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Muscle strength and weight-bearing symmetry relate to sit-to-stand performance in individuals with stroke

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Abstract

This study investigated the relationship of lower extremity joint torques and weight-bearing symmetry to sit-to-stand (STS) performance in individuals with chronic stroke. A motion analysis system and two force plates measured STS duration and weight-bearing symmetry (determined by ground reaction forces) during three self-paced and three fast-paced conditions. An isokinetic dynamometer measured maximum concentric joint torques of the paretic and non-paretic ankle, knee, and hip, which were normalized by body mass. Pearson correlations indicated that (a) paretic ankle dorsiflexion and knee extension torques related to the duration of the self-paced STS condition ($r = -0.450, -0.716$, respectively), (b) paretic ankle dorsiflexion, plantar flexion, and knee extension torques related to the duration of the fast-paced STS condition ($r = -0.466, -0.616, -0.736$, respectively), and (c) greater weight-bearing symmetry related to faster STS performance for both self-paced and fast-paced STS conditions ($r = -0.565, -0.564$, respectively) ($P < 0.05$). This evidence suggests that paretic muscle strength and the ability to load the paretic limb are important factors underlying the ability to rise from a chair in individuals with chronic stroke.

Keywords: Stroke; Sit-to-stand; Torque; Weight-bearing

1. Introduction

The ability to stand-up from a seated position is an important functional task performed several times throughout the day. The sit-to-stand (STS) movement is biomechanically demanding, requiring more lower extremity joint torque and range of motion than walking or stair climbing [1]. It is a prerequisite for upright mobility and is an important factor for independent living.

Difficulty in rising from a chair can be a problem for older adults with lower extremity muscle weakness. Alexander et al. [2] have shown that older individuals generate less isokinetic knee extension torque than younger individuals (81 N m versus 130 N m) and utilize up to 87% of their available knee torque to rise from a chair, versus up to 49% in younger adults. Muscle strength is further impaired in individuals who have had a stroke [3–5], and several authors have reported that individuals with hemiparesis demonstrate an increase in STS time when compared to older adults without neurological impairment [6–10]. A recent correlational study by Inkster et al. [11] demonstrated a relationship between isokinetic hip extension torque and STS duration in individuals with Parkinson's disease both on and off medication ($r = -0.71$ and $r = -0.80$, respectively). In addition, Kim and Eng [12] found a relationship between lower extremity isokinetic joint torques and locomotor performance (gait and stair climbing speed) in individuals with chronic stroke, revealing moderate to high correlations for paretic ankle plantar flexion, hip flexion, and knee flexion ($r = 0.50$–0.80). The results of these studies provide evidence supporting the relationship between the ability to generate lower extremity joint torques and functional activities, however a relationship between the major lower

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Table 1
Subject characteristics ($N = 22$)

Variable	Mean	S.D.	Range
Age (years)	67.0	8.8	51–80
Mass (kg)	84.8	15.6	47.0–110.5
Height (m)	1.64	0.34	1.58–1.86
Time since stroke (years)	5.3	2.1	2.0–10.0
American Heart Association-Functional Classification level (I–V)	1.95	0.84	I–III
Type of stroke (ischemic/hemorrhagic/unspecified)	7/10/5		
Sex (M/F)	19/3		
Involved side (R/L)	12/10		
Sit-to-stand duration (s), self-paced	1.45	0.32	0.98–2.08
Sit-to-stand duration (s), fast-paced	1.12	0.21	0.82–1.48
Symmetry at lift off (paretic/non-paretic), self-paced	0.84	0.20	0.33–1.21
Symmetry at lift off (paretic/non-paretic), fast-paced	0.84	0.20	0.22–1.16

extremity joint torques (ankle, knee, and hip) and STS performance in individuals with chronic stroke has not been previously undertaken.

