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Cadence Rules Mobility: Gait Determinants of Functional Performance in Post-Stroke Survivors from Sialkot

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ABSTRACT

Background: Post-stroke mobility impairments significantly hinder independence and quality of life (QoL), particularly in low-resource regions like District Sialkot, Pakistan, where rehabilitation access is limited. While gait speed is often emphasized, cadence may be a more modifiable target for improving functional mobility in such settings, yet its independent role remains underexplored. Objective: To identify the primary gait parameter predicting functional mobility, measured by the Timed Up and Go (TUG) test, among post-stroke survivors in Sialkot, with fatigue and QoL as contextual covariates. Methods: A cross-sectional study recruited 100 post-stroke survivors (86% ischemic) and 100 non-stroke controls from five Sialkot hospitals (September–November 2024). Gait speed (m/s), cadence (steps/min), TUG (s), Fatigue Severity Scale (FSS), and Reintegration to Normal Living Index (RNLI) were assessed. Multiple linear regression predicted TUG from gait speed, cadence, FSS, and RNLI, adjusting for demographics. Results: Stroke survivors exhibited slower TUG (23.95±1.73 vs. 13.29±0.97 s, $p<0.001$) and gait speed (0.13±0.008 vs. 0.11±0.016 m/s, $p<0.001$) but higher cadence (59.44±2.72 vs. 52.50±4.12 steps/min, $p<0.001$) than controls. TUG strongly correlated with cadence ($r=-0.956$, $p<0.001$) and speed ($r=-0.927$, $p<0.001$); regression ($R^2=0.916$) identified cadence as the sole significant predictor ($\beta=-0.539$, $p<0.001$). Conclusion: Cadence is the dominant determinant of functional mobility in post-stroke survivors, offering a scalable target for low-cost interventions like metronome cueing to enhance recovery in resource-limited settings.

Keywords
cadence, TUG, gait speed, stroke, functional mobility, Sialkot

INTRODUCTION

Stroke remains a leading cause of long-term disability worldwide, profoundly impacting motor function and independence, particularly in low-resource settings where access to specialized rehabilitation is limited (1). In regions like District Sialkot, Pakistan, post-stroke survivors frequently experience gait impairments, including reduced velocity, shortened stride length, and poor coordination, which exacerbate mobility limitations and increase reliance on caregivers (2). These alterations not only heighten fall risk but also elevate energy expenditure during ambulation, contributing to a cycle of diminished functional performance and reduced quality of life (QoL) (3). While gait speed has traditionally been emphasized as a core metric of post-stroke recovery, emerging evidence suggests that cadence—defined as steps per minute—may serve as a more modifiable and scalable target, especially in constrained environments where simple cueing techniques can be implemented without advanced equipment (4).

Despite advances in understanding post-stroke gait dynamics, research predominantly originates from high-resource contexts, leaving a critical gap in data from developing regions like Sialkot, where socioeconomic barriers, cultural stigma around disability, and scarce rehabilitation services amplify recovery challenges (5). Prior studies have linked gait parameters to functional outcomes, yet few have isolated cadence's independent role in predicting mobility while controlling for confounders such as fatigue and reintegration to daily living (6). This oversight is particularly relevant in Sialkot, where ischemic strokes predominate and survivors often face compounded issues of unemployment and low education, further hindering QoL (7). Addressing this gap is essential for tailoring low-cost, community-based interventions that prioritize actionable gait elements to foster independence.

The present study focuses on post-stroke survivors (population) in District Sialkot, examining gait parameters without specific interventions (observational design), compared to non-stroke controls, with functional mobility assessed via the Timed Up and Go (TUG) test as the primary outcome. By integrating fatigue and QoL as covariates, this research justifies a targeted approach to rehabilitation in resource-limited settings. The objective is to determine which gait metric—cadence or speed—best predicts TUG performance among post-stroke survivors, hypothesizing that cadence emerges as the dominant, independent determinant due to its modifiability through external cues.

