Differences in Kinematic Variables in Single-Leg Stance between Patients with Stroke and Healthy Elderly People Measured with Inertial Sensors: A Cross-Sectional Study

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Objective: The study aimed to analyze the differences between kinematic parameters in the single-leg stance (SLS) in patients with stroke and in healthy elderly people measured with 2 inertial sensors—1 in the trunk and 1 in the lumbar region. *Methods:* Two groups of participants were measured: the first group consisted of 5 healthy elderly people over 65 years of age; the second group consisted of 5 patients with stroke over 65 years of age, recovering for more than 6 months after suffering a stroke, and who had been undergoing rehabilitation treatment for at least 6 months. Two inertial sensors were located in the participants: in the trunk region (T7-T8) and in the lumbar region (L5-S1). The SLS test was performed in 4 conditions: right-dominant leg, open eyes; right-dominant leg, closed eyes; left-nondominant leg, open eyes; and left-nondominant leg, closed eyes. *Results:* Significant differences in displacement in the lumbar and trunk sensors are highlighted in 6 of 36 variables. In the velocity variables, significant differences were only found in 1 variable. Differences during SLS between the affected and the nonaffected legs in patients with stroke were found in 5 of the 36 analyzed variables and in 1 variable in velocity. The intraclass correlation coefficients were higher than .866 (95% confidence interval: .828-.857) for all variables. *Conclusions:* Only significant differences were found in 7 of the 128 kinematic variables analyzed in both groups, so that it could be confirmed that there are no significant differences in the static balance between healthy elderly people and people with stroke who undergo the rehabilitative treatment. **Key Words:** Stroke—elderly people—rehabilitation—body balance—static balance—kinematic.
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Introduction

Loss of balance is one of the main problems that prevent people with diseases from carrying out their daily activities.[1,2] It is one of the main side effects of stroke and causes an increased risk of falling in patients with stroke.[3]

The single-leg stance (SLS) is an appropriate test to measure the maintenance of static balance in healthy people[4-6] and in patients with stroke.[7-9] This test is widely used in research and clinical practice due to its ease of use.[7]

Rehabilitation is very important for people who suffer a stroke, especially in the first stage.[8] Rehabilitation

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treatment can help the patient with stroke regain lost strength and mobility or balance functions.[9] Recovery of balance in patients with stroke is very important because this gives them greater independence in carrying out their daily activities and reduces the risk of falling.[10]

Inertial sensors are tools that help us to measure the kinematic parameters of a gesture,[11,12] and these instruments have been used in balance tests on healthy people[13,14] and in patients with stroke [15,16] with a range validity of .66-.99[17] and a reliability of .84-.97,[18] which has led to their wider use in research and in clinical practice.

Despite inertial sensors having been used in patients with stroke and in healthy people to measure balance, there are no studies that analyze the differences between the kinematic parameters in these groups of people with SLS.

The main objective of the present study was to analyze the differences between kinematic parameters in the SLS in patients with stroke and in healthy elderly people measured with 2 inertial sensors—1 in the trunk and 1 in the lumbar region. Our hypothesis is that there will be no significant differences between the 2 groups in the SLS due to the rehabilitation treatment that the patients with stroke are undergoing.

Methods

Design and Participants

A cross-sectional study was conducted. Two groups of participants were measured: the first group consisted of 5 healthy elderly people over 65 years of age who were not suffering from any illness that affected their motor skills or balance and who were required be right-handed; the second group consisted of 5 patients with stroke over 65 years of age, recovering for more than 6 months after suffering a stroke, able to walk at least 15 meters without help and to stand for more than 30 seconds without any help, whose affected leg was the left leg, and who had been undergoing rehabilitation treatment for at least 6 months, including deep-water running and exercises of stretching and strengthening of the affected leg 3 sessions weekly, with a total duration of 12 weeks. In the group of patients with stroke, the exclusion criteria were severe heminegligence, another neurological or musculoskeletal pathology, or sharp pain.

Ethical approval for the study was granted by the Ethics Committee of the Faculty of Health Sciences, University of Málaga. The study complied with the principles established in the Declaration of Helsinki.

Before carrying out the SLS, each participant obtained information about the procedure and was asked to sign a declaration of informed consent for study participation. All participants declared that participation was voluntary and that they could withdraw at any time. We also made sure that their data were treated according to the Organic Law on Data Protection (Law 15/1999).

