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ASSOCIATIONS BETWEEN LOWER LIMB IMPAIRMENTS, LOCOMOTOR CAPACITIES AND KINEMATIC VARIABLES IN THE FRONTAL PLANE DURING WALKING IN ADULTS WITH CHRONIC STROKE

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Objective: **The objective was to examine the associations between impairments of the paretic limb, locomotor capacities and kinematic variables in the frontal plane during walking.**

Design: **Cross-sectional study.**

Subjects: **Ten community-dwelling individuals with chronic hemiparesis due to a cerebrovascular accident.**

Methods: **Frontal plane kinematics of the shoulders and pelvis were assessed during treadmill walking in a gait lab using a videographic system to obtain the lateral displacements and lateral accelerations. The percentages of time spent in single stance were determined with foot-switches. Index of asymmetry for the lateral accelerations and single stance were also calculated. Subject motor and functional characteristics were measured by standardised clinical tests.**

Results: **Correlation analyses with Pearson product-moment correlation or Spearman's rank correlation revealed that, except for spasticity, the clinical scores were moderately to strongly associated with frontal kinematics and the single stance. In the multiple step-wise regression analysis, only the pelvic lateral displacements and the index of asymmetry in single stance were explained at more than 70% by the clinical scores with the Time Up and Go test explaining a high proportion of the total variance of these frontal parameters.**

Conclusion: **Findings demonstrated associations between physical impairments, locomotor capacities and the frontal kinematics in adults with chronic stroke.**

Key words: gait, stroke, balance, symmetry, frontal kinematic.

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INTRODUCTION

Individuals who have sustained a stroke show an abnormal gait pattern in the frontal plane compared with healthy persons (1). They present an asymmetrical pattern of lateral movements and greater lateral excursions of the pelvis and the shoulders than healthy subjects walking at similar speeds. Moreover, the accelerations are asymmetrical, with the highest values occurring when weight bearing is on the paretic side. These findings might indicate difficulty in controlling balance during gait and may be associated with laterally directed falls and a high risk of femoral fractures in these subjects (2, 3).

Previous studies of the standing position in post-acute and chronic stroke subjects have revealed balance impairments. It has been shown that post-stroke hemiparetic persons sway more than healthy persons along the medio-lateral axis (4). They have deficits in their ability to weight-shift on the affected leg (5–7) and to control a push at the pelvis level, particularly on the unaffected side (8). They also present increased weight bearing on the non-paretic lower limb, which supports about 70% of their body weight (9, 10). It is expected that the asymmetrical weight bearing and the difficulty to transfer the weight from one leg to the other will explain, in part, the modifications of the frontal kinematics observed during gait.

In the sagittal plane, the deviations of the kinematic pattern (11) have been attributed to physical impairments caused by the stroke (11–13). However, to our knowledge, no studies have tried to relate clinical findings to the frontal gait pattern and it is therefore still unknown how the frontal kinematics during walking is related to motor deficits and locomotor capacities in stroke subjects.

The main purpose of this pilot study was to examine the association between the experimental variables (lateral displacements (LDs), asymmetry in lateral accelerations (LAs) of the pelvis and shoulders, asymmetry in percentages of single stance and the clinical variables (physical impairments and locomotor capacities) of individuals with stroke. If the level of impairments and locomotor capacities are important for normal kinematics of the pelvic and shoulders in the frontal plane, it would be expected that less affected hemiparetic stroke subjects would be those having the most symmetrical gait patterns.

METHODS

Subjects

A sample of 10 subjects (1 female, 9 males) with hemiparesis due to a cerebrovascular accident (CVA) was studied. The stroke subjects had a

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mean age of 57.7 (±7.9) years, ranging from 37 to 65 years, and the mean time post CVA was 69.1 (±26.1) months. Among the 10 subjects, 6 presented with left-sided hemiparesis. Their somatosensory sensation was intact in the lower limb and they were able to walk without a cane indoors, although 5 of them (#1, #3, #4, #5 and #6) used a cane to go outdoors.

Subjects eligible for participation in this study were persons diagnosed with CVA, confirmed by a clinical evaluation and CT scan, persons who did not present with other relevant health problems and persons without cognitive impairments or cerebellar involvement. All the subjects had been treated at the Institute of Rehabilitation of Montreal and an informed consent was obtained from each before the study. The project was approved by the internal Ethics Committee of the Institute.

