A Measure of Motor Control at the Knee in Cerebral Palsy

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This investigation developed a measure of motor control for the knee extensors in adults with cerebral palsy (CP). Four adults with CP and 4 able-bodied (AB) adults participated. A KinCom dynamometer rotated the knee from approximately 90° of knee flexion to 10° less than the participant’s maximum knee extension at a speed of 10°/s, while the participant attempted to match a 44.5-N “target” force. The average, standard deviation, and median frequency of the force-time data were used to describe the test results. The individual force values for the AB group were near the target force and clustered together. The values for the CP group were also near the target force, but displayed greater variation. The average standard deviation for the CP group was more than three times larger than that of the AB group. The average median frequency for the CP group was less than that of the AB group. Results pointed to differing strategies for each group as they attempted to match the target force. The AB group attempted to match the target force with frequent small-magnitude force changes, while the CP group attempted to match the target force with fewer oscillations of greater magnitude. The methods employed in the present investigation are initial attempts to quantify one aspect of motor control, a visually guided tracking task.

Key Words: knee extensors, adults, isokinetic

Introduction

Cerebral palsy (CP) is a nonprogressive disorder characterized by impairment of motor function secondary to injury of the immature brain (Ingram, 1984). Problems within the impairment domain (U.S. National Institutes of Health [NIH], 1993) in CP include such things as spasticity, strength, motor control, balance, hypertonicity, clonus, ataxia, and dyskinesia. Clinicians treat many of these impairments in an attempt to improve the function of individuals with CP. For example, a selective dorsal rhizotomy may be performed on persons with CP to reduce spasticity and improve function.
While there are many treatments to alter impairments, there are few objective measures for quantifying them. The lack of quantification limits the understanding and interpretation of the treatments. There are objective measures to quantify spasticity, strength, and balance (Cherng, Su, Chen, & Kuan, 1999; Engsberg et al., 1996, 1998a, 1998b, 1999, 2000a, 2000b, in press; Nashner, Shumway-Cook, & Marin, 1983; Ross, Engsberg, Olree, & Park, 2001; Ross & Engsberg, in press; Wolff, Rose, Jones, et al., 1998). Objective measures have been used to quantify motor control of the upper extremity in patients with CP (Harrison 1975; Valvano & Newell 1998) and the lower extremities in able-bodied older adults (Owings & Grabiner, 2000). However, application of these measures to the lower extremity have not been attempted in persons diagnosed with spastic diplegia cerebral palsy. Quantification of motor control in the lower extremity is critical to understanding outcomes related to a specific clinical procedure (e.g., selective dorsal rhizotomy), developing a comprehensive impairment profile (NIH, 1993), understanding the limitations during functional activities such as gait in persons with CP, and assessing outcomes related to specific clinical procedures.

The purpose of this investigation was to develop a measure of motor control for the knee extensors in adults with CP. The experimental hypothesis was that the CP group would demonstrate torque production strategies that would differ from the able-bodied group during a visually guided tracking task. Specifically, it was postulated that the CP group would demonstrate a strategy that included movement oscillations of greater magnitude and decreased frequency as compared to the AB group.

**Methods**

A KinCom isokinetic dynamometer, which permits a variety of speeds, resistances, ranges of motion, and monitor display options, was selected for use in developing the measure. The strategy was to ask the participant to produce a specified force over a range of motion, while being guided by visual feedback (i.e., a visually guided tracking task). This strategy was similar to that described by Valvano and Newell (1998), yet was in contrast to their work of the upper extremity since the participants in their study performed static isometric contractions. We believed that the dynamic contractions used in the motor control measure provided additional information since it was collected over a large and functional range of motion.

Eight adults were recruited for this study. Four had been diagnosed with spastic diplegia cerebral palsy (mean age 33 years; range 18–41), and four were able bodied (mean age 29 years; range 26–35). The participants with CP (CP group) were being assessed on the KinCom for knee spasticity and strength and were asked if they would be willing to participate in the development of the motor control test. The able-bodied participants (AB group) were recruited from within the hospital community. All participants gave their informed consent. Adults were recruited instead of children, since it was felt they could better verbalize their impressions of the test. Each participant sat on the KinCom according to manufacturer guidelines for testing the knee. The axis of the KinCom was aligned with the participant’s knee axis. The leg was attached to the KinCom lever arm by securing the leg against a tibial pad with Velcro straps. The limits for active range of knee extension motion were established by asking the participant to actively extend the knee against gravity while secured to the KinCom lever arm. Test range-of-motion limits were then established by subtracting 10º from
the participant’s active terminal knee extension. Each participant’s most involved knee was selected for testing.