Inertial Sensors

The inertial sensors used were InertialCube3 (Intersense Inc., Bedford, MA), with a sampling frequency of 180 Hz. The InertiaCube3 is a sensor based on microelectromechanical systems technology and does not incorporate castors, which might generate noise and inertial forces and increase the risk of mechanical failure. The InertiaCube3 measures 3 physical properties simultaneously, namely, angular rates, linear accelerations, and magnetic field components along the 3 axes (yaw, pitch, and roll). Miniature vibrating elements were used to measure all angular velocities and linear accelerations.

Inertial sensors were located in the trunk region (T7-T8) and in the lumbar region (L5-S1) to obtain kinematic data. Sensors were placed with tape and reinforced with elastic surrounding the entire participant to ensure that the sensor did not move from this position. Movement was recorded 3 seconds before the participant carried out the test and the recording was finished 3 seconds after the participant had finished; this allowed the SLS to identify in the kinematic data when the participant started and finished the test.

The origin of the coordinate sensor was positioned in the left posterior inferior corner.

Procedure: Single-Leg Stance

The SLS is performed as follows: participants had to stand on 1 leg and with their arms on their hips; when the participant was in this position, the time that the participant could stand in this position until their foot touched the ground or until their arms were separated from the hip was recorded.[19]

Soft modifications of the test were made to carry out the SLS on all the participants. All participants were asked to perform the test for 20 seconds, regardless of whether their arms left the hip or the leg was not sustained at 90° of knee flexion (Fig 1). Two researchers were around the participant to provide more security in case of loss of balance or falling. The patients were also surrounded by mats to minimize the effects if a fall occurred. All participants had a rest of 60 seconds between each test run to minimize the effects of fatigue.

The SLS test was performed in 4 conditions: right-dominant leg, open eyes; right-dominant leg, closed eyes; left-nondominant leg, open eyes; and left-nondominant leg, closed eyes.

Before the test was performed and the data recorded, the test was explained to the participants and they were given the opportunity to practice for as much time as they felt was necessary to perform the test properly when the sensor measurement was started.

Variables

Displacement: rotation (left or right side): maximum positive displacement (right) and negative displacement

Figure 1. *Performance of the single-leg stance.*

(left) relative to the x-axis. Flexion and extension: maximum positive displacement (flexion) and negative displacement (extension) relative to the y-axis. Inclination (left or right side): maximum positive displacement (right) and negative displacement (left) in the z-axis. Mean displacement: mean displacement of each axis (x, y, and z).

Velocity: rotation (left or right side): maximum positive velocity (right) and negative velocity (left) in the x-axis. Flexion and extension: maximum positive velocity (flexion) and negative velocity (extension) relative to the y-axis. Inclination (left or right side): maximum positive velocity (right) and negative velocity (left) relative to the z-axis. Resultant velocity: the resultant velocity vector was calculated using the formula $R_V = \sqrt{(Vx^2 + Vy^2 + Vz^2)}$.

Data Analysis

Anthropometric measurements and the data obtained from various self-report questionnaires designed for use by patients with neurological impairments were analyzed. A descriptive analysis of the kinematic data from the 2 inertial sensors (trunk and lumbar region) was made.

The Kolmogorov-Smirnov test was used to assess the distribution of kinematic data. Following this test, we compared data from the trunk and the lumbar sensors. The normally distributed data were analyzed using the parametric Student t-test, and non-normally distributed data were analyzed using the nonparametric Wilcoxon test. A significance threshold with a P value of .05 or lower was used.

Reliability measures were calculated by analyzing the internal consistency of the measures (intraclass correlation coefficients [ICC 3.1] were calculated for intraobserver and interobserver reliabilities) with 95% confidence intervals (CIs) for each outcome variable. Reliability was classified as follows: excellent (ICC > .80), good (.80 > ICC > .60), moderate (.60 > ICC > .40), or poor (ICC < .40).[20]

Data analysis was performed with SPSS (version 17.0 for Windows; SPS Inc., Chicago, IL).

Results

The mean age of the patients with stroke was 72.33 (±3.97) years old, and that of the healthy elderly people was 73.04 (±3.58) years old. Anthropometric data are presented in Table 1. All variables were measured in all samples.

