



## Validity of the gait variability index for individuals after a stroke in a chronic stage of recovery

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### ABSTRACT

**Background:** Increased variability in spatiotemporal variables has been demonstrated in individuals after stroke. Gait Variability Index (GVI) has recently been proposed, potentially to be used as a standardized tool for quantifying gait impairment due to spatiotemporal variables. The experience with the GVI in patients after stroke is unknown.

**Research question:** The aim of this study was to investigate the validity of the GVI as an outcome measure of gait disturbance after stroke.

**Methods:** 50 individuals (mean age  $60.9 \pm 11.2$  years) after stroke at a chronic phase of recovery were included. The control group comprised 50 healthy subjects without gait disorders, matched for age and gender. Data on functional mobility and spatiotemporal gait parameters (BTS Smart system) was collected.

**Results:** The results showed lower mean GVI (mGVI) scores (mean  $78.53 \pm 6.12$ ), lower GVI for the affected leg (mean  $76.32 \pm 7.98$ ) and for the unaffected leg (mean  $80.74 \pm 4.68$ ) in the individuals after stroke compared to the healthy subjects (mean  $98.00 \pm 6.32$ ). This was significantly different from the control group mean for both mGVI, affected and unaffected leg -  $p < 0.001$ . The GVI for the affected leg and unaffected leg as well as the mGVI were significantly correlated with all clinical measures of functional mobility ( $0.7 \leq |R| < 0.9$ ,  $0.5 \leq |R| < 0.7$ ,  $p < 0.001$ ).

**Significance:** The validity of the GVI appears to be confirmed for individuals after stroke at a chronic stage of recovery. The GVI is lower in individuals after stroke compared to healthy controls. The GVI showed moderate to strong correlations with validated clinical measures of functional mobility. Application of the GVI in the clinical practice will significantly facilitate assessment of gait in individuals after stroke, in comparison to the necessity to interpret a large number of data from 3-dimensional gait analysis.

**Clinical trial registration:** Data are parts of the following clinical trial: ACTRN12617000436370 ([anzctr.org.au](http://anzctr.org.au))

### 1. Introduction

Gait in people with post-stroke hemiparesis is a combination of deviations and compensatory movements dictated by residual functions and due to this all patients must be examined and their unique gait patterns must be identified and documented [1]. Increased variability in spatiotemporal variables has been demonstrated in individuals after stroke [2–5]. Research shows that step variability is altered in patients with stroke compared to healthy subjects, reflecting hemiparetic walking performance. Specifically, the differences between the affected and the unaffected leg in swing time and pre-swing variability,

increased step length and stride time variability can be used as quantifiable markers of impaired gait post-stroke [2]. Asymmetrical step lengths after stroke are highly variable among subjects and may be indicative of underlying deficits and compensatory mechanisms used [3]. It has also been pointed out that spatiotemporal gait variability estimators demonstrate a similar sensitivity to concurrent cognitive tasks and improvements in walking ability occurring during recovery from stroke [4]. Moreover, research suggests that cerebellar stroke typically results in increased variability in both step time and step length [5].

To characterize gait disturbances in individuals after stroke, the

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profile of post-stroke gait has been studied using numerous methods, including the assessment of the spatiotemporal parameters [1]. 3-dimensional gait analysis (3DGA) provides objective data related to spatiotemporal parameters [6]. However, 3DGA produces a large amount of complex information, frequently difficult to interpret, therefore a simplification of the numerous data and their presentation as a single parameter reflecting changes in gait pattern after stroke would be valuable in the clinical practice. Gait Variability Index (GVI) is calculated based on nine spatiotemporal gait parameters obtained from 3DGA [7]. Relevant information regarding gait changes may be represented by this index, being the only one parameter, and as a result extensive interpretation of multiple data becomes unnecessary. The GVI has recently been proposed, potentially to be used as a standardized tool for quantifying gait impairment due to spatiotemporal variables [7]. Once the GVI is calculated, it is possible to use a single numerical value representing a subject's gait and showing in what way it differs from the mean value corresponding to normal gait [8,9]. Gouelle et al. carried out an initial validation demonstrated by a decrease in the GVI in patients with Friedreich's Ataxia, suggesting that the GVI was linked to mobility function [7]. Balasubramanian et al. imply that the GVI is a valid assessment for gauging spatiotemporal gait variability in older adults, with a capacity to differentiate between high-functioning older adults and those with mild to moderate mobility deficits [8]. Conversely, Rennie et al. showed that validity of the GVI could not be confirmed for individuals with mild to moderate Parkinson's disease due to insufficient correspondence to validated tests for functional balance and mobility and its poor discriminatory ability [9]. The experience with the GVI in patients after stroke is unknown. A review of the related literature shows that currently there are no studies evaluating changes in the gait pattern of chronic hemiparetic subjects post-stroke based on the GVI. The aim of this study was to investigate the validity of the GVI as an outcome measure of gait disturbance after stroke.