In addition to muscle weakness, impaired postural control often occurs following a stroke and may lead to asymmetrical limb loading during functional tasks such as STS [6–10,13,14]. Lee et al. [13] found that individuals with hemiparesis who put less weight through their paretic leg during STS had lower mobility scores on the functional independence measure. Cheng et al. [6] reported that individuals with stroke and a history of falls placed less weight on their paretic limb during STS than those with stroke that did not fall, although the difference did not reach statistically significant levels. They also reported that the fallers with stroke took a significantly longer time to stand-up than the non-fallers with stroke [6].

The purpose of this study was two-fold: (1) to quantify the relationship between the major lower extremity joint torques (ankle, knee, and hip) with STS performance and (2) to quantify the relationship between weight-bearing symmetry and STS performance in individuals with chronic stroke.

2. Methods

Twenty-two individuals with chronic stroke were recruited on a volunteer basis. Disability was assessed using the stroke functional classification levels (AHASFC) from the American Heart Association Stroke Outcome Classification Score [15]. Level I represents complete independence in basic and instrumental activities of daily living, and level V represents complete dependence; requires full-time care. Criteria for inclusion in the study were as follows: (1) over 50 years old, (2) first stroke, (3) at least 1 year post-stroke onset, (4) able to rise from a chair independently, and (5) able to follow two-step commands. Individuals with musculoskeletal and neurological disorders in addition to their stroke were excluded from the study. Ethics approval was obtained from the local university and hospital ethics committees. Each individual was informed of the study procedures before giving their consent to participate in the study. Characteristics of the individuals are summarized in Table 1.

STS performance, weight-bearing symmetry, and bilateral lower extremity joint torques were measured as follows.

2.1. STS performance

STS performance was measured by the time (in seconds) to complete one STS maneuver (Table 1). The stabilization period identified by Schenkman et al. [16] was not included in the time to complete the STS task because of the difficulty in distinguishing the point in time where stabilization from the task ends and normal postural sway begins. Individuals were seated on an armless, backless chair, which was adjusted to allow for approximate 90° angles at the hip and knee joints. The distance between their feet was not constrained and the STS task was performed with shoes on. Individuals performed three self-paced, followed by three fast-paced STS trials without the use of their arms (arms remained relaxed by their sides). Before each trial, the same individual gave the instruction ‘‘Whenever you are ready, stand-up at a comfortable pace’’, or ‘‘Whenever you are ready, stand-up as fast as you can’’.

Two force plates (Bertec, Columbus, OH), one placed under each foot, were used to determine STS movement onset. More specifically, movement onset was identified visually from the force plate data as an initial change in the vertical ground reaction force beyond the quiet sitting baseline level (the subject’s feet were resting on the force plates). Force plate data was sampled at 600 Hz for all self-paced and fast-paced trials. A MATLAB software package was used to filter (second-order, 50 Hz low-pass filter), calibrate the vertical force plate data, identify frame ranges and force values, and calculate mean vertical forces over specified frame ranges. An optoelectric sensor (Northern Digital, Waterloo, Canada) that tracked an infrared-emitting diode (IRED) attached to the individual’s right acromion was used to determine STS movement termination. More specifically, movement termination was visually identified as the point in time when vertical movement of the IRED reached a plateau, thus indicating that the subject was fully upright with the hips and knees extended. Kinematic data were collected at 60 Hz and the error of locating the coordinates of an IRED in space was 0.90 mm in the forward/backward direction and 0.45 mm in the up/down direction. Six seconds of simultaneous force plate and kinematic data were collected for each trial. All points of interest were identified by the same person who used an interactive computer program that magnified the appropriate graphical window of data prior to the selection of the points. For each condition (self-paced and fast-paced), all three trials were used for analysis.

2.2. Weight-bearing symmetry

The two force plates were also used to measure weight-bearing symmetry; one force plate under each foot. At lift off, the subject's buttock leaves the chair, reducing the support surface from three points to two as weight is transferred to the lower limbs. In addition, the body's center of mass moves away from the center of force and it is at this critical point where the subject's postural stability is most challenged [16]. Thus, a symmetry ratio was calculated at lift off by dividing the peak vertical force in newtons of the paretic limb by the non-paretic limb (Table 1). A ratio of 1.00 indicated perfect symmetry, while less than 1.00 indicated a reduced amount of force through the paretic limb.