Significant differences in flexion-extension movement in the lumbar sensor are highlighted (extension: right-dominant leg, open eyes difference [Diff.] 8.26 [±3.51]) (flexion: left-nondominant leg, open eyes, Diff. −11.04 [±3.98]) (mean flexion-extension: left-nondominant leg, open eyes, Diff. −4.61 [±1.91]). Data of the comparison in the displacement during the SLS in the lumbar sensor are presented in Table 2.

Table 1. *Characteristic of the participants*

	Stroke survivors (SD)	Healthy elderly (SD)
Age (y)	72.33 (±3.97)	73.04 (±3.58)
Weight (kg)	71.26 (±14.19)	72.38 (±11.94)
Height (cm)	162.65 (±7.83)	163.11 (±7.02)
BMI (kg/m^2)	26.69 (±3.11)	27.07 (±3.87)
Canadian Neurological Scale (0-10)	9.175 (±.485)	—
Barthel Index (0-100)	90.25 (±4.575)	—
Stroke Index Scale_16 (0-80)	71.00 (±6.934)	—
N (women-men)	5 (3-2)	5 (3-2)

Abbreviations: BMI, body mass index; SD, standard deviation.

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Table 2. *Mean values of the kinematic variables during 1 single–leg-stance test (Lumbar sensor)*