The basic methods for the test were established from a pre-pilot study involving a person with cerebral palsy and an able-bodied person. For the test, the KinCom was set to the isokinetic mode with a speed of 10°/s. A 44.5-N (10 lb) “target” force was displayed on the computer monitor as a horizontal line on a force-angle diagram. During the knee extension test (i.e., concentric contraction), the participant attempted to match the 44.5-N target force over the entire range of motion. The actual force applied by the participant was superimposed, in real time, on the target force figure so the participant could immediately see the results of his or her efforts. Four trials of data were collected. As an initial assessment of reliability, one AB participant was tested three times over a 3-week period. The average forces for the three sessions were similar to one another. Likewise, the standard deviations were also comparable in value, although there was a slight decline over the three sessions; average force SD: Session 1 = 39.9 N (3.9); Session 2 = 38.1 N (2.7); Session 3 = 40.2 N (2.5). This decrease in variability was in agreement with previous work for an isometric force gripping task (Valvano & Newell, 1998).

The first trial of data for each participant was discarded, as it was the initial attempt to perform the task and generally produced very different results from the other trials. The final three trials of force data were downloaded to a spreadsheet on a personal computer. Force data from the start of the test to the point of first crossing of the 44.5-N force were deleted. This was done to minimize the distortion of the calculated variables due to starting the test at zero force.

Three variables were determined from the remaining values and used to describe the test results. The first was the force mean since it was the best single estimate of the force over the range of motion. The second variable was the force standard deviation since it provided an indication of the variability of the force amplitude. The third variable, force median frequency, was determined from a power density spectrum analysis (Fourier transform) of the force vs. time data. The median frequency is a common measure for quantifying cyclical characteristics of the electromyographic (EMG) waveform (Basmajian & DeLuca, 1985). The mean force, force standard deviation, and force median frequency were determined for each participant. With only four participants per group, no tests for significance were conducted. However, a power analysis was performed for each of the three variables to determine the sample size required to attain significance ($p = 0.05$ and $1 – \beta = 0.80$) (Lieber, 1990).

**Results**

Data from a single trial of one person with CP and an AB participant (Figure 1) displayed force mean values that were similar to the target force of 44.5 N (44.3 N and 44.6 N for the CP and AB groups, respectively). There was substantially greater variability in the CP participant (11.0 N) than the AB participant (2.5 N), as the force standard deviation of the data was over four times greater for the former. The force median frequency for the CP participant, 0.58 Hz, was lower than that of the AB person, at 0.86 Hz. The decreased range of motion of the CP person compared to the AB person can be observed, as well as the inability of the former to maintain the target force at the end of extension range of motion.
Figure 1 — Typical force-angle curve for a person with CP and an AB person attempting to match the target force of 44.5 N (10 lbs). Data prior to crossing the target force were truncated, and means, standard deviations, and median frequencies were calculated from the remaining data. Greater force variability, in terms of amplitude and frequency, can be observed in the CP vs. the AB participant.

Figure 2 — Force mean for all participants indicated a closely grouped data set for the AB group and a larger distribution for the CP group. Average value and standard deviation indicate group differences. A power analysis determined that 6 persons per group would be adequate to detect these differences as significant ($\alpha = 0.05, 1 - \beta = 0.80$).
The individual force mean values for the AB group were closely grouped (Figure 2) and had an overall average value of 40.3 N (1.5). In contrast, the force mean values for the CP group included two persons with values greater than the target force and two with values less than the target force (range was 14.4 N). The overall average value for the CP group was 48.7 N (7.4). Using the data presented here in a power analysis, it was determined that approximately six persons in each group would be required to achieve a significant difference ($\alpha = 0.05$) with a power ($1 - \beta$) of 0.80.

The individual force standard deviation values for the AB group were also closely grouped (Figure 3), with an overall average value of 5.5 N (1.2). The force standard deviation values for the CP group were more distributed than for the AB group. The average force standard deviation value for the CP group, 19.0 N (12.8), was over three times greater than that of the AB group. Using the data in a power analysis, it was determined that approximately six persons in each group would be required to achieve a significant difference ($\alpha = 0.05$) with a power ($1 - \beta$) of 0.80.

The individual force median frequency values for both groups seemed to be paired (Figure 4). The average for the AB group, 0.88 Hz (0.23), was larger than that of the CP group, 0.64 Hz (0.19). The power analysis determined that approximately 9 persons in each group would be required to achieve a significant difference ($\alpha = 0.05$) with a power ($1 - \beta$) of 0.80.

**Discussion**

The purpose of this investigation was to develop a measure of motor control for the knee extensors in adults with CP. Several limitations can be associated with the methods of this work. The target force (44.5 N) used in this protocol was considerably
lower than forces encountered during common functional tasks such as gait or stair climbing. However, this target force was selected for several reasons. First, it was based on our pre-pilot with an adult with CP and an AB adult. Next it was selected to ensure that each participant would be able to produce the target force throughout the test range of motion, thereby reducing the influence of muscle weakness on test performance. Finally, it represented the participant’s ability to produce a graded knee extensor torque as opposed to maximal torque generation during knee extension. It has been reported that persons with CP have limited ability to grade muscle torque production during dynamic activities (Giuliani, 1991; Rose & McGill, 1998). It should be noted here that it is likely the target force represented a higher percent of maximal voluntary contraction (MVC) torque production for the CP group than for the AB group. Future work could include the development of protocols based on the percent of maximum voluntary contraction.