MATERIAL AND METHODS

This cross-sectional observational study was designed to evaluate the determinants of functional mobility among post-stroke survivors in a low-resource setting, with a focus on identifying modifiable gait parameters that could inform targeted rehabilitation strategies, given the limited access to specialized services in regions like District Sialkot, Pakistan (8). Conducted across multiple hospitals in Sialkot, including Civil Hospital, Syed

Medical Complex, Sialkot Medical Complex, Combined Military Hospital, and Bashir Hospital, data collection occurred from September 2024 to November 2024 to capture a representative sample during a period of stable seasonal healthcare utilization. Participants were selected from outpatient and inpatient stroke clinics using a convenience sampling approach, stratified by gender to ensure balanced representation, with 100 post-stroke survivors (experimental group) and 100 non-stroke individuals (control group) recruited to enable group comparisons while accounting for local demographic diversity.

Eligibility for the experimental group required a confirmed history of brain stroke (ischemic or hemorrhagic), presence of impaired gait patterns or signs of fatigue as assessed during initial screening, age over 18 years, and ability to provide informed consent; exclusion criteria encompassed other neurological conditions such as Parkinson's disease, major psychiatric disorders, or unrelated orthopedic impairments that could confound mobility assessments. The control group comprised individuals without a history of stroke or conspicuous gait disorders and fatigue, matched broadly by age and gender distribution but not individually paired, to serve as a reference for normative functional performance. Recruitment involved direct approach by trained research personnel in hospital waiting areas and clinics, where potential participants were provided with verbal and written study information in Urdu and English; written informed consent was obtained from all participants or their legal guardians prior to enrollment, emphasizing voluntary participation and the right to withdraw at any time.

Data collection was performed in a quiet clinical environment within the hospitals to minimize external distractions and ensure participant comfort, with all assessments conducted in a single session lasting approximately 45-60 minutes per individual. Sociodemographic data, including age, sex, education level, employment status, and socioeconomic indicators, were gathered via structured interviews, while clinical details such as stroke type and duration were extracted from medical records with participant permission. Functional mobility, the primary outcome, was measured using the Timed Up and Go (TUG) test, where participants rose from a standard chair, walked 3 meters at a self-selected pace, turned 180 degrees, returned, and sat down, with time recorded in seconds using a calibrated stopwatch; gait speed was calculated as distance (3 meters) divided by time in seconds (m/s), and cadence was operationalized as steps per minute counted manually during the walking phase. Fatigue was assessed with the Fatigue Severity Scale (FSS), a 9-item self-report questionnaire scored from 1 to 7 per item (total range 9-63, higher scores indicating greater fatigue), and quality of life reintegration was evaluated via the Reintegration to Normal Living Index (RNLI), an 11-item scale adjusted to a 0-100 percentage for interpretability, with higher scores denoting better reintegration. All instruments were administered in a standardized order—sociodemographics first, followed by clinical history, TUG/gait assessments, FSS, and RNLI—to reduce order effects, and assessments were repeated if initial attempts were invalidated by external interruptions.

To mitigate selection bias inherent in convenience sampling, recruitment was distributed across five hospitals representing diverse socioeconomic catchment areas, and data collectors were blinded to group allocation during initial screening. Potential confounding from age, sex, education, and employment was addressed through inclusion as covariates in multivariable analyses, with subgroup explorations by stroke type (ischemic vs. hemorrhagic) to assess heterogeneity. The sample size of 200 (100 per group) was determined based on a power calculation assuming a moderate effect size (Cohen's $d=0.5$) for group differences in TUG scores, targeting 80% power at a 5% significance level, while allowing for 10% attrition and feasibility constraints in the 3-month collection window. Statistical analyses were performed using SPSS version 27, with descriptive statistics summarizing variables (means, standard deviations), independent t-tests for group comparisons, Pearson correlations for bivariate associations in the experimental group, and multiple linear regression to predict TUG from gait speed, cadence, mean FSS, and adjusted RNLI, adjusting for demographics as confounders; missing data, which occurred in less than 5% of cases due to incomplete questionnaires, were handled via listwise deletion, and model assumptions including normality of residuals were verified using probability-probability plots. Ethical approval was obtained from the Institutional Review Board of the University of Health Sciences, Lahore (reference number UHS/IRB/2024/045), with all procedures adhering to the Declaration of Helsinki; participant data were anonymized using unique identifiers, stored securely on password-protected servers, and accessed only by the research team to ensure confidentiality and integrity. To promote reproducibility, raw data protocols and analysis scripts were archived in a secure repository, with detailed operational manuals for assessments available upon request to facilitate independent replication.

