ORIGINAL ARTICLE

Association of Activity Limitations and Lower-Limb Explosive Extensor Power in Ambulatory People With Stroke

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ABSTRACT. Saunders DH, Greig CA, Young A, Mead GE. Association of activity limitations and lower-limb explosive extensor power in ambulatory people with stroke. Arch Phys Med Rehabil 2008;89:677-83.

Objective: To determine whether the explosive lower-limb extensor power of the affected and unaffected sides, and any asymmetry, are associated with activity limitations after stroke.

Design: Cross-sectional observational study of baseline data from a randomized controlled trial.

Setting: Measurements made in a hospital clinical research facility.

Participants: Community-dwelling (N=66) subjects with stroke who were independently ambulatory. Subjects' mean age was 72±10 years.

Interventions: Not applicable.

Main Outcome Measures: The lower-limb extensor power of each lower limb (in W/kg), performance of specific functional activities (comfortable walking velocity, Functional Reach Test, chair-rise time, Timed Up & Go test), and global indices of activity limitation (FIM instrument, Rivermead Mobility Index, Nottingham Extended Activities of Daily Living).

Results: Low lower-limb extensor power in either lower limb was the principal factor from among the confounders we recorded that significantly (R^2 range, .21–.46) predicted the limitation of specific functional activities, and low lower-limb extensor power in either lower limb was the principal predictive factor for global indices of activity limitation (R^2 range, .13–.38). The degree of asymmetry of lower-limb extensor power between legs was low and had little or no predictive value.

Conclusions: In ambulatory persons with stroke, activity limitations are associated with deficits in lower-limb extensor power of both lower limbs, and not the severity of any residual asymmetry. These findings suggest that interventions to increase lower-limb extensor power in both lower limbs might reduce activity limitations after stroke.

Key Words: Activities of daily living; Cerebrovascular accident; Physical fitness; Rehabilitation.

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THE ABILITY OF MUSCLE to generate force can be described in terms of muscle strength and explosive power. Strength is the magnitude of maximal force generation whereas explosive power output is a velocity-dependent characteristic defined as the greatest rate of work achieved during a single, ballistic, resisted contraction.[1] Explosive power deteriorates faster than strength (3%–4% vs 1%–2% a year) during healthy aging.[2]

Although strength and power are both important for execution of functional activities, lower-limb extensor power is more important than knee extensor strength for stair climbing, chair rising, and walking,[3-5] and when impairment is asymmetrical, lower-limb extensor power is a better predictor of the frequency of falling than strength alone.[6]

Although people who have survived a stroke are often elderly, may be less active than prior to their stroke, and may have unilateral limb weakness, surprisingly little is known about the extent to which explosive power might be impaired and whether this might have adverse functional consequences. A pilot study of 11 ambulatory subjects 1 year after stroke with virtually no residual neurologic deficit[7] found that both lower-limb extensor power and knee extensor muscle strength of both lower limbs were substantially lower than that of age- and sex-matched healthy subjects.[8,9] Further unpublished data indicated that impairment in lower-limb extensor power was approximately double that of muscle strength.

Bilateral impairment in explosive power,[7] or muscle strength,[7,10,11] observed after stroke could arise for several reasons both directly and indirectly associated with stroke. First, bilateral motor deficits can arise directly from a unilateral lesion.[12] Second, reduced habitual physical activity, either before and/or after stroke may cause muscle atrophy.[13] Third, the presence of comorbid disease (including poor nutrition) before and/or after stroke could impair motor function.

Low muscle strength after stroke is associated with poor performance of walking and stair climbing,[14] chair rising,[15] and impaired motor function.[16] Only 1 small study (N=14) has explored the functional associations of explosive power after stroke.[17] It showed that asymmetry in lower-limb extensor power was associated with reduced walking performance. The participants were unusually young (mean, 46.4±8.4y), and this relationship should be examined in people with stroke of more typical age (ie, >70y).[18] Moreover, the relationship of power with other aspects of activity limitation should be examined to explore the potential benefits that might result from attempts to improve explosive power after stroke. This is important because fitness training can be presented in such a way as to specifically improve explosive power[19] and this might reduce activity limitations, and so reduce participation restriction after stroke.

