The Relationship of Lower-Extremity Muscle Torque to Locomotor Performance in People With Stroke

Background and Purpose. Improved walking is a common goal after stroke. The purpose of this study was to examine the relationship between the torque generated by the muscles of both lower extremities and 2 locomotor tasks: gait on level surfaces and stair climbing in people who had strokes. **Subjects.** Twenty community-dwelling individuals (mean age=61.2 years, SD=8.4, range=52–82) who had strokes and who were able to walk independently participated in the study. The mean time since stroke was 4.0 years (SD=2.6, range=1.5–10.0). **Methods.** Pearson correlations and multiple regression were used to measure the relationship between concentric isokinetic torque of the flexor and extensor muscles of the hip, knee, and ankle bilaterally and locomotor performance (gait on level surfaces and stair-climbing speed). **Results.** The isokinetic torques of the paretic ankle plantar flexors, hip flexors, and knee flexors had moderate to high correlations (r=.5–.8) with gait and stair-climbing speeds. Muscle force could explain 66% to 72% of the variability in gait and stair-climbing speeds. Correlations for the nonparetic side were as high as or higher than those for the paretic side for some muscle groups. **Discussion and Conclusion.** Muscle performance measurements of both limbs should be included in the evaluation of locomotion and treatment of people following a stroke. [Kim CM, Eng JJ. The relationship of lower-extremity muscle torque to locomotor performance in people with stroke. *Phys Ther.* 2003;83:49–57.]

Key Words: *Gait, Strength, Stroke.*

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The most often stated goal of patients following a stroke is to improve walking.[1] Therefore, retraining of locomotor skills is a major goal in the rehabilitation of people following a stroke. Although 65% to 85% of people with stroke learn to walk independently by 6 months poststroke,[2] gait abnormalities, particularly reduced speed, may diminish the usefulness of this method of mobility.

Although many traditional approaches to stroke rehabilitation have focused on the reduction of abnormal reflex activity and abnormal movement,[3] there is growing evidence that muscle weakness, rather than abnormal reflex activity (which is measured by the resistance to passive movement), is a major limiting factor in physical function, particularly for locomotor tasks, following stroke.[4–6] Muscle weakness is a common consequence of stroke.[7–9] Possible factors contributing to muscle weakness following cerebral lesions include decreased number of motor units,[10] disrupted recruitment order of motor units,[11] and decreased motor unit firing rates,[12] in addition to muscle atrophy following disuse.[13] Recent lower-extremity exercise programs that predominantly consisted of exercises designed to enhance force generation through a large range of motion have shown promising effects on gait and stair-climbing locomotor performance.[14–16]

Identifying the contribution of the force generated by muscle groups to locomotor function after stroke would help to provide a focus in the assessment and treatment programs aimed at improving locomotor tasks. Muscle force generation and locomotor function have been correlated in people with stroke.[17–20] Relationships between isometric forces and tasks such as walking ability on level surfaces,[17,18] stair-climbing ability,[19] and transfer capacity[20] have been identified. Bohannon[17] found that the isometric torque of paretic hip extensors, knee flexors, ankle dorsiflexors, and ankle plantar flexors (all measured at a 90° angle) were moderately correlated with gait speed on level surfaces (r=.47–.60), whereas hip flexors, hip abductors, and knee extensors were not correlated. In subsequent studies,[4,18] however, Bohannon and colleagues found that the isometric torque of paretic knee extensors also was moderately correlated with gait speed (r=.54–.67).

Although the majority of correlational studies of muscle performance and function have evaluated gait ability on level surfaces, Bohannon and Walsh[19] also have studied the locomotor task of stair climbing. They found that the isometric torque of all 5 paretic muscle groups that they tested (hip flexors and extensors, knee flexors and extensors, and ankle dorsiflexors) were correlated with a 6-point descriptive stair-climbing score (r=.73–.85). This ordinal scale consisted of 4 points for level of assistance, 1 point for handrail use, and 1 point for pattern (step-through versus step-to).

Isometric forces, however, reflect only forces at one selected point in the range of motion. Other types of force measurements that evaluate forces throughout a range of motion may be more appropriate in establishing relationships with locomotor activities, which require force to be exerted through a large range of motion. Nakamura et al[6] reported that isokinetic torque measurements of the paretic knee extensors were more strongly correlated (r=.79–.87) with gait speed than isometric torque measurements (r=.60–.76) in people with stroke.

