ORIGINAL ARTICLE

Relationships Between Spasticity, Strength, Gait, and the GMFM-66 in Persons With Spastic Diplegia Cerebral Palsy

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ABSTRACT. Ross SA, Engsberg JR. Relationships between spasticity, strength, gait, and the GMFM-66 in persons with spastic diplegia cerebral palsy. Arch Phys Med Rehabil 2007; 88:1114-20.

Objective: To determine the relationships between spasticity, strength, and the functional measures of gait and gross motor function in persons with spastic diplegia cerebral palsy (CP).

Design: Retrospective, cross-sectional study.

Setting: Hospital clinic.

Participants: Ninety-seven participants (49 boys, 48 girls; mean age ± standard deviation, 9.11±4.8y) with spastic diplegia CP were tested once.

Interventions: Not applicable.

Main Outcome Measures: A KinCom dynamometer was used to objectively measure spasticity (ankle plantarflexors, knee flexors, hip adductors) and maximum strength (ankle dorsiflexors and plantarflexors, knee flexors and extensors, hip abductors and adductors). A gait analysis was conducted to evaluate linear variables (gait speed, stride length, cadence) and kinematic variables (ankle dorsiflexion, foot progression, knee and hip flexion, pelvic tilt at initial contact and ankle dorsiflexion, knee and hip flexion, pelvic tilt, trunk rotation range of motion) during gait. Gross motor function was measured using the Gross Motor Function Measure (GMFM-66) and separately, the GMFM walking, running & jumping dimension. Multiple linear regression analysis was used to determine the relationships between spasticity, strength, gait, and the GMFM ($P<.05$).

Results: Spasticity did not account for a substantial amount of explained variance in gait and gross motor function (up to 8% for the GMFM walking, running & jumping dimension). Moderate to high correlations existed between strength and gait linear data and function, accounting for up to 69% of the explained variance (strength and GMFM-66, $r^2=.69$).

Conclusions: For this cohort of participants with spastic diplegia CP who ambulated with or without an assistive device, strength was highly related to function and explained far more of the variance than spasticity. The results may not be generalized to those with more severe forms of CP.

Key Words: Cerebral palsy; Gait; Muscle spasticity; Rehabilitation.

SPASTICITY AND A LACK of muscle strength (weakness) are primary impairments associated with people with cerebral palsy (CP). The main goal of most interventions is to improve function, but the relationships between spasticity and function or between strength and function, have rarely been reported in the same group of people with CP. Historically, spasticity was considered a primary limiting impairment in people with CP; therefore, if spasticity was reduced, function would automatically be improved.[1] Strength, especially in spastic muscle groups, was not a therapeutic focus in people with CP because spastic muscles were thought to already be overly strong or active and there was an assumed risk of increasing spasticity or abnormal movement patterns if strength was increased.[2] Interventions, such as botulinum toxin, tendon lengthening, and selective dorsal rhizotomy (SDR), have been based on assumptions about the relationships between spasticity, strength, and function without adequate research.

There are many assumptions about the relationship between spasticity, strength, and function in people with CP. Spasticity is thought to be inversely related to gross motor function and gait, so the greater the spasticity the lower the level of function. Spasticity of the hamstrings has been attributed to a knee-flexed gait pattern and spasticity of the plantarflexors has been attributed to a toe-walking gait pattern.[3] However, because most researchers do not objectively quantify spasticity, there has been limited research on the correlation between the amount of spasticity, the associated gait deviation, and the level of gross motor function. Unlike spasticity, strength is thought to be directly related to gross motor function and gait: the greater the strength the higher the level of function. Increasingly, investigators have objectively documented strength in people with upper motoneuron damage but rarely did investigators objectively measure both strength and spasticity, so it remains unclear whether it is spasticity, weakness, or some combination of the 2 that could be the cause of the functional deficits seen in people with CP.

