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Return to Employment After Stroke in Young Adults

How Important Is the Speed and Energy Cost of Walking?

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Background and Purpose—A quarter of individuals who experience a stroke are under the age of 65 years (defined as young adults), and up to 44% will be unable to return to work poststroke, predominantly because of walking difficulties. No research study has comprehensively analyzed walking performance in young adult's poststroke. The primary aim of this study is to investigate how a stroke in young adults affects walking performance (eg, walking speed and metabolic cost) compared with healthy age-matched controls. The secondary aim is to determine the predictive ability of walking performance parameters for return to employment poststroke.

Methods—Forty-six individuals (18–40 years: n=6, 41–54 years: n=21, 55–65 years: n=19) who have had a stroke and 15 healthy age-matched able-bodied controls were recruited from 6 hospital sites in Wales, United Kingdom. Type, location, cause of stroke, and demographic factors (eg, employment status) were recorded. Temporal and spatial walking parameters were measured using 3-dimensional gait analysis. Metabolic energy expenditure and metabolic cost of walking were captured during 3 minutes of walking at self-selected speed from measurements of oxygen consumption.

Results—Stroke participants walked slower ($P<0.004$) and less efficiently ($P<0.002$) than the controls. Only 23% of stroke participants returned to employment poststroke. Walking speed was the strongest predictor (sensitivity, 0.90; specificity, 0.82) for return to work ($P=0.004$) with a threshold of 0.93 m/s identified: individuals able to walk faster than 0.93 m/s were significantly more likely to return to work poststroke than those who walked slower than this threshold.

Conclusions—This study is the first to capture walking performance parameters of young adults who have had a stroke and identifies slower and less efficient walking. Walking speed emerged as the strongest predictor for return to employment. It is recommended that walking speed be used as a simple but sensitive clinical indicator of functional performance to guide rehabilitation and inform readiness for return to work poststroke. **(*Stroke*. 2019;50:3198-3204. DOI: 10.1161/STROKEAHA.119.025614.)**

Key Words: adult ■ return to work ■ stroke ■ walking speed ■ young adult

A quarter of individuals who experience a stroke are under the age of 65 years[1] and up to 44% of these people will be unable to return to work, with the resulting loss of productivity costing the United Kingdom ≈$1.9 billion.[2] This high economic cost and particularly significant effect on quality of life relative to functional requirements following stroke in young adults (defined as those of working age and under the age of 65 years) is an important health issue justifying particular focus on this age group.[1]

Many young adults who have had a stroke are unable to return to work, education, or participate in social activities because of their difficulties walking and completing activities of daily living.[3,4] However, nearly all stroke literature to date has focused on older adults who have very different functional requirements and potentially do not need to return to work, in contrast to young adults.

Previous literature[5,6] has established that young adults who have had a stroke walk markedly slower (range, 0.39–0.78 m/s) and have a higher metabolic cost of walking (0.63 mL/kg/m) compared with age-matched healthy-able-bodied participants (1.27–1.34 m/s[6–8] and 0.16 mL/kg/m,[7] respectively). Although reports of decrements to walking performance seem similar in

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nature to those of older adults who have had a stroke, Platts et al[6] and Nadeau et al[5] included a large age range in participants and small sample sizes (27–54 and 18–73 years, respectively). A focus on young adults specifically and further grouping into age subgroups will help to elucidate any age-specific effects of stroke and to further understand the physiological and biomechanical sources of the high within-group variability, potentially helping to uncover important mechanisms. Important factors to consider include the type and cause of stroke, region of brain affected by the stroke, level of physical and cognitive disability, the intensity and duration of rehabilitation, and motivation of the individual.[9,10]

Considering the central importance of return to work poststroke for young adults and the crucial role of walking performance parameters, examining their predictive capability for return to work is of high reliance for treatment and rehabilitation. These walking performance parameters could include temporal (walking speed, stance time, stance time symmetry ratio) and spatial (stride length, stride width, step length, and step length symmetry ratio) measures and metabolic cost. Previous studies[11] have used walking speed and self-reported physical function[12] to predict return to employment and ability to begin running during rehabilitation in patients with traumatic brain injury, but this has not been investigated in young adults who have had a stroke, nor has temporal, spatial, or metabolic cost measures been tested as potential predictor parameters.

The aim of this study was to (1) investigate the effect of stroke in young adults on walking performance parameters: walking speed, stance time, stance time symmetry ratio, stride length, stride width, step length, step length symmetry ratio, metabolic energy expenditure, and metabolic cost and (2) determine the predictive ability of these walking performance parameters for return to employment poststroke. It is hypothesized that young adults affected by stroke will walk significantly slower than controls, which will be associated with a higher metabolic cost of walking and greater walking asymmetry. It is hypothesized that walking speed and metabolic cost will best predict return to employment status.

Methods

The data that support the findings of this study are available from the corresponding author on reasonable request.

