{yx2}{}^2)})(\sqrt{(1 - r_{x1x2}{}^2)})]$$

Differences in variables between the two groups based on BBS levels were tested for significance by single factor ANOVA and the normality of distribution of measurements in the 52-subject sample was tested by χ^2 analyses. Probability levels of differences or correlation coefficients less than or equal to 0.05 were taken to be significant.

3. Results

The inclusion criteria were met by 52 participants. Demographic and mobility characteristics are presented in Table 1.

3.1. Correlations with mechanical efficiency

The performance measures of the participants are shown in Table 2. The assumption of normality was acceptable at the 0.05 level for ME, age, height, weight, BMI, 6minWT and 10mWT. The distribution for the 52 BBS scores was bimodal and not acceptable for normality.

Because ME during stair climbing is an integrated measure of ambulatory ability that includes mechanical, physiological and motor control components, the other mobility performance measures correlated significantly with ME. The 6minWT ranked highest in significance, followed by the 10mWT speed and GMFCS

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