Spasticity related to function in a group of 18 participants with CP was reported by Tuzson et al.[4] Tuzson determined a spastic threshold velocity, using electromyography during isokinetic testing, for the quadriceps and hamstrings and found it correlated with the Gross Motor Function Measure (GMFM) walk and run domain ($r=.58$) and walking velocity ($r=.64$), indicating the milder the spasticity the higher the function. They also reported that the Ashworth Scale score correlated significantly with the GMFM ($r=.83$). Damiano et al[5] recently reported on a group of 25 children with CP, 9 of whom exhibited a spastic stretch response in both quadriceps and hamstrings with significantly slower knee angular velocities during the swing phase of gait compared with others with CP, but reported no significant correlations between spasticity measures (resistance to passive stretch) and gait parameters. Abel et al[6] reported on a group of 129 ambulatory children with CP and found that the Ashworth scores for hip flexion and extension, abduction, and knee flexion and extension all correlated mildly negatively with the GMFM-66 (r range, −.22 to −.34). They found no significant correlation between ankle spasticity and gross motor function. Most recently, Østensjø et al[7] re-

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ported a significant correlation between the Modified Ashworth Scale (for hip, knee, and ankle) and the GMFM-66 (r=.64) in a group of 95 children with CP. Most of the researchers used the Ashworth Scale to determine the amount of spasticity and the objectivity of this measure has been questioned.[8] In addition, none of the above investigations also measured strength.

Strength related to function in a group of 17 adolescents with CP was reported by Kramer and MacPhail.[9] They found that knee extensor strength (eccentric, concentric) related moderately (range, .57−.69) with the GMFM. Damiano and Abel[10] found similar results in a group of 11 participants (6 with diplegia, 5 with hemiplegia): lower-extremity strength (hip, knee, ankle) correlated highly with gait speed (r=.71) and moderately with the GMFM (r=.59). In a later study of a group of 10 children with spastic CP, Damiano et al[11] reported a moderate correlation between knee extensor strength and gait speed (r=.68) and knee extensor strength and the GMFM (r=.57). However, Damiano found no significant correlation between hamstring strength and function. None of the above investigations also measured spasticity.

The only group of investigators that has reported on spasticity and strength and how this relates to function in the same group of participants with CP is Damiano and colleagues. According to Damiano et al,[12] increased knee flexor spasticity (only at the fastest speed 120°/s) was mildly related (r=−.44) to lower GMFM scores. Knee extensor spasticity at 30° and 60°/s related moderately with the GMFM (r=−.57, r=−.52, respectively). They reported that knee strength, both quadriceps and hamstrings, was highly related (r range, .70–.83) to the GMFM. This study involved only the knee muscles of the lower extremity and did not examine gait.

To further explore the relationship among impairments and function in persons with CP, Abel et al[6] performed a stepwise regression analysis to determine if any combination of variables could predict function to a substantial degree (r^2>50%). The study included 129 children with spastic diplegia and hemiplegia CP and the variables analyzed included Ashworth scores, passive range of motion (ROM), and gait kinematics to predict motor function in the GMFM and Pediatric Outcomes Data Collection Instrument (PODCI). They found that the above variables explained 33% of the variance (r^2=.33) for the PODCI and a lower r^2 value for the GMFM (not reported). They concluded that strength, which was not measured, might have increased the predictability of the impairments because it has been shown to correlate moderately with gait velocity and the GMFM.[10]

There is no single study addressing the relationship between hip, knee, and ankle impairments (spasticity, strength), gait, and gross motor function in the same group of participants with CP. The purpose of this investigation was to determine the relationships between lower-extremity spasticity, strength, and the functional measures of gait and gross motor function in subjects with spastic diplegia CP.

METHODS

A retrospective analysis was performed on the spasticity, strength, and function results from data collected on 97 participants with spastic diplegia CP (49 boys, 48 girls; mean age ± standard deviation [SD], 9.11±4.8y; range, 4–23y). A neurosurgeon or neurologist had referred the participants to the Human Performance Laboratory for testing and they were participating in an SDR study.[13] All participants were candidates for the SDR surgery and all measures were taken preintervention. The sample included participants from 23 states within the United States; 15 (16%) of 97 participants were from the St. Louis metropolitan area, and 71 (73%) of 97 were from out of state. The participants were at least 1 year post orthopedic surgery, 6 months post botulinum toxin type A (Botox) injections, and had no history of spasticity-altering surgeries (baclofen pump, SDR) prior to testing. The majority of the participants (66%) were independent ambulators with a relatively equal distribution between Gross Motor Function Classification System (GMFCS) levels I through III (table 1). Persons with GMFCS level I ambulate independently without limitations, but may have limitations in more advanced gross motor skills; persons with level II ambulate independently but have limitations walking outdoors and in the community; and persons with level III ambulate with an assistive device.[14] All participants or parents (when appropriate) signed an informed consent approved by the Washington University Internal Review Board.

