Can an observational gait scale produce a result consistent with 3-dimensional gait analysis?: a prospective observational study

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Abstract

Background: To investigate whether a simple observational tool may be a substitute to the time-consuming and costly 3-dimensional (3D) analysis, the study applied the Wisconsin Gait Scale (WGS), enabling assessment which is highly consistent with 3D gait parameters in individuals after stroke. The aim of this study was to determine whether, and to what extent, observational information obtained from WGS-based assessment can be applied to predict results of 3D gait analysis for selected symmetry indicators related to spatiotemporal and kinematic gait parameters. Methods: Fifty individuals at a chronic stage of recovery post-stroke were enrolled in the study. The spatiotemporal and kinematic gait parameters were measured using a movement analysis system. The Symmetry Index (SI), was calculated for selected gait parameters. The study participants' gait was evaluated by means of the WGS. The regression analysis was applied to investigate whether a simple observational tool may be a substitute to the time-consuming and costly 3D analysis. Results: It was shown that 3D SI, related to Stance Time [s], Stance %, Hip and Knee Flexion-Extension Range of Motion may be described with fairly high accuracy using item questions of the WGS ($0.7 \leq |R| < 0.9$; $0.9 \leq |R| < 1$). This initial finding provided a rationale for the assumption that a combination of selected WGS items may enable even more accurate estimation of SI for 3D parameters. It was shown that Stance % SI, Hip and Knee Flexion-Extension Range of Motion SI can most effectively be substituted by WGS-based estimations – coefficient of determination exceeding 80%. Conclusions: It was shown that information acquired based on the WGS can be used to obtain results comparable to those achieved in 3D assessment for selected SIs of spatiotemporal and kinematic gait parameters. The study confirms that observation of gait using the WGS, which is an ordinal scale, is consistent with the main aims of 3D assessment, therefore the scale can be recommended as a substitute tool in gait assessment. Trial registration: ANZCTR, ACTRN12617000436370. Registered 24 March 2017, https://www.anzctr.org.au/Trial/Registration/TrialReview.aspx?id=372248.

Background

Despite the fact that 3-dimensional gait analysis (3DGA) is the most accurate method enabling gait assessment, and recognised as a key outcome measure by gait researchers and healthcare professionals [1], for many facilities it is inaccessible due to the considerable costs involved. Consequently, observational gait analysis is more commonly used in practice, being a fast, simple and inexpensive method [2]. To investigate whether a simple observational tool may be a substitute to the time-consuming and costly 3-dimensional (3D) analysis, the study applied the Wisconsin Gait Scale (WGS) whose effectiveness was shown in previous studies [3,4].

The WGS consists of four subscales, and assesses 14 observable gait parameters occurring during the consecutive gait phases, i.e. stance phase, toe off, swing phase and heel strike of the affected leg [5]. The WGS has been shown to be accurate and reliable, therefore it can effectively be used to evaluate progress in gait rehabilitation after stroke [5-8]. The specific items of the scale focus on positions assumed by parts of the lower extremities and joints during the gait cycle, taking into account both the affected and the unaffected leg, which are then compared. As a result, the walking pattern is described mainly in terms of gait symmetry [5,8]. Therefore, in the current study the authors decided to apply Symmetry Indexes (SI), calculated based on 3D gait parameters, and to compare the results of equipment-based 3D assessment to those obtained using observational gait analysis performed using the subjective WGS.

Since it reflects similarities in spatiotemporal and kinematic parameters of the right and left lower limb, symmetry is a significant measure of gait assessment, and can more effectively describe post-stroke gait mechanisms, compared to conventional methods. Quality of gait, reflected by symmetry in step length and duration of gait phases, tends to change towards greater asymmetry at later stages post stroke [9-11]. Additionally, Patterson et al. [12] argue that stance time, step length and swing time are the most important spatiotemporal parameters of gait symmetry post-stroke. On the other hand, Boudarham et al. [13] reported that predictors of walking performance in hemiplegic patients include hip impairment and inadequate knee function, affecting kinematic gait parameters. The WGS enables observational assessment of gait symmetry for such factors as stance time (temporal symmetry), step length (spatial symmetry), hip and knee range of motion (kinematic symmetry) [5,8].