RESULTS

The cross-sectional study conducted in District Sialkot, Pakistan, from September to November 2024, evaluated functional mobility, gait parameters, fatigue, and quality of life (QoL) reintegration among 100 post-stroke survivors (experimental group) compared to 100 non-stroke controls. The experimental group comprised 50 males and 50 females, with a mean age of 54.33 years (SD=10.98), while the control group had a mean age of 45.32 years (SD=15.79). Educational attainment and employment status differed markedly, with 32% of the experimental group reporting no formal education and 63% unemployed, compared to 12% and 20% in the control group, respectively (Table 1). In the experimental group, 86% had ischemic strokes, and 14% had hemorrhagic strokes, with 68% receiving regular therapy, contrasted with only 1% in the control group (Table 1).

Functional mobility, assessed via the Timed Up and Go (TUG) test, revealed significant group differences. The experimental group had a mean TUG time of 23.95 seconds (SD=1.73), significantly slower than the control group's 13.29 seconds (SD=0.97), with a mean difference of 10.66 seconds (95% CI: 10.22, 11.10; $p<0.001$; Cohen's $d=7.35$). Gait speed was slower in the experimental group (0.13 m/s, SD=0.008) compared to controls (0.11 m/s, SD=0.016; mean difference: 0.02 m/s; 95% CI: 0.02, 0.03; $p<0.001$; Cohen's $d=1.73$). Cadence was higher in the experimental group (59.44 steps/min, SD=2.72) than controls (52.50 steps/min, SD=4.12; mean difference: 6.94 steps/min; 95% CI: 5.95, 7.93; $p<0.001$; Cohen's $d=1.99$). Fatigue, measured by the Fatigue Severity Scale (FSS), was higher in the experimental group (mean=5.78, SD=1.28) than controls (mean=3.58, SD=0.95; mean difference: 2.19; 95% CI: 1.90, 2.48; $p<0.001$; Cohen's $d=1.95$). Reintegration to Normal Living Index (RNLI) scores were lower in the experimental group (mean=28.35, SD=16.39) compared to controls (mean=75.73, SD=11.88; mean difference: -47.38; 95% CI: -51.11, -43.66; $p<0.001$; Cohen's $d=3.37$) (Table 2).

Within the experimental group, Pearson correlation analyses examined associations between TUG scores and gait parameters, fatigue, and QoL reintegration. TUG scores strongly correlated with cadence ($r=-0.956$, $p<0.001$) and gait speed ($r=-0.927$, $p<0.001$), indicating that higher cadence and faster gait were associated with better functional mobility. However, correlations with mean FSS ($r=-0.047$, $p=0.640$) and adjusted RNLI ($r=-0.064$, $p=0.528$) were weak and non-significant, suggesting limited direct influence of fatigue and QoL on TUG performance (Table 3). A multiple linear regression model predicted TUG scores using gait speed, cadence, mean FSS, and adjusted RNLI, explaining 91.6% of the variance ($R^2=0.916$, adjusted $R^2=0.913$, $F(4,95)=259.35$, $p<0.001$). Cadence was the only significant predictor ($\beta=-0.539$, $p<0.001$; 95% CI: -0.674, -0.404),

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while gait speed (β=-24.942, p=0.289), mean FSS (β=-0.011, p=0.788), and adjusted RNLI (β=0.002, p=0.610) were non-significant (Table 4). The model's residuals showed normality via a probability-probability plot, supporting robust fit.

