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The use of the Gait Variability Index for the evaluation of individuals after a stroke

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Purpose: The Gait Variability Index (GVI) summarizes overall gait quality, taking into account spatiotemporal parameters from a 3-dimensional gait analysis. However, there are no studies evaluating changes in gait patterns after stroke, based on the GVI. The study was designed to assess usefulness of the GVI for evaluation of gait pathology in subjects with stroke, compared to healthy individuals. *Methods:* Spatiotemporal gait parameters were examined in a group of 50 subjects at a chronic stage post-stroke and in 50 healthy controls. The GVI was calculated based on the 9 spatiotemporal data. *Results:* The findings show statistically significant differences between the values of the GVI for paretic and non-paretic limbs ($p < 0.001$). Higher values of the index were identified in the case of non-paretic limb: 80.74 vs. 76.32. The GVI scores were decreased for both paretic and non-paretic limbs, compared to the controls – $p < 0.001$. *Conclusions:* The GDI score seems to be a viable tool for quantifying changes in gait pattern during evaluation of subjects with chronic post-stroke hemiparesis. Further studies should be conducted to validate the use of GVI in the post-stroke population.

Key words: *stroke, gait analysis, Gait Variability Index, spatiotemporal parameters*

1. Introduction

Walking ability in individuals with stroke is frequently characterised by impaired spatiotemporal gait parameters. Post-stroke temporal gait asymmetry is found in such parameters such as stance time, swing time, step time and double support time. On the other hand, post-stroke spatial gait asymmetry involves step length and stride length [9], [15], [16]. This leads to considerable changes in the duration of the gait phases, step length and lower limbs loading, manifested by the non-paretic limb overloading. Such gait pattern asymmetry adversely affects postural stability as well as walking speed, consequently reducing gait efficiency and increasing energy expenditure [3], [14], [18]. At present computer-aided 3-dimensional gait analysis (3DGA) is commonly used as an objective quantitative gait assessment method, constituting a gold standard in this area. 3DGA is widely applied in examinations and as a tool for planning and managing gait re-education process [11], [12], [17]. However, because of the large number and complexity of data acquired during 3DGA, easy-to-use Gait Indexes have been introduced as a new way to quantify the magnitude of fluctuations in gait parameters [2], [4], [8], [10], [13], [21].

Some researchers believe that gait variability, understood as the fluctuation in spatiotemporal characteristics between steps, is a sensitive indicator of mobility deficits occurring with age and resulting from pathological processes [4]. The Gait Variability Index (GVI) is calculated from spatiotemporal gait parameters acquired through 3DGA. By computing the GVI, it is possible to apply a single numerical value reflecting the patient's gait and to show in what way it differs from the mean value representing normal gait [4], [8]. The GVI was originally introduced to improve objective quantification of gait variability [8]. Deficits in the spatiotemporal parameters may reflect

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in abnormal gait pattern characterized by asymmetry. According to Patterson et al., the most important spatiotemporal parameters reflecting gait symmetry after stroke include stance time, step length, swing time and double support time [15]. In addition to those mentioned above, the following parameters are also taken into account while calculating GVI: stride length, step time, stride time, single support time, velocity and standard deviations of each parameter [8]. It would be very hard to assess gait impairment after stroke taking into account all of the above factors, and interpretation of the results would be very difficult due to the large volume of data. If changes in gait pattern are represented by a single number, gait analysis is greatly facilitated and, consequently, management of gait rehabilitation process is considerably simplified [4], [20].

Review of literature suggests there are no studies evaluating gait pattern changes with the use of the GVI in subjects with chronic post-stroke hemiparesis. The only research reports related to the GVI focus on patients with Friedreich's Ataxia [8] and Parkinson's disease [19] as well as on older adults [4]. This fact provided a motivation for the present study and for investigating whether or not the GVI could be used as a single measure to identify gait pattern impairments after stroke. Therefore, the purpose of the study was to assess usefulness of GVI, based on spatiotemporal data set, for the evaluation of gait pathology in patients with chronic post-stroke hemiparesis, compared to healthy individuals.