There are few studies in which the relationship between isokinetic lower-extremity torque and function in people with stroke has been quantified, and in these studies, only a few selected muscle groups have been explored.[5,6,21,22] Nadeau et al[5] examined the isokinetic torque of paretic hip flexors and ankle plantar flexors and found the hip flexor torque to be highly correlated with gait speed when walking at a self-selected pace (r=.83) and at a maximum pace (r=.88), whereas ankle plantar-flexor torque was only partly associated with maximum pace (r=.41). Three groups[6,21,22] examined the relationship between the isokinetic torque of the paretic knee extensors and gait speed and reported

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correlations (r=.43–.69 for self-selected pace, r=.47–.87 for maximum pace). Lindmark and Hamrin[21] also investigated the knee flexor torque and found correlations (r=.43–.72 for self-selected pace, r=.47–.70 for maximum pace). The contribution of the nonparetic limb to function, we believe, has been largely ignored in the past, and only the nonparetic knee extensors have been evaluated, with conflicting results. The isometric torque of nonparetic knee extensors either lacked a correlation with gait speed[6] or had low correlations.[18]

Although these studies contribute to the growing body of evidence supporting the relationship between muscle force and functional abilities, we contend that there is a lack of comprehensive studies relating muscle force measured through a range of motion to function in people with stroke. The purposes of this study were: (1) to quantify the relationship between isokinetic torque of individual lower-limb muscle groups and 2 locomotor tasks important for independent living (ie, gait on level surfaces and stair-climbing speeds) and (2) to determine whether a multiple linear regression model incorporating the torque of the paretic and nonparetic muscle groups could predict gait and stair-climbing speeds in people with stroke. The major flexor and extensor muscles of both lower extremities were selected because of their important role in walking. Eng and Winter[23] reported that the flexion and extension forces of the hip, knee, and ankle accounted for 82% of the total work over a stride as opposed to 15% and 3% in the frontal and transverse planes, respectively.

Method

Participants

Only people with a history of a single cerebrovascular accident (unilateral) at least 6 months prior to the beginning of the study were included. Inclusion criteria, using descriptors of the *International Classification of Functioning, Disability and Health* (ICIDH-2),[24] were as follows: at the level of body functions,[24] participants were required to achieve a minimum of stage 3 (ie, active voluntary movement occurs without facilitation) for the leg and foot on the Chedoke-McMaster Stroke Assessment,[25] and at the activity level,[24] participants were required to have the ability to walk independently for a minimum of 40 m (with rest intervals) with or without an assistive device and have an activity tolerance of 45 minutes with rest intervals. Twenty community-dwelling people who had had a stroke were selected from the 29 volunteers who were screened. Reasons for exclusion from the study included: (1) medical instability (ie, uncontrolled hypertension, arrhythmia, congestive heart failure, or unstable cardiovascular status), (2) musculoskeletal problems due to conditions other than stroke, and (3) absence of active movement in the paretic lower limb. A letter was sent to the each participant's physician, who was later contacted by telephone to ensure that the inclusion and exclusion criteria were met prior to the beginning of the study. Written consent also was obtained from each participant.

Table 1.
Characteristics of the Participants (N=20)

	$\overline{X}$	SD	Range
Age (y)	61.2	8.4	52–82
Mass (kg)	76.2	13.8	52.0–99.4
Height (m)	1.71	0.12	1.43–1.88
Time since stroke (y)	4.0	2.6	1.5–10.0
American Heart Association Functional Classification[a]	1.7	0.7	1–3
Chedoke-McMaster Stroke Assessment[b] for leg (stage)	4.7	0.8	3–6
Chedoke-McMaster Stroke Assessment[b] for foot (stage)	3.5	0.8	3–5
Modified Ashworth Scale[c] for knee/ankle (grade)	0.4/0.9	0.6/0.5	0–2
Type of stroke (ischemic/hemorrhagic/unspecified)			9/7/4
Sex (male/female)			14/6
Involved side (right/left)			11/9
Dominance (right/left)			17/3
Mobility aid (cane/none)			7/13

[a] American Heart Association Functional Classification[26] ranges from 1=independent to 5=completely dependent.