Recruitment

This study was approved by the NHS Ethics Committee (Wales Regional Ethics Committee 6) and Health Research Authority (United Kingdom) and Manchester Metropolitan University Research Ethics Committee. Informed written consent to take part in this study was obtained from each participant.

Forty-six individuals aged between 18 and 65 years were recruited and agreed to participate from 6 health boards in Wales, United Kingdom: Cardiff and Vale University Health Board, Cwm Taf University Health Board, Betsi Cadwaladr University Health Board, Powys Teaching Health Board, Abertawe Bro Morgannwg University Health Board and Hywel Dda University Health Board, between September 2018 and October 2018. Stroke participants were recruited into 1 of 3 age groups (18–40 years [18–40 y], 41–54 years [41–54 y], 54–65 years [55–65 y]) because this was felt to best represent different stages in adult life (eg, employment, family responsibilities[13]).

Inclusion criteria were that stroke participants were between 18 and 65 years of age, have had a hemorrhage or infarct stroke within the last 3 years that is evident from a computerized tomography scan and be able to walk continuously for at least 3 minutes. Stroke participants who had a stroke, but were also diagnosed with a respiratory disease, musculoskeletal disease, injury or an autoimmune disease that was the predominant health concern or the major factor that limited their ability to walk rather than the stroke, were excluded from this study. Control participants had no history of stroke, neurological, musculoskeletal, cardiovascular, autoimmune, or respiratory disease. Very physically active (eg, elite/subelite athletes) individuals, or participants who smoke or have smoked in the past were excluded from this study.

Outcome Measures

Demographic Data

Demographic data included age, body mass, height, age at stroke, type of stroke, and region of brain affected by stroke, most likely cause of stroke (if known), and whether the right or left side was predominantly affected by the stroke which was used to determine the paretic and nonparetic limb. Participants were asked to state prestroke and poststroke their employment status, driving status, smoking status, and alcohol consumption.

Walking Speed and Metabolic Cost of Walking

To capture metabolic energy expenditure during walking, participants were fitted with a gas analyzer (Cortex Metalyser, Biophysik), which measures oxygen consumption. All participants walked at their self-selected speed for 3 minutes up and down a 15-m long runway with timing gates situated 5 m from either end of the runway to measure walking speed. The last minute of oxygen consumption data from each participant was used for analysis. Oxygen consumption underwent normalization to body mass and to calculate the cost of walking, which is a measure of efficiency, oxygen consumption was divided by walking speed, which indicates the milliliters of oxygen uptake required per kilogram of bodyweight to cover a meter of ground.

Temporal and Spatial Parameters

An eight-camera optoelectronic motion capture system (Miqus, Qualysis motion capture system, Qualysis, Sweden, data collected at 120 Hz) was placed around a 15-m walkway with 4 ground-embedded Kistler force plates (Kistler, Winterthur, Switzerland, data collected at 1000 Hz). Retroreflective markers were placed on anatomic landmarks to define joint centers and body segments using the marker set previously described by us.[7] A static standing trial was recorded for each participant to calculate a participant-specific calculation of the location of joint centers and then participants completed 7 walking trials of ≈5 m in length. Data were digitized in Qualysis Track Manager (Qualysis, Sweden) and then exported for modeling and analysis within Visual 3-dimensional (C-Motion, Rochelle). Within Visual 3-dimensional, a model specific to the height and body mass of each participant was created and with gait events (initial contact and toe off) defined from contact with the force plates specific temporal and spatial parameters were extracted.

Analyzed parameters included walking speed, stance time (from heel strike to toe off on the same leg), stride length (distance between proximal end position of the foot at heel strike to the proximal end position of the foot at the next heel strike), stride width (medio-lateral distance between proximal end position of the foot at heel strike to the proximal end position of the foot at the next contralateral heel strike), step length (distance between proximal end position of the contralateral foot at the previous contralateral heel strike to the proximal end position of the foot at the heel strike) parameters were extracted. Symmetry ratios were calculated using the recommended calculation by other studies[14]; which involves dividing the step length/stance time of the paretic limb by the nonparetic limb.

Statistical Analysis

Statistical analysis was conducted using SPSS Version 24. All data were checked for normality using the Shapiro-Wilko test and measures of skewness and kurtosis. Mean, 95% CI, and range were calculated for each parameter. Data were compared between groups of stroke participants versus control per age group or between stroke participants for employment status (return to work or not return to work) using an independent *t* test was used for parametric data and a Mann-Whitney *U* test used for nonparametric data. For comparison between paretic, nonparetic, and control limbs, a 1-way ANOVA with post hoc analysis using least significant difference was used for parametric data and a Kruskal-Wallis test with individual Mann-Whitney *U* tests was used for nonparametric data.