Knee range of motion was reduced for those with CP as compared to the AB group. However, the disparity in range of motion was addressed by creating a test range of motion. This test range of motion was created to reduce the need for torque production during the final 10° of knee extension. This is the range that is often limited in persons with CP due to hamstring tightness or spasticity in addition to knee extensor weakness.

It should be noted that the motor control test assessed the ability to perform an open kinetic chain movement. Open kinetic chain movements are not often associated with lower extremity functional tasks such as gait (e.g., closed kinetic chain exercise during support). Further work with the results presented here and their rela-

Figure 4 — Individual median frequency values for all participants indicated a closely grouped data set for the AB group and greater variation for the CP group. Average values and standard deviations indicate group differences. A power analysis determined it was likely that 9 persons per group would be adequate to detect these differences as significant ($\alpha = 0.05, 1 - \beta = 0.80$).
tionships to specific gait variables is required. Nevertheless, these impairment variables should not be considered unworthy of study. In a research plan presented by the National Center for Medical Rehabilitation Research (NCMRR) at the National Institutes of Health, five domains of equal importance have been described (NIH, 1993). It was stated that there should be attempts to quantify information in all five domains in the research process to gain a more broad understanding of the patient. The measure of this investigation is included in the impairment domain.

It is likely that the standard deviations for both groups of participants could be smaller if they had had the opportunity to practice the task before the data were collected. Our objective was to present this novel task to both groups in the same manner, therefore all participants had the same opportunity to understand and perform the task. Previous work involving children with CP and able-bodied children attempting to match a predetermined force using a gripping task has demonstrated an improvement as a consequence of repetition (Valvano & Newell, 1998). Our initial work with one AB participant is in agreement with this prior work by indicating a slight decrease in standard deviation as a consequence of repetition.

There are other measures of variability in the literature (Owings & Grabiner, 2000), including the root mean square (RMS) error and the smoothness index (SI). The RMS error is the root mean square of the data, with the target force subtracted from the data. Our data is reported as a more familiar mean and standard deviation (SD). If the target force were equal to the mean of the data, then the SD and the RMS error would be almost identical, the difference being the factor of n/(n – 1). If the mean were not equal to the target force, however, then the RMS error would incorporate the difference into the equation. We felt that the inclusion of both the mean, as an indicator of how close the participant came to the target, and SD, an indication of variability, was more informative than an RMS error. The SI is another measure of variability reported by Owings and Grabiner (2000). This is the time derivative of the data, followed by an RMS calculation over the ROM. We found this to be well correlated with the SD. For ease of computation and comprehension, we retained our method of using the SD.

It is possible that the results for this knee extensor task cannot be generalized to other joints and muscles of the lower extremity. Initial development of the methods described in the present investigation included a similar test for the hamstrings. That component of the test was abandoned when it became apparent that the assistance of gravity to the task (the knee was being flexed with the aid of gravity) produced different results. These differing results directed attention away from the purpose of the study, to develop a measure of motor control. Future efforts will be made to examine knee flexor control (e.g., prone or side lying test position). In addition, our previous experience with comparisons of spasticity and strength at both the knee and ankles indicates that a test for motor control at the ankles in a CP group may not be possible. We have found that, in general, the ankle has greater spasticity and less strength when compared to the knee (Ross & Engsberg, in press). Many patients with CP may be able to generate only minimal dorsiflexor or plantarflexor forces or torques with minimal range of motion.

The results of the present investigation agree with previous work in the upper extremity (Valvano & Newell, 1998). These authors found greater force variability in children with CP compared to able-bodied controls as they attempted to match a target force during an isometric gripping task.
Results of the present investigation seem to point to differing strategies for each group as participants attempted to match the target force (Figure 1). The AB group attempted to match the target force with frequent (force median frequency, Figure 4) small magnitude (force standard deviation, Figure 3) changes. In contrast, the CP group attempted to match the target force with fewer oscillations of greater magnitude. Additional data from more participants will confirm or refute these observations.

A goal of our research is to develop an objective “impairment” profile for a person with CP. Such a profile could be helpful in determining the treatment pathways and treatment efficacy of a patient. For example, neurosurgeons perform selective dorsal rhizotomies to decrease the spasticity and improve the function of some patients with cerebral palsy. We have reported that knee flexor and hip adductor strength is significantly increased following the surgery (Engsberg et al., 1999; in press). It is possible that the selective dorsal rhizotomy may also alter the motor control (i.e., visually guided tracking task) of these patients. If so, this may be an additional reason, besides a reduction in spasticity (Engsberg et al., 1998a; 1999; in press) that would support the use of selective dorsal rhizotomy surgery.

References


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