[b] Recovery stage level on the Chedoke-McMaster Stroke Assessment[25] for the paretic foot and leg of our participants ranged between 3 (active voluntary movement occurs without facilitation, but stereotyped synergistic patterns persist) and 6 (coordination and patterns of movement are near normal, abnormal patterns of movement emerge when rapid or complex actions required).

[c] Resistance to passive movement measured by the Modified Ashworth Scale[28] of our participants ranged between 0 (no increase in muscle tone) and 2 (more marked increase in muscle tone through most of the range of motion).

Demographic data collected from all participants included age, sex, time since the onset of stroke, the paretic side, level of independence in activities of daily living according to the American Heart Association Functional Classification,[26] degree of resistance to passive movement in the knee extensors and ankle plantar flexors, and use of assistive devices. The characteristics of the participants are summarized in Table 1. Resistance to passive movement was evaluated by one of the investigators (CMK) passively flexing and extending the limb using the method described by Ashworth.[27] Participants were in a supine position, and the resistance was graded on an ordinal scale from 0 to 5 based on the Modified Ashworth Scale.[28]

Procedure

Lower-extremity force, gait performance, and stair-climbing ability were measured as follows.

Lower-extremity torque. The Kin-Com isokinetic dynamometer* was used to measure the torque of the hip flexors and extensors, knee flexors and extensors, and ankle dorsiflexors and plantar flexors bilaterally. The calibration of the instrument was tested prior to the study with known weights and was accurate to within ±1 N. All participants had a practice session 2 to 4 days before the actual testing day to reduce the learning effect, as recommended by Eng et al.[29]

An angular velocity of 60°/s was used for the isokinetic tests. This angular velocity was selected because it was similar to the peak angular velocity of the hip and ankle joints during the gait of people with stroke (unpublished data collected by the authors on 5 subjects with chronic stroke walking at their self-selected speed). If a participant was not able to produce torque at an angular velocity of 60°/s, an angular velocity of 30°/s was used for that joint for both limbs. Although we chose these angular velocities to mimic those used during functional activities, we acknowledge that during function there is acceleration and deceleration, not movement at a constant velocity, which occurs with an isokinetic dynamometer.

Average torque was determined for each of the 6 muscle groups for the paretic and nonparetic limbs throughout their available range of motion. This torque measurement protocol has been described previously, and the measurements have been shown to be reliable in people with stroke, with intraclass correlation coefficients greater than .85 for average torque values.[29] Positioning and stabilization were done as follows:

- Hip—Subjects were in a semireclined (30° angle from horizontal) position, with the pelvis fixed by a strap and the back supported. The contralateral thigh was supported by a pad attached to the seat. The greater trochanter of the lower extremity being tested was aligned with the Kin-Com system's axis of rotation. The force transducer was placed 3 finger breadths proximal to the popliteal fossa.
- Knee—Subjects were seated with the back support set at a 90-degree sitting angle. Large straps were applied horizontally across the pelvis and diagonally across the trunk to minimize body movement during testing. Subjects were asked to place their hands on their lap. The lateral femoral condyle was aligned with the dynamometer's rotational axis. The force transducer was placed 3 finger breadths proximal to the lateral malleoli.
- Ankle—Subjects were in a semireclined (45°) position with their back supported. The lower extremity being tested was placed on a pad attached to the seat, which allowed the knee to flex slightly. The foot was secured in a metal brace attached to the Kin-Com dynamometer with the lateral malleolus aligned with the dynamometer's rotational axis. The contralateral foot rested on a foot support attached to the seat.

Gait performance. For the assessment of gait performance, participants were asked to walk at their "most comfortable speed" (ie, self-selected pace) using their usual assistive device for a distance of 8 m 5 times, and then "as fast as possible" but safely (ie, maximum pace) 5 more times. Participants walked in their own shoes without the use of an orthosis.