For correlation analysis, a Pearson correlation was used for parametric data and a Spearman correlation was used for nonparametric data. Logistic regression was preformed to determine the impact of predictor variables (walking speed, step length symmetry ratio, and stance time symmetry ratio) on employment status. Although metabolic cost is a significant factor in walking performance the high correlation between it and walking speed suggests that only walking speed should be used as a predictor variable. For the factors that predicted employment status, receiver operator characteristic curves were used to generate performance thresholds for the predictor variables.

Results

Demographic Data

Demographic data can be found in Table I in the online-only Data Supplement. Stroke participants were a similar age, height, and body mass to their respective group of age-matched healthy able-bodied controls for the 18 to 40 y (P=0.372). Stroke participants in the 41 to 54 y were younger (P=0.001), but a similar height and weight (P=0.155), and in the 55 to 65 y stroke participants body mass was heavier (P=0.04), but participants were a similar age and height (P=0.08).

The majority of stroke participants experienced an infarct (18–40 y, n=3; 41–54 y, n=15; 55–65 y, n=16) compared with hemorrhage (18–40 y, n=3; 41–54 y, n=5; 55–65 y, n=3) stroke. Time since stroke and location of stroke was variable within each group (Table I in the online-only Data Supplement). Eight participants had preexisting medical conditions (other than hypertension or hyperlipidemia) that have been attributed to cause stroke. This included arteriovenous malformation (18–40 y, n=1), patent foramen ovule CADASIL syndrome (41–54 y, n=2) and type 2 diabetes mellitus, aortic stenosis, carotid stenosis, ischemic heart disease, and hydrocephalus (55–65 y, n=8).

Eight participants aged 41 to 54 y and 10 aged 55 to 65 y smoked, with 6 of those participants continuing to smoke poststroke. All participants with the exception of 4 in the 41 to 54 y and 8 in the 55 to 65 y age group consumed alcohol prestroke. All participants were in full-time employment prestroke with the exception of 4. Two who had retired (45–54 y, n=1; 55–65 y, n=1) and 2 (45–54 y, n=1; 55–65 y, n=1) who chose not to work; poststroke only 10 participants (18–40 y, n=3; 41–54 y, n=5; 55–65 y, n=2) had returned to employment from the time of experiencing a stroke until the time of data collection. All participants were able to drive a car prestroke with exception of one in the 18 to 40 y age group who had not learnt how to drive prestroke. One participant (excluding the participant who could not drive prestroke) in the 18 to 40 y, 12 participants in the 41 to 54 y, and 13 participants in the 55 to 65 y age group were unable to return to driving a car from the time of experiencing a stroke until the time of data collection.

Walking Speed and Metabolic Cost of Walking

Stroke participants walked slower (mean [95% CI]; 18–40 y, 0.97 m/s [0.46–1.47]), 41 to 54 y (0.80 m/s [0.47–1.19]), 55 to 65 y (0.79 m/s [0.29–1.25]) than controls (18–40, y, 1.40 m/s [1.39–1.51], P=0.004; 41–54 y, 1.45 m/s (1.31–1.58), P=0.001; and 55–65 y, 1.37 m/s (1.04–1.49), P=0.001; Table 1). There was a considerable range in the walking speed across all stroke participant age groups with some stroke participants walking slower than others by 1 m/s within the same age group (Figure 1A; Table II in the online-only Data Supplement).

Metabolic energy expenditure was similar between stroke participants and controls across all age groups (P>0.124; Table 1). In the 18 to 40 y age group, the metabolic cost of walking for stroke participants (0.27 mL/kg/m [0.07–0.45]) was higher than for controls (0.14 mL/kg/m [0.13–0.15]; P=0.345). There was considerable variation within the stroke group (range, 0.12–0.54 mL/kg/m), Table II in the online-only Data Supplement. The 95% CIs (0.07–0.45 mL/kg/m; Table 1) and Figure 1B provide an estimation of the difference between stroke and control participants for this and other parameters. Stroke participants aged 41 to 54 y (0.27 mL/kg/m [0.17–0.31]) and 55–65 y (0.35 mL/kg/m [0.09–0.58]; Table 1) had a higher cost of walking than controls (0.14 mL/kg/m [0.13–0.16], P<0.001 and 0.15 mL/kg/m [0.12–0.18], P=0.002), with the 95% CIs, Figure 1B and Table II in the online-only Data Supplement used to indicate the interparticipant variation.