Research has shown correlations between 3D gait parameters and WGS-based assessment in individuals after stroke, both in the total score and in the specific items of the WGS [3,4]. The aim of this study was to determine whether, and to what extent, observational information obtained from WGS-based assessment can be applied to predict results of 3D gait analysis for selected symmetry indicators related to spatiotemporal and kinematic gait parameters.

Methods

Participants

The study included 50 patients at a chronic period after stroke (18 females, 32 males); mean age 60.9 ± 11.2 years (range 30-75); mean time from stroke 42 months (range 8-120); 15 patients with right hemisphere lesions, 35 patients with left hemisphere lesions. Inclusion criteria were: ischaemic stroke, time from stroke at least 6 months, independent walking (use of a cane, crutches or AFO orthosis was permitted), Brunnström recovery stage 3–4. Stroke was confirmed by computed tomography or magnetic resonance imaging. Exclusion criteria were: unstable haemodynamic state, peripheral vascular disease, cognitive impairment (Mini Mental Scale < 20) and mobility deficits significantly limiting and disrupting the patients’ ability to walk. Table 1 (in the Supplementary Files) describes the laboratory characteristics of study participants’ gait.

Study protocol

This prospective observational study was conducted among patients treated at Rehabilitation Clinic of Provincial Hospital No. 2 in Rzeszow, Poland. All qualified patients were fully informed about the procedure and signed informed consent to participate in the study. The research protocol was approved by the local Bioethics Commission of the Medical Faculty (5/2/2017) and the study was registered at the Australian New Zealand Clinical Trials Registry (ACTRN12617000436370).

Outcome measures

Primary outcome measure: spatiotemporal and kinematic parameters of gait. The patients' walking abilities were assessed at the Laboratory of Biomechanics of the Institute of Physiotherapy, University of Rzeszów. A 3-dimensional gait analysis was carried out using the SMART system (6 cameras, 120 Hz), manufactured by BTS Bioengineering (BTS Bioengineering, Milan, Italy). The internal protocol of the system (Helen Hayes (Davis) Marker Placement) was applied in selecting locations for reference markers; these were placed 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) [14]. The patients were asked to walk at a comfortable self-selected speed and were allowed to use auxiliary equipment, such as canes and elbow crutches, during the examination. During one trial, six passes of the patient were recorded. At the next stage spatiotemporal and kinematic parameters were calculated with the use of Tracker and Analyzer programs (BTS Bioengineering), averaging the results to a single session. The analysis took into account: 1) spatiotemporal parameters including stance time [s], stance phase (% of gait cycle), step length [m], stride length [m] of the paretic and of the non-paretic limb; 2) kinematic parameters including hip flexion/extension range of motion (Hip FE ROM) and knee flexion/extension range of motion (Knee FE ROM) of the paretic and of the non-paretic limb.

The video recording and 3D recording were carried out concurrently. Positioning of the two video cameras (BTS Vixta, BTS Bioengineering Corp.), working in synchronicity, was selected in such a way as to obtain images in the frontal and the sagittal plane. The walking path was 10 metres long. One camera was set in line with the direction of the gait in the frontal plane, the other camera, recording sagittal plane view, was positioned halfway along the walking path, two metres away from the path. The cameras were programmed to allow visualization of three walking trials examining the paretic and the non-paretic sides for a total of six ambulation trials. The subjects were asked to walk the specified distance at a self-selected (comfortable) speed, with the support of orthopaedic aids if used on a regular basis.

Secondary outcomes: The recordings and WGS-based gait assessment were reviewed and interpreted by a physical therapist with over 10 years of experience in working with patients post-stroke, and with expertise in using the WGS and interpreting the scores. The WGS allows to assess 14 observable gait parameters (as described in the Introduction above). The total score, in the range of 13.35 - 42 points, is calculated for all the items. The points assigned to items 2–10 and 12-14 are added up. Responses to items 1 and 11 are weighted by 3/5 and 3/4, respectively and then the points are added to the total score.