Infrared-emitting diodes (IREDs) were attached to the participants' lateral malleoli, and an optoelectronic sensor† was used to track the markers. In this camera setup, the error of locating the coordinates of an IRED in space was 0.9 mm in an anterior-posterior direction and 0.45 mm in an up-down direction. Data were collected at 60 Hz. Gait speed was calculated using the distance covered by the markers and the corresponding elapsed time during each gait cycle. The mean of the 5 trials (in meters per second) was calculated. Gait speed has been recognized as an indicator of gait performance[30] and sensitive enough to reflect physiological and functional changes,[31] and it has been shown to yield reliable measurements in adults without known pathology.[32]

Stair-climbing ability. Participants were asked to climb up four 18-cm steps at their "most comfortable speed" (ie, self-selected pace) using their usual pattern of foot placement and hand support and then "safely as fast as possible" (ie, maximum pace). The average time of ascent over 2 trials was calculated for each testing condition (ie, self-selected pace and maximum pace) and converted to stairs per second. This protocol has been described elsewhere[32] and has been shown to yield reliable measurements, with reliability coefficients of .90 in 26 adults without known pathology. The reliability of the measurements in people with stroke, however, is not known.

Data Analysis

Descriptive statistics were calculated using SPSS‡ 9.0 for participants' characteristics, gait speed, stair-climbing speed, and torque measures. For the torque measures, average torque values were normalized to body mass. The correlation between each average torque value and the self-selected speed of each task (gait and stair climbing) was established using the Pearson product moment correlation (*r*) with a significance level of

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† Northern Digital, 103 Randall Dr, Waterloo, Ontario, Canada N2V 1C5.

‡ SPSS Inc, 233 S Wacker Dr, Chicago, IL 60606.

$P<.05$ (2-tailed). Scatterplots of correlations were visually examined to ensure outliers did not compromise the results of the correlations. The strength of the correlations was described using Munro's[33] correlational descriptors (very high=.90–1.00, high=.70–.89, moderate=.50–.69, and low=.26–.49), which provides one method of interpretation for correlation coefficients. Four stepwise multiple linear regression analyses were further used to test whether a model incorporating muscle torque from both lower limbs could predict locomotor performance as measured by (1) self-selected gait speed, (2) maximum gait speed, (3) self-selected stair-climbing speed, and (4) maximum stair-climbing speed. The 12 variables (ie, torque of 2 limbs, 3 joints in flexion and extension) were entered in the model at a significance level of $P<.05$ and removed from it at $P>.10$. Normal probability plots for the residuals were checked to ensure that the assumptions of multiple regression were met.

Results

Torque, Gait, and Stair-Climbing Measures

The mean joint ranges of motion (ROM) used during the isokinetic tests were 54 degrees (SD=7, range=45–65) for the hip, 60 degrees (SD=6, range=45–70) for the knee, and 23 degrees (SD=4, range=15–30) for the ankle. The mean ROM occurred within 40–94 degrees of flexion for the hip (where 0° = neutral position with pelvis and thigh segment aligned), 15 to 76 degrees of flexion for the knee (0° = neutral position with thigh and shank segments aligned), and 10 to 33 degrees of plantar flexion for the ankle (0° = foot segment perpendicular to shank segment). All 20 participants were able to complete the isokinetic muscle torque test at an angular velocity of 60°/s bilaterally at the hip. Six participants could not complete the test at 60°/s at the knee and were tested bilaterally at 30°/s. Only 2 participants completed the test at 60°/s at the ankle, and the remaining 18 participants were tested at 30°/s bilaterally. The torques were lower for the paretic limb than for the nonparetic limb. Paretic limb average torque values ranged from 21% to 83% of the nonparetic limb values, with the greatest asymmetry found at the ankle joint (Tab. 2).

The mean maximum gait speed was 154% of the mean self-selected gait speed. Except for 2 individuals, all participants in this study walked more slowly than 1 m/s in both testing conditions (ie, self-selected pace and maximum pace) (Tab. 3). That is, even when asked to walk at their maximum pace, their gait speed did not exceed the self-selected gait speed of the elderly participants without known pathology reported in other studies.[34,35] Overall, subjects who required the use of an assistive device walked more slowly than subjects who did not use an assistive device (mean self-selected speed was 0.34 m/s for subjects who used an assistive device and 0.51 m/s for subjects who did not use an assistive device).