2.3. Lower-extremity joint torques

A Kin-Com isokinetic dynamometer (Chattanooga Group, TN) was used to measure bilateral concentric joint torques of the ankle, knee, and hip flexors and extensors throughout the available active range of motion. The calibration of the instrument was tested prior to the study with known weights and was accurate to within ±1 N. One submaximal cycle and one maximal cycle were completed as practice before testing began.

Individuals were tested in a seated position with the trunk supported by crossing lab belts. Bilateral ankle torques were tested in a 45° semi-reclined position, knee torques were tested at a 90° sitting angle, and hip torques were tested in a 30° semi-reclined position. Detailed descriptions of positioning and stabilization have been previously described by Eng et al. [17].

An angular velocity of 30°/s was used for the ankle isokinetic tests and 60°/s for the knee and hip. For each movement tested, a single ensemble-averaged torque–angle curve was calculated from three maximal repetitions. The mean torques were calculated from these curves and normalized to body mass (Table 2). This measurement protocol has been shown to be reliable with intraclass correlation coefficients of greater than 0.88 in individuals with chronic stroke [17]. Note, a 0 value was assigned when there was no evidence of an active muscle contraction.

Preliminary analysis of the independent variables, using two sample *t*-tests, revealed no statistically significant differences between individuals with right and left hemiparesis; therefore the data were pooled together.

For both self-paced and fast-paced conditions, Pearson correlations (r) assessed the relationship between STS duration with lower extremity joint torques (ankle, knee and hip, flexion and extension), and STS duration with weight-bearing symmetry (paretic/non-paretic force ratio). Scatterplots of the correlations were visually examined and one outlier was removed from the correlation between STS duration and paretic knee extension torque for both the self-paced and fast-paced conditions, as was one outlier for STS duration and paretic ankle plantar flexion torque for the

Table 2
Average torque (N m/kg) for each joint and direction of motion ($N = 22$)

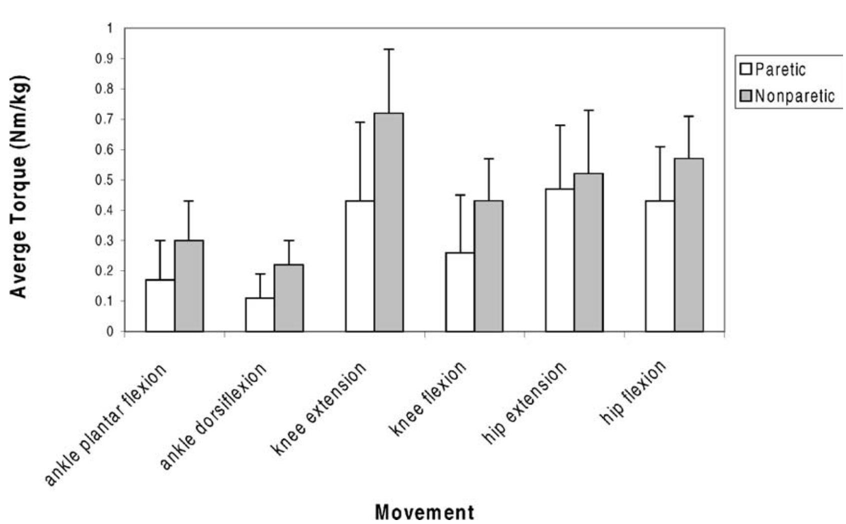

Table 3
Pearson product moment correlation (r) between sit-to-stand duration (self-paced and fast-paced) with joint torque values and weight-bearing symmetry (N = 22)

Movement	STS self-paced		STS fast-paced	
	Paretic	Non-paretic	Paretic	Non-paretic
Ankle plantar flexion	−0.355	0.111	−0.616[a,**]	−0.239
Ankle dorsiflexion	−0.450[*]	0.064	−0.466[*]	−0.323
Knee extension	−0.716[a,**]	0.250	−0.736[a,**]	0.005
Knee flexion	−0.232	0.237	−0.252	0.039
Hip extension	0.025	0.250	−0.101	−0.087
Hip flexion	−0.068	0.028	−0.420	−0.237
Asymmetry	−0.565[**]		−0.564[**]	