## 2. Material and methods

### 2.1. Participants

50 individuals (32 males, 18 females; mean age  $60.9 \pm 11.2$  years) after stroke at a chronic phase of recovery (mean time from stroke 42 months; 8–120 months) were included based on the following criteria: single ischaemic stroke incident confirmed by computed tomography or magnetic resonance imaging, age 30–75 years, time from stroke at least 6 months, unilateral paresis, independent walking (walking speed  $> 0.4$  m/s), and Brunnström recovery stage 3–4. Participants were excluded if they had second or another stroke incident, cognitive function deficits impairing the ability to understand and follow instructions, unstable medical condition and orthopaedic, rheumatic and other neurological co-morbidities impairing ambulation. The recruitment procedure involved patients treated at the Rehabilitation Clinic in the Provincial Hospital No. 2 in Rzeszow. The control group comprised 50 healthy subjects without gait disorders, matched for age and gender (30 males and 20 females with an average age of  $60 \pm 10.9$  years). Gait data acquired from the healthy subjects were used to calculate the normal values of GVI.

Ethical approval was given by the local Bioethics Commission of the Medical Faculty. Experimental conditions met the requirements of the Declaration of Helsinki, and all participants gave their informed consent.

### 2.2. Procedures

The spatiotemporal gait parameters were obtained using a movement analysis tool - BTS Smart system (DX700, 6 cameras, maximum acquisition frequency 1000fps, Sensor Resolution 1.5Mpixel) manufactured by BTS Bioengineering (BTS Bioengineering, Milan, Italy). The

examinations were carried out at University of Rzeszow's Biomechanics Laboratory of the Physiotherapy Institute. The placement of the passive reference markers was in compliance with the system protocol (Helen Hayes (Davis) Marker Placement), i.e. on the sacrum, pelvis (anterior and posterior iliac spine), femur (lateral epicondyle, great trochanter and the lower one-third of the shank), fibula (lateral malleolus, lateral end of the condyle in the lower one-third of the shank) and foot (metatarsal head and heel) [10]. During the trial the subjects walked at a comfortable speed and could use aids, such as canes, elbow crutches and tripods. A minimum of 6 passages at a distance of 10 m were registered for each participant during the trial. Mean values of spatiotemporal parameters, based on complete records, were calculated using Tracker and Analyzer programs (BTS Bioengineering).

#### 2.2.1. GVI calculations

The following nine spatiotemporal parameters were used in calculating the GVI: step length (cm), stride length (cm), step time (s), stride time (s), swing time (s), stance time (s), single support time (s), double support time (s), and velocity (cm/s) as well as standard deviations (SD) of all the above rates. A total of 18 variables were taken into account for each leg. GVI values were computed in the Excel spreadsheet developed by Gouelle et al. [7]. The adopted mean score and SD of the reference population were 100 and 10, respectively. A  $GVI \geq 100$  corresponds to a similar level of variability as that observed in healthy subjects (neither too low nor too high). A difference of 10 points corresponds to a distance of one SD from the normal score, indicating a greater or lower variability than found in gait of healthy subjects [7]. As an example, a GVI of 70 represents gait variability deviating from normal gait by 3 standard deviations. Conversely, a score greater than 100 reflects gait variability which is closer to mean variability of normal gait than in an average member of the control group [9]. The mean GVI (mGVI) values were calculated as the average GDI scores of the left and right leg.