Clinical variables

The physical impairments and the locomotor capacities of the subjects were evaluated with valid and reliable clinical evaluation tools: The Chedoke-McMaster Stroke Assessment (14) and the Levin & Hui-Chan Spasticity Index (15) were used to determine the level of physical impairments, while the locomotor capacities were evaluated by the following tests: walking speed over 5 meters, the Step Test (16), the Timed Up and Go Test (17) and the Climbing Stairs Test (18, 19).

The Chedoke-McMaster Stroke Assessment (14), a valid and reliable tool for identifying the stage of motor impairment of the lower limb, comprises 6 parts, each measured on a 7-point scale corresponding to the 7 stages of motor recovery (1 to 7; primitive to normal) identified by Brunnstrom (20). In the present study, only the leg and foot were evaluated. The Levin & Hui-Chan Spasticity Index (15) was used to determine the level of spasticity of the ankle. This is a clinical assessment comprising 3 measurements: achilles tendon jerks (0–8 points: no reflex to maximal response), passive ankle dorsiflexion (0–8 points: no resistance to maximal increased resistance) and ankle clonus (0–4 points: no clonus to maximal sustained clonus). The total score of the 3 measurements gives the level of ankle spasticity and range from 0 to 16. Cut offs have been establish for normal tone (0–5), mild spasticity (6–9), moderate spasticity (10–12) and severe spasticity (13–16). This scale has shown good discriminating validity (13), internal consistency (21) and test-retest reliability (Intraclass correlation coefficient (ICC): 0.87) (22).

For the assessment of the locomotor capacities, the natural and maximal walking speed on the ground were evaluated. The subjects were asked to walk 5 meters, twice at natural speed and twice at maximal speed, and the mean speed of each pair was calculated. The Step Test was used to evaluate weight bearing and balance capacities (23). For this test, the subjects had to repeatedly lift one foot onto a step 10 cm high as many times as they could for 15 seconds. Stepping with one leg involves a weight transfer and loading on the opposite leg. The task was executed twice for each leg and the mean number of repetitions was calculated for each side. According to the results of Hill et al. (16), the test has concurrent validity and high test-retest reliability (ICC $>$0.90). The Timed Up and Go Test consisted of rising from a standard armchair, walking a distance of 3 meters, returning to the chair and sitting down, performing the whole task as fast as possible. This task was executed twice and the mean completion time was calculated in seconds. The Timed Up and Go Test is a reliable (between and within raters: ICC = 0.99) and valid tool for quantifying functional mobility (17). To determine their stair-climbing capacity, the stroke subjects were asked to climb 5 standard stairs at natural speed, with or without hand support. The cadence, which corresponds to the number of steps per minute, was then calculated. The test shows an inter-rater reliability coefficient of 0.90 in healthy subjects (18). According to Perry (24), independent locomotion necessitates the capacity to walk, climb stairs and stand up from the sitting position alone, with or without external supports.

Experimental variables

To quantify the movements in the frontal plane during gait, the stroke subjects were asked to walk on a treadmill. Each patient was assessed at a natural and a maximal safe speed. For each speed, 3 trials of 6 seconds were recorded and averaged. Kinematic data of pelvic and shoulder movements were obtained with the Peak Performance videographic acquisition system. A camera placed behind the subject at 4.10 meters from the treadmill (Burdick, T500) recorded the displacements of reflective markers located at the pelvic and shoulder levels (corresponding to the posterior superior iliac spines and the seventh cervical vertebra, respectively) at a sampling frequency of 60 frames per second. Three foot-switches were placed under the heel, the metatarsal heads, and the toes. Their signals were amplified and subsequently converted into digital format by an analog-to-digital converter.

The trajectory of markers tracked by the Peak Performance system was digitized to obtain the 2-D co-ordinates in pixels of the pelvis and the shoulders using an automatic digitizing module. The co-ordinates of the markers were then smoothed using a Butterworth filter set at an optimal frequency and transformed into meters. They were used to calculate the total LDs of the pelvis and shoulders, as well as the LAs in the frontal plane.

The shoulder and pelvis LDs correspond to the mean of 9 peak-to-peak amplitudes taken over the 3 trials. The LAs were determined by calculating the second derivative of the marker positions. The LAs on the affected and non-affected sides are the mean of the maximal LAs for each side. The percentage of time spent in single stance (SS) was determined from the foot-switches by considering the proportion of the gait cycle during which the opposite leg is swinging forward.