The aim of this study was to determine in older, ambulatory people with stroke, whether the lower-limb extensor power of the affected and unaffected sides, and any asymmetry, were associated with (1) performance of specific functional activities (reaching, walking, and rising from a chair), and (2) global indices of activity limitation (FIM instrument, Nottingham

Table 1: Participant Characteristics

Characteristics	n	Mean ± SD	Median (IQR)
Age (y)	NA	71.85±9.91	NA
Sex (male/female)	36/30	NA	NA
Stature (m)	NA	1.67±0.09	NA
Time from stroke (d)	NA	NA	152 (83–278)
Smoking history			
Smoker/Ex-/Non-/UC	25/12/28/1	NA	NA
Walking aids			
Stick/orthosis/zimmer/none	28/4/2/32	NA	NA
Body mass (kg)	NA	72.64±15.29	NA
Stroke type (TAC/LAC/PAC/POC/UC)	2/19/32/12/1	NA	NA
Lesion type (ischemic/hemorrhagic/UC)	60/5/1	NA	NA
Lesion side (left/right/both/UC)	37/27/1/1	NA	NA
Hospital care (inpatient/outpatient)	56/10	NA	NA
Inpatient length of stay (d)	NA	NA	19 (9–44)
Blood pressure			
Systolic (mmHg)	NA	140.03±18.10	NA
Diastolic (mmHg)	NA	73.16±9.50	NA
Comorbidities			
Prior stroke	11	NA	NA
Prior transient ischemic attack	4	NA	NA
Ischemic heart disease	22	NA	NA
Left ventricular failure	2	NA	NA
Hypertension	31	NA	NA
Prior malignancy	7	NA	NA
Diabetes	3	NA	NA
Miscellaneous	50	NA	NA
None	5	NA	NA
Total no. per participant	NA	1.97±1.35	NA

Abbreviations: IQR, interquartile range; LAC, lacunar; NA, not applicable; PAC, partial anterior circulation; POC, posterior circulation; SD, standard deviation; TAC, total anterior circulation; UC, unclear.

Extended Activities of Daily Living [NEADL], Rivermead Mobility Index [RMI]).

METHODS

Participants

All participants in this study (N=66) were recruited to a randomized trial of exercise or relaxation after stroke (table 1).[20] We selected these 66 patients after screening 301 patients for trial eligibility (all 301 had required either inpatient or outpatient care after an acute stroke in 1 of 4 Edinburgh hospitals). Trial inclusion criteria were (1) independently ambulatory (with or without walking aids), (2) living within the recruitment catchment area, (3) completion of inpatient and outpatient stroke rehabilitation, and (4) absence of dysphasia or confusion judged severe enough to prevent safe participation in exercise

Table 2: Untransformed Data for Lower-Limb Extensor Power, Measures of Performance of Specific Functional Activities, and Global Indices of Activity Limitation

Variable	n	Mean ± SD	Median (IQR)
Lower-limb extensor power			
Affected side LLEP (W/kg)	64	NA	0.92 (0.53–1.49)*†
Unaffected side LLEP (W/kg)	61	NA	1.05 (0.73–1.56)†
Asymmetry ratio (aff LLEP/unaff LLEP)	60	0.89±0.24	NA
Specific functional activities			
FRT (cm)	63	26.53±6.65	NA
Comfortable walking velocity (m/s)	64	0.67±0.24	NA
TUG test (s)	61	NA	11.68 (8.17–16.09)‡
Chair-rise time (s)	60	NA	1.28 (0.83–1.70)‡
Global indices of activity limitation			
FIM instrument	66	NA	117.5 (114–122)§
RMI	66	NA	13 (11–14)§
NEADL	65	NA	17 (12–19)§

Abbreviations: aff, affected; LLEP, lower-limb extensor power; unaff, unaffected.
*Affected LLEP lower than unaffected LLEP (t=3.77, P<.001).
†The non-normal data included in this table could be transformed to a normal distribution using square root.
‡The non-normal data included in this table could be transformed to a normal distribution using reciprocal.
§The non-normal data included in this table could be transformed to a normal distribution using square root of reflected data.