Table 1: Participant Demographics, GMFCS Level, and Gait Status

Parameter	Demographics
Participants (N)	97
Mean age ± SD (range), y	9.1±4.8 (4–23)
Sex (male/female)	49/48
GMFCS	
Level I	32
Level II	34
Level III	31
Primary mobility device	
Independent	66
Canes	12
Crutches	13
Walker	6

The general methods used in this investigation to measure spasticity and strength have been described elsewhere for the hip, knee, and the ankle.[15-20] They will be briefly summarized here. Spasticity was tested for the hip adductors, knee flexors, and ankle plantarflexors. Strength was tested for the hip abductors and adductors, knee extensors and flexors, and ankle dorsiflexors and plantarflexors. For the sake of brevity, only the methods used at the ankle will be presented; similar methods were used at the knee and hip.

The participants were secured on the KinCom isokinetic dynamometer[a] seat with a pelvic and thigh strap. The joint axis was aligned with the KinCom lever arm. Ankle dorsiflexion and plantarflexion ROM limits were established. For the spasticity tests, the participant was instructed to remain as relaxed as possible while the passive ankle joint was rotated from maximum plantarflexion to the participant's maximum dorsiflexed position, thereby stretching the ankle plantarflexor muscles. Spasticity tests were conducted at speeds of 10°, 30°, 60°, 90°, and 120°/s (the 120°/s speed was only at the ankle). Only 1 trial at each speed was actually used in the analysis. The therapist saved the trial when variation between trials was minimal or nonexistent for a given speed.

Immediately following the passive spasticity test at a joint, the participant was asked to perform a maximum concentric contraction of either the ankle plantarflexors or dorsiflexors while the lever arm moved (passive mode) at 10°/s. The speed of 10°/s was chosen because some participants with CP did not have enough strength to initiate motion of the lever arm. In addition, testing strength throughout the passive ROM was possible using this method. Three to 5 trials were conducted to permit the participant to achieve his/her best performance. Only the trial indicating the greatest amount of torque was used in the analysis.

For the spasticity test, torque-angle data were processed to partial out the effects of gravity and minimize acceleration and machine dynamic responses. Areas within the torque-angle curves were calculated to yield work values. The work values were determined for each speed (ie, 10°, 30°, 60°, 90°, and 120°/s). Linear regression was used to determine the line of best fit for the work values as a function of speed. The slope of the linear regression line was the magnitude of the spasticity. A steeper slope indicated a greater amount of work was required to stretch that muscle group and a greater amount of spasticity. For the strength measures, maximum torque values were recorded. All values were normalized by dividing by participant mass to permit interparticipant comparison.[9,15,17,18,20]

The general methods for the gait analysis used in this investigation have been reported elsewhere and will briefly be described here.[13,21,22] Three 9-mm diameter spherical reflective surface markers were placed on each of the trunk, thighs, legs, and feet of each participant. The participant walked barefoot at a self-selected pace along a 9-m walkway and video data were collected (6-camera HiRes)[b] during the middle 3m. At least 6 trials of data were collected from each participant. Rest periods were provided as needed. Temporal gait variables including speed, stride length, and cadence were determined. The location-time data of the surface markers were tracked (digitized) and converted to 3-dimensional coordinates as a function of time. The tracked data were uploaded into KinTrak software[b] for further processing. The software produced data describing the averaged joint angle as a function of the complete gait cycle for each of the 3 principal planes of the body. The variables calculated included in the sagittal plane; pelvic tilt, hip, and knee flexion and extension and ankle dorsiflexion and plantarflexion, and in the transverse plane; trunk rotation and foot progression angle.

GMFM data were collected. The GMFM is a standard criterion-referenced test designed to assess change in gross motor function in persons with CP.[23] The 88 items of the test (GMFM-88) assess activities in 5 dimensions: (1) lying and rolling, (2) sitting, (3) crawling and kneeling, (4) standing, and (5) walking, running & jumping. Each item is scored using a 4-point Likert scale (0, does not initiate; 1, initiates; 2, partially completes; 3, completes). Totals from each category for a participant were divided by the total possible points to produce a category percentage score. These percentages were averaged to yield an overall score. The GMFM-66 uses 66 of the 88 items and was developed using Rasch analysis to improve the sensitivity and interpretability of the test.[24] To account for a potential ceiling effect of the GMFM, we also evaluated the GMFM walking, running & jumping dimension.[4] The GMFM walking, running & jumping is the fifth dimension and represents the highest gross motor function level in this test and thus is the most difficult for people to score 100% on, even those in GMFCS levels I and II.