Temporal and Spatial Walking Parameters

For participants aged 18 to 40 years, stride length, stride width, and step length of the paretic and nonparetic limbs were similar to controls (P≥0.110; Table 1), with large individual variation within the stroke participant groups. Stride length was shorter and wider for stroke participants aged 41 to 54 y (stride length: 0.93 m [0.79–1.07], stride width: 0.18 m [0.17–0.20]) and 55 to 65 y (stride length: 0.81 m [0.63–0.97], stride width: 0.19 m [0.16–0.22]; Table 1) compared with their respective controls (41–54 y [P<0.002] and 55–65 y [P<0.03]; Table 1). Step length was similar for stroke participants aged 41 to 54 y and 55 to 65 y between the paretic and nonparetic, both were significantly shorter than controls (P<0.001). Symmetry ratios for step length were similar for stroke participants and the control (P>0.08). Symmetry ratios for stance time were similar for stroke participants and controls for the 18 to 40 y and 55 to 65 y age groups (P>0.421), but stance time symmetry ratio was greater for the 41 to 54 y stroke participants than the control (P=0.01; Table 1).

Relationship Between Walking Speed, Step Length Symmetry Ratio, and Stance Time Symmetry Ratio to Employment Status for Stroke Participants

Stroke participants who had returned to employment walked significantly faster (1.18 m/s [0.96–1.40]) than those who were unable to return to work poststroke (0.74 m/s [0.46–1.02]; P=0.001; Table 2). Step length and stance time symmetry were similar for those able to and not able to return to work (P>0.356; Table 2). Logistic regression was performed

Table 1. Mean (95% CI) With Comparison of Walking Speed, Metabolic Energy Expenditure, Metabolic Cost, Stride Length, Stride Width, Step Length, Step Length Symmetry Ratio, Stance Time, and Stance Time Symmetry Ratio of Stroke Participants Vs Control Participants During Walking

	18–40 y			41–54 y			55–65 y		
Parameter	Stroke (n=6)		Control (n=5)	Stroke (n=20)		Control (n=5)	Stroke (n=15)		Control (n=5)
Walking speed, m/s	0.97 (0.46–1.47)		1.45 (1.39–1.51)	0.80 (0.47–1.19)		1.45 (1.31–1.58)	0.79 (0.29–1.25)		1.37 (1.04–1.49)
P value	0.004			<0.001			0.001		
Metabolic energy expenditure, mL/kg/min	11.00 (6.90–15.09)		12.20 (11.64–12.75)	11.24 (9.13–12.51)		12.40 (10.98–13.81)	10.89 (8.60–13.35)		12.60 (11.18–14.01)
P value	0.662			0.393			0.124		
Metabolic cost, mL/kg/m	0.27 (0.07–0.45)		0.14 (0.13–0.15)	0.27 (0.17–0.31)		0.14 (0.13–0.16)	0.35 (0.09–0.58)		0.15 (0.12–0.18)
P value	0.329			<0.001			0.002		
Stride length, m	1.07 (0.60–1.54)		1.44 (1.30–1.58)	0.93 (0.79–1.07)		1.27 (1.11–1.43)	0.82 (0.63–0.97)		1.28 (1.06–1.49)
P value	0.111			0.02			0.005		
Stride width, m	0.17 (0.09–0.24)		0.12 (0.09–0.14)	0.18 (0.17–0.20)		0.14 (0.11–0.18)	0.20 (0.16–0.22)		0.11 (0.08–0.14)
P value	0.152			0.022			0.002		
	Paretic	Nonparetic	Control	Paretic	Nonparetic	Control	Paretic	Nonparetic	Control
Step length, m	0.56 (0.33–0.79)	0.51 (0.26–0.75)	0.73 (0.66–0.79)	0.32 (0.25–0.38)	0.33 (0.26–0.43)	0.63 (0.58–0.68)	0.28 (0.22–0.39)	0.32 (0.23–0.42)	0.67 (0.50–0.84)
P value (ANOVA)			(0.183)	<0.001	0.787 <0.001	(<0.001)	<0.001	0.732 <0.001	(<0.001)
Step length symmetry ratio	1.16 (0.92–1.39)		0.95 (0.87–1.03)	1.07 (0.88–1.27)		0.94 (0.86–1.01)	2.2 (−0.73–5.14)		0.89 (0.69–1.09)
P value			0.08			0.312			0.477
Stance time (%)	63.2 (55.84–70.47)	67.0 (50.15–83.84)	61.0 (59.18–62.87)	64.5 (61.35–67.54)	67.9 (64.42–71.28)	61.1 (59.33–62.84)	61.0 (61.82–68.57)	70.0 (63.58–73.75)	59.4 (53.92–64.92)
P value (ANOVA)			(0.638)			(0.09)			(0.07)
Stance time symmetry ratio	0.98 (0.73–1.23)		1.07 (0.97–1.02)	0.93 (0.89–0.98)		1.00 (0.97–1.02)	0.96 (0.91–1.00)		0.95 (0.86–1.03)
P value			0.421			0.01			0.957

P value (<0.05) represents comparison between stroke participants and control. For step length and stance time, *P* value in brackets represents ANOVA or Kruskal-Wallis test with post hoc analysis, *P* value under corresponding groups.

to assess the impact of walking speed, step length symmetry ratio, and stance time symmetry ratio on employment status. The full logistic regression model correctly classified 75.0% of participants. As reported in Table 2, only walking speed contributed significantly to the final model (P=0.004), with an estimated odds ratio of 135.347, and the lower 95% CI (4.762) indicates the data are consistent with a strong association.