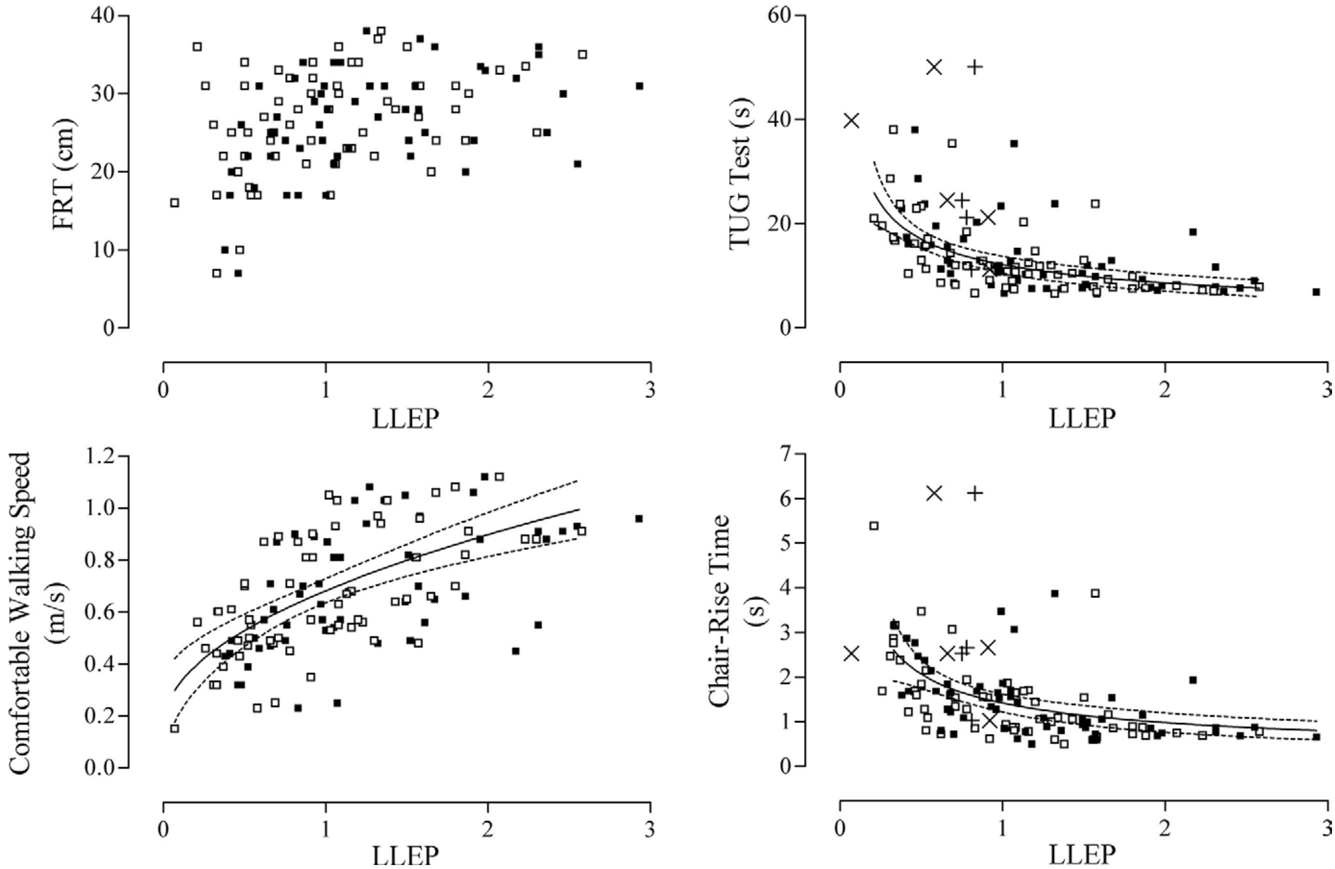


Fig 1. The relationships between the explosive lower-limb extensor power (LLEP), measured in W/kg, of the affected (■) and unaffected (□) lower limbs and performance of specific functional activities assessed using the FRT, TUG test, chair-rising time, and comfortable walking velocity. When arms were used for assistance during chair rising and TUG test the data are marked differently (× affected, + unaffected). For clarity the lines of best fit with 95% CIs are included only for the unaffected lower-limb extensor power data.

or relaxation classes or to preclude informed consent. Absolute contraindications to exercise in elderly people[21] and walking limited by pain were applied as exclusion criteria. Approval was obtained from the local research ethics committee.