	Open eyes						Closed eyes					
	Nonaffected-dominant leg			Affected-nondominant leg			Nonaffected-dominant leg			Affected-nondominant leg		
	Stroke (SD)	Healthy (SD)	Diff. (SD)	Stroke (SD)	Healthy (SD)	Diff. (SD)	Stroke (SD)	Healthy (SD)	Diff. (SD)	Stroke (SD)	Healthy (SD)	Diff. (SD)
Flexion displacement* (°)	3.28	10.57	7.29	2.14	13.15	11.04‡	10.21	13.64	3.43	6.39	18.60	12.21
	(±9.83)	(±6.19)	(±5.54)	(±4.31)	(±6.91)	(±3.98)	(±2.24)	(±7.09)	(±3.72)	(±2.39)	(±12.55)	(±7.55)
Extension displacement* (°)	2.62	5.64	8.26‡	3.78	2.54	1.24	1.73	9.51	7.78	6.38	2.82	3.56
	(±2.86)	(±5.52)	(±3.51)	(±3.47)	(±2.45)	(±1.96)	(±4.04)	(±10.79)	(±4.76)	(±2.30)	(±2.40)	(±1.73)
F/E mean displacement† (°)	4.80_{F}	4.19_{F}	.61	$.48_{E}$	4.13_{F}	4.61‡	7.18_{F}	$.44_{F}$	6.77	1.10_{F}	2.55_{F}	1.45
	(±3.58)	(±4.43)	(±3.03)	(±2.93)	(±2.79)	(±1.91)	(±1.07)	(±6.81)	(±3.44)	(±1.52)	(±1.91)	(±1.31)
Left rotation displacement* (°)	4.55	51.25	46.70	14.93	59.27	44.33	3.42	21.70	18.28	19.28	67.85	48.56
	(±6.75)	(±48.68)	(±29.16)	(±6.20)	(±64.24)	(±38.39)	(±4.16)	(±24.63)	(±12.48)	(±8.38)	(±81.58)	(±28.67)
Right rotation displacement* (°)	7.54	21.41	13.86	3.86	36.57	32.71	13.52	35.86	22.34	18.22	19.05	.83
	(±2.36)	(±22.72)	(±13.58)	(±9.60)	(±48.71)	(±25.06)	(±12.29)	(±16.83)	(±10.42)	(±20.75)	(±21.61)	(±15.57)
Rotation mean displacement* (°)	$.45_{R}$	12.32_{R}	12.77	16.76_{R}	4.82_{R}	11.94	5.01_{L}	4.59_{L}	.42	3.55_{R}	30.57_{R}	27.02
	(±4.22)	(±26.12)	(±15.67)	(±20.27)	(±4.91)	(±23.97)	(±7.32)	(±22.61)	(±11.88)	(±7.03)	(±57.44)	(±34.38)
Right inclination displacement† (°)	13.74	24.85	11.10	11.54	41.08	–29.53	24.70	31.39	6.69	22.66	19.18	3.47
	(±12.54)	(±28.86)	(±18.00)	(±11.90)	(±46.16)	(±23.98)	(±15.15)	(±15.76)	(±10.93)	(±11.41)	(±24.03)	(±15.11)
Left inclination displacement* (°)	2.72	57.09	54.36	21.44	43.01	21.56	1.07	20.43	19.36	24.39	76.61	52.22
	(±4.75)	(±55.52)	(±33.16)	(±21.23)	(±43.88)	(±24.13)	(±5.27)	(±19.19)	(±8.94)	(±7.73)	(±77.58)	(±46.37)
R/L mean inclination displacement* (°)	7.69_{R}	13.05_{L}	20.74	7.07_{L}	1.60_{R}	8.67	13.61_{R}	1.57_{R}	12.04	2.71_{L}	39.41_{L}	36.71
	(±10.12)	(±42.01)	(±25.41)	(±25.30)	(±40.85)	(±23.51)	(±9.87)	(±24.97)	(±7.42)	(±8.83)	(±56.13)	(±22.13)
Flexion velocity* (°/s)	30.85	39.40	8.54	30.69	35.52	4.84	54.15	22.35	–29.10	24.26	46.70	22.34‡
	(±15.35)	(±19.22)	(±11.85)	(±23.91)	(±33.15)	(±19.81)	(±65.30)	(±7.46)	(±26.31)	(±8.79)	(±25.81)	(±19.36)
Extension velocity* (°/s)	31.78	40.97	9.18	21.86	29.79	7.93	23.61	27.39	.87	47.28	40.31	3.82
	(±22.38)	(±19.84)	(±14.06)	(±18.44)	(±22.81)	(±14.12)	(±12.57)	(±11.01)	(±25.79)	(±43.14)	(±18.22)	(±17.17)
Left rotation velocity† (°/s)	37.75	25.18	12.57	25.07	36.37	–11.30	23.89	52.99	31.80	23.50	65.60	22.44
	(±19.89)	(±8.98)	(±9.85)	(±9.32)	(±41.50)	(±7.43)	(±12.31)	(±51.16)	(±32.88)	(±3.44)	(±23.00)	(±15.82)
Right rotation velocity† (°/s)	30.20	23.68	6.52	41.67	29.27	12.41	40.45	41.32	3.78	37.32	41.14	6.96
	(±13.70)	(±8.13)	(±7.30)	(±51.46)	(±29.50)	(±27.10)	(±40.23)	(±32.29)	(±8.36)	(±15.02)	(±26.77)	(±21.18)
Right inclination velocity† (°/s)	44.17	31.48	12.69	41.65	26.11	15.54	45.57	25.05	20.52	49.43	28.67	20.76
	(±26.91)	(±18.42)	(±15.06)	(±18.27)	(±15.33)	(±11.17)	(±20.91)	(±14.34)	(±12.67)	(±23.74)	(±15.99)	(±13.83)
Left inclination velocity† (°/s)	44.46	33.23	11.23	45.81	27.49	18.32	34.80	19.56	–15.24	41.78	41.60	.18
	(±22.68)	(±16.22)	(±12.91)	(±17.43)	(±14.91)	(±10.76)	(±8.16)	(±23.11)	(±12.26)	(±18.99)	(±19.43)	(±13.41)
Resultant velocity (°/s), right side*	66.37	58.41	7.96	60.21	59.15	1.06	71.84	54.99	–16.85	60.84	88.17	27.33
	(±33.95)	(±22.46)	(±18.76)	(±23.76)	(±52.58)	(±28.63)	(±44.10)	(±48.15)	(±9.58)	(±21.83)	(±29.47)	(±19.84)
Resultant velocity (°/s), left side*	62.28	59.36	2.92	15.36	51.99	36.66	61.13	47.68	13.44	76.66	76.38	.28
	(±28.37)	(±24.60)	(±17.63)	(±27.49)	(±36.86)	(±27.54)	(±37.42)	(±35.65)	(±24.43)	(±39.85)	(±21.09)	(±20.99)

Abbreviations: Diff., difference; E, extension; F, flexion; L, left; R, right; SD, standard deviation.

*Parametric variables.

†Nonparametric variables.

‡Less than .05.