2. Materials and methods

2.1. Participants

The study group comprised of 50 subjects post-stroke at a chronic phase of recovery (mean time post-stroke 42 months (range 8–120 months); 18 females, 32 males; mean age 60.9 ± 11.2 years; paretic limb 35 right, 15 left; Brunnström recovery stage 3–4; mean gait speed 0.65 ± 0.20 m/s). The control group comprised of 50 healthy subjects (HS) without gait disorders (30 males and 20 females with an average age of 60 ± 10.9 years; mean gait speed 1.3 ± 0.21 m/s). The study involved patients treated at the Rehabilitation Clinic in the Provincial Hospital No. 2 in Rzeszów. The following inclusion criteria were defined: single ischaemic stroke incident confirmed by computed tomography or magnetic resonance imaging, age 30–75 years, time post-stroke at least 6 months, unilateral paresis, independent locomotion (walking speed > 0.4 m/s**).** Exclusion criteria: second or another stroke incident, cognitive function deficits impairing the ability to understand and follow instructions, unstable medical condition and orthopaedic disorders of the lower limbs. The research protocol was approved by the local Bioethics Commission of the Medical Faculty (5/2/2017). The study was registered at the Australian New Zealand Clinical Trials Registry (ACTRN12617000436370). Experimental conditions met the requirements of the Declaration of Helsinki. All subjects gave their informed written consent to participate in the study.

2.2. Measurements

The spatiotemporal gait parameters were examined in the Biomechanics Laboratory of the Physiotherapy Institute of the University of Rzeszów. Three dimensional walk tests were performed with the use of the BTS Smart system from BTS Bioengineering (BTS Bioengineering, Milan, Italy). Passive reference markers were positioned in compliance with the internal protocol of the system (Helen Hayes (Davis) Marker Placement) on the sacrum, pelvis (anterior posterior iliac spine), femur (lateral epicondyle, great trochanter and in lower one-third of the shank), fibula (lateral malleolus, lateral condyle end in lower one-third of the shank), foot (metatarsal head and heel) [6]. The subjects were asked to walk at a comfortable speed and during the trials they were allowed to use auxiliary devices, such as canes, tripods and elbow crutches. During the test, a minimum of 6 passages were recorded at a distance of 10 meters for each participant. Tracker and Analyzer programs (BTS Bioengineering) were used to calculate mean values of spatiotemporal parameters based on complete records. The GVI was calculated based on the spatiotemporal data.

The GVI was determined based on the following nine spatiotemporal parameters: 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], velocity [cm/s] and standard deviations (SD) of each parameter, which resulted in the total of 18 parameters. In order to obtain GVI values, we used an Excel spreadsheet developed by Gouelle et al. [8] was used.

The control group comprised of 50 HS and its scores were used to determine the normal values of GVI (50 × 2 × 18 parameters).

For an individual α, the 18 parameters p_n were multiplied by their corresponding correlation coefficients c_n, subsequently, the total of the products was calculated following the formula:

$$s^{\alpha} = \Sigma_1^{18}(pn \cdot cn),$$

s^{HS} represented the mean total in the HS. The distance separating the parameters of a subject α and those of the HS ($d^{\alpha,\mathrm{HS}}$) was computed as follows:

$$d^{\alpha,\mathrm{HS}} = \| s^{\alpha} - s^{\mathrm{HS}} \|.$$

A raw index was obtained in accordance with the formula:

$$\mathrm{GVI}_{\mathrm{raw}}^{\alpha} = \ln(d^{\alpha,\mathrm{HS}}).$$

Next, the *z*-score was calculated, i.e., the number of SDs separating the raw score of a subject α from the raw score of the HS:

$$\mathrm{zGVI}_{\mathrm{raw}}^{\alpha} = \frac{\mathrm{GVI}_{\mathrm{raw}}^{\alpha} - \mathrm{Mean}(\mathrm{GVI}_{\mathrm{HS}}^{\mathrm{raw}})}{\mathrm{SD}(\mathrm{GVI}_{\mathrm{HS}}^{\mathrm{raw}})}.$$

Finally, the *z*-score was multiplied by 10 and subtracted from 100:

$$\mathrm{GVI}_{\mathrm{raw}}^{\alpha} = 100 - 10 \times \mathrm{zGVI}_{\mathrm{raw}}^{\alpha}.$$

By definition, the mean score and SD of the reference population are 100 and 10, respectively. When GVI ≥ 100, the subject's gait resembles walking skills of a healthy individual. Each decrease in the index by 10 points below 100, means one standard deviation from the mean for normal gait [8].