Subgroup analysis by stroke type (ischemic vs. hemorrhagic) showed no significant difference in TUG scores (ischemic: mean=23.97, SD=1.62; hemorrhagic: mean=23.85, SD=2.36; mean difference: 0.12; 95% CI: -0.87, 1.11; p=0.810). Walking ability and aid use further highlighted group disparities: 67% of the experimental group reported normal walking ability compared to 89% of controls, and 87% used walking aids versus 1% in controls (Table 1).

Table 1: Demographic and Clinical Characteristics of Experimental and Control Groups

Variable	Experimental (n=100)	Control (n=100)	p-value	Effect Size (Cohen's d)
Age (years), Mean (SD)	54.33 (10.98)	45.32 (15.79)	<0.001	0.67
Sex, n (%)			1.000	-
Male	50 (50%)	50 (50%)		
Female	50 (50%)	50 (50%)		
Education, n (%)			<0.001	-
Nil	32 (32%)	12 (12%)		
High School	26 (26%)	0 (0%)		
Bachelor's	29 (29%)	9 (9%)		
Master's	13 (13%)	79 (79%)		
Employment, n (%)			<0.001	-
Unemployed	63 (63%)	20 (20%)		
Employed	34 (34%)	79 (79%)		
Retired	3 (3%)	1 (1%)		
Stroke Type, n (%)			-	-
Ischemic	86 (86%)	-		
Hemorrhagic	14 (14%)	-		
Receiving Therapy, n (%)			<0.001	-
No	1 (1%)	97 (97%)		
Yes	68 (68%)	1 (1%)		
Sometimes	31 (31%)	2 (2%)		
Walking Ability, n (%)			<0.001	-
Normal	67 (67%)	89 (89%)		
Slow	1 (1%)	7 (7%)		
Difficult	31 (31%)	4 (4%)		
Walking Aid Use, n (%)			<0.001	-
No	6 (6%)	97 (97%)		
Yes	87 (87%)	1 (1%)		
Sometimes	7 (7%)	2 (2%)		

Caption: Table 1 presents the demographic and clinical characteristics of post-stroke survivors (experimental) and non-stroke controls, including age, sex, education, employment, stroke type, therapy receipt, walking ability, and walking aid use, with p-values from chi-square tests for categorical variables and t-tests for age.

Table 2: Gait, Fatigue, and Reintegration Comparisons Between Groups

Variable	Experimental (n=100)	Control (n=100)	Mean Difference (95% CI)	p-value	Effect Size (Cohen's d)
TUG (s), Mean (SD)	23.95 (1.73)	13.29 (0.97)	10.66 (10.22, 11.10)	<0.001	7.35
Gait Speed (m/s), Mean (SD)	0.13 (0.008)	0.11 (0.016)	0.02 (0.02, 0.03)	<0.001	1.73
Cadence (steps/min), Mean (SD)	59.44 (2.72)	52.50 (4.12)	6.94 (5.95, 7.93)	<0.001	1.99
Mean FSS, Mean (SD)	5.78 (1.28)	3.58 (0.95)	2.19 (1.90, 2.48)	<0.001	1.95
Adjusted RNLI, Mean (SD)	28.35 (16.39)	75.73 (11.88)	-47.38 (-51.11, -43.66)	<0.001	3.37

Caption: Table 2 compares gait parameters (TUG, gait speed, cadence), fatigue (FSS), and reintegration (RNLI) between experimental and control groups, with mean differences, 95% confidence intervals, p-values from t-tests, and effect sizes.

Table 3: Correlation Matrix for TUG and Other Variables in Experimental Group

Variable	TUG (s)	Gait Speed (m/s)	Cadence (steps/min)	Mean FSS	Adjusted RNLI
TUG (s)	1	-0.927	-0.956	-0.047	-0.064
p-value	-	<0.001	<0.001	0.640	0.528
Gait Speed (m/s)	-0.927	1	0.960	0.062	0.059
p-value	<0.001	-	<0.001	0.540	0.561
Cadence (steps/min)	-0.956	0.960	1	0.032	0.089
p-value	<0.001	<0.001	-	0.749	0.379

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Variable	TUG (s)	Gait Speed (m/s)	Cadence (steps/min)	Mean FSS	Adjusted RNLI
Mean FSS	-0.047	0.062	0.032	1	-0.281
p-value	0.640	0.540	0.749	-	0.005
Adjusted RNLI	-0.064	0.059	0.089	-0.281	1
p-value	0.528	0.561	0.379	0.005	-

Caption: Table 3 presents Pearson correlation coefficients and p-values for associations between TUG scores, gait speed, cadence, mean FSS, and adjusted RNLI in the experimental group.