Higher scores correspond to poorer overall walking performance and more visible gait deviations [5.8]. Good intra- and inter-rater reliability of the WGS was demonstrated by a number of studies [6,8,15-17].

Data analysis

The analyses took into account six gait symmetry indexes calculated based on 3D assessment involving 50 study participants. Measurement of gait symmetry applied the most commonly used method – absolute index proposed by Robinson [18], which is calculated as a quotient of the absolute difference between the measures for both legs and the mean of these measures, multiplied by 100. The absolute value of the difference between the affected and the unaffected side was taken into account because gait defects are reflected by the disparity between the results identified for both legs, regardless the fact whether higher result is found for the right or the left leg. Given the method applied in determining the symmetry index (it can only assume positive values), we can expect that its distribution will be concentrated around values approaching 0. Zero value of the above index reflects perfect symmetry [18]. SI was calculated from the formula:

$$SI = 2(xn - xi)/(xn + xi) * 100$$

where: xn – the value of the variable obtained from the non-paretic limb, xi – the value of the corresponding variable obtained from the paretic limb [18].

The results of measurements obtained in 3D assessment for the non-paretic and paretic limb as well as the specific SIs were presented in the form of descriptive statistics and histograms. Analysis of the correlations between 3D symmetry indexes and the specific components of as well as the total score in WGS-based assessment is shown in the form of a correlation matrix presenting values of Spearman's rank correlation coefficients. The strength of all the correlations were interpreted as: 0.3£|R|<0.5 low correlation; 0.5£|R|<0.7 moderate correlation; 0.7£|R|<0.9 strong correlation; 0.9£|R|<1 very strong correlation [19].

At the next stage, regression analysis was applied to investigate whether a simple observational tool may be a substitute to the time-consuming and costly 3D analysis. Symmetry indexes based on 3D assessment of the relevant parameters were adopted as dependent variables for the specific models, while scores in items 1-14 of the WGS were applied as independent variables. Subsequently stepwise regression with forward selection was applied to find a model combining two desired characteristics: it would only contain statistically significant factors and would most successfully describe variability of the indexes. Determined based on such calculations, a regression model for each 3D symmetry index allows to estimate its value using selected WGS scores [20].

Statistical significance was assumed to be p<0.05. Statistical analyses were conducted with the use of Statistica 10.0 program (StatSoft, Poland).

Results

Gait Symmetry Indexes

Symmetry indexes were determined for the six gait parameters taken into account in the study (Table 2, Figure 1). Notably, there are clearly visible differences in median values for most symmetry indexes as well as very high maxima, which reflects the fact that for majority of the subjects SIs assume low or average values while in a few outstanding cases they are high or extremely high. It can be noticed that the SI is characterised by significant right-side asymmetry, which is shown by the skewness coefficient approaching or even exceeding 1– Table 2.

Analysis of the SI values identified for the specific parameters and the related graphic presentation suggest that considerably greater relative differences between the two limbs are found in the parameters of Step Length [s], Hip FE ROM and Knee FE ROM (Figure 1).

Correlations between symmetry indexes and scores in the WGS

It was shown that 3D symmetry indexes, related to Stance Time [s], Stance %, Hip FE ROM and Knee FE ROM may be described with fairly high accuracy using item questions of the WGS (the identified correlations were strong 0.7£|*R*|<0.9 or very strong 0.9£ |*R*|<1). The weakest correlation to WGS scores was found in the case of Step Length [m] SI (0.3£|R|<0.5) - Table 3 (in the Supplementary Files). The subsequent stage involved construction of regression models.