An index of asymmetry (IA) for the LA of the shoulders and pelvis as well as for SS was determined by calculating the difference between the non-paretic (NP) and the paretic (P) side relative to the total sum of the 2 sides according to the following formula: $[(NP - P)/(NP + P)]$. An IA greater than zero means that the LA or the SS is greater on the non-paretic side, an IA lower than zero indicates a greater LA or SS on the paretic side while an IA at zero indicates symmetry between the 2 sides.

Statistical analysis

Descriptive statistics were calculated for subject characteristics, clinical scores (physical impairment measures and locomotor capacities), kinematic (LDs and LAs) and temporal (SS) gait variables. The associations between the experimental variables (LDs, LAs and IA) and the clinical scores were first examined by determining correlation coefficients and then by effecting multiple linear regressions. Spearman's correlation coefficients were used to identify the relationships between the dependent variables (experimental variables) and the categorical independent variables (the score of the Chedoke-McMaster and the index of spasticity), whereas Pearson's product-moment correlation coefficients were used to examine the associations in continuous dependent and independent variables (locomotor capacity scores). All data were analysed using the SPSS (version 10.0 for Windows) statistical analysis software.

A stepwise method of multiple regression was used to determine the most predictive clinical variables of the kinematic and temporal parameters of gait. The 4 following clinical variables were selected into the analysis: the Chedoke-McMaster for the leg, the Levin and Hui-Chan Spasticity Index, the Step Test for the non-paretic leg (weight-bearing on the paretic side) and the Timed Up and Go Test. These tests were chosen because together they best represent the different physical clinical status of stroke subjects and are expected to be related to the asymmetry of weight bearing and LAs of these subjects during gait. The variables were entered in the model with a significance level of $p \leq 0.15$ and removed when $p \geq 0.2$.

RESULTS

Clinical variables

The motor recovery stage of the hemiparetic stroke subjects ranged between 4/7 and 7/7 for the leg (mean 5.5/7 ± 0.85) and between 2/7 and 7/7 for the foot (mean 3.9/7 ± 1.45) according to the Chedoke-McMaster Stroke Assessment (Table I). The mean level of ankle spasticity was 6.1/16 ± 1.9/16 and varied from 4/16 to 9/16, indicating normal to mild spasticity.

Concerning locomotor capacities (Table I), the hemiparetic subjects walked on the ground at mean natural and maximal speeds of 0.9 meters/sec (± 0.3) and 1.2 meters/sec (± 0.4),

Table I. *Individual clinical scores for stroke subjects (*n *= 10) sorted by increasing order of natural gait speed*

	Chedoke McMaster (/7)			Step test (repetitions)†				Gait speed (m/s)	
	Leg	Foot	Ankle spasticity (/16)	P	N–P	TUG (s)	Stair test (stairs/min)	Natural	Maximal
1 R	5	2	9	5.5	6.8	19.7	46.3	0.50	0.57
2 L	5	3	8	6.0	7.5	17.4	46.2	0.62	0.97
3 L	4	3	6	7.8	9.0	20.6	59.9	0.64	0.76
4 R	5	3	5	9.0	11.0	14.0	70.1	0.80	1.07
5 L	6	5	4	9.5	11.5	12.5	69.6	0.92	1.13
6 R	6	3	5	9.0	10.8	12.6	61.1	0.92	1.15
7 L	6	4	9	9.0	11.0	12.3	61.0	0.97	1.23
8 L	5	5	5	12.0	13.0	9.20	62.2	1.02	1.68
9 R	6	4	4	13.0	13.0	9.50	77.5	1.18	1.46
10 L	7	7	6	17.0	20.0	9.20	90.6	1.34	1.80
Mean	5.5	3.9	6.1	9.8	11.4	13.7	64.5	0.9	1.2
SD	0.8	1.4	1.9	3.4	3.7	4.2	13.4	0.3	0.4
Range	4–7	2–7	4–9	5.5–17	6.8–20	9.2–20.6	46.2–90.6	0.5–1.34	0.57–1.80

† The number of repetitions is significantly different between the 2 sides ($p < 0.05$).
P = paretic side; NP = non-paretic side, TUG: Timed Up and Go, R = right cerebral lesion; L = left cerebral lesion.

respectively. In the Step Test, more repetitions were made with the non-paretic leg (paretic weight bearing) than with the paretic leg ($p < 0.05$). The mean time to effect the Timed Up and Go Test corresponded to 13.7 s (± 4.2), and they could climb a mean of 64.5 stairs per minute.