2.3. Statistical analysis

The statistical analysis of the results was carried out by means of the programme Statistica ver. 13.1 (StatSoft, Poland). The normality of the distribution of the features examined was evaluated using the Shapiro–Wilk test. Descriptive statistics were calculated for all numerical variables. Assessment of inter-group variability in the two populations was performed using Wilcoxon matched pairs test. Comparison of GVI scores for paretic and non-paretic limbs was conducted for the study group. On the other hand, the study group and the controls were compared for their GVI scores for the right and left limbs. Correlations between the GVI (paretic/non-paretic limbs and divided into: right/left limb) and the subjects' age were examined using the Spearman Rank Order Correlation Coefficient. Mean difference and a confidence interval at 95% were used for statistical comparisons. A graphical description of the results was made in a form of scatter plot and box-plot. The findings also comprise the results of analyses which tested the significance of correlation coefficient (p). Statistical significance was assumed at $p < 0.05$.

3. Results

Analysis of GVI scores in the study group showed statistically significant differences in the GVI for the paretic and non-paretic limbs (score in Wilcoxon matched pairs test: Z = 5.97; mean difference: 4.45, 95% CI [3.14 – 5.76]; $p < 0.001$). Higher values of the parameter were identified in the non-paretic limb: mean 80.74 ± 4.68 vs. paretic limb: mean 76.32 ± 7.98 (Fig. 1).

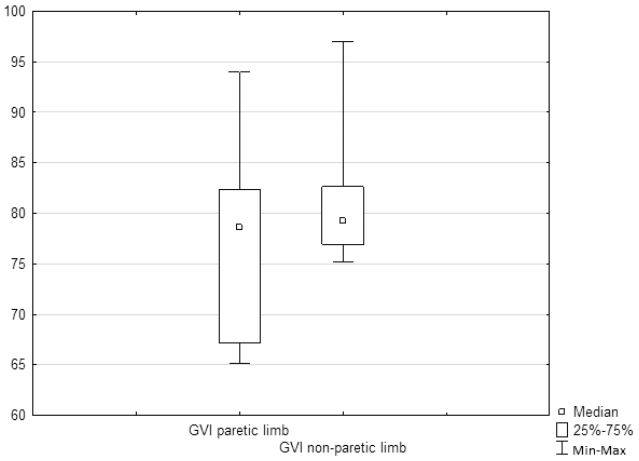

Fig. 1. The value of the GVI for the paretic and non-paretic limbs in the study group