Regression models describing 3D Symmetry Indexes using WGS scores

Table 4 (in the Supplementary Files) presents the determined regression models which can be used to estimate corresponding symmetry indexes based on selected components of the WGS. Feasibility of substituting symmetry indexes with estimations based on the WGS is rather high for such rates as Stance % SI, Hip FE ROM SI and Knee FE ROM SI. However, in the case of the remaining three symmetry indexes, the values determined using appropriate equations did not reflect the distribution of 3D measurements as effectively. The poorest results were found for Step Length [m] SI - the coefficient of determination at a level of approx. 24% shows that modelling of the index using WGS scores does not produce satisfying results.

Discussion

The present study has a practical dimension as it confirms that the WGS is a valuable gait assessment tool and in the circumstances when the use of costly objective methods is not feasible, the WGS may effectively be applied as a diagnostic instrument to perform evaluation of post-stroke gait pattern asymmetry.

Hsu et al. [21] demonstrated that individuals after a stroke frequently present asymmetric gait patterns, in terms of both temporal and spatial parameters. Patterson et al. [22] indicated that quality of gait, as measured by spatial and temporal symmetry, appears to deteriorate at a later period following stroke. Bensoussan et al. [23], Balaban and Tok [24] reported that asymmetry in hemiplegic gait also applies to kinematic parameters. Gait pattern asymmetry may contribute to postural instability, musculoskeletal disorders as well as ineffective gait leading to greater energy expenditure [11,25,26]. The present findings provide evidence for gait pattern asymmetry observed in individuals who have experienced a stroke and are in a chronic stage of recovery. Analysis of SI values related to the specific parameter showed that considerably greater relative differences between the two limbs were found in Step Length [s], Hip FE ROM and Knee FE ROM. This suggests that spatiotemporal and kinematic gait pattern asymmetry in individuals after stroke is a serious problem. Therefore, researchers continue to look for tools enabling effective observational gait pattern assessment after stroke [7].

In order to answer the question formulated in the purpose of the study, and determine whether, and to what extent, observational information obtained from WGS-based assessment can be applied to predict results of 3D gait analysis for selected symmetry indicators related to spatiotemporal and kinematic gait parameters, the current analyses were designed to examine correlations of 3D symmetry indexes and the specific items of (as well as the total score in) the WGS. It was shown that 3D symmetry indexes, related to Stance Time [s], Stance %, Hip FE ROM and Knee FE ROM may be described with fairly high accuracy using item questions of the WGS (0.7£|*R*|<0.9; 0.9£ |*R*|<1). This initial finding provided a rationale for the assumption that a combination of selected WGS items may enable even more accurate estimation of symmetry indexes for 3D parameters. Therefore, the next stage involved building regression models, where gait symmetry indexes for selected 3D parameters were used as dependent variables, and specific components of WGS (items 1-14) were applied as independent variables. Given the fact that values of dependent variable do not have to be significantly related to all independent variables applied in a regression model, the analyses were designed to find an optimum model which would only contain statistically significant factors and would most effectively describe variability of the dependent characteristic. A formula determined as a result of this procedure allows to estimate a 3D symmetry index based on WGS scores. It was shown that Stance % SI, Hip FE ROM SI and Knee FE ROM SI can most effectively be substituted by WGS based estimations – coefficient of determination exceeding 80%. In the case of Stance Time [s] SI and Stride Length [m] SI, the WGS values determined using appropriate equations did not reflect the distribution of 3D measurements as effectively. The least satisfying results were found in the case of Step Length [m] SI – coefficient of determination at a level of approx. 24%. We believe that the poor result related to Step Length may be linked with the fact that video recording and processing were carried out only at a basic level.

Our study provides evidence for effectiveness of the observational gait analysis based on the WGS, which also enables comprehensive objective assessment of both spatiotemporal and kinematic parameters asymmetry. In situations when equipment-based gait assessment systems are not available, the regression models described here may be helpful for physicians and physiotherapists, enabling fairly accurate estimation of selected 3D symmetry indexes from WGS scores.