[a] N = 21.
[*] Significant at $P < 0.05$.
[**] Significant at $P < 0.01$.

fast-paced condition. Correlation strength was described using Munroe's [18] correlational descriptors (low = 0.26–0.49, moderate = 0.50–0.69, high = 0.70–0.89 and very high = 0.90–1.00). A significance level of $P < 0.05$ (two-tailed) was selected for all statistical tests. All statistical analyses were performed using SPSS 11.0 software.

3. Results

The average joint torques for the paretic leg were significantly lower than the non-paretic leg for all movements tested. The values for the paretic side ranged from 50 to 90% of the non-paretic side with the ankle demonstrating the most asymmetry and the hip demonstrating the least (Table 2).

Paretic ankle dorsiflexion and knee extension torques were significantly correlated with the self-paced STS duration ($r = -0.450$ and -0.716, respectively). In the fast-paced condition, paretic ankle dorsiflexion, ankle plantar flexion, as well as knee extension torques ($r = -0.466$, -0.616 and -0.736, respectively) were significant correlates. The joint torques of the non-paretic leg were not correlated to STS duration for either condition (Table 3).

The relationship between weight-bearing symmetry and STS duration was moderate for both self-paced ($r = -0.565$) and fast-paced ($r = -0.564$) STS conditions (Table 3).

4. Discussion

The ability to transfer from STS is one of the most commonly performed tasks of daily living and is an important goal of neurological rehabilitation. In order for clinicians to develop effective interventions, it is essential to identify the physical impairments that are contributing to the altered movement conditions demonstrated by their clients.

In older individuals, quadriceps muscle activity peaks during the critical transition phase from anterior to vertical movement of the STS transfer, and remains active until full extension of the hip and knee are achieved [19]. Our study revealed a high correlation between paretic knee extension strength and STS performance in individuals with chronic stroke. Similarly in older adults, a relationship between knee extension strength and STS duration ($r = -0.383$ to -0.430) has been demonstrated, though at a lower correlation than our study [20,21]. Although the relationship between lower extremity strength and the time to rise from a chair has not been previously explored in individuals with chronic stroke, Cameron et al. [22] found that isometric knee extension strength was related to the kinetic energy (calculation based on the vertical displacement of the center of mass) during STS in individuals with acute stroke ($r = 0.49$). Furthermore, Eriksrud and Bohannon [23] reported that isometric knee extension strength was a strong predictor of independence during the STS transfer (explaining 66% of the variance without hand support and 58% with support) in individuals in the acute stage of rehabilitation.

One of the strengths of our study was the quantification of multiple key lower extremity muscle groups. Several previous studies have concluded that knee extensor strength is key to the sit-to-stand performance; however, they did not measure any other lower extremity muscles, which may have had more or less influence on the task performance. In addition to paretic knee extension, we identified two additional muscle groups, paretic ankle dorsiflexion and ankle plantar flexion, that related to STS performance in individuals with chronic stroke.

Activation of the tibialis anterior muscle, the prime ankle dorsiflexor, is necessary during the early stages of the STS movement to stabilize the foot on the ground during forward trunk flexion [13], thus explaining its importance to and correlation with STS performance.

In order to maintain postural stability, activation of the ankle plantar flexors may be required to eccentrically control the forward translation of the body during the extension phase of the STS transfer, particularly during the fast-paced condition where individuals generate more forward momentum. This interpretation is supported by Pai and Rogers [24], who found an increase in the center of force antero-posterior sway when eight healthy adults changed from a self-paced to a fast-paced STS condition. It is important to note that the moderate correlation between paretic ankle plantar flexion strength with the fast-paced STS condition in our study may have been higher if the stabilization period was included in the analysis.