Figure 2 presents the area under the receiver operator characteristic curve, which is large and statistically significant (area, 0.867; SE, 0.074; 95% CI, 0.722–1.00; P<0.001) indicating that a walking speed threshold of 0.93 m/s provides a prediction for return to work with a sensitivity of 0.90 (90%) and a specificity of 0.82 (82%). Figure 3 presents a strong negative correlation between walking speed and metabolic cost of walking (r=−0.862; P<0.001) with walking speed threshold cutoff defined at 0.93 m/s.

Discussion

Only 23% (n=10/44) of the young adults in this study returned to work (from when they experienced a stroke until the time of data collection), although returning to work and participating in social activities were some of their key aims.[1,6] The results presented here strongly indicate that a key reason for this could be their difficulties walking. Young adults who have had a stroke walked more slowly and had a higher metabolic cost of walking than controls, which although intuitive and potentially regarded as lacking novelty, is one of the first studies to document these results in young adults affected by stroke and to predict return to work.

This study proposes for the first time, a critical threshold value for walking speed, which can be used in clinical practice and future research as a predictor for return to work following stroke. Stroke participants who walked slower than 0.93 m/s were less likely to return to work than those who walked faster than this critical threshold value. Although only findings from a single study that requires further confirmation, this may have implications for the design of rehabilitation programs and could help in defining key rehabilitation outcomes/goals with real-world application following stroke.

This is the first study to date to report walking performance parameters in different age groups (18–40, 41–54, 55–65 y) of

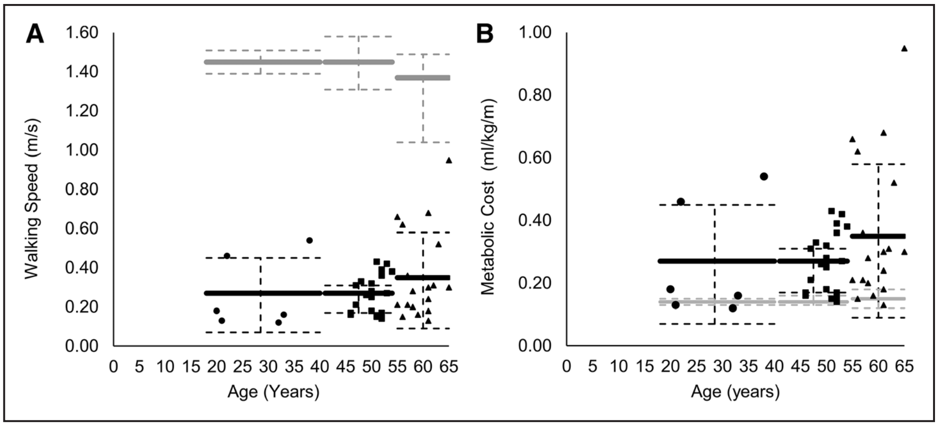

Figure 1. A, Scatter plot of age and walking speed for stroke participants aged 18 to 40 y (circles), 41 to 54 y (squares), and 55 to 65 y (triangles). Solid black line represents the mean, black dashed lines represents 95% CIs. Control participants are presented in gray solid line for the mean and gray dashed line represent 95% CI only. Correlation for stroke participants r^s=0.216 (*P*=0.145). **B**, Scatter plot of age and metabolic cost for stroke participants aged 18 to 40 y (circles), 41 to 54 y (squares), and 55 to 65 y (triangles). Solid black line represents the mean, black dashed lines represents 95% CIs. Control participants are presented in gray solid line for mean and gray dashed line represent 95% CI only. Correlation analysis for stroke participants r^s=0.246 (*P*=0.100).

young adults who have had a stroke, which also takes into account demographic factors such as employment status, type of stroke, and smoking status. The return to work rate in this study (23%) is lower than most other studies conducted in the United Kingdom who have a mean return to work rate of 32% (range 4% to 60%).[15] Although return to work rates poststroke have been documented, they are predominantly based on qualitative data feedback via questionnaires rather than key objective determinants of movement and walking performance such as walking speed.

In the present study, of the 23% who were able to return to work, 90% walked faster than the identified critical threshold speed of 0.93 m/s. Although not captured in the present study (and should be acknowledged as a limitation), factors including upper limb function, vision impairment, or reduced cognitive function poststroke as well as the physical demands of the type of employment itself, play important roles in return to work.[4] However, a slow walking speed seems to be one of the key defining parameters in the multitude of disabling factors a stroke can cause.