#### 2.2.2. Clinical measures of functional mobility

The following clinical measures of functional mobility were used: walking speed in a 10-meter walk test, number of steps performed by the affected leg in the walkway test, walking distance in a 2-minute walk test, self-reliant mobility using the Up and Go Test. During the trials assessing gait speed (m/s) over a distance of 10 m, the subjects walked at a self-selected speed matching their orthopaedic capacities [11]. The result was calculated as a mean from two trials. The 2-minute walk test (m) was conducted in a corridor where a distance of 30 m was marked with two lines [12]. Additional lines were marked every 5 m. The subjects walked for 2 min along the 30-metre distance between the two basic lines. During the trial, the subjects walked at a self-selected speed and were allowed to use their own orthopaedic aids. During the Up and Go Test, the subjects were instructed to get up from a chair with a standard-height backrest and to walk 3 m, turn round at a specified location, return to the chair and resume the sitting position unassisted [13]. During the task the subjects were allowed to choose their own walking speed and could use their orthopaedic aids.

#### 2.3. Statistical analyses

GVI distributions for the healthy subjects and the individuals after stroke were examined with descriptive statistics. Assessment of inter-group variability in the two populations was performed using Mann-Whitney U test (spatiotemporal gait parameters, GVI affected leg, GVI unaffected leg, mGVI for individuals after stroke and healthy subjects). Assessment of differences between GVI for the affected and unaffected leg was performed using Wilcoxon matched pairs test. Pearson's correlation coefficient was used to analyse the relationship between the GVI and the clinical measures of functional mobility. The strength of all the correlations were interpreted as:  $0.3 \leq |R| < 0.5$  low correlation;  $0.5 \leq |R| < 0.7$  moderate correlation;  $0.7 \leq |R| < 0.9$  strong correlation;  $0.9 \leq |R| < 1$  very strong correlation [14]. Significance level was set to

**Table 1**  
Clinical characteristics of mobility in individuals after stroke.

Clinical measures	Descriptive statistics							
	n	$\bar{x}$	Me	Min	Max	Q1	Q3	SD
10-meter walk test (m/s)	50	0.59	0.57	0.25	1.02	0.49	0.70	0.17
Number of steps	50	13.36	12.00	7.00	30.00	11.00	15.00	4.73
2-minute walk test (m)	50	72.28	7.75	25.10	141.00	46.50	89.90	28.46
“Up and Go” test (s)	50	17.55	15.73	8.36	40.14	12.14	22.41	7.46

n—number of subjects,  $\bar{x}$  – mean, Me – median, Min – minimal value, Max – maximal value, Q<sub>1</sub> – lower quartile, Q<sub>3</sub> – upper quartile, SD – standard deviation.

p < 0.05, mean difference and a confidence interval at 95% were used for the statistical comparisons. Data were analysed using Statistica 13.1 program (StatSoft, Poland).

### 3. Results

Clinical characteristics of mobility in individuals after stroke are shown in Table 1.

#### 3.1. Comparison of all the spatiotemporal variables between the individuals after stroke and the control group

The 18 spatiotemporal parameters investigated in individuals after stroke and the control group are presented in Table 2. It was shown that there were highly significant differences in 12 parameters for affected leg and 11 for unaffected leg in the individuals after stroke compared to the healthy subjects (p < 0.001). The smallest differences were seen in stride time SD (p = 0.039). In the case of step length, step length SD, stride length, stride time SD, and velocity, statistically higher values were recorded in the control group. On the other hand, the study group achieved higher scores in step time, stride time, swing time SD, stance time, single support time, double support time, and double support time SD.