Unexpectedly, paretic hip extension strength did not relate to STS performance. This is in contrast with the aforementioned study by Inkster et al. [11] who demonstrated a strong relationship between hip extension strength and STS performance in individuals with mild Parkinson's disease (PD). However, the mean strength value for paretic hip extension in our study was 90% of the value of the non-paretic side. With other lower extremity muscles demonstrating greater strength deficits, hip extension strength was not likely the limiting factor in this particular group of individuals.

Individuals with high symmetry ratios demonstrated faster STS times than individuals who were more asymmetrical. The mean symmetry ratio of 0.84 in our study is more symmetrical than previously reported values of 0.60 [8] when rising habitually and 0.68 after seat-off using a self-selected speed [10]. However, these previous studies involved individuals who had a mean stroke interval of 38 days and 18 weeks, respectively, versus 5.3 years in our study. This suggests that with completion of spontaneous recovery and rehabilitation, individuals with chronic stroke may be able to better utilize their paretic leg during the STS task. This is in agreement with Sackley [25] who demonstrated a significant improvement in weight-bearing symmetry with recovery when evaluated at 2 months and again at 9 months post-stroke.

The right hemisphere has been shown to play a dominant role in postural control and balance [26], and individuals with left hemiparesis have been shown to have more sway and lateral displacement of the center of pressure toward the non-paretic side than individuals with right hemiparesis [27]. This evidence suggests that individuals with right hemiparesis may have better postural control than those with left hemiparesis, and therefore it can be argued that a separate analysis should be performed. However, in our study there were no significant differences between individuals with right and left hemiparesis for all muscle torques and symmetry ratios calculated, thus justifying the use of pooled data.

Correlation studies do not infer causation. Although Monger et al. [28] has demonstrated that a task-specific strengthening program can improve STS performance, the results are preliminary and involved only six individuals with chronic stroke and no control group. Therefore, a large randomized controlled trial is recommended to provide further evidence to support a strengthening program with an emphasis on symmetrical limb loading to improve STS performance.

Although we did examine the major sagittal lower extremity muscle groups, trunk musculature and lateral stabilizing muscles such as the hip abductors may also play an important role in rising from a chair.

Lastly, our data can be generalized only to individuals with mild to moderate stroke deficits (our subjects ranged from AHASFC I to III). This, however, was partly constrained by the protocol, which required independence with the STS transfer.

The results of this study provide preliminary evidence to support a strengthening program, which focuses on paretic knee extension, ankle dorsiflexion, and ankle plantar flexion, with concomitant emphasis on paretic limb loading to improve STS performance in individuals with chronic stroke.

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References

[1] Berger RA, Riley PO, Mann RW, Hodge WA. Total body dynamics in ascending stairs and rising from a chair following total knee arthroplasty. Trans Orthop Res Soc 1988;13:542.

[2] Alexander NB, Gu MJ, Branch M, Schultz AB, Ashton-Miller JA, Gross MM. Geriatrics: does leg torque influence rising from a chair in older adults. Rehabil R D Prog Rep 1995;32:101–2.

[3] Adams RW, Gandevia SC, Skuse NF. The distribution of muscle weakness in upper motorneuron lesions affecting the lower limb. Brain 1990;113:1459–76.

[4] Canning CG, Ada L, O'Dwyer N. Slowness to develop force contributes to weakness after stroke. Arch Phys Med Rehabil 1987;68:155–7.

[5] McCrea PH, Eng JJ, Hodgson AJ. Time and magnitude of torque generation is impaired in both arms following stroke. Muscle Nerve 2003;28:46–53.

[6] Cheng PT, Liaw MY, Wong MK, Tang FT, Lee MY, Lin PS. The sit-to-stand movement in stroke patients and its correlation with falling. Arch Phys Med Rehabil 1998;79:1043–6.

[7] Chou SW, Wong AM, Leong CP, Hong WS, Tang FT, Lin TH. Postural control during sit-to-stand and gait in stroke patients. Am J Phys Med Rehabil 2003;82:42–7.