Conclusions

It was shown that information acquired based on the WGS can be used to obtain results comparable to those achieved in 3D assessment for selected SIs of spatiotemporal and kinematic gait parameters. 3D symmetry indexes, related to the parameters of Stance %, Hip FE ROM and Knee FE ROM can be fairly accurately described using item questions of WGS. In the case of Step Length [m] SI, the values of WGS determined using appropriate equations reflected the distribution of 3D measurements least effectively. The study confirms that observation of gait using the WGS, which is an ordinal scale, is consistent with the main aims of 3D assessment, therefore the scale can be recommended as a substitute tool in gait assessment.

Abbreviations

3D: 3-dimensional

WGS: Wisconsin Gait Scale

SI: Symmetry Index

3DGA: 3-dimensional gait analysis

Hip FE ROM: hip flexion/extension range of motion

Knee FE ROM: knee flexion/extension range of motion

Declarations

Ethics approval and consent to participate

The study was reviewed and approved by the Bioethics Commission of the Medical Faculty at University of Rzeszow (5/2/2017). According to the Declaration of Helsinki all participants were informed about the purpose and course of the study and about their rights to withdraw from the study. All of them gave their written, informed and voluntary consent for participation in the study.

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

AG: conceptualized and designed the study, ran the data collection, performed the analysis, drafted the initial manuscript, and approved the final manuscript as submitted. MD: carried out the analyses, drafted the initial manuscript, approved the final version as submitted. LP: supervised the project and reviewed and revised the manuscript making important intellectual contributions. JPB: coordinated and supervised data collection, critically reviewed the manuscript, and approved the final manuscript as submitted. All authors read and approved the final manuscript.

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Tables

Table 1. Characteristics of spatiotemporal and kinematic gait parameters in the study group

3-dimensional gait parameters		*s*	95% c.i.	Me	min	max
paretic limb						
Stance Time [s]	1.11	0.33	(1.01; 1.21)	1.02	0.62	1.86
Stance %	0.66	0.06	(0.64; 0.68)	0.67	0.54	0.79
Step Length [m]	0.24	0.11	(0.20; 0.27)	0.21	0.07	0.56
Stride Length [m]	0.60	0.24	(0.53; 0.67)	0.55	0.22	1.17
Hip FE ROM	27.4	8.2	(25.0; 29.8)	26.3	10.9	47.7
Knee FE ROM	28.8	11.8	(25.3; 32.2)	27.5	9.6	48.2
non-paretic limb						
Stance Time [s]	1.24	0.40	(1.12; 1.35)	1.19	0.69	2.10
Stance %	0.74	0.07	(0.72; 0.76)	0.74	0.58	0.89
Step Length [m]	0.27	0.11	(0.24; 0.30)	0.27	0.09	0.59
Stride Length [m]	0.62	0.24	(0.55; 0.69)	0.59	0.20	1.22
Hip FE ROM	33.5	5.7	(31.8; 35.1)	33.6	18.2	45.0
Knee FE ROM	40.2	7.6	(37.9; 42.4)	39.4	26.6	60.6

– mean, s – standard deviation, 95% c.i - 95 % confidence interval, Me-median, min – minimum value, max – maximum value, Hip FE ROM - hip flexion/extension range of motion, Knee FE ROM – knee flexion/extension range of motion

Table 2. SI for six gait parameters

SI for spatiotemporal and kinematic parameters		Me	*s*	min	max	*A*
Stance Time [s]	11.7	10.3	11.0	0.0	55.0	1.78
Stance %	11.9	10.6	10.1	0.3	46.9	1.33
Step Length [m]	32.8	23.6	28.9	0.8	107.5	0.85
Stride Length [m]	9.7	6.1	10.2	0.4	48.8	1.80
Hip FE ROM	25.1	16.3	22.0	0.3	84.9	1.23
Knee FE ROM	40.2	30.6	31.7	1.0	114.3	0.75

– mean, Me-median, s – standard deviation, min – minimum value, max – maximum value, *A* – skewness coefficient, Hip FE ROM - hip flexion/extension range of motion, Knee FE ROM – knee flexion/extension range of motion