**Table 2**  
Characteristics of spatiotemporal gait parameters in the individuals after stroke and the controls.

Variables	Control group			Study group affected leg			Z	p	Study group unaffected leg			Z	p
	$\bar{x}$	Me	SD	$\bar{x}$	Me	SD			$\bar{x}$	Me	SD		
Step Length (cm)	55.47	54.80	7.50	23.01	20.54	11.12	-8.39	0.000	26.76	26.59	10.62	-8.24	0.000
SD	1.86	1.80	0.67	1.04	1.00	0.73	-5.65	0.000	1.04	1.00	0.73	-5.65	0.000
Stride Length (cm)	125.11	124.33	18.36	58.97	53.17	23.97	-8.28	0.000	60.75	57.46	24.66	-8.20	0.000
SD	1.84	2.00	0.85	1.90	1.65	1.01	0.09	0.926	1.90	1.65	1.01	0.09	0.926
Step Time (s)	0.36	0.35	0.03	0.57	0.52	0.17	8.01	0.000	0.68	0.57	0.66	8.20	0.000
SD	0.05	0.02	0.08	0.03	0.02	0.03	1.22	0.223	0.03	0.02	0.03	1.22	0.223
Stride Time (s)	1.07	1.05	0.09	1.71	1.55	0.51	8.01	0.000	2.04	1.70	1.99	8.20	0.000
SD	0.02	0.02	0.01	0.02	0.02	0.01	-2.06	0.039	0.01	0.02	0.01	-2.04	0.036
Swing Time (s)	0.42	0.43	0.03	0.60	0.61	0.16	6.06	0.000	0.47	0.45	0.16	0.92	0.357
SD	0.02	0.01	0.03	0.02	0.02	0.01	4.20	0.000	0.02	0.02	0.03	2.58	0.010
Stance Time (s)	0.64	0.62	0.07	1.16	1.05	0.44	7.88	0.000	1.31	1.21	0.54	8.32	0.000
SD	0.03	0.02	0.05	0.02	0.02	0.03	1.79	0.073	0.02	0.02	0.03	0.20	0.844
Single Support Time (s)	0.53	0.52	0.05	0.96	0.84	0.44	6.79	0.000	1.12	1.03	0.54	7.68	0.000
SD	0.02	0.02	0.01	0.02	0.02	0.02	0.85	0.393	0.02	0.02	0.02	0.85	0.393
Double Support Time (s)	0.12	0.11	0.03	0.20	0.20	0.03	8.15	0.000	0.19	0.20	0.05	7.05	0.000
SD	0.01	0.01	0.02	0.03	0.04	0.01	6.63	0.000	0.02	0.02	0.01	5.39	0.000
Velocity (cm/s)	105.27	110.80	20.66	44.87	34.50	22.75	-7.98	0.000	47.75	37.00	23.22	-7.85	0.000
SD	1.14	0.80	0.65	0.90	0.75	0.61	-1.83	0.067	0.90	0.75	0.61	-1.83	0.067

$\bar{x}$  – mean, Me – median, SD – standard deviation, Z- score in U Mann-Whitney’s test, p – test probability values.

#### 3.2. GVI values for the individuals after stroke and the control group

The findings show lower mGVI scores (mean 78.53 ± 6.12), lower GVI for the affected leg (mean 76.32 ± 7.98) and for the unaffected leg (mean 80.74 ± 4.68) in the individuals after stroke compared to the healthy subjects (mean 98.00 ± 6.32) – Table 3. This is significantly different from the control group mean for both mGVI (mean difference: 19.47, 95% CI [16.96–21.98], p < 0.001), affected leg (mean difference: 21.68, 95% CI [18.71–24.64], p < 0.001), and unaffected leg (mean difference: 17.26, 95% CI [15.09–19.43], p < 0.001). A comparison of the GVI values for the affected and unaffected leg in individuals after stroke also showed statistically significant differences (mean difference: 4.42, 95% CI [3.1–5.74], p < 0.001). Lower GVI scores were recorded for the affected leg (mean 76.32 ± 7.98) compared to the unaffected leg (mean 80.74 ± 4.68).

#### 3.3. Relationship between the GVI and clinical measures of functional mobility

The GVI for the affected leg and unaffected leg as well as the mGVI were significantly correlated with all clinical measures of functional mobility (p < 0.001), the correlations with walking speed in a 10-meter walk test and walking distance in a 2-minute walk test being positive, and those with the number of steps and time needed for the performance of Up and Go Test being negative. Except for the walking distance in a 2-min walk test and GVI scores for the unaffected leg which were strongly related (R = 0.71, p < 0.001), all the correlations were moderate in strength (0.5 ≤ |R| < 0.7, p < 0.001). Relationships between GVI and all the clinical measures are shown in Table 4.