The data analysis included 4 steps. First, spasticity and strength variables were tested for normality. The spasticity variables were found not to be normally distributed and were transformed using natural log to achieve a normal distribution. Second, multivariate linear regression analyses were used to examine the relationships between aggregate spasticity, aggregate strength, and the functional measures of gait (linear data and kinematics) and gross motor function (eg, all 6 lower-extremity strength variables were compared with the dependent variable GMFM-66 and GMFM walking, running & jumping dimension). Aggregate values that represent spasticity and strength (impairments) of the lower extremity were chosen to answer the clinical question "Which impairment (spasticity or strength) is most related to function in people with CP?" Aggregate values for spasticity included 3 variables: the individual hip adductor, knee flexor, and ankle plantarflexor values right and left sides averaged for each variable. Aggregate values for strength included 6 variables: the individual hip abductor and adductor, knee flexor and extensor, and ankle dorsiflexor and plantarflexor values with the right and left sides averaged for each variable. Colinearity statistics for the aggregate spasticity and strength values were within the acceptable range of tolerance with no variable less than .20. Third, partial correlations, controlling for age and the GMFCS, were performed for significant relationships between spasticity, strength, and function. Last, a forward stepwise linear multiple regression analysis, similar to that used in the Abel et al[6] study on children with CP, was used to examine the relationships between the strength and spasticity variables and the 2 most clinically relevant function variables: gross motor function (GMFM-66) and gait speed. The stepwise analysis was chosen to attempt to answer the clinically significant question "Which impairment (spasticity or strength) at which joint explained the greatest amount of variance in function?" For correlations, an r of 0.90 to 1.00 was considered very high, 0.70 to 0.89 was considered high, 0.50 to 0.69 was considerate moderate, 0.26 to 0.49 was fair (mild), and 0.00 to 0.25 indicated little to no relationship.[25] A significance level of P less than .05 was used in the analysis.

RESULTS

Spasticity and Strength Relationship With Gross Motor Function

Aggregate spasticity consisting of individual values for the ankle plantarflexors, knee flexors, and hip adductors averaged across sides did not relate significantly to the GMFM-66 (r=.27) (fig 1) or GMFM walking, running & jumping dimension (r=.29) (table 2). Aggregate strength consisting of values for the ankle dorsiflexors and plantarflexors, knee extensors and flexors, and hip abductors and adductors averaged across sides was highly related to the GMFM-66 (r=.83) (see fig 1) and GMFM walking, running & jumping dimension (r=.81). Forward stepwise linear multiple regression showed that strength of the hip abductors followed by the ankle plantarflexors and knee flexors explained 68% of the variance in the GMFM-66 and 64% of the variance in the GMFM walking, running & jumping dimension (table 3).

Spasticity and Strength Relationship With Gait Speed

Aggregate spasticity was not related to gait speed (r=.19) (fig 2) or cadence (r=.26) but was mildly related to stride length (r=.33) (see table 2). Aggregate strength was moderately related to gait speed (r=.61) (see fig 2), highly related to stride length (r=.71), and mildly related to cadence (r=.39). Forward stepwise linear multiple regression showed that strength of the hip abductors, followed by the ankle dorsiflexors, explained 36% of the variance in gait speed. For stride length, 47% of the variance was explained by strength of the ankle dorsiflexors followed by the knee extensors and hip abductors. Strength of the ankle plantarflexors explained 32% of the variance in cadence (see table 3).

Spasticity and Strength Relationship With Gait Kinematics

Aggregate spasticity was not significantly related to any gait kinematic variables (table 4). Aggregate strength was moderately related to pelvic tilt ROM (r=−.55) and knee flexion at initial contact (r=−.50), mildly related to ankle dorsiflexion (r=.47) and internal foot progression angle (r=−.39) at initial contact, and mildly related to knee flexion (r=.46) and trunk