Table 2.
Average Torque (in Newton-meters Per Kilogram) for Each Joint and Direction of Motion (N=20)

Side	Test	$\bar{X}$	SD	Range
Paretic	Hip extension	0.77	0.47	0.08–2.14
	Hip flexion	0.46	0.18	0.09–0.72
	Knee extension	0.55	0.32	0.11–1.27
	Knee flexion	0.12	0.12	0.00–0.40
	Ankle plantar flexion	0.19	0.14	0.00–0.51
	Ankle dorsiflexion	0.15	0.13	0.00–0.42
Nonparetic	Hip extension	0.87	0.37	0.16–1.69
	Hip flexion	0.73	0.22	0.14–1.13
	Knee extension	1.18	0.41	0.38–1.96
	Knee flexion	0.50	0.20	0.10–1.01
	Ankle plantar flexion	0.93	0.29	0.21–1.46
	Ankle dorsiflexion	0.49	0.13	0.22–0.76

Table 3.
Gait Speed (in Meters Per Second) and Stair-Climbing Speed (in Stairs Per Second) (N=20)

Task	Pace	$\bar{X}$	SD	Range
Gait	Self-selected	0.45	0.25	0.20–1.10
	Maximum	0.69	0.35	0.26–1.56
Stair climbing	Self-selected	0.63	0.23	0.31–1.18
	Maximum	0.83	0.26	0.36–1.50

The maximum stair-climbing speed was 135% of the mean self-selected speed, and the speeds in both conditions were slower than the reported self-selected stair-climbing speed (1.9 stairs/s) of subjects without known pathology[32] (Tab. 3). Nineteen participants used the handrail on the nonparetic side for assistance during stair ascent. Seven participants used a "step-to" pattern, and 13 participants used a "step-through" pattern.

Relationship Between Torque and Gait Speed on a Level Surface

Although the gait speed on level surfaces of subjects who required the use of an assistive device was only 67% of the speed of those subjects who did not use an assistive device, we found similar correlations between muscle torque and function when subjects were separated into 2 groups (ie, subjects who used an assistive device and subjects who did not use an assistive device). Thus, the data for both groups were pooled for further analyses.

The Pearson product moment correlations (r) between the average torques and gait speeds are presented in Table 4. On the paretic side, the average torques of the

Table 4.
Pearson Product Moment Correlations (r) for Average Torque Values Versus Self-Selected Gait Speed and Stair-Climbing Speed (N=20)

Side	Test	Gait Speed	Stair-Climbing Speed
Paretic	Hip extension	.351	.273
	Hip flexion	.574[a]	.544[b]
	Knee extension	.408	.337
	Knee flexion	.555[b]	.482[b]
	Ankle plantar flexion	.845[a]	.709[a]
	Ankle dorsiflexion	.329	.328
Nonparetic	Hip extension	.346	.324
	Hip flexion	.380	.289
	Knee extension	.331	.443
	Knee flexion	.615[a]	.477[b]
	Ankle plantar flexion	.486[b]	.450[b]
	Ankle dorsiflexion	.294	.367

[a] Correlation is significant at the .01 level (2-tailed).
[b] Correlation is significant at the .05 level (2-tailed).

hip flexors, knee flexors, and ankle plantar flexors were correlated with gait speed. The correlations (r) were .85 for the ankle plantar flexors, .57 for the hip flexors, and .56 for the knee flexors. On the nonparetic side, only the torques of the knee flexors and ankle plantar flexors were correlated with the gait speeds.

Table 5 provides the independent variables selected by the multiple regression procedure (R^2) and the standard error of the estimate[36] (a measure of the accuracy of predictions made with the regression line). Only the paretic ankle plantar-flexor torque was retained for both self-selected and maximum gait speeds (Tab. 5). The variance (R^2) in gait speed explained by the paretic ankle plantar flexors ranged from 67% for the maximum pace condition to 72% for the self-paced condition.

Relationship Between Torque and Stair-Climbing Speed

The torques obtained for the same 3 muscle groups (hip flexors, knee flexors, and ankle plantar flexors) found to be related to gait speed on level surfaces were correlated with stair-climbing speed on the paretic side. The highest correlation was found with ankle plantar flexors. On the nonparetic side, the torques of the knee flexors and ankle plantar flexors were correlated with stair-climbing speed, but the correlations were low (Tab. 4). Of all 12 torque measures (ie, 2 limbs, 3 joints, flexion and extension motion), the torque of the paretic ankle plantar flexors was most highly correlated with gait speed ($r=.85$) and stair-climbing speed ($r=.71$).