In the present study, stroke participants aged 18 to 40 y walked faster and more efficiently than previously reported by others.[5,6] Stroke participants aged 41 to 54 y walked at a similar speed to some,[5,16] but faster than others.[6] Stroke participants aged 55 to 65 y walked at a similar speed to some,[17,18] but faster than others.[19] The metabolic cost of walking in this study for participants 18 to 40 y was 0.27 mL/kg/m, and for the 41 to 54 y it was also 0.27 mL/kg/m. This is much lower than values reported by Platts et al[6] (0.63 mL/kg/m) for a similar age group. The cost of walking in the present study was 0.35 mL/kg/m for participants in the 55 to 65 y group, which is higher than Awad et al[17] (0.289 mL/kg/m) and Brouwer et al[18] (0.19 mL/kg/m). This suggests that although participants in this study are walking at a similar speed, the effort required to walk for participants in the present study is greater and therefore they are less efficient compared with previous reports in the 55 to 65 y age group.

The temporal and spatial parameters indicate several potential causes of the slow walking speed in participants after a stroke. Nearly all stroke participants walked with a wider

Table 2. Mean (95% CI) and Comparison of Walking Speed, Step Length Symmetry Ratio, and Stance Time Symmetry Ratio for Stroke Participants Who Were Able to Return to Work Poststroke and Those Who Are Unable to Return to Work Poststroke

Parameter	Able to Return to Work (n=10)	Not Able to Return to Work (n=36)	B	SE	Wald	df	*P* Value	Odds Ratio	95% Confidence Limit	
									Low	High
Walking speed (m/s)	0.74 (0.46–1.02)	1.18 (0.96–1.40)	4.908	1.708	8.259	1	0.004	135.347	4.762	3846.556
P value	<0.001									
Step length symmetry ratio	1.13 (0.98–1.28)	1.09 (1.00–1.18)	0.029	1.261	0.001	1	0.982	1.029	0.087	12.189
P value	0.604									
Stance time symmetry ratio	0.94 (0.82–0.97)	0.98 (0.85–1.10)	1.051	3.373	0.097	1	0.755	2.860	0.004	2126.319
P value	0.356									
Constant			−6.873	4.037	2.898	1	0.089	0.001		

Logistic regression modeling is used to determine the impact of the predictor variables (walking speed, step length symmetry ratio, and stance time symmetry ratio) on employment status; *P*≤0.05.

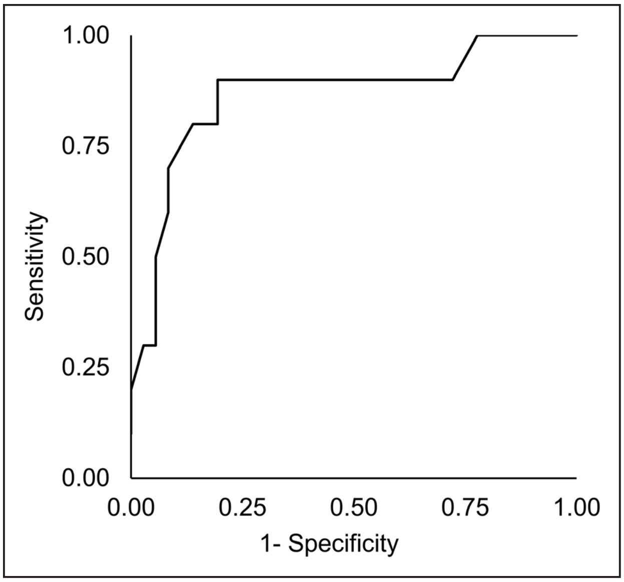

Figure 2. Receiver operating characteristic (ROC) curve for self-selected walking speed. The ROC curve demonstrates the sensitivity and specificity for classifying the ability to return to employment at a 0.93 m/s self-selected walking speed threshold.

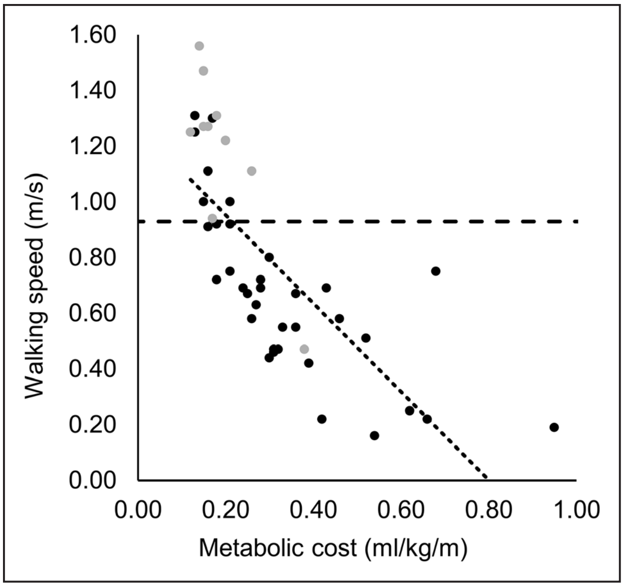

Figure 3. Individual data for walking speed and metabolic cost of walking ($r=-0.862$; $P<0.001$) for stroke participants. Participants in black were unable to return to work and participants in gray returned to work poststroke. Black dashed horizontal line indicates walking speed threshold (0.93 m/s). Black dotted line represents trendline.