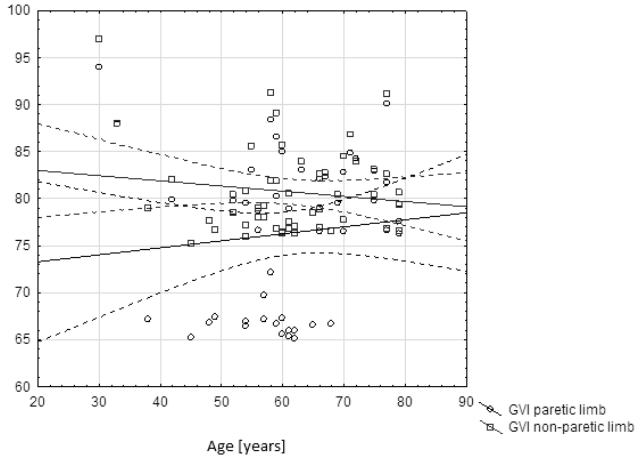

Fig. 2. The correlations between the GVI paretic/non-paretic limbs and age

Table 1. GVI paretic limb and sex

GVI paretic limb		Descriptive statistics								Significance (p)	
		n	$\bar{x}$	Me	Min	Max	Q1	Q3	SD	U	p
Overall	Females	18	75.52	78.06	65.34	83.01	67.40	79.77	6.25	258.0	0.555
	Males	32	76.77	78.89	65.09	93.99	66.84	83.62	8.87		
Paretic right limb	Females	13	76.22	78.90	65.34	83.01	72.11	80.26	6.40	113.0	0.319
	Males	22	78.66	79.82	65.09	93.99	66.65	84.81	8.96		
Paretic left limb	Females	5	73.71	76.44	66.81	79.37	67.40	78.53	6.13	21.0	0.678
	Males	10	72.62	68.46	65.20	84.93	66.96	79.08	7.48		

n – number of subjects, $\bar{x}$ – mean, Me – median, Min – minimal value, Max – maximal value, Q1 – lower quartile, Q3 – upper quartile, SD – standard deviation, U – score in Wilcoxon matched pairs test, p – test probability values.

Table 2. GVI non-paretic limb and sex

GVI non-paretic limb		Descriptive statistics								Significance (p)	
		n	$\bar{x}$	Me	Min	Max	Q1	Q3	SD	U	p
Overall	Females	18	79.78	79.85	76.66	85.55	77.53	81.80	2.51	280.0	0.881
	Males	32	81.28	79.01	75.15	97.04	76.79	84.19	5.51		
Non-paretic right limb	Females	13	80.40	80.39	76.74	85.55	78.94	81.83	2.59	124.0	0.533
	Males	22	82.51	81.33	76.20	97.04	77.14	86.79	5.87		
Non-paretic left limb	Females	5	78.18	77.68	76.66	80.60	77.53	78.43	1.49	21.0	0.678
	Males	10	78.59	77.23	75.15	85.75	76.41	79.14	3.55		

n – number of subjects, $\bar{x}$ – mean, Me – median, Min – minimal value, Max – maximal value, Q1 – lower quartile, Q3 – upper quartile, SD – standard deviation, U – score in Wilcoxon matched pairs test, p – test probability values.

The analysis of correlations between the GVI scores for paretic and non-paretic limbs and the age did not show statistically significant differences between the GVI for the paretic limb (R = 0.14; p = 0.319), non-paretic limb (R = 0.07; p = 0.626), paretic right limb (R = 0.04; p = 0.806), left limb (R = 0.50; p = 0.057), non-paretic right limb (R = –0.03; p = 0.880), left limb (R = 0.30; p = 0.276), and the age (Fig. 2).

A comparison of GVI scores between the females and males showed that there were no statistically significant differences between the GVI for the paretic limb – overall (p = 0.555) and related to the specific limbs: paretic right limb (p = 0.319), paretic left limb (p = 0.678) – Table 1. Similarly, there were not statistically significant differences in the values of the GVI for the non-paretic limb – overall (p = 0.881) and related to the specific limbs: non-paretic right limb (p = 0.533), non-paretic left limb (p = 0.678)– Table 2.

A comparison of GVI scores between the study group and the controls, related to the specific limbs, showed statistically significant differences between the GVI for the paretic right limb and control right limb (score in Wilcoxon matched pairs test: Z = 7.00; mean difference: 20.59, 95% CI [19.68 – 21.49]; p < 0.001). Higher values of the parameter were identified in the case of the control right limb: mean 98.34 ± 6.83 vs. paretic right limb: mean 77.75 ± 8.09 (Fig. 3). It was also shown that there were statistically significant differences in the value of the GVI for the paretic left limb and control left limb (mean difference: 23.32, 95% CI (21.85–24.78); p < 0.001). Higher values of the parameter were identified in the case of the control left limb: mean 96.30 ± 7.19 vs. paretic left limb: mean 72.99 ± 6.85 (Fig. 4).