In the trunk sensor, significant differences in flexion-extension movement (flexion: right-dominant leg, open eyes, Diff. 12.87 [±2.84]) (flexion: left-nondominant leg, open eyes, Diff. 7.72 [±3.03]) and in right-left inclination (right inclination, right-dominant leg, open eyes, Diff. 47.21 [±20.77]) are highlighted. The other trunk sensor results are presented in Table 3.

In the velocity variables, significant differences were found in the lumbar sensor (flexion velocity: left-nondominant leg, closed eyes, Diff. 22.34 [±19.36]). In the other variables, significant differences were not found between the 2 groups. The rest of the data can be checked in Table 2 (lumbar sensor) and in Table 3 (trunk sensor).

In the present study, significant differences were found in 5 of the 36 analyzed variables in displacement during the SLS between the affected and the nonaffected legs in patients with stroke (lumbar sensor—extension displacement, open eyes, mean flexion/extension displacement, open eyes; trunk sensor—extension displacement, closed eyes, mean flexion/extension displacement, closed eyes, right inclination closed eyes) and in 1 variable in velocity (negative result, open eyes). In the healthy elderly people, significant differences were not found between the dominant and the nondominant legs. The results of the differences between legs are presented in Figure 2 for displacement and Figure 3 for velocity.

The ICCs were higher than .866 (95% CI: .828-.857) for all variables. Intraobserver reliability of the trunk sensor ranged from .895 to .935 for the displacement and from .866 to .894 for velocity. Intraobserver reliability of the lumbar sensor was between .904 and .947 for the displacement and between .879 and .901 for velocity. Interobserver reliability of trunk sensor was between .887 and .918 for the displacement and between .859 and .881 for velocity. Interobserver reliability of the lumbar sensor was between .893 and .927 for the displacement and between .870 and .894 for velocity. Other values for the reliability of the variables are presented in Table 4.

Discussion

The objective of the present study was to analyze the differences in the SLS between healthy elderly people and patients with stroke. Our hypothesis has been affirmed: we only found significant differences in 7 of the 128 variables between the 2 groups, so we can confirm that significant differences do not exist between healthy elderly people and patients with stroke who undergo rehabilitation treatment.

Kinematic Variables

Displacement

The results of the present study are not consistent with other previously published studies.[21-23] Although in the present study we found significant differences in 6 of the 24 variables analyzed in the **mediolateral axis**, other studies found significant differences in semistatic balance: Chern et al ($F = 15.47$, $P < .001$),[21] Lin et al ($F = 4.26$, $P = .043$),[22] and Tessem et al ($F = 16.00$, $P < .001$)[24]; and in static balance: Sawacha et al (open eyes in SLS, mean Diff. = 185.3, $P = .018$) (closed eyes in SLS, mean Diff. = 189.3, $P = .008$).[23] Therapeutic exercise can be one of the reasons that explain the lack of consistency between the studies. In the present study, all patients with stroke who took part had to have performed continuous rehabilitation treatment including therapeutic exercise for the 6 months before the study, whereas in the study of Sawacha et al,[23] this requirement was an exclusion criterion. In addition, the mean age of the participants in the present study is higher than the mean ages in the previously consulted studies,[21,22,24] so the improvement caused by the rehabilitation treatment, in addition to the natural deterioration of physical abilities in elderly people, can explain the lack of significant differences between the 2 groups analyzed.

In the present study, significant differences were not found in the **anteroposterior axis** except for one of the 24 analyzed variables (right inclination, right-dominant leg, open eyes, Diff. 47.21 [±20.77]). These results are consistent with the study of Chern et al ($F = 4.11$, $P = .005$)[21] and with the study of Lin et al ($F = 1.41$, $P = .24$).[22] In contrast, Sawacha et al[23] found significant differences in the mean displacement in this axis when the SLS was performed with open eyes (mean Diff. = 198.5, $P = .032$); these results in the study of Sawacha et al[23] are different from the results presented in the current study in the same condition (open eyes) because we did not find significant differences in this axis in the lumbar sensor (right-dominant leg, $F = 4.129$, $P = .88$; left-nondominant leg, $F = 3.389$, $P = .108$) or in the trunk sensor (right-dominant leg, $F = 1.961$, $P = .211$; left-nondominant leg, $F = .626$, $P = .459$). In contrast, Sawacha et al[23] did not find significant differences in the displacement of this axis when the test was performed with closed eyes (mean Diff. = 59.7, $P = .153$); these results are consistent with the results of the present study where significant differences have not been found when the test was performed in the same condition (closed eyes) in the lumbar sensor (right-dominant leg, $F = 8.061$, $P = .973$; left-nondominant leg, $F = 12.755$, $P = .462$) or in the trunk sensor (right-dominant leg, $F = 2.957$, $P = .89$; left-nondominant leg, Diff. = .372, $P = .361$). The differences between the results of both studies when the test was performed with open eyes could be explained by the fact that in the study of Sawacha et al,[23] the participants did not undergo rehabilitation treatment.