The variables selected by the multiple regression procedure as predictors of self-selected stair-climbing speed were the paretic ankle plantar flexors, nonparetic knee extensors, and paretic hip extensors, whereas for the maximum stair-climbing speed, only the paretic ankle plantar flexors and the nonparetic knee extensors were retained (Tab. 5).

Discussion

We examined the relationship between lower-limb muscle torque and the tasks of walking and stair climbing, and we explored some of the variables that may predict the performance of these tasks. An obvious limitation of this study is the small sample size given the types of analysis used. Running multiple correlations on the same data increases the risk for type I error. However, apart from the regression procedure, which has the advantage of providing a predictive model, correlations provide additional information regarding important variables that the regression procedure may have removed from the model due to their close relationship to the best predictor. Another limitation of our study is that 7 subjects required the use of an assistive device to walk and 19 subjects required the use of the rail during stair climbing, which could potentially confound the results. The subjects, however, could not perform the tasks otherwise, and a subanalysis of the data when subjects were divided into groups who did and did not use an assistive device (or when data on the one subject not using the rail was removed from the data pool in the case of stair climbing) did not alter the relationships between torque and function.

A third limitation is the method in which torque was measured. Not all participants were tested at the same testing speed (eg, for the knee joint, 16 participants were tested at 60°/s and 4 participants were tested at 30°/s), which may have affected the relationship between torque and function. A *post hoc* subanalysis comparing the regression coefficients[36] of the data with and without the data of 6 participants tested at 30°/s for the knee and 2 participants tested at 60°/s for the ankle resulted in no difference between the coefficients, which we believed justified the pooling of the data collected at different speeds. In addition, torque was measured as the average torque generated on a dynamometer without further examination of the strategy (eg, type of activation pattern) used by the subjects to achieve the movements being tested. We believe studies in which electromyographic activity is monitored during testing may be of benefit in understanding the cause of the reduced force output. Likewise, we contend that the assessment of locomotor performance was limited to speed measures without analyzing the strategies used.

Stepwise multiple regression analyses were used to identify the paretic ankle plantar-flexor torque as the single most important variable in predicting gait speed and alone explained 67% to 72% of the variance in gait speeds on level surfaces. For stair-climbing speeds, the torque of the paretic ankle plantar flexors explained

Table 5.
Stepwise Regression Analysis for Average Torque Predictor Variables of Gait and Stair-Climbing Speeds

Dependent Variable	Independent Variable(s)	F	R^2	P	SEE[a]
Gait speed (self-paced)	Paretic ankle plantar flexion	45.1	.715	.000	0.13
Gait speed (maximum pace)	Paretic ankle plantar flexion	37.0	.673	.000	0.21
Stair-climbing speed (self-paced)	Paretic ankle plantar flexion	18.2	.503	.000	0.16
	Nonparetic knee extension	14.0	.623	.000	0.15
	Paretic hip extension	13.0	.709	.000	0.13
Stair speed (maximum pace)	Paretic ankle plantar flexion	20.9	.537	.000	0.18
	Nonparetic knee extension	16.4	.659	.000	0.16

[a] SEE=standard error of the estimate:
Self-selected gait speed=1.455×(paretic ankle plantar-flexor torque)+0.175
Maximum gait speed=2.004×(paretic ankle plantar-flexor torque)+0.306
Self-selected stair-climbing speed=1.243×(paretic ankle plantar-flexor torque)+0.337×(nonparetic knee extensor torque)−0.202×(paretic hip extensor torque)+0.151
Maximum stair-climbing speed=1.251×(paretic ankle plantar-flexor torque)+0.227×(nonparetic knee extensor torque)+0.324

50% to 54% of the variance. Up to 71% of the variance in self-selected stair-climbing speeds could be explained when the torques of the nonparetic knee extensors and paretic hip extensors were added to the model. Similarly, up to 66% of the variance in maximum stair-climbing speeds could be explained when the torques of the nonparetic knee extensors were added to the model. We consider these findings important because a number of factors (eg, balance, coordination, sensation, postural control), in addition to muscle force, may influence the performance of these locomotor tasks.