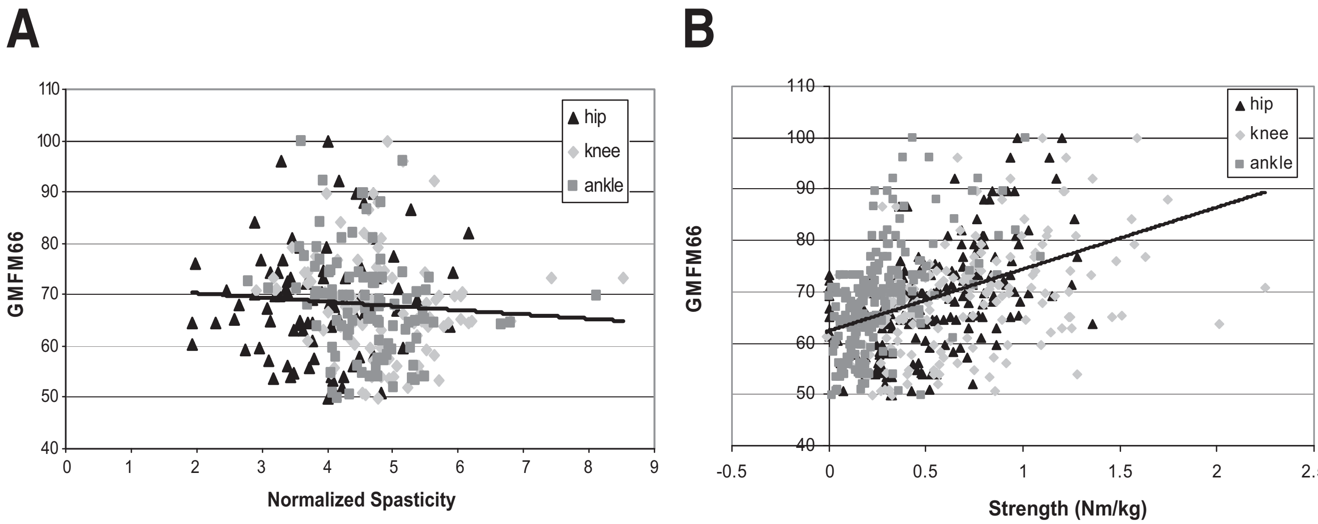

Fig 1. (A) A scatterplot showing the relationship between aggregate spasticity (normalized data for the hip adductors, knee flexors, and ankle plantarflexors) and the GMFM-66. (B) A scatterplot showing the relationship between aggregate strength (maximum values of the hip abductors and adductors, knee extensors and flexors, and ankle dorsiflexors and plantarflexors) and the GMFM-66.

rotation ($r=-.48$) ROM during gait. Forward stepwise linear multiple regression was performed but data are omitted for brevity because explained variance for kinematic variables was very low. The largest variance (21%) was for knee flexion at initial contact explained by strength of the hip abductors and ankle plantarflexors.

Age and GMFCS Relationships With Function: Controlling for Each Variable

Age was not related to the GMFM-66 ($r=.03$) or GMFM walking, running & jumping dimension ($r=.08$) but was moderately related with stride length ($r=.64$) and mildly related with gait speed ($r=.23$) and cadence ($r=-.34$). Given that age correlated significantly with stride length, partial correlations were performed controlling for age. The mild relationship between aggregate spasticity and stride length was no longer significant; thus age, not spasticity, accounted for most of the variance in stride length. When controlling for age, the significant relationships between strength and function did not change.

The GMFCS was highly related to the GMFM-66 ($r=-.77$) and GMFM walking, running & jumping dimension ($r=-.82$), and mildly related to gait speed ($r=-.49$), stride length ($r=-.31$), and cadence ($r=-.44$). Partial correlations were performed controlling for GMFCS level to determine if a relationship existed between spasticity and function. When controlling for the GMFCS, stride length was significantly related to spasticity, however, only for the hip adductors. The relationship between spasticity and gait speed and cadence remained unchanged. When controlling for the GMFCS, the significant relationships between strength and function did not change.

Table 2: Multivariate Linear Regressions (*r* values) Between Spasticity, Strength, and Gross Motor Function and Gait Linear Data

Item	Aggregate Spasticity	Aggregate Strength
GMFM-66	.27	.83†
GMFM walking, running & jumping dimension	.29	.81†
Gait speed	.19	.61†
Stride length	.33*	.71†
Cadence	.26	.39*

NOTE. Aggregate Spasticity is spasticity of the hip adductors, knee flexors, and ankle plantarflexors; Aggregate Strength is strength of the hip abductors and adductors, knee extensors and flexors, and ankle dorsiflexors and plantarflexors.
*$P<.05$; †$P<.01$.