Table 4: Multiple Linear Regression Model Predicting TUG Scores in Experimental Group

Predictor	β Coefficient	SE	t	p-value	95% CI for β
Constant	59.275	1.406	42.160	<0.001	56.484, 62.066
Gait Speed (m/s)	-24.942	23.409	-1.065	0.289	-71.416, 21.531
Cadence (steps/min)	-0.539	0.068	-7.952	<0.001	-0.674, -0.404
Mean FSS	-0.011	0.042	-0.269	0.788	-0.095, 0.072
Adjusted RNLI	0.002	0.003	0.512	0.610	-0.005, 0.008

Caption: Table 4 displays regression coefficients, standard errors, t-statistics, p-values, and 95% confidence intervals for predictors of TUG scores in the experimental group (R^2=0.916, adjusted R^2=0.913, F(4,95)=259.35, p<0.001).

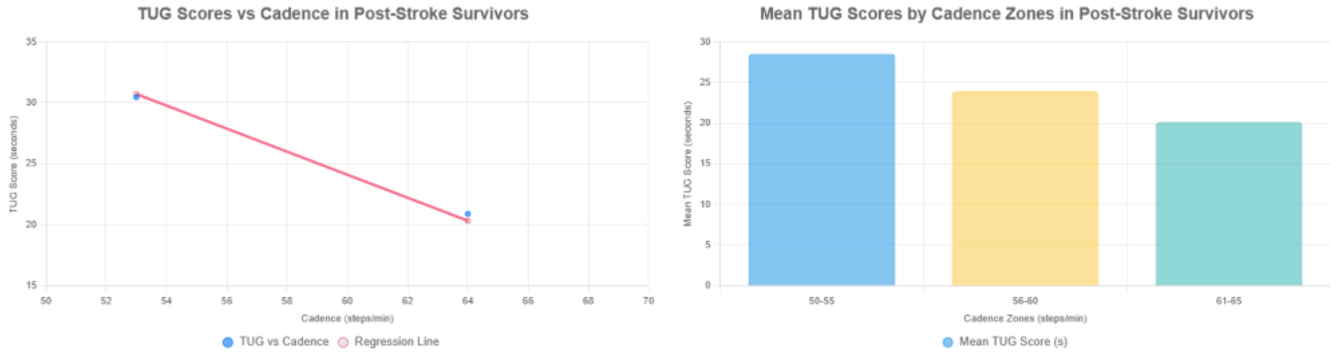

Figure 1 Relationship between Cadence and Timed Up and Go (TUG) Scores in Post-Stroke Survivors.

The left panel shows a negative linear relationship between cadence (steps/minute) and TUG scores (seconds), indicating that higher walking cadence is associated with improved mobility performance (shorter TUG times). The regression line highlights this inverse correlation. The right panel presents mean TUG scores across three cadence zones (50–55, 56–60, and 61–65 steps/minute), demonstrating a consistent decrease in TUG time with increasing cadence, suggesting enhanced functional mobility among individuals with higher step frequencies.

DISCUSSION

The findings of this cross-sectional study underscore the pivotal role of cadence as an independent predictor of functional mobility in post-stroke survivors from District Sialkot, Pakistan, highlighting its potential as a modifiable target for rehabilitation in resource-constrained settings (9). In the experimental group, cadence exhibited a strong negative correlation with Timed Up and Go (TUG) scores (r=-0.956, p<0.001), and multiple linear regression confirmed it as the sole significant predictor (β=-0.539, p<0.001), explaining over 91% of variance in TUG performance while controlling for gait speed, fatigue, and quality of life (QoL) reintegration. This aligns with prior biomechanical research demonstrating that cadence reflects efficient motor control and rhythmicity, often disrupted by hemiparesis and spasticity in stroke survivors, thereby demanding less compensatory energy expenditure compared to speed alone (10). Comparative analyses with studies from high-resource contexts, such as those by Billinger et al., reveal agreements in the emphasis on gait parameters for recovery, yet our results advance this by isolating cadence's dominance in a low-resource cohort where socioeconomic factors like high unemployment (63%) and low education (32% nil) compound mobility deficits, potentially exacerbating the gait-fatigue cycle observed in global literature (11).