### 4. Discussion

The results obtained in the individuals after stroke seem to support the use of the GVI in this group of patients. Moreover, the GVI score seems to be a helpful tool which makes it possible to determine changes in spatiotemporal parameters in hemiplegic gait.

Rennie et al. [9] investigated construct validity of the GVI for individuals with Parkinson’s disease, and showed that the mean mGVI was 97.5 ± 11.7 and for the more affected side 94.5 ± 10.6. This was significantly different from the reported reference group mean of 100.3 ± 7.6 (according to Gouelle et al. [7]) for both mGVI (p = 0.04) and the more affected side (p < 0.001). The mean GVI was similar to

**Table 3**  
GVI values in the individuals after stroke versus the control group.

Variables	Study group					Control group					Z	p
	$\bar{x}$	Me	Min.	Max.	SD	$\bar{x}$	Me	Min	Max	SD		
mGVI	78.53	78.64	70.18	95.51	6.12	98.00	97.01	87.97	111.68	6.32	-8.40	< 0.001
GVI affected leg	76.32	78.62	65.09	93.99	7.98	98.00	97.01	87.97	111.68	6.32	-8.47	< 0.001
GVI unaffected leg	80.74	79.23	75.15	97.04	4.68	98.00	97.01	87.97	111.68	6.32	-8.30	< 0.001

$\bar{x}$  – mean, Me – median, Min – minimal value, Max – maximal value, SD – standard deviation, Z- score in U Mann-Whitney's test, p – test probability values, mGVI – mean Gait Variability Index.

**Table 4**  
Correlations between the GVI and the clinical measures of functional mobility.

Variables	GVI affected leg		GVI unaffected leg		mGVI	
	R	p	R	p	R	p
10-meter walk test (m/s)	0.61	< 0.001	0.64	< 0.001	0.61	< 0.001
Number of steps	-0.59	< 0.001	-0.66	< 0.001	-0.60	< 0.001
2-minute walk test (m)	0.65	< 0.001	0.71	< 0.001	0.68	< 0.001
“Up and Go” test (s)	-0.61	< 0.001	-0.69	< 0.001	-0.64	< 0.001

R – Spearman rank correlation coefficient, p – test probability values, mGVI – mean Gait Variability Index.

the previously reported values related to older adults, contrary to the increased gait variability consistently observed in Parkinson's disease, compared to healthy subjects. As a result, these authors pointed out that the GVI could not be effectively validated for patients with mild to moderate Parkinson's disease. Conversely, Balasubramanian et al. [8] argue that the GVI is a valid tool for measuring spatiotemporal gait variability in older adults, and it can effectively differentiate between high-functioning older subjects and those with mild to moderate mobility impairments. The authors showed that in older adults the GVI was significantly lower than in younger adults ( $91.92 \pm 8.75$  and  $100.79 \pm 7.99$ , respectively) [8].

Another issue investigated by the present study was the relationship between the GVI and the clinical measures of functional mobility. It has been shown that the GVI for the affected and unaffected leg was significantly correlated with the clinical measures of functional mobility ( $p < 0.001$ ). Similarly, Balasubramanian et al. [8] showed that the GVI is associated with some clinical measures of functional mobility. The researchers reported that the GVI demonstrated positive strong correlation with walking speed in older adults. The present findings also show a positive correlation of the GVI with walking speed, which reflects a better functional performance in those with a greater GVI; the strength of this correlation, however, was moderate for affected leg ( $R = 0.61$ ,  $p < 0.001$ ), unaffected leg ( $R = 0.64$ ,  $p < 0.001$ ) as well as mGVI ( $R = 0.61$ ,  $p < 0.001$ ). Gait velocity is a powerful indicator of function and prognosis after stroke [15]; moreover, it has been established that velocity is a key gait parameter in patients with hemiparesis post-stroke, and it can be used as an indicator of the quality of life and determinant of functional performance [15–19]. Given the above, the correlation between GVI scores and gait velocity further validates the GVI as an outcome measure for mobility function in individuals after stroke.