DISCUSSION

The purpose of this investigation was to determine the relationship between the impairments of spasticity and strength and the functional measures of gait and gross motor function in persons with CP. Interpretation of a regression analysis that only captures a single time point of the relationship between variables should not infer causation. In other words, strength was highly related and spasticity was minimally related to gross motor function, but this does not imply that increasing strength or decreasing spasticity in a child with CP will automatically result in an improvement in function. In addition, the study was conducted with children in GMFCS levels I through III or independent ambulators with or without assistive devices to allow a gait analysis to be conducted. If children who were more limited in gross motor function or nonambulators (GMFCS levels IV and V) had been included, the results might have changed, especially with regard to spasticity. The relationship between spasticity and gross motor function in children with greater involvement was not a part of this investigation.

A limitation of the study was the lack of electromyography during spasticity testing. Electromyography would have added to the measure of spasticity (velocity-dependent resistance to passive stretch) by confirming a spastic response during stretch. This measure of spasticity (work values at increasing speeds) has been shown to be reliable in children with CP.[26] All of the participants in this study were candidates for SDR and none of the individual impairment results were used to determine candidacy for the surgery. Although the results of

Table 3: Forward Stepwise Linear Multiple Regression Between Individual Impairment Variables and Gross Motor Function and Gait Linear Data

Item	GMFM-66	GMFM Walking, Running & Jumping Dimension	Gait Speed	Stride Length	Cadence
HAd spasticity					
KF spasticity					
AP spasticity					
HAb strength	.54	.51	.32	.04	
HAd strength					
KE strength				.08	
KF strength	.03	.04			
AD strength			.04	.35	
AP strength	.11	.09			.32
Explained variance (r^2)	.68*	.64*	.36*	.47*	.32*

NOTE. The r^2 value indicates the total explained variance for each dependent measure.
Abbreviations: AD, ankle dorsiflexor; AP, ankle plantarflexor; HAb, hip abductor; HAd, hip adductor; KE, knee extensor; KF, knee flexor.
*$P<.01$.

this study showed a minimal relationship between spasticity and function, it should not be inferred that a rhizotomy will be ineffective in improving function. Rhizotomy, in a meta-analysis of randomized clinical trials,[27] has been shown to be effective in improving gross motor function. It may be that, as spasticity is reduced as a result of the rhizotomy, children have a window of opportunity during which they can more effectively work on muscle strength and expand their repertoire of movement patterns, which then may result in functional gains.

There tends to be a common assumption that impairments, especially spasticity, are strongly related to gait and gross motor development. Of the 15 variables measured, aggregate spasticity was mildly related only to 1 variable: stride length. When controlling for age, stride length was no longer significantly related to spasticity. When controlling for the GMFCS, stride length was only significantly related to hip adductor spasticity. Aggregate strength was significantly related to 11 of the 15 variables measured and moderately or highly related to 6 of these variables: the GMFM-66, GMFM walking, running & jumping dimension, gait speed, stride length, knee flexion at initial contact, and pelvic tilt ROM during gait. Controlling for age or GMFCS level did not change the significant relationships between strength and function. Based on the results, it appears that strength rather than spasticity accounted for a substantial degree of the variance in gait and gross motor function in persons with spastic diplegia CP. Strength accounted for up to 69% of the variance in the GMFM-66, whereas spasticity accounted for only up to 8% of the variance in the GMFM walking, running & jumping dimension.

The findings are in agreement with Damiano et al[12] with regard to strength, which correlated highly with the GMFM, but they were not in agreement with regard to spasticity and the GMFM. According to Damiano, spasticity, in 1 of 3 speeds for the hamstrings and 2 of 3 speeds for the quadriceps, related moderately to the GMFM for the 23 participants tested. The results of our study indicated that spasticity was not significantly related to the GMFM (N=97). One possible reason for the difference is that we measured individual spasticity values at the hip, knee, and ankle and combined the values in the analysis, whereas Damiano measured spasticity only at the knee and analyzed the muscles at individual speeds. The finding showed that only 1 of 3 speeds for the hamstrings spasticity was significantly related to the GMFM; thus if the speeds had been combined into a single value for spasticity for that muscle