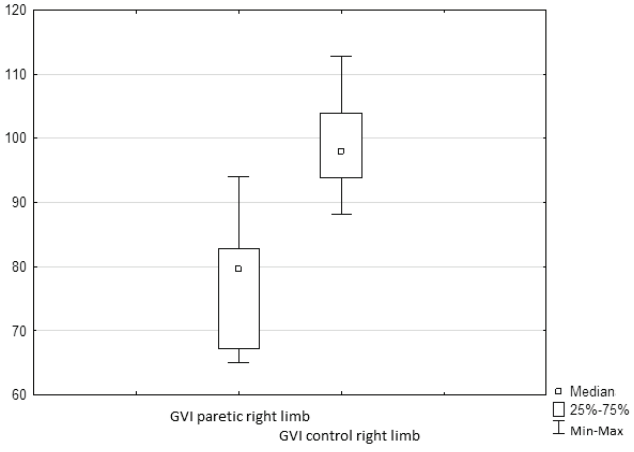

Fig. 3. The value of the GVI for the paretic right limb and the control right limb

Analysis of the GVI scores for the non-paretic and control limbs showed statistically significant differences between the GVI values for the non-paretic

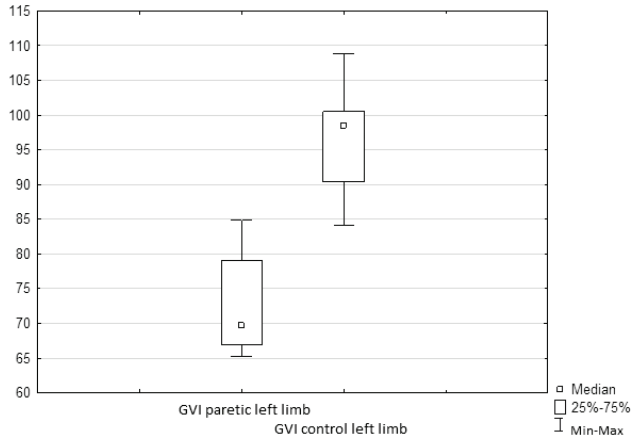

Fig. 4. The value of the GVI for the paretic left limb and the control left limb

ables comprehensive assessment of changes in gait pattern after stroke as well as classification of gait as normal or pathological, compared to healthy individuals. Moreover, the current study is the first to characterize the GVI of patients post-stroke.

The present findings show statistically significant differences between the GVI scores for paretic and non-paretic limbs ($p < 0.001$). Higher values of the index were identified in the case of the non-paretic limb. A comparison of GVI scores between the study group and the controls, related to the specific limbs, also showed statistically significant differences ($p < 0.001$). The GVI score was lower both for the paretic and non-paretic limbs, compared to the control group.

Table 3. Significance assessment of the differences between the value of the GVI for the non-paretic right/left limbs and the control right/left limbs

GVI	Descriptive statistics							
	n	$\bar{x}$	Me	Min	Max	Q1	Q3	SD
GVI non-paretic right limb	35	81.72	80.50	76.20	97.04	77.48	83.94	4.97
GVI control right limb	35	98.34	98.01	88.09	112.74	93.79	103.92	6.83
Significance (p)	$Z = -6.78$ $p < 0.001$							
GVI non-paretic left limb	15	78.46	77.68	75.15	85.75	76.45	79.14	2.96
GVI control left limb	15	96.30	98.44	84.05	108.82	90.38	100.52	7.19
Significance (p)	$Z = -4.56$ $p < 0.001$							

n – number of subjects, $\bar{x}$ – mean, Me – median, Min – minimal value, Max – maximal value, Q1 – lower quartile, Q3 – upper quartile, SD – standard deviation, Z – score in Wilcoxon matched pairs test, p – test probability values.

right limb and control right limb (mean difference: 16.62, 95% CI [15.75 – 17.48]; $p < 0.001$). Higher values of the parameter were shown in the case of the control right limb 98.34 vs. 81.72 (Table 3). Similarly, there were statistically significant differences in the values of the GVI for the non-paretic left limb and the control left limb (mean difference: 17.84, 95% CI (15.20–20.49]; $p < 0.001$). Higher values of the parameters were identified in the case of the control left limb 96.30 vs. 78.46 (Table 3).