Table 3. Correlations of 3D symmetry indexes to the specific components of and total score in the WGS

WGS (items)	Symmetry Indexes identified for 3D gait parameters					
	Stance Time [s]	**Stance %**	**Step Length [m]**	**Stride Length [m]**	**Hip FE ROM**	**Knee FE ROM**
STANCE PHASE AFFECTED LEG	0.12	0.22	0.00	0.13	0.15	**0.37****
1. use of hand held gait aid						
2. stance time on impaired side	**0.80*****	**0.91*****	0.14	**0.43****	**0.43****	**0.49*****
3. step length of unaffected side	0.23	**0.36***	0.10	**0.55*****	**0.57*****	**0.51*****
4. weight shift to the affected side	-0.16	-0.21	0.00	0.15	0.15	0.20
5. stance width	0.04	0.21	0.11	**0.25**	0.00	0.20
TOE OFF AFFECTED LEG	0.24	**0.38****	**0.36***	**0.32***	**0.38****	**0.47*****
6. guardedness (pause prior to advancing affected leg)						
7. hip extension of affected side	**0.44****	**0.50*****	0.03	**0.42****	**0.90*****	**0.63*****
SWING PHASE AFFECTED LEG	**0.31***	**0.26**	0.06	0.12	0.24	**0.50*****
8. external rotation during initial swing						
9. circumduction at mid swing	**0.36***	**0.40****	0.20	0.11	**0.25**	**0.48*****
10. hip hiking at mid swing	0.23	**0.36***	0.20	**0.36***	**0.74*****	**0.64*****
11. knee flexion from toe off to mid swing	**0.46****	**0.54*****	**0.37****	**0.47*****	**0.57*****	**0.94*****
12. toe clearance	0.23	**0.37****	**0.26**	0.18	**0.34***	**0.34***
13. pelvic rotation at terminal swing	0.13	**0.25**	**0.31***	0.19	**0.27**	**0.58*****
HEEL STRIKE AFFECTED LEG	**0.29***	**0.39****	**0.40****	**0.29***	**0.51*****	**0.60*****
14. initial foot contact						
15. Total score	**0.43****	**0.57*****	**0.29***	**0.43****	**0.65*****	**0.82*****

Hip FE ROM - hip flexion/extension range of motion, Knee FE ROM – knee flexion/extension range of motion, * - $p < 0.05$, ** - $p < 0.01$, *** - $p < 0.001$

Table 4. Presentation of the regression models describing 3D Symmetry Indexes with the use of WGS scores

Dependent variable	R^2	Regression model formula
Stance Time [s] SI	65.4%	$-8.84 + 12.65 \cdot WGS_2$
Stance % SI	82.7%	$-9.27 + 13.04 \cdot WGS_2$
Step Length [m] SI	23.7%	$13.58 - 12.58 \cdot WGS_7 + 22.05 \cdot WGS_{14}$
Stride Length [m] SI	46.4%	$-15.55 + 5.74 \cdot WGS_2 + 6.66 \cdot WGS_3 + 4.19 \cdot WGS_4$
Hip FE ROM SI	87.5%	$-20.22 + 22.10 \cdot WGS_7 - 4.37 \cdot WGS_9 + 8.62 \cdot WGS_{10}$
Knee FE ROM SI	88.6%	$-40.48+8.87 \cdot WGS_1 + 10.22 \cdot WGS_7 + 28.67 \cdot WGS_{11} - 6.01 \cdot WGS_{14}$

R^{2}- coefficient of determination, assuming values in the range from 0 to 100% (where 0% reflects a lack of any relationships between the independent variables and the values of the dependent variable, and 100% shows close association between them – the latter extremely rarely encountered in practice), Hip FE ROM - hip flexion/extension range of motion, Knee FE ROM – knee flexion/extension range of motion, $WGS_{2,14,4,10}$ – items number 2,14,4,10 in WGS