Gait variables

The mean natural and maximal walking speed on the treadmill (0.62 meters/sec and 0.78 meters/sec) corresponded to 70.6% and 67.4% of the stroke subjects' natural and maximal walking speed on the ground. The frontal kinematics of the shoulders and pelvis showed that the LDs as well as the IA of LAs and SS were not significantly different for natural and maximal gait speeds. Moreover, the values of IA suggested that the asymmetry is greater for the SS than for the LAs (Table II). The mean (SD) IA of SS of hemiparetics walking at natural and maximal speeds corresponded to 0.12 (±0.09) and 0.08 (±0.08) for those with a left ($n = 6$) cerebral lesion and to 0.26 (±0.18) and 0.24 (±0.12) for those with a right ($n = 4$) cerebral lesion.

Table II. *Lateral displacement (LD) of the shoulders and pelvis, and index of asymmetry (IA) for the lateral accelerations at the shoulders (LAS) and pelvis (LAP), and for single stance (SS). The mean, standard deviation ( ) and range [ ] are reported at natural and maximal speeds*

	Natural	Maximal
LD		
Shoulders	0.09 (0.03) [0.05 to 0.13]	0.08 (0.03) [0.04 to 0.14]
Pelvis	0.09 (0.03) [0.05 to 0.14]	0.08 (0.03) [0.05 to 0.14]
IA		
LAS	−0.10 (0.10) [−0.29 to 0.03]	−0.09 (0.11) [−0.29 to 0.09]
LAP	−0.07 (0.08) [−0.17 to 0.08]	−0.04 (0.13) [−0.21 to 0.14]
SS	0.17 (0.14) [0.03 to 0.45]	0.15 (0.12) [0.01 to 0.33]

Correlations between clinical and experimental variables

The Spearman correlations between the frontal dependant kinematic variables and the level of physical impairments showed that the LDs of the shoulders at maximal speed and of the pelvis at both speeds correlated significantly with the motor recovery stage of the leg and the foot ($r = -0.70$ to -0.87; Table III). Correlation analyses also revealed significant negative relationships between, on one hand, the asymmetry in LAs of the shoulder and the pelvis, as well as in the percentages of SS at natural speed, and, on the other hand, with the motor recovery stage of the leg ($r = -0.67$ to -0.85). The stroke subjects who presented greater motor recuperation at the leg showed a tendency to have the lowest values of asymmetry in SS (Fig. 1A) and LAs of the pelvis (Fig. 1B) during treadmill walking. No significant associations were found between the spasticity score at the ankle and the frontal kinematic variables of the trunk.

For the locomotor capacities, Pearson's correlation coefficients (Table III) revealed that these clinical scores were moderately to highly related to the pelvic and shoulder LDs ($r = 0.66$ to 0.86). The locomotor capacity scores were also strongly associated with the IA of LAs of the shoulders at maximal speed ($r = 0.78$ to 0.90) and with the IA of SS ($r = 0.64$ to 0.93) at natural and maximal speeds, except for the scores obtained in the Climbing Stairs Test.

Multi-variate analyses

Multiple regression models explaining more than 70% of the variance in the experimental data are presented in Table IV, along with the predictive equations associated with each model. The first clinical test retained as a predictor of the pelvic LDs at

Table III. *Correlation coefficients obtained between experimental variables (lateral displacement (LD), index of asymmetry (IA)) and clinical scores (Impairments and locomotor capacities) for stroke subjects walking at natural (Nat) and maximal (Max) speeds*