stride, likely as part of a strategy to help with balance, but this will in-turn decrease walking speed as it reduces the distance covered in the forwards direction in agreement with Chen et al.[19] Adopting a wider base of support in the standing position may be more stable. However, walking involves transitioning between single and double stance and will therefore mean that the body center of mass experiences greater medio-lateral sway, potentially challenging balance more as seen in other patient groups[20] and increasing metabolic energy cost.[21]

Following a stroke, many previous studies report that patients experience spasticity in muscles and weakness (hemiparesis) of the paretic limb and that the limb is unable to support body weight and remain stable as the stance phase leg.[22] This can mean that the nonparetic limb is unable to swing past the paretic limb because of the need to off-load the paretic limb as quickly as possible. Contractures of the hip flexors and extensors (often because of sedentary behavior) and reduced propulsion of the ankle joint plantarflexors reduce sagittal plane facilitation forwards and during the swing phase the paretic leg will circumduction the weight bearing limb rather than the leg swinging forwards in the direction of travel. Weakness of the lower leg muscles (eg, tibialis anterior)[19] causes in early ground contact (eg, drop foot) shortening step length of the paretic limb.

Rehabilitation strategies that focus on trying to improve how efficiently young adults walk and how fast they are able to walk after stroke may help more return to and stay in employment poststroke. Specifically, we propose a critical threshold value for walking speed at 0.93 m/s as an indicator for return to work (in conjunction with other factors e.g cognition, vision). Although we should emphasize caution based on only this single study, this could be particularly important when considering the physical demands of employment. For example, the practicality of needing to walk at a certain speed to be able to use public transport, walk from a car park to place of work and move within a building or place of work are key requirements of a workspace environment regardless of occupation.[1,6,15]

While there is large variation within each group in our study, it demonstrates that even the youngest group of adults can be as severely affected as older adults in terms of walking speed and cost of walking, but equally some are only mildly affected. The large interparticipant variation within each stroke participant age group in this study and within other previous studies may be at least partly because of the considerable difference in the location of the brain where the stroke occurred (Table I in the online-only Data Supplement). Most studies do not report the location of the stroke, type of stroke or most likely cause of stroke, but depending on these factors and the magnitude of the stroke will determine the effect it has on an individual and in particular how they walk poststroke.

The limitations of this study are that although it was adequately powered for the majority of variables and statistical comparisons, the sample could be considered relatively small in the 18 to 40 y age group (n=6), which does limit the clinical application of this data. However, it should be considered that this is the first time some of these parameters in stroke participants under the age of 40 have been reported. Ideally, we would have segmented groups of participants within each age group according to demographic factors, but the sample size was too small for this analysis and therefore we combined the age groups. The wide range in walking performance poststroke is not necessarily a limitation, but the mean has limited value, which is why the range value and 95% CIs have been presented. We did not record duration, type of or adherence to the rehabilitation administered, which means we cannot account for the effect the rehabilitation has on the walking performance of an individual.

Summary

Young adults who have had a stroke walk slower and are less efficient at walking than age-matched able-bodied controls. This study cautiously proposes for the first time, a critical threshold value for walking speed of 0.93 m/s, with a sensitivity of 0.90 and specificity of 0.82, which could help inform clinical practice and future research as a predictor for return to work following stroke. Many young adults experience difficulties with walking which can mean that they are unable to return to work or participate in social activities. The socioeconomic cost of loss of employment is likely to be considerable to young adults themselves and society as they are likely to be in full-time employment, be home owners and have a family to support. Providing research and clinical guidelines to maximize potential poststroke could have considerable physical, psychological, and financial benefits, which has not yet been fully appreciated.