[8] Engardt M, Olsen E. Body weight-bearing while rising and sitting down in patients with stroke. Scand J Rehabil Med 1992; 24:67–74.

[9] Engardt M. Long-term effects of auditory feedback training on relearned symmetrical body weight distribution in stroke patients: a follow-up study. Scand J Rehabil Med 1994;26:65–9.

[10] Hesse S, Schauer M, Malezec M, Jahnke M, Mauritz KH. Quantitative analysis of rising from a chair in healthy and hemiparetic subjects. Scand J Rehabil Med 1994;26:161–6.

[11] Inkster L, Eng JJ, MacIntyre DL, Stoessl AJ. Leg muscle torque is reduced in Parkinson's disease and relates to the ability to rise from a chair. Movement Disord 2003;18:157–62.

[12] Kim MC, Eng JJ. The relationship of lower-extremity muscle torque to locomotor performance in people with stroke. Phys Ther 2003; 83:49–57.

[13] Lee MY, Wong MK, Tang FT, Cheng PT, Lin PS. Comparison of balance responses and motor patterns during sit-to-stand task with functional mobility in stroke patients. Am J Phys Med Rehabil 1997;76:401–10.

[14] Eng JJ, Chu KS. Reliability and comparison of weight-bearing ability during standing tasks for individuals with chronic stroke. Arch Phys Med Rehabil 2002;83:1138–44.

[15] Kelly-Hayes M, Robertson JT, Broderick JP, Duncan PW, Hershey LA, Roth EJ, et al. The American Heart Association stroke outcome classification: executive summary. Circulation 1998;97:2474–8.

[16] Schenkman M, Berger RA, Riley PO, Mann RW, Hodge WA. Whole-body movements during rising to standing from sitting. Phys Ther 1990;70:638–51.

[17] Eng JJ, Kim CM, MacIntyre DL. Reliability of lower extremity torque measures in persons with chronic stroke. Arch Phys Med Rehabil 2002;83:322–8.

[18] Munroe BH. Correlations. In: Munro BH, Visintainer MA, Page EB, editors. Statistical methods for health care research. Philadelphia, PA: JV Lippincott Co.; 1993. p. 181.

[19] Millington PJ, Myklebust BM, Shambes GM. Biomechanical analysis of the sit-to-stand motion in elderly persons. Arch Phys Med Rehabil 1992;73:609–17.

[20] Lord SR, Murray SM, Chapman K, Munro B, Tiedemann A. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to torque in older people. J Gerontol Ser A Biol Sci Med Sci 2002;57:539–43.

[21] Corrigan D, Bohannon RW. Relationship between knee extension force and stand-up performance in community-dwelling elderly women. Arch Phys Med Rehabil 2001;82:1666–72.

[22] Cameron DM, Bohannon RW, Garrett GE, Owen SV, Cameron DA. Physical impairments related to kinetic energy during sit-to-stand and curb-climbing following stroke. Clin Biomech 2003;18:332–40.

[23] Eriksrud O, Bohannon RW. Relationship of knee extension force to independence in sit-to-stand performance in patients receiving acute rehabilitation. Phys Ther 2003;83:544–51.

[24] Pai YC, Rogers MW. Control of body mass transfer as a function of speed ascent in sit-to-stand. Med Sci Sports Exerc 1990;22: 378–84.

[25] Sackley CM. Falls, sway, and symmetry of weight-bearing after stroke. Int Disabil Stud 1991;13:1–4.

[26] Perennou D, Benaim C, Rouget E, Rousseaux M, Blard JM, Pelissier J. Postural balance following stroke: towards a disadvantage of the right brain-damaged hemisphere (French). Rev Neurol 1999;155:281–90.

[27] Rode G, Tiliket C, Boisson D. Predominance of postural imbalance in left hemiparetic patients. Scand J Rehabil Med 1997;29:11–6.

[28] Monger C, Carr JH, Fowler V. Evaluation of a home-based exercise and training program to improve sit-to-stand in patients with chronic stroke. Clin Rehabil 2002;16:361–7.