Experimental variables	LD (S)		LD (P)		IA (LAS)		IA (LAP)		IA (SS)	
Clinical variables	Nat	Max	Nat	Max	Nat	Max	Nat	Max	Nat	Max
Impairments†										
Chedoke leg	−0.43	**−0.80***	**−0.72***	**−0.70***	**−0.67***	**−0.80***	**−0.74***	**−0.81****	**−0.85****	−0.59
Chedoke foot	−0.59	**−0.77***	**−0.87****	**−0.82****	−0.50	**−0.74***	−0.44	−0.31	−0.62	**−0.70***
Spasticity	0.38	0.25	0.28	0.38	0.07	0.28	0.19	0.48	0.41	0.15
Locomotor capacities‡										
Up and Go	**0.68***	**0.71***	**0.82****	**0.86****	0.55	**0.82****	**0.71***	0.61	**0.93****	**0.85****
Climbing stairs	**−0.72***	**−0.77***	**−0.71***	**−0.76***	−0.53	**−0.78****	−0.47	**−0.64***	−0.56	−0.42
Step test (P)	**−0.83****	**−0.76***	**−0.80***	**−0.78***	−0.60	**−0.86****	−0.49	−0.53	**−0.68***	**−0.68***
Step test (NP)	**−0.77***	**−0.70***	**−0.79***	**−0.75***	−0.55	**−0.84****	−0.44	−0.51	**−0.65***	**−0.64***
Speed (Nat)	**−0.79***	**−0.75***	**−0.86****	**−0.83****	−0.62	**−0.90****	**−0.69***	**−0.67***	**−0.85****	**−0.79***
Speed (Max)	**−0.75***	**−0.66***	**−0.79***	**−0.76***	−0.48	**−0.79***	−0.55	−0.41	**−0.81****	**−0.86****

* $p < 0.05$; ** $p < 0.01$.
S = shoulders; P = pelvis; LAS = lateral acceleration of the shoulders; LAP = lateral acceleration of the pelvis; SS = single stance.
† Spearman's correlation coefficient. ‡ Pearson's correlation coefficient.

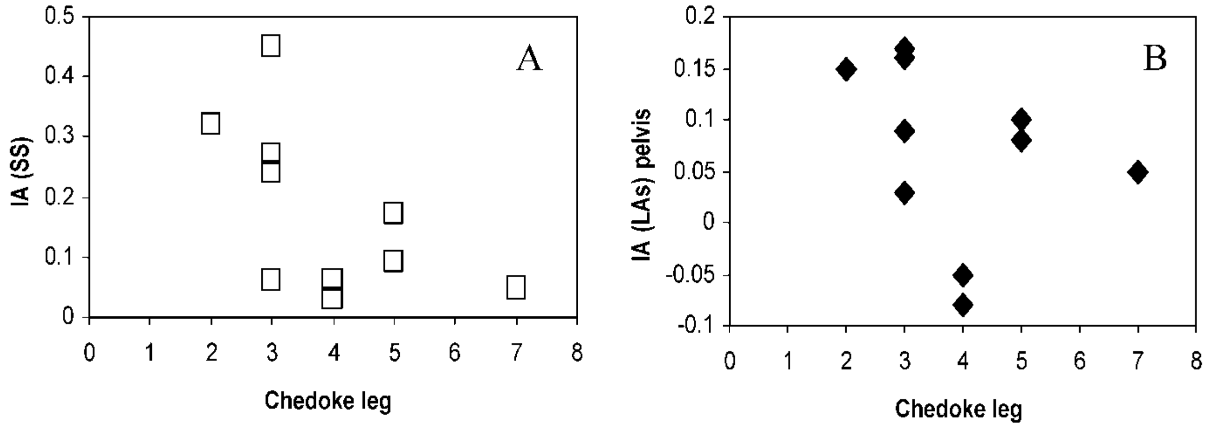

Fig. 1. Scatterplots of the relations between the Chedoke-McMaster's motor stage recovery of the leg for the 10 stroke subjects and A) the index of asymmetry (IA) for single stance (SS), and B) (IA) for lateral accelerations (LAs) of the pelvis.

natural speed, as well as for the IA of SS at natural and maximal speeds, was the Timed Up and Go Test. It explained respectively 71%, 85% and 68% of the adjusted variance (R^2) of the experimental variables. For the IA of SS at natural speed, the R^2 reached a value of 94% when the motor recovery stage of the leg and the scores of the Step Test were added to the model. At maximal speed, the level of spasticity was also entered in the model with the score of the Timed Up and Go Test and together they explained 77% of the variance in the IA of SS. The other experimental values, such as the LDs of the shoulders, the pelvic LDs at maximal speed and the IA of LAs of the shoulders, were explained at less than 70% by the clinical scores.