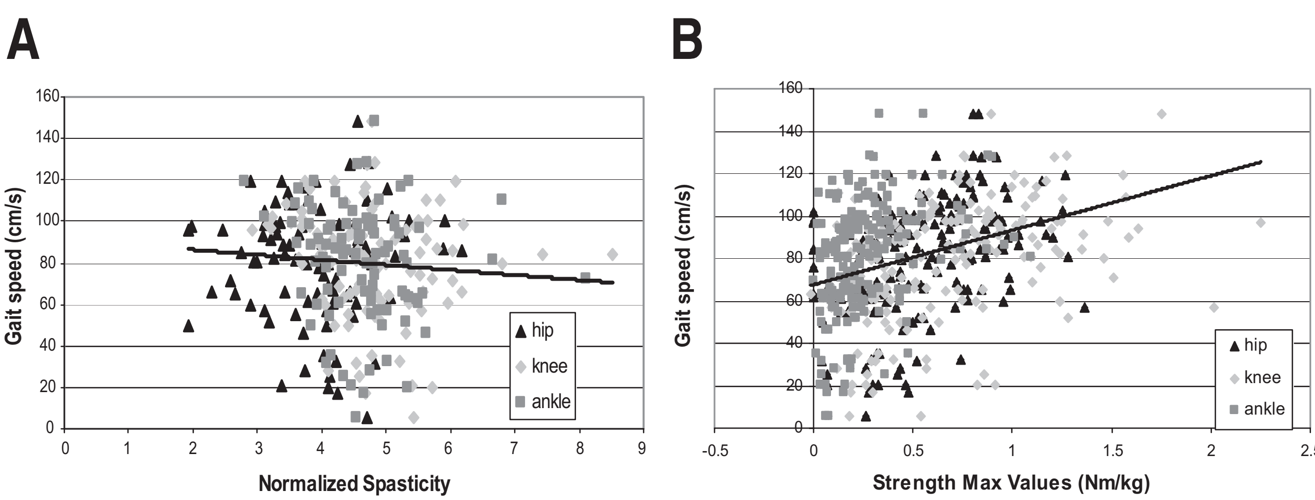

Fig 2. (A) A scatterplot showing the relationship between aggregate spasticity (normalized data for the hip adductors, knee flexors, and ankle plantarflexors) and gait speed. (B) A scatterplot showing the relationship between aggregate strength (maximum values of the hip abductors and adductors, knee extensors and flexors, and ankle dorsiflexors and plantarflexors) and gait speed.

Table 4: Multivariate Linear Regressions (*r* values) Between Spasticity, Strength, and Gait Kinematics

Kinematics	Aggregate Spasticity	Aggregate Strength
DF at initial contact	.20	.47†
DF ROM	−.15	.26
Flpro at initial contact	−.29	−.39*
KF at initial contact	−.18	−.50†
KF ROM	−.29	.46†
HF at initial contact	−.09	.30
HF ROM	−.29	.33
Pelvic tilt at initial contact	−.18	.29
Pelvic tilt ROM	.16	−.55†
Trot ROM	.28	−.48†

NOTE. Aggregate Spasticity is spasticity of the hip adductors, knee flexors, and ankle plantarflexors; Aggregate Strength is strength of the hip abductors and adductors, knee extensors and flexors, and ankle dorsiflexors and plantarflexors.
Abbreviations: DF, dorsiflexion; Flpro, foot internal progression; HF, hip flexion; KF, knee flexion; ROM, ROM excursion during gait; Trot, trunk rotation.
*$P<.05$; †$P<.01$.

group (similar to our measure), the results might have been similar to the present study. Another possibility is that the participants in Damiano's study included children with moderate to severe spastic quadriplegia, which may explain their more significant spasticity results. With regard to spasticity and gait, the results of the study are in agreement with Damiano et al,[5] who found that resistance to passive knee flexion or extension (spasticity) was not related to gait parameters. Abel et al[6] used the Modified Ashworth Scale to measure hip, knee, and ankle spasticity, which has been considered a subjective measure of spasticity,[28] and reported a significant mild relationship between hip and knee spasticity and the GMFM, but no significant relationship between ankle spasticity and the GMFM. It may be possible that spasticity of one muscle group is more related to the GMFM than that of other muscle groups. Further individual muscle group analysis of our data indicated no relationship between spasticity of the hip adductors or knee flexors and the GMFM. There was a mild relationship between ankle plantarflexor spasticity and the GMFM (r=.23). A consistent pattern of spasticity in individual muscle groups having a greater relationship to the GMFM than that of other muscle groups has not been established. Although our results show little to no relationship between lower-extremity spasticity at the hip, knee, and ankle, and gross motor function, additional work may be needed to confirm these relationships.