For participants who presented with no lateralizing signs but had relevant stroke lesions evident on brain imaging, we considered the affected side to be ipsilateral to the side of posterior circulation lesions, and contralateral for all others.

Measurements

Prior to randomization, we measured lower-limb extensor power during hip and knee extension while the subject was seated on a Nottingham Power Rig.[22,a] Ten maximal pushes were encouraged using each lower limb with a rest (minimum 30s) between each push. Mitchell et al[23] reported that 10 repetitions were sufficient to obtain peak lower-limb extensor power values in elderly people rehabilitating after proximal femoral fracture. Power to body mass ratio (W/kg of body mass) was recorded for each push and the highest value achieved was recorded for the affected and unaffected lower limbs. Asymmetry in lower-limb extensor power was expressed as a ratio (affected lower-limb extensor power/unaffected lower-limb extensor power) and used to indicate hemiparesis. The lower-limb extensor power technique is valid and reliable in healthy elderly people[22] and reliable in persons with stroke.[17]

Functional Reach Test (FRT),[24] Timed Up & Go (TUG) test,[25] and chair-rising time[9] were recorded in triplicate. Participants were asked not to use walking aids or arms during chair rising. The average velocity of comfortable walking was determined during three 3-minute bouts of self-paced walking around a 17-m circuit with a 5-minute break between each walk. Participants were instructed to walk at their "comfortable pace."[26] The following global indices of activity limitation were recorded during face-to-face interview: FIM instrument,[27] RMI,[28] and NEADL.[29] The above measures have been found to be reliable in persons with stroke[30-33] or elderly people.[34]

We recorded age, sex, time since stroke, stature, smoking, use of walking aids, the incidence of key comorbid diseases, and the total number of comorbid diseases (see table 1) as potential confounding factors.[8,10,35]

Data Analysis

Normally distributed data were reported as mean and standard deviation (SD). Non-normal data were expressed as median and interquartile range (IQR) and transformed to a normative distribution prior to any statistical analysis. Affected and unaffected legs were compared using a paired *t* test. Stepwise multiple linear regression was used to identify (1) whether any of the confounders predicted lower-limb extensor power, and (2) whether lower-limb extensor power and confounders predicted activity limitation measures. When lower-

Table 3: The Results of Stepwise Multiple Linear Regression Analysis of the Lower-Limb Extensor Power (affected side, unaffected side, ratio) and Potential Confounding Predictor Variables (age, sex, stature, time since stroke, use of walking aids, comorbid disease, smoking history) on Performance of Specific Functional Activities and Global Indices of Activity Limitation

	Measure of LLEP Included in Regression Model								
Dependent Variable	Affected Side for LLEP			Unaffected Side for LLEP			Asymmetry Ratio (affected LLEP/unaffected LLEP)		
Specific functional activities									
FRT*	LLEP	.32	$P<.01$	LLEP	.48	$P<.001$	Stature	.38	
	Stature	.28	$P<.023$	Stature	.54	$P<.001$			
				Sex	.39	$P<.019$			
	R^2	.21	$P<.001$	R^2	.33	$P<.001$	R^2	.13	$P<.003$
Comfortable walking speed	LLEP	.54		LLEP	.65		Age	−.31	
	R^2	.28	$P<.001$	R^2	.41	$P<.001$	R^2	.08	$P<.020$
TUG test	LLEP	.68		LLEP	.60				
	R^2	.46	$P<.001$	R^2	.35	$P<.001$	R^2	NA	NS
Chair-rise time*	LLEP	.63		LLEP	.56		Age	−.30	
	R^2	.38	$P<.001$	R^2	.30	$P<.001$	R^2	.07	$P<.026$
Global indices of activity limitation									
FIM instrument	LLEP	−.64	$P<.001$	LLEP	−.38				
	Stature	.23	$P<.039$						
	R^2	.35	$P<.001$	R^2	.13	$P<.003$	R^2	NA	NS
RMI	LLEP	−.58		LLEP	−.53				
	R^2	.33	$P<.001$	R^2	.27	$P<.001$	R^2	NA	NS
NEADL	LLEP	−.64	$P<.001$	LLEP	−.41		LLEP	−.29	
	Smoking	.21	$P<.045$						
	R^2	.38	$P<.001$	R^2	.16	$P<.001$	R^2	.07	$P<.027$