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References

1. Coole C, Radford K, Grant M, Terry J. Returning to work after stroke: perspectives of employer stakeholders, a qualitative study. *J Occup Rehabil*. 2013;23:406–418. doi: 10.1007/s10926-012-9401-1
2. Saka O, McGuire A, Wolfe C. Cost of stroke in the United Kingdom. *Age Ageing*. 2009;38:27–32. doi: 10.1093/ageing/afn281
3. Leung LY, Melkumova E, Thaler DE. Longitudinal care for young adults with stroke. *JAMA Neurol*. 2017;74:1163–1164. doi: 10.1001/jamaneurol.2017.1874
4. Winstein CJ, Stein J, Arena R, Bates B, Cherney LR, Cramer SC, et al; American Heart Association Stroke Council, Council on Cardiovascular and Stroke Nursing, Council on Clinical Cardiology, and Council on Quality of Care and Outcomes Research. Guidelines for adult stroke rehabilitation and recovery: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2016;47:e98–e169. doi: 10.1161/STR.0000000000000098
5. Nadeau S, Betschart M, Bethoux F. Gait analysis for poststroke rehabilitation: the relevance of biomechanical analysis and the impact of gait speed. *Phys Med Rehabil Clin N Am*. 2013;24:265–276. doi: 10.1016/j.pmr.2012.11.007
6. Platts MM, Rafferty D, Paul L. Metabolic cost of over ground gait in younger stroke patients and healthy controls. *Med Sci Sports Exerc*. 2006;38:1041–1046. doi: 10.1249/01.mss.0000222829.34111.9c
7. Jarvis HL, Bennett AN, Twiste M, Phillip RD, Etherington J, Baker R. Temporal spatial and metabolic mjeasures of walking in highly functional individuals with lower limb amputations. *Arch Phys Med Rehabil*. 2017;98:1389–1399. doi: 10.1016/j.apmr.2016.09.134
8. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. *J Orthop Res*. 1990;8:383–392. doi: 10.1002/jor.1100080310
9. Rohr J, Kittner S, Feeser B, Hebel JR, Whyte MG, Weinstein A, et al. Traditional risk factors and ischemic stroke in young adults: the Baltimore-Washington Cooperative Young Stroke Study. *Arch Neurol*. 1996;53:603–607. doi: 10.1001/archneur.1996.00550070041010
10. Kramer S, Johnson L, Bernhardt J, Cumming T. Energy expenditure and cost during walking after stroke: a systematic review. *Arch Phys Med Rehabil*. 2016;97:619–632.e1. doi: 10.1016/j.apmr.2015.11.007
11. Williams G, Schache AG, Morris ME. Self-selected walking speed predicts ability to run following traumatic brain injury. *J Head Trauma Rehabil*. 2013;28:379–385. doi: 10.1097/HTR.0b013e3182575f80
12. Lindström B, Röding J, Sundelin G. Positive attitudes and preserved high level of motor performance are important factors for return to work in younger persons after stroke: a national survey. *J Rehabil Med*. 2009;41:714–718. doi: 10.2340/16501977-0423
13. Rolfs A, Fazekas F, Grittner U, Dichgans M, Martus P, Holzhausen M, et al; Stroke in Young Fabry Patients (sifap) Investigators. Acute cerebrovascular disease in the young: the stroke in young fabry patients study. *Stroke*. 2013;44:340–349. doi: 10.1161/STROKEAHA.112.663708
14. Lewek MD, Randall EP. Reliability of spatiotemporal asymmetry during overground walking for individuals following chronic stroke. *J Neurol Phys Ther*. 2011;35:116–121. doi: 10.1097/NPT.0b013e318227fe70
15. Daniel K, Wolfe CD, Busch MA, McKevitt C. What are the social consequences of stroke for working-aged adults? A systematic review. *Stroke*. 2009;40:e431–e440. doi: 10.1161/STROKEAHA.108.534487
16. Boudarham J, Roche N, Pradon D, Bonnyaud C, Bensmail D, Zory R. Variations in kinematics during clinical gait analysis in stroke patients. *PLoS One*. 2013;8:e66421. doi: 10.1371/journal.pone.0066421
17. Awad LN, Palmer JA, Pohlig RT, Binder-Macleod SA, Reisman DS. Walking speed and step length asymmetry modify the energy cost of walking after stroke. *Neurorehabil Neural Repair*. 2015;29:416–423. doi: 10.1177/1545968314552528
18. Brouwer B, Parvataneni K, Olney SJ. A comparison of gait biomechanics and metabolic requirements of overground and treadmill walking in people with stroke. *Clin Biomech (Bristol, Avon)*. 2009;24:729–734. doi: 10.1016/j.clinbiomech.2009.07.004
19. Chen G, Patten C, Kothari DH, Zajac FE. Gait differences between individuals with post-stroke hemiparesis and non-disabled controls at matched speeds. *Gait Posture*. 2005;22:51–56. doi: 10.1016/j.gaitpost.2004.06.009
20. Brown SJ, Handsaker JC, Bowling FL, Boulton AJ, Reeves ND. Diabetic peripheral neuropathy compromises balance during daily activities. *Diabetes Care*. 2015;38:1116–1122. doi: 10.2337/dc14-1982
21. Petrovic M, Deschamps K, Verschueren SM, Bowling FL, Maganaris CN, Boulton AJ, et al. Is the metabolic cost of walking higher in people with diabetes? *J Appl Physiol (1985)*. 2016;120:55–62. doi: 10.1152/japplphysiol.00413.2015
22. Serra MC, Treuth MS, Hafer-Macko CE, Ryan AS. Increased energy cost of mobility in chronic stroke. *J Gerontol Geriatr Res*. 2016;5:356–363.