Dynamic Constraint of Spasticity on Muscle Lengthening Velocity During Walking

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Introduction

The influence of spasticity may be represented as a dynamical constraint on functional performance. Spasticity has been defined as "a motor disorder characterized by a velocity dependent increase in stretch reflexes …"[4]. This pathologic reflex behavior is associated with increased resistance to motion at increased velocities[1;2] thereby limiting the velocity and frequency of voluntary movement[3;6]. The velocity threshold at which spastic myoelectric response is initiated, i.e. spastic threshold velocity (STV), has been identified as a quantifiable correlate with spastic severity[5]. Our previous analyses[7] demonstrated the STV is highly correlated with knee angular velocity during fast walking and Gross Motor Function Measure scores in children with spastic cerebral palsy (CP). However, in that study the knee angular velocities were consistently faster than the measured STV. In fact the linear regression demonstrated a slope that indicated peak knee velocities during walking were twice as fast as the STV. This is potentially because joint velocities rather than muscle behavior was quantified. It was hypothesized that the threshold velocity for spasticity recorded in terms of muscle lengthening velocity must agree with the peak rate of muscle lengthening during fast walking.

Statement of Clinical Significance

The objective of this study was to determine the constraints imposed by spastic muscle behavior upon functional performance. Results indicate that spasticity may impose an upper limit to muscle lengthening velocity during walking that may adversely influence gait performance.

Methodology

A quantitative study was performed to determine the relationship between the muscle spastic threshold velocity (STV) recorded from controlled isokinetic measurements and the maximum muscle lengthening velocity determined during walking. A convenience sample of 18 children (ages 5-24) with spastic cerebral palsy volunteered to participate in isokinetic trials and gait analysis in a single session. Using an isokinetic dynamometer (Biodex, Shirley NY) the STV was recorded by comparing knee angular velocity and EMG response from the quadriceps and hamstring muscles. Knees were passively moved through the available range of motion at increasing speeds from 30 to 240 deg/sec. A minimum of five flexion and extension cycles were performed at each velocity with at least 4 sec rest between motions. Typically, at low velocities no consistent spastic response was observed but as the velocity increased a repeatable response became clearly identifiable in the EMG. The velocity at which the spastic response was consistently elicited was identified as the STV, independently quantified for hamstrings and quadriceps. Standard 3-D gait analyses were performed to record kinematics of knee movement during walking. Subjects were asked to walk as fast as possible along a 10 m walkway while motions were recorded from reflective markers by a video-based movement analysis system (Oxford Metrics). Dynamic muscle lengths were determined in both sets of data (isokinetic and gait kinematics) using SIMM modeling software. Maximum velocities were determined using numerical derivatives.

Results

Three subjects were excluded as a result of occluded video motion analysis markers. 11 of the remaining 15 children exhibited an STV in the dynamometer (i.e. spastic EMG responses were observed at measured velocities). Using these 11 patients, a linear regression analysis comparing the muscle STV with maximum muscle lengthening velocity during walking showed a high correlation ($r=0.83$, slope $=0.97$, $p=0.0014$). Note that the slope indicates an approximately one-to-one relationship between the velocity of muscle lengthening from the STV and fast walking. A comparison of maximum muscle lengthening velocity during gait, between the patients who exhibited a spastic response in the isokinetic measurement (STV) and those who did not (non-STV), showed a slower hamstring velocity in the spastic group (0.16m/s vs. 0.25m/s, $p=0.0040$), and a statistically insignificant difference in the quadriceps velocities (0.20m/s vs. 0.18m/s, $p=0.47$)

Discussion

The study shows there is a direct and significant correlation between spastic velocity threshold and velocity of muscle lengthening during gait. Specifically, a one-to-one relationship exists between the STV recorded during isokinetic measurement and walking performance when recorded in terms of muscle lengthening velocity. Hence, results suggest the spastic velocity threshold introduces a velocity limit that constrains muscle lengthening during fast walking. This requires compensatory behavior to accommodate the constraint while maintaining stable walking performance, potentially contributing to characteristic movement patterns such as crouched walking and reduced cadence. This illustrates that spasticity forms a dynamic constraint limiting functional performance. It also confirms that isokinetic measurement can be used to establish the STV. These analytical methods could be useful in assessing treatments that affect the STV. The discrepancy between the hamstring and quadriceps velocities in the STV vs. non-STV groups may imply that spasticity in the hamstrings is the limiting factor for swing phase knee extension. Future studies will investigate these issues further. Although factors including passive ROM, strength and voluntary control undoubtedly contribute to gait performance results from the current study support the hypothesis that spasticity may act as a dynamic constraint to function in a predicable manner.

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