NOTE. Standardized β coefficients are reported for each individual independent variable having significant predictive value, and adjusted R^2 values for each overall model where this could be fitted.
Abbreviation: NS, no significant regression model solution.
*Use of walking aids omitted from models.

limb extensor power was the only significant predictor of activity limitation, the regression coefficients were used to generate nonlinear models (and 95% confidence interval [CI]) of the untransformed graphed data. Analyses were performed with SPSS[b] and Graphpad Prizm.[c] A P value of less than .05 was considered statistically significant.

RESULTS

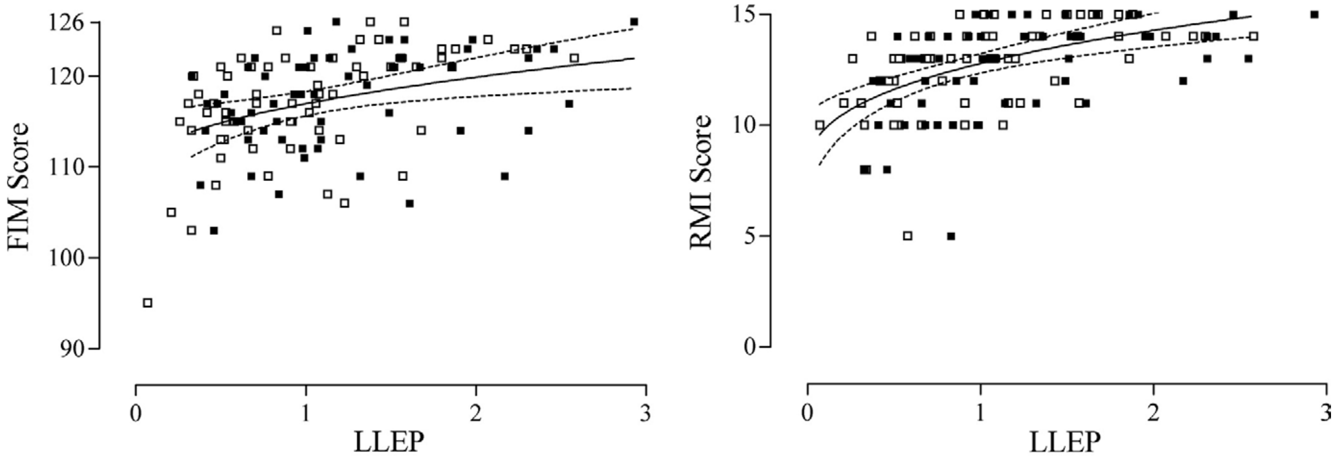
A successful measure of lower-limb extensor power was achieved in both legs of 60 (91%) of 66 participants and at least 1 leg of 65 (98%) of 66 participants. The reasons preventing data collection were leg pain (n=4) and equipment failure (n=2). The average lower-limb extensor power increased by 76% (affected) and 55% (unaffected) throughout the 10 repetitions, but approached asymptotic values between repetitions 8 and 10 during which further increase was trivial (2.3% affected leg, 0.3% unaffected leg). The proportion of participants with ceiling values in the global indices was low (FIM instrument, 2/66; RMI, 11/66; NEADL, 3/66). The data for lower-limb extensor power, specific functional activities, and global indices of activity limitation are summarized in table 2.

Median affected lower-limb extensor power was 42% (IQR, 27–66) and unaffected lower-limb extensor power was 54% (IQR, 37–71) of that expected in age- and sex-matched subjects.[8,9] Affected lower-limb extensor power was significantly lower than unaffected lower-limb extensor power (t=3.77, $P<.001$), but the difference was small (≈10%; median, .14W/kg) and the extensor power of each lower limb were highly correlated (R^2=.68, $P<.001$). When the influence of age, sex, time since stroke, smoking, and incidence of comorbid disease(s) on lower-limb extensor power was examined, unaffected lower-limb extensor power was predicted (weakly) only by sex and age (R^2=.18, P=.001), and affected lower-limb extensor power by sex only (R^2=.14, P=.002). None of the factors predicted the asymmetry ratio.