Assessment of individuals after stroke for walking speed in a 10-meter walk test is frequently accompanied with assessment of walking distance in a 2-, 6-, or 12-minute walk tests [20–24], the 2-minute walk test arguably being the most time-effective of the three. It seems to be the best tool for documenting patients' self-selected walking speed as it minimizes the fatigue effects. Additionally, the distance covered in 2 min also correlates well with the scores acquired during the longer 6- and 12-minute walk tests. [20]. The present study has demonstrated

that the GVI significantly and positively correlates with the 2-minute walk test, which reflects better functional performance in those with a greater GVI, like in the case of walking speed.

The GVI significantly and negatively correlated with the Up and Go Test, which is routinely used in assessing individuals after stroke [25]. This easy and quick examination includes motor tasks frequently occurring in daily life (standing up, walking, turning, sitting down) and is recommended for measuring basic mobility skills after stroke [25,26]. A moderate correlation was found between Up and Go Test and the GVI (mGVI:  $R = -0.64$ ,  $p < 0.001$ , GVI affected leg:  $R = -0.61$ ,  $p < 0.001$ , GVI unaffected leg:  $R = -0.69$ ,  $p < 0.001$ ). The trend in the relationships was consistent, with the GVI decreasing with poorer outcomes and longer time needed in the Up and Go Test. The study by Balasubramanian et al. [8] did not show statistically significant ( $p > 0.05$ ) relationships between the GVI and Up and Go Test in older adults. Nevertheless, there were trends indicative of a link between the GVI and Up and Go Test ( $R = -0.330$ ,  $p = 0.057$ ). According to these authors, the lack of statistical significance could be attributed to the small sample size of the sub-sets used in these analyses. On the other hand, Rennie et al. [9] showed statistically significant but low correlation between the Up and Go Test and the GVI (mGVI:  $R = 0.42$ ,  $p < 0.001$ , GVI most affected side:  $R = 0.42$ ,  $p < 0.001$ ).

Importantly, the strength of the present findings lies in the fact that the control group was created specifically for this study and the controls were matched for age and sex to the study group. Mean age in the control group was  $60 \pm 10.9$  years, so the subjects were likely to have certain deficits in spatiotemporal parameters, such as decreased gait speed, adequately to their age [27]. By contrast, in the study by Rennie et al. [9] the controls were not recruited as part of the study and they represented gait variability typically observed in mature adult populations, rather than in age matched older adults. Rennie et al. applied existing control GVI data made available by Gouelle et al. [7] Hence, the differences in the results reported by the two studies may result from the varied testing protocols applied.

Unquestionably 3D gait analysis provides the most comprehensive information regarding walking ability. Nevertheless, since a large amount of temporal and spatial parameters is used in this case, it is difficult to achieve overall understanding of the patient's gait. It seems that a single parameter, applied to express assessment, facilitates the entire process and may be useful in evaluating effects of gait re-education and in monitoring of changes in gait pattern over time. Indeed, GVI is exactly this kind of tool, and the current analysis has validated GVI as an outcome measure in individuals after a stroke in a chronic stage of recovery. Moreover, this study showed difference between healthy and stroke individuals in GVI which resulted correlated with clinical scales.

The study limitations are linked with the fact that the present findings are only applicable to gait variability measured in individuals at a chronic phase of recovery after stroke. Further research should also assess gait variability at an early phase of recovery post-stroke.

## 5. Conclusions

The validity of the GVI appears to be confirmed for individuals after

stroke at a chronic stage of recovery. The GVI is lower in individuals after stroke compared to healthy controls both in affected leg and unaffected leg as well as in mGVI. The GVI showed moderate to strong correlations with validated clinical measures of functional mobility. Application of the GVI in the clinical practice will significantly facilitate assessment of gait in individuals after stroke, in comparison to the necessity to interpret a large number of data from 3DGA. Further research should perform detailed analyses of clinimetric properties of the GVI in individuals at varied stages post-stroke and with varied levels of disability.

#### Conflict of interest statement

None of the authors have any financial or personal relationships or affiliations that inappropriately influence decisions, work or the content of the manuscript.

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