Figures

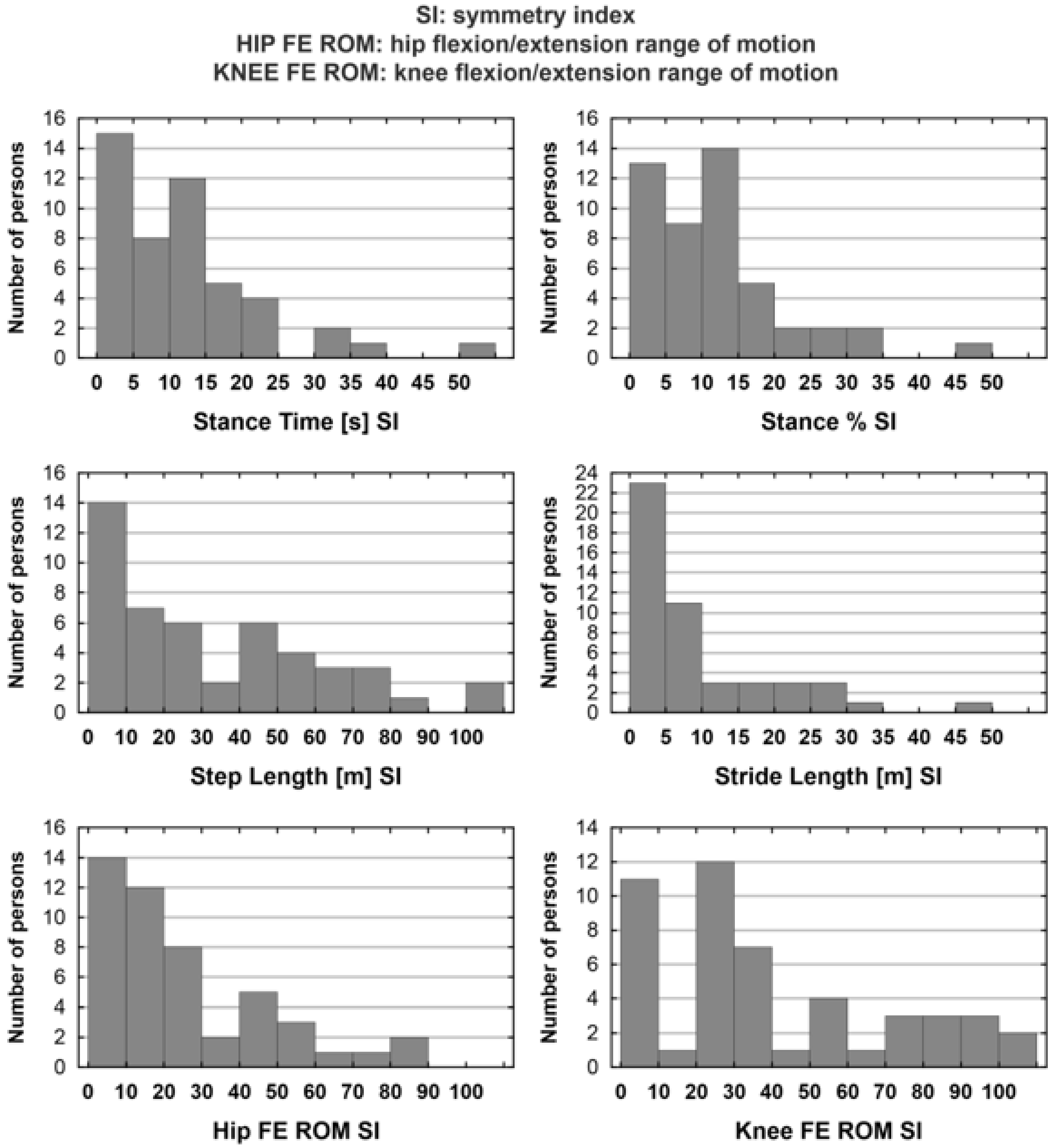

Figure 1

SI distribution for the specific gait parameters