Low values of affected or unaffected lower-limb extensor power appear associated with limitation in each specific functional activity (fig 1). Lower-limb extensor power showed pronounced curvilinear associations with chair-rising time, and TUG test. When walking speed (in m/s) was expressed as a function of time (in s/m), the same curvilinear association was observed. All 3 dynamic physical functions showed reduced performance when lower-limb extensor power was below approximately 1W/kg with no increase in performance above this value.

Both affected and unaffected lower-limb extensor power were significant predictors of performance in each functional activity (table 3). Comfortable walking velocity, chair-rise time, and TUG test performance were predicted exclusively by affected and unaffected lower-limb extensor power, with each leg having similar influence. Five participants with low values of lower-limb extensor power (<1W/kg) found chair rising impossible without using their arms; their data were excluded from the regression analysis of the TUG test and chair rising. Functional reach was predicted by lower-limb extensor power, but not exclusively or as strongly as were other activities. The ratio of affected/unaffected lower-limb extensor power had no predictive importance for performance of specific functional activities.

Lower-limb extensor power was nearly exclusive as a predictor of global indices of activity limitation from among the variables included in the regression models (fig 2, see table 3), the only exceptions being marginal contributions of stature to FIM instrument, and smoking to NEADL scores. Associations



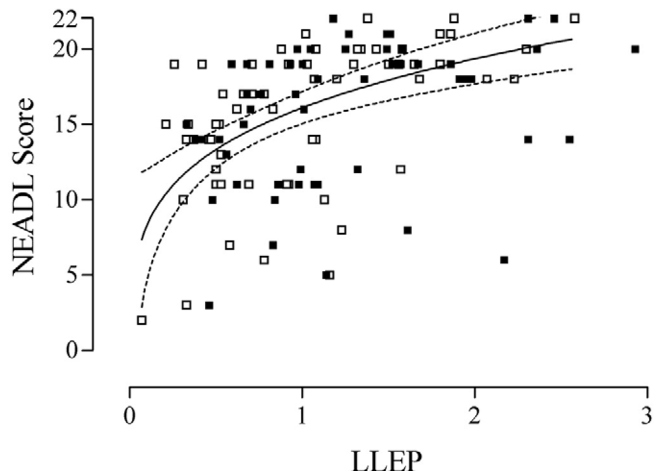


Fig 2. The relationship between the explosive lower-limb extensor power, measured in W/kg, of the affected (■) and unaffected (□) lower limbs and global indices of activity limitation assessed using FIM instrument, RMI, and NEADL. For clarity the lines of best fit with 95% CIs are included only for the unaffected explosive lower-limb extensor power data.

tended to be stronger for affected lower-limb extensor power than unaffected lower-limb extensor power, but asymmetry in lower-limb extensor power did not predict FIM instrument or RMI scores and had only marginal predictive value for NEADL scores.

When statistical analyses were repeated after excluding subjects with prior stroke (11/66) the multivariate R^2 values increased slightly and marginal variables were dropped from the models, leaving affected and unaffected lower-limb extensor power as the exclusive predictors of performance or limitation of activities.

DISCUSSION

This study shows that among a sample of ambulatory subjects with stroke (mean age, 72y), the unaffected lower-limb extensor power was lower than expected and that low lower-limb extensor power in either leg was associated with (1) reduced performance in some everyday dynamic functional activities that involve the legs, and (2) activity limitation as assessed using more global scale indices. Asymmetry in lower-limb extensor power was small and not predictive of limitations.

Our data suggest lower-limb extensor power is important for the performance of dynamic day-to-day lower-limb activities that require rapid rates of muscle contraction. Associations were strongest with comfortable walking velocity, TUG test, and chair-rising time. When lower-limb extensor power is very low, performance of chair rising may be impossible for some unless modified (eg, use of arms). This is compatible with similar observations in healthy elderly people.[2] As expected, the weakest association between lower-limb extensor power (of either leg) and physical function was with functional reach, probably because this is not limited by speed of movement.