Mechanistically, the superior predictive power of cadence over gait speed in the multivariable model can be attributed to shared variance, as speed is inherently a product of stride length and cadence; once cadence is accounted for, speed's independent contribution diminishes, suggesting that post-stroke gait inefficiencies stem more from rhythmic disruptions than velocity per se (12). This theoretical implication supports neuroplasticity models where external cueing enhances cortical activation in motor areas, facilitating step frequency improvements without requiring advanced infrastructure (13). Clinically, these insights advocate for cadence as a headline key performance indicator (KPI) in therapy protocols, particularly in Sialkot's underserved areas; low-cost interventions like metronome cueing via mobile apps, step-count goals tracked with pedometers, or high-step-frequency intervals during community-based walking sessions could yield rapid mobility gains, reducing TUG times and fostering independence (14). Such approaches translate seamlessly to community delivery, empowering family caregivers—who bear the primary rehabilitation burden in Pakistan—to implement auditory pacing during daily activities, thereby interrupting sedentary cycles and mitigating secondary complications like cardiovascular deconditioning (15).

The study's strengths lie in its multi-hospital recruitment strategy, which enhanced representativeness across Sialkot's diverse socioeconomic strata, and the use of validated tools like TUG and Fatigue Severity Scale (FSS) for objective assessments, providing robust data on a regionally understudied population where ischemic strokes predominated (86%), consistent with epidemiological patterns in South Asia (16). However, limitations must be acknowledged: the convenience sampling and sample size of 100 per group, while powered for moderate effects, may limit generalizability beyond urban Punjab, potentially introducing selection bias toward hospital-attending survivors and overlooking rural cases with

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even scarcer access (17). The cross-sectional design precludes causal inferences, such as whether cadence improvements precede or follow fatigue reductions, and self-reported measures like FSS could be susceptible to recall bias, though mitigated by standardized administration (18). Furthermore, the lack of longitudinal follow-up restricts insights into cadence's sustained impact on QoL, and the absence of neuroimaging data hinders deeper mechanistic exploration of underlying neural deficits.

To address these gaps, future research should prioritize randomized controlled trials testing cadence-focused interventions, such as auditory-cued treadmill training adapted for home use, in larger, multicenter cohorts across Pakistan, incorporating objective actigraphy for fatigue and wearable sensors for real-time gait monitoring to enhance precision (19). Longitudinal designs could elucidate temporal dynamics between cadence, fatigue (mean FSS=5.78 in our cohort, higher than controls), and RNLI scores, while subgroup analyses by stroke severity or duration might reveal tailored applications, ultimately informing policy for scalable, culturally sensitive rehabilitation programs in low-resource settings (20).

CONCLUSION

This cross-sectional study in District Sialkot, Pakistan, revealed cadence as the dominant determinant of functional mobility (TUG scores) in post-stroke survivors, with a strong negative correlation ($r=-0.956$, $p<0.001$) and significant predictive power ($\beta=-0.539$, $p<0.001$) in a regression model explaining 91.6% of variance, underscoring its potential as a scalable, modifiable target for rehabilitation in low-resource settings (21). These findings advocate for prioritizing cadence-focused interventions, such as metronome-paced walking or step-count goals, to enhance mobility and independence, offering a practical, low-cost strategy for clinicians in underserved regions like Sialkot to interrupt the gait-fatigue cycle and improve quality of life (22). Future research should explore longitudinal effects of cadence-targeted therapies and integrate objective gait sensors to refine rehabilitation protocols, ultimately informing policy to address mobility disparities in post-stroke care across South Asia (23).

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