ORIGINAL ARTICLE

Fatigue Resistance During a Voluntary Performance Task Is Associated With Lower Levels of Mobility in Cerebral Palsy

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ABSTRACT. Moreau NG, Li L, Geaghan JP, Damiano DL. Fatigue resistance during a voluntary performance task is associated with lower levels of mobility in cerebral palsy. Arch Phys Med Rehabil 2008;89:2011-6.

Objectives: To investigate muscle fatigue of the knee flexors and extensors in people with cerebral palsy (CP) compared with those without motor disability during performance of a voluntary fatigue protocol and to investigate the relationship with functional mobility.

Design: A case-control study.

Setting: A biomechanics laboratory.

Participants: Ambulatory subjects with CP (n=18; mean age, 17.5y) in Gross Motor Function Classification System (GMFCS) levels I, II, and III and a comparison group of age-matched subjects (n=16) without motor disability (mean age, 16.6y).

Interventions: Not applicable.

Main Outcome Measures: The voluntary muscle fatigue protocol consisted of concentric knee flexion and extension at 60° a second for 35 repetitions on an isokinetic dynamometer. Peak torque for each repetition was normalized by the maximum peak torque value. Muscle fatigue was calculated as the rate of decline in normalized peak torque across all repetitions, represented by the slope of the linear regression. Self-selected and fast gait velocities were measured as well as the Pediatric Outcomes Data Collection Instrument (PODCI).

Results: Greater fatigability (slope) was observed in the comparison group for both knee flexors and extensors than in the group with CP. Within CP, lower knee extensor fatigue (slope) was associated with lower functioning GMFCS levels and lower levels of activity and participation as measured by the PODCI transfers and basic mobility.

Conclusions: Even after adjusting for maximum peak torque, the knee flexors and extensors of participants with CP were observed to be less fatigable than age-matched peers without motor disability. The lower rate of muscle fatigue was also associated with lower functional mobility in CP. These results may be related to strength or activation differences and/or muscle property alterations. Future investigations are warranted.

Key Words: Muscle fatigue; Muscle spasticity; Muscle strength; Quadriceps muscle; Rehabilitation.

MEASURES OF PHYSIOLOGIC capacity, such as lower-extremity muscle strength, have been correlated with functional measures in people with CP and other disabilities.[1-3] However, neither muscle strength nor measures of physical function have been shown to be related to psychosocial aspects of QOL, such as comfort and happiness.[4] Self-reported physical fatigue, on the other hand, has been significantly associated with QOL measures of psychosocial well being, such as bodily pain, limitations in physical and emotion role function, and low life satisfaction in adults with CP.[5] Furthermore, adults with CP report fatigue as a main cause of the deterioration or cessation of their walking ability.[6-8] However, these studies assessed fatigue using questionnaires and interviews and did not attempt to differentiate among the different types of fatigue.

Previous objective clinical measures of fatigue in people with CP were focused primarily on the cardiorespiratory system. Although it has been well documented that children and adolescents with CP have lower $\dot{V}O_2max$ than their typically developing peers, most authors concluded that local muscle factors, such as muscle fatigue, were responsible for the lower $\dot{V}O_2max$ and limitations in activity.[9-11] Following this same argument, Lundberg[10] and Hoofwijk et al[9] suggested that spastic muscles may have decreased venous return and inhibited muscle lactate clearance during exercise, thereby increasing muscle fatigue and leading to a decrease in $\dot{V}O_2max$ values.

There are different definitions of muscle fatigue in the literature. *Muscle fatigue* is defined here as a reduction in force output that occurs during sustained voluntary activity.[12] *Fatigue resistance*, or the ability to withstand fatigue, is also referred to as *muscle endurance* in the literature. Muscle fatigue can occur at any point along the activation process, from the central nervous system to the level of the motor neuron. Techniques that use electric stimulation (ie, twitch interpolation, electrically elicited contractions) are capable of isolating peripheral aspects of muscle fatigue from central aspects. For example, Stackhouse et al[13] investigated peripheral muscle fatigue of the quadriceps and triceps surae through the use of

List of Abbreviations

CP	cerebral palsy
GMFCS	Gross Motor Function Classification System
$\dot{V}O_2max$	maximal oxygen consumption
PODCI	Pediatric Outcomes Data Collection Instrument
QOL	quality of life
ROM	range of motion

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Presented to the American Academy of Cerebral Palsy and Developmental Medicine, September 14, 2006, Boston, MA.

Supported by the American Physical Therapy Association Section on Pediatrics Clinical Research Grant, the Louisiana Board of Regents Fellowship, and the National Institute of Child Health and Human Development (grant no. T32HD007434).

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

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Published online August 22, 2008 at *www.archives-pmr.org*.