On the paretic side, the torques obtained for the same 3 muscle groups (hip flexors, knee flexors, and ankle plantar flexors) were found to relate to gait on level surfaces and stair-climbing speed. We did not expect this finding because of the different requirements of these 2 locomotor tasks. In people without strokes or other pathologies, the plantar flexors and hip flexors generate the largest power bursts (ie, largest amount of energy generated to move the body forward) during the entire gait cycle on level surfaces,[23] whereas the plantar flexors and knee extensors generate the largest power bursts during stair climbing.[37]

Thus, the importance of the weakness in the plantar flexors (as identified by the regression analysis and the high correlation coefficient) and hip flexors (as reflected by the moderate correlation coefficient) during gait on level surfaces is logical in view of the power burst that plantar flexors generate during “push-off” and the torques the hip flexors generate to pull the swinging limb forward.[23] The isokinetic torques of the paretic hip flexors and plantar flexors have been previously identified as important factors in determining gait speed.[5,38]

The correlation between the paretic knee flexor torque and gait performance on level surfaces was surprising to us. The knee flexors’ primary function in gait is normally to absorb energy from the swinging limb in late swing.[23] The role of the knee flexors during gait in people with hemiparesis, however, may be different from that seen in the gait of people without pathology. Our participants may have needed to flex their knee during propulsion in preparation for swing to compensate for the lack of hip flexion and plantar-flexor push-off, which normally would result in a passive collapse of the knee.[39,40] Future investigations on the role of knee flexors in the gait of people with stroke are needed to confirm these hypotheses.

Contrary to the findings of other researchers,[6,21,22] the torque of the paretic knees was not associated with gait speed on level surfaces. These contrasting findings may be due to the relatively lower level of function of our subjects. The mean maximum gait speed of our subjects was only 0.69 m/s as compared with the 0.9 to 1.26 m/s documented in other studies.[6,21,22] Our findings suggest that weakness in the paretic knee extensors is less limiting than that in other muscle groups during the gait of people with stroke.

The correlations, although low to moderate, of the nonparetic knee flexor and plantar-flexor torques with self-selected gait speed, coupled with reports of bilateral weakness in individuals with stroke,[41,42] suggest that torque measurements of the supposedly “unaffected” limb (as the nonparetic limb is sometimes called) should be included in evaluations.

Ours was the first study in which there was quantification of the relationship between lower-extremity isokinetic torque and the locomotor task of stair climbing in individuals with stroke. Generally, the torque of the paretic limb showed higher correlations with stair-climbing speed than the torque of the nonparetic limb. This finding suggested to us that the weakness in the paretic limb is a more important limiting variable than that of the nonparetic limb during stair climbing.

On the paretic side, the correlations (ranging from low to high) between stair-climbing speed and the torque of hip flexors, knee flexors, and ankle plantar flexors, in addition to the selection of ankle plantar-flexor torque as the best predictor by the regression procedure, can be explained by some of the biomechanical requirements of the stair-climbing task. When ascending stairs, ankle plantar flexors generate power during the latter part of stance to elevate the body.[37] The hip and knee flexors concentrically flex the limb during swing in preparation for foot placement on the following step.[37] Interestingly, although hip and knee extensors play important roles during the early to mid-stance phases of stair ascent in people without known pathology,[37] these variables were not associated with stair ascent in our participants. Because all except one of the participants used the handrail to ascend the stairs, the lifting action of the hip and knee flexors may have been more important than the pushing action of the extensors on the paretic limb in increasing the speed of stair ascent. The arm pulling on the handrail possibly compensated for the lack of hip and knee extensor torque.

Because correlational studies do not infer causation, further research is needed to evaluate whether changing the torque of muscle groups tested in our study would lead to better locomotor performance. Moreover, following stroke, several factors (eg, muscle atrophy, abnormal activation patterns) may contribute to the inability to generate force and, in turn, affect gait performance. The cause of reduced force output needs to be explored in order to determine the type of intervention that may lead to improved torque and function.

Conclusions

In our study, we demonstrated that the isokinetic torques of various muscle groups of the paretic and nonparetic limbs were associated with walking and stair-climbing speeds, particularly the torques of the paretic hip flexors, knee flexors, and ankle plantar flexors. Furthermore, the torque of the paretic ankle plantar flexors alone could explain up to 72% of the variability in gait speed. Correlations of torque and function for the nonparetic limb were in some conditions as high or even higher than for the paretic limb. This finding suggested to us that nonparetic limb function should not be neglected during evaluation of locomotor performance and treatment.

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