Table IV. *Multiple regression analyses used to relate kinematic variables (LD and IA) to clinical variables [Step Test (NP), Timed Up and Go (TUG), Chedoke (leg) and Spasticity] at natural and maximal speeds*

Dependent variables	Independent variables	F	R^2	p
LD (P)	TUG	22.9	0.741	<0.001
IA (SS) at natural speed	TUG	50.8	0.864	<0.000
	Chedoke (leg)	37.2	0.914	<0.000
	Step test (NP)	39.1	0.951	<0.000
IA (SS) at maximal speed	TUG	20.1	0.715	<0.002
	Spasticity	16.1	0.821	<0.002

LD (P) = 0.006 (TUG) − 0.009.
IA (SS) at natural speed = 0.030 (TUG) − 0.076 (Chedoke (leg)) + 0.015 (Step Test (NP)) + 0.008.
IA (SS) at maximal speed = 0.030 (TUG) − 0.024 (Spasticity) − 0.120.

DISCUSSION

In this study, the associations existing between the clinical scores of stroke subjects and their lateral linear kinematics of the trunk at the shoulders and pelvis during treadmill walking were examined. During walking, the majority of persons with a stroke exhibits lateral movement abnormalities. This suggests difficulties in controlling the lateral motion of the trunk segment, which might be very important for maintaining balance in locomotor activities (25, 26).

The correlation analysis revealed many significant associations between the clinical variables and the experimental variables. The motor recovery at the leg and, albeit less, at the foot correlated more strongly with the kinematics of the trunk in the frontal plane than did the index of spasticity at the ankle. Similar results, i.e. low correlations between the locomotor function and the level of spasticity in the lower limb in ambulant chronic-stroke individuals have also been found in many other studies (13, 27, 28). However, as in the present study, the level of spasticity was low. A different association could be found with subjects having a high level of spasticity.

MacKinnon & Winter (29) conducted an analysis of the whole body balance in the frontal plane during gait and identified the abductor/adductor muscles as having a more important role than the invertor/evertor ankle muscles. Many studies have emphasized the role of the hip muscles (not measured in this study) in balance (7, 24), which could explain the more consistent relationship found between frontal kinematics and the recovery level of the paretic lower leg. This also supports the idea that treatment techniques improving the motor function of the paretic lower limb, particularly those aiming to strengthen the hip abductor/adductor muscles, would improve symmetry and lateral balance and might consequently reduce the risk of falling in adults with chronic stroke.

A strong negative association was identified between the LDs of the pelvis and shoulders and the gait speed on level ground (rho > -0.75). This could corroborate the result of a previous study (10), which found that lateral sway during standing was indicative of restricted velocity performance during walking.

The other locomotor tests (Timed Up and Go, Step Test, Climbing Stairs Test) were also significantly related to most of the kinematic variables. Among them, the Timed Up and Go appeared to be a very important test for predicting pelvic LDs. The score in this test was selected as the first predictor in the model explaining 71% of the variance. The score of the Timed Up and Go Test was also the strongest predictor for the symmetry of SS at natural and maximal speeds (85% and 68% of the variance are explained). At natural speed, the motor recovery stage of the leg and the scores of the Step Test also contributed to explaining the asymmetry values of SS at natural speed, whereas at maximal speed, the spasticity of the ankle was retained.

The results of the multi-variate analyses suggest that the locomotor capacities, which are well reflected by the Timed Up and Go Test, are more predictive of the LDs and the asymmetry of SS than the physical impairment measures. However, the impairment scores (Chedoke and Spasticity) might contribute to predicting the asymmetry of SS when added to the model.

The small size of our sample does not allow us to discuss the effect of the lesion side on the frontal kinematics of the trunk. It would be interesting in future studies to examine the effect of the side and area of the lesion on the frontal kinematics of hemiparetics during walking.

CONCLUSION

This study has demonstrated the existence of relationships between physical impairments, locomotor capacities and frontal plane gait parameters in hemiparetic post-stroke subjects. Those with the most impaired legs presented the greatest LDs and asymmetries, which suggests that they have a greater lateral imbalance. An abnormal lateral pattern of movement at the pelvis and shoulders during gait also appears to be associated with worse locomotor capacities. Commonly used clinical tests evaluating the physical impairments and locomotor capacities, more particularly the Timed Up and Go Test, might be used to provide information about the frontal kinematics of the pelvis and shoulders and the SS during gait in persons with a stroke.

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