0003-9993/08/8910-00123$34.00/0
doi:10.1016/j.apmr.2008.03.012

electrically elicited contractions in children with CP. In that study, the quadriceps, but not the triceps surae, were observed to be less fatigable compared with a control group. However, in their study, the influence of the central nervous system was removed. Because muscle activity depends on the integration of the entire chain of events, muscle fatigue as assessed through voluntary performance may occur at both central and peripheral sites simultaneously.[14]

Because muscles adapt to the amount and type of neural stimulation being imposed on them, secondary effects of spasticity on muscle tissue can also have a profound impact on the ability to generate and maintain muscle force. Muscle abnormalities such as alterations in muscle fiber size and fiber type distribution, excessive collagen accumulation, and increased muscle stiffness (elastic modulus) of spastic muscle cells have also been reported in CP.[15-20] These alterations of muscle properties can have significant implications for essential aspects of muscle performance, such as the ability to generate force and to sustain force output. In CP and other motor disorders, different muscle groups can be affected to varying degrees; therefore, these changes may be muscle-specific, rather than generalizable across all muscles.

Isokinetic fatigue protocols for the knee flexors and extensors have been extensively developed in the healthy adult population[21,22] and have been modified for use with children[23] and with other neurologic populations such as multiple sclerosis.[24] An advantage of isokinetic dynamometry is that it provides a safe, controlled environment in which a muscle or group of muscles can be isolated with stabilization of other joints.[25] An isokinetic fatigue protocol similar to the ones mentioned was developed recently by the authors[26] for use in children and young adults with mild-to-moderate CP and was shown to be feasible for testing the knee flexors and extensors.

The primary purpose of this study was to determine whether muscle fatigue in the knee flexors and extensors in people with CP differs from those without a motor disability during the performance of a voluntary fatigue test. A secondary purpose of the study was to determine the relationship of muscle fatigue to functional level, walking velocity, and activity/participation as measured by the PODCI. The quadriceps and hamstrings muscle groups were chosen because of the importance of these muscles in gait and function.[1-3] We hypothesized that people with CP would have greater levels of muscle fatigue than nondisabled peers and that muscle fatigue would be inversely related to functional level, walking velocity, and activity and participation.

METHODS

Participants

A group of 18 participants with CP and a comparison group of 16 participants without motor disability between the ages of 10 and 25 years were recruited for the study. An attempt was made to ensure that sex and age distributions were similar across groups. Participant characteristics are listed in table 1. Participants with CP were ambulatory with or without assistive devices. They were excluded if they had orthopedic surgery within 12 months prior to the testing, received botulinum toxin injections to the quadriceps or hamstrings within 6 months prior to the testing, or complained of existing knee pain.

The study was approved by the human studies committee at our institution. Written informed consent from each participant over 18 years of age was obtained. Parental consent forms for participants younger than 18 years of age were obtained from their parents or legal guardians.

Fatigue Testing

An isokinetic dynamometer[a] was used to record torque of the knee flexors and extensors during maximum voluntary exertions throughout the available passive ROM. Participants performed 8 to 12 submaximal concentric, reciprocal knee flexion and extension repetitions to familiarize themselves with the task. The fatigue protocol consisted of reciprocal, maximal concentric knee extension and flexion at 60° a second for 35 repetitions and has been published elsewhere.[26] During pilot testing, peak torque during the fatigue test for both knee extension and flexion showed a consistent pattern of decline during the first 30 to 40 repetitions and then began to level off in subjects with and without CP who were asked to complete 100 repetitions. This pattern has been demonstrated for the knee extensors during similar protocols in other studies.[27,28] Therefore, 35 repetitions were chosen for this protocol. Strong verbal encouragement on every repetition as well as visual biofeedback of torque production was provided to encourage maximal effort on all repetitions. Data were gravity-corrected, and only the constant velocity portion was used for calculation. The following calculations were made separately for knee flexion and extension repetitions. For each subject, peak torque was measured as the highest value achieved during each repetition. Maximum peak torque for each subject was measured as the single highest peak torque value across all repetitions. Peak torque for each repetition was then normalized by the maximum peak torque value. Normalized peak torque data were averaged for each group, and muscle fatigue was calculated as the rate of decline in normalized peak torque across all repetitions, represented by the slope of the linear regression.[21] The first repetition was excluded from analysis because it is usually unreliable.

Functional Measures

Each subject was assigned a GMFCS level as a measure of functional mobility, restricted to I, II, or III because of the ambulatory requirements of the study. Although the GMFCS was not originally intended for those over 12 years of age, it has been shown to be reliable[29] and stable over time in adults with CP.[30] Activity and participation were assessed with the PODCI.[31] The PODCI questionnaire was completed by the parents of participants under 18 or by the participants themselves who were 18 or older (American Academy of Orthopaedic Surgeons/Pediatric Orthopaedic Society of North America, Version 2.0). The PODCI was designed to assess

Table 1: Participant Characteristics

Group	Sex	Age Range (y)	Age ± SD (y)	Height ± SD (m)	Weight ± SD (kg)
CP	13F/5M	10–25	17.49±5.03	1.52±0.08	47.57±9.92
Comparison	13F/3M	10–23	16.61±4.45	1.59±0.09*	53.97±9.72

Abbreviations: F, female; M, male.
*The comparison group was significantly taller than the CP group (P=.02).