The results indicated that muscle strength was highly related to gross motor function and moderately related to gait. The results are in agreement with a preponderance of recent literature indicating a positive significant correlation between strength and gait and function in persons with CP.[9-12] The results of this study indicated the muscle groups that explained the largest variance in gait and gross motor function were the strength of the hip abductors, followed by the ankle plantarflexors and ankle dorsiflexors. We have found little to no literature about the relationship between strength of individual muscle groups and function in children with CP. Hip abduction strength in children with CP has been reported as significantly less than in their able-bodied peers.[29,30] There is no literature about the relationship between hip abduction strength and function. Hip abductor strength may be important for tall kneel and half kneel skills, single-limb balance, and gait. According to Perry,[31] weak hip abductors (grade 3 or less on manual muscle testing) will result in a contralateral pelvic drop and excessive hip adduction during gait. For this cohort of participants, hip abductor strength appeared to be most closely related to function than any other lower-extremity muscle group. The second muscle group that most explained function was the strength of the ankle plantarflexors. There is no literature on the relationship between plantarflexor strength and function in cerebral palsy. Rodda and Graham[32] referred to the ankle plantarflexion-knee extension force couple during gait as a critical biomechanic concept in studying gait patterns in children with CP. They described the role of a competent gastroc-soleus as controlling the progression of the tibia over the planted foot during stance. Dodd et al[33] strengthened the plantarflexors and knee extensors using a home-based strength training program for 6 weeks and found significant gains in strength and trends toward increased function, but no significant increase in the GMFM. Engsberg et al[34] strengthened the ankle dorsiflexors, plantarflexors, or both in a group of 12 children with spastic diplegia for 12 weeks and reported a significant improvement in the GMFM walking, running & jumping dimension. They also reported the correlation between change in ankle strength and change in the GMFM walking, running & jumping dimension was highly related (r=.84). The third muscle group to account for the explained variance in function was the ankle dorsiflexors. There is a great deal of research on ankle dorsiflexion strength and treatments to improve gait pattern, but no information on how this correlates to function.[34,35] The dorsiflexors are critical for initial contact, loading response and swing during gait.[36] It was no surprise that ankle dorsiflexor strength appeared to be the third most important muscle group with regard to function in persons with CP. Improving strength of the hip abductors and ankle plantarflexors and dorsiflexors and the effect on gait and gross motor function warrants further investigation.

Our results showed that for this cohort of participants with spastic diplegia CP, strength was highly related to function and explained far more of the variance than spasticity. Damiano et al[5,12] were the only group found to examine both spasticity and strength in the lower extremity, at the knee joint only, as they relate to gait and the GMFM in subjects with CP. This is the first study to examine the relationship between spasticity and strength at the hip, knee, and ankle and gait and gross motor function in subjects with spastic diplegia CP.

CONCLUSIONS

The relationship between spasticity, strength, and function in the same group of subjects with CP has been unclear among clinicians and researchers. For this cohort of participants who ambulated with or without an assistive device, the results indicated that there was little to no significant relationship between spasticity and function. Unlike spasticity, strength correlated significantly with 11 of the 15 variables tested and correlated moderately or highly with 6 variables (GMFM-66, GMFM walking, running & jumping dimension, gait speed, stride length, knee flexion at initial contact, pelvic tilt ROM during gait). Forward stepwise linear multiple regression showed that the muscle groups that explained the largest variance in gait and gross motor function were the strength of the hip abductors followed by the ankle plantarflexors and ankle dorsiflexors. The results may not be generalized to those with more severe forms of CP.

Although it is difficult to draw clinical implications based on the results of a regression analysis, it is possible that strength may be very important in improving function in people with CP. Strength and spasticity should be objectively measured pre- and postintervention to continue to clarify the relationship between impairment and function and how these change with regard to different interventions. Strength, rather than spasticity, might be given greater consideration when determining if a child with spastic diplegia may benefit from an intervention to improve functional outcomes. Future research is needed to see if functional outcomes, following any intervention, would be improved if rehabilitation focused on intensive strengthening exercises. The results support future work focusing on strengthening the hip abductors and ankle plantarflexors and dorsiflexors in people with spastic diplegia CP.

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