Our data show a convincing association between low lower-limb extensor power and increased global indices of activity limitation even though not all questions within each scale directly addressed performance of activities involving the lower-limb extensors.

In elderly persons with functional impairments, power output during leg-press exercise, a procedure similar to lower-limb extensor power determination, was found to be associated with stair climbing ability, chair-rise time and habitual gait velocity,[36] and with self-reported functional status.[5] These observations resemble the types of association found in our study.

In a small study of unusually young (46y) ambulatory subjects with stroke[17] substantial asymmetry in lower-limb extensor power was observed (mean, 43%) and this was inversely associated with walking speed (Spearman $\rho=-.76$, $P<.01$). These younger participants had RMI values with a mean of 13 and walking speeds with a mean of .70m/s, which were similar to our data (see table 2). It is plausible that the greater lower-limb extensor power of their stronger side, with a mean of 1.99W/kg, allowed functional compensation. Asymmetry in our typically older participants (mean age, 72y) was not predictive of activity limitation to any important extent, probably because little asymmetry (10%) existed. This lack of asymmetry may have occurred because our participants had made a good neurologic recovery. Second, substantial asymmetry may be unusual in the older ambulatory person with stroke simply because lower-limb extensor power is already low prior to stroke, and a threshold effect limits the reduction in lower-limb extensor power that can occur without rendering the participant nonambulatory. The lack of asymmetry in our data suggests that the low values of lower-limb extensor power could have arisen due to the influence of factors that act bilaterally (ie, bilateral motor effects, comorbid disease, habitual physical inactivity).

Longitudinal poststroke deterioration could cause bilateral loss of lower-limb extensor power. Although no longitudinal data of lower-limb extensor power are available, 1 small study has reported an approximate 30% loss of strength of the ipsilateral leg during the week after stroke.[10] Another, however, found no poststroke deterioration.[37] In our study, neither time after stroke nor comorbid disease(s) were predictive of lower-limb extensor power or activity limitations, perhaps because our sample was homogeneous due to restrictive eligibility criteria. Although it is not possible to identify the underlying cause for low lower-limb extensor power and activity limitations, habitual physical inactivity before and/or after stroke remains a possible cause.

High-velocity resistance training in 25 healthy elderly persons (age, 60–80y) increased explosive power of the knee extensors and this is associated with significant improvements in chair rising, walking, and reaching ability.[38] Extrapolating findings from studies of elderly people suggest that increasing affected and unaffected lower-limb extensor power might improve activity and independence after stroke. We are unaware of any studies to date that have examined this type of training after stroke.

We successfully measured peak lower-limb extensor power in more than 90% of our participants; this compares favorably with our experience of this measurement in healthy elderly people (78%) using the same equipment.[8] This suggests that ambulatory persons who have had stroke can perform the repeated, high-velocity, resisted muscle contractions needed to improve explosive power. In addition, if lower-limb extensor power is impaired due to reduced habitual physical activity, there is no reason why reversal through suitable training should not occur. Therefore training lower-limb extensor power after stroke may be feasible.

Study Limitations

The main limitation of this study was that we recruited a homogeneous sample of high functioning independently ambulatory subjects with stroke. Homogeneity may have limited the strength of the observed associations. The potential self-selection of fitter participants would also tend give rise to a higher functioning cohort. Participants had minimal hemiparesis so it is difficult to speculate on the functional importance of lower-limb extensor power for those with more severe impairment. Future work should therefore include more impaired participants and examine the role of other confounding factors, such as stage of motor recovery and pre- and poststroke habitual physical activity levels. Outcome measures could be extended to include indices of participation restriction.

CONCLUSIONS

In a sample of ambulatory subjects with stroke of mean age 72 years activity limitations were associated with bilateral deficits in lower-limb extensor power and not with the severity of any residual asymmetry. These data suggest that the feasibility and effectiveness of training interventions to improve muscle explosive power after stroke should be explored.

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Suppliers

a. Medical Engineering Unit, University of Nottingham, Queens Medical Centre, Nottingham, NG7 2UH, UK.
b. Version 12; SPSS, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.
c. Version 4.0; Graphpad Prizm, 11452 El Camino Real, #215, San Diego, CA 92130.