4. Discussion

Gait is one of the functions which are most frequently assessed for signs of neurological disorders after stroke [5], [7]. The GVI allows to quantify changes in gait pattern, treated as a single parameter, and requiring less complex interpretation than a set of data presented separately [8]. The present study was designed to investigate whether or not the GVI en-

Similar research focusing on subjects with post-stroke hemiparesis was conducted by Alcantara et al., yet it assessed kinematic gait parameters with the Gait Deviation Index (GDI) [1]. The study was carried out on a group of 30 patients at a chronic phase following unilateral, ischemic or haemorrhagic stroke (time post-stroke > 6 months). The control group consisted of 87 healthy subjects. The authors showed that the GDI scores were decreased for both paretic (64.69 ± 16.29) and non-paretic limbs (64.88 ± 15.00), compared to the controls (101.01 ± 10.12; $p < 0.001$). On the other hand, no significant differences were reported in GDI values between paretic and non-paretic limbs ($p > 0.99$). According to the authors, the limitations of the study were linked with the facts that the controls and the study group were not matched for gender and age, and the study group was not homogeneous as far as the type of stroke was concerned. Despite that the researchers argue that the GDI may be a sensitive parameter to identify gait pattern changes in subjects with chronic post-stroke hemiparesis.

In the present study, the healthy controls were matched for gender and age to the study participants post-stroke. Furthermore, the study group consisted of patients with ischemic stroke only. GVI scores for the healthy subjects were 98.34 ± 6.83 – right limb; 96.30 ± 7.19 – left limb and were significantly reduced in the individuals after stroke (76.32 ± 7.98 – paretic limb; 80.74 ± 4.68 – non-paretic limb).

Similar findings were reported by Gouelle et al. [8] who examined variability of spatiotemporal gait parameters with the use of GVI, yet their study focused on a different disorder and involved 31 subjects diagnosed with Friedreich's ataxia. Normal values of the GVI were calculated based on the results obtained by the control group consisting of 123 healthy subjects. The authors showed that GVI score for the healthy subjects was 100.3 ± 8.6 and was significantly reduced in patients with Friedreich's ataxia (70.4 ± 7.9). They also suggest that the results obtained in patients with Friedreich's ataxia seem to support the use of the GVI. Balasubramanian et al. [4] also investigated the use of the GVI, yet in this study the index was applied to assess gait pattern in an older adult population. The study involved 105 younger adults (age < 65) and 81 older adults (age ≥ 65). The authors reported that the GVI of older adults (91.92 ± 8.75) was significantly lower compared to the GVI of younger adults (100.79 ± 7.99). Within the group of older adults, the GVI was significantly lower (p < 0.0001) in subjects with mobility deficits (84.35 ± 9.03), compared to those with high mobility function (96.35 ± 8.86). According to these researchers, the GVI is a reliable tool for assessing spatiotemporal gait variability in older subjects, and it can effectively differentiate between high-functioning individuals and those with mild to moderate deficits in mobility. Rennie et al., on the other hand, conducted a study designed to explore mean GVI score and investigate construct validity of the index for individuals with mild to moderate Parkinson's disease [19]. The study was conducted on a group of 100 subjects (57 males) with idiopathic Parkinson's disease, aged ≥ 60 years. The results showed a mean overall GVI – 97.5 ± 11.7 and mean GVI for the most affected side – 94.5 ± 10.6. Mean GVI scores corresponded with the values reported earlier for older adults, which was in conflict with the widely established increase in gait variability in patients with Parkinson's disease compared to healthy subjects representing the same age group.

The findings of the present study add to our understanding of the variability in spatiotemporal gait characteristics in subjects with chronic post-stroke hemiparesis. Furthermore, the GVI score seems to be a helpful tool to quantify the changes in gait pattern during evaluation of chronic hemiparetic post-stroke subjects.

5. Conclusions

A decrease in the GVI score identified by the present study during gait analysis in patients at a chronic phase post-stroke, in comparison to healthy individuals, suggests that the index is a useful tool that enables the determination of changes in spatiotemporal parameters in hemiplegic gait. Further studies should be conducted to validate the use of the GVI in post-stroke populations. It also seems sensitivity of this index to changes in gait, following gait rehabilitation programs, should also be examined.

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