The results found in the present study in the **longitudinal axis** that enables left-right rotation show that there are no significant differences in the SLS between the 2 groups. There are no similar studies in the bibliography that we could compare results of this study to, because the published studies use a pressure platform to measure

Table 3. *Mean values of the kinematic variables during 1 single–leg-stance test (trunk sensor)*

	Open eyes						Closed eyes					
	Nonaffected-dominant leg			Affected-nondominant leg			Nonaffected-dominant leg			Affected-nondominant leg		
	Stroke (SD)	Healthy (SD)	Diff. (SD)	Stroke (SD)	Healthy (SD)	Diff. (SD)	Stroke (SD)	Healthy (SD)	Diff. (SD)	Stroke (SD)	Healthy (SD)	Diff. (SD)
Flexion displacement* (°)	2.06	14.93	12.87‡	5.65	13.37	7.72‡	11.56	13.11	1.55	12.56	16.62	4.07
	(±6.29)	(±1.73)	(±2.84)	(±2.58)	(±4.74)	(±3.03)	(±4.49)	(±3.61)	(±3.05)	(±5.68)	(±8.02)	(±6.37)
Extension displacement* (°)	3.14	1.84	1.30	1.85	3.63	1.78	.58	1.46	2.05	5.47	3.33	2.13
	(±1.78)	(±2.51)	(±1.67)	(±2.09)	(±3.43)	(±2.22)	(±2.89)	(±1.58)	(±1.68)	(±.88)	(±3.04)	(±2.30)
F/E mean displacement† (°)	.45$_F$	5.13$_F$	4.68	0.06$_F$	3.16$_F$	3.10	5.15$_F$	5.09$_F$	.06	2.87$_F$	5.21$_F$	2.35
	(±4.51)	(±2.35)	(±2.36)	(±3.41)	(±3.31)	(±2.44)	(±2.37)	(±0.59)	(±1.20)	(±2.88)	(±6.88)	(±5.26)
Left rotation displacement* (°)	8.12	21.46	13.35	8.45	22.13	13.67	1.98	23.81	21.83	15.73	19.69	3.96
	(±2.94)	(±26.49)	(±15.85)	(±5.13)	(±13.04)	(±8.07)	(±3.78)	(±18.39)	(±11.03)	(±4.17)	(±21.51)	(±16.17)
Right rotation displacement* (°)	2.25	44.52	42.27	0.45	20.73	20.28	10.36	22.72	12.36	22.63	92.77	70.14
	(±0.59)	(±46.87)	(±27.95)	(±6.32)	(±22.45)	(±13.64)	(±8.02)	(±19.52)	(±12.18)	(±22.44)	(±109.31)	(±82.23)
Rotation mean displacement* (°)	2.45$_R$	11.03$_L$	13.48	2.17$_R$	1.01$_L$	3.18	7.19$_L$	6.85$_R$	14.04	4.96$_L$	26.65$_L$	21.70
	(±3.59)	(±28.11)	(±16.83)	(±5.74)	(±12.23)	(±7.69)	(±6.23)	(±10.03)	(±6.65)	(±16.31)	(±27.64)	(±21.57)
Right inclination displacement† (°)	5.92	53.12	47.21‡	7.52	20.04	12.53	12.56	22.64	10.09	25.19	85.58	60.39
	(±2.00)	(±34.79)	(±20.77)	(±7.70)	(±19.77)	(±12.26)	(±2.61)	(±8.11)	(±4.96)	(±20.26)	(±101.08)	(±73.03)
Left inclination displacement* (°)	0.78	19.17	18.38	13.24	20.69	7.45	2.75	14.02	11.27	18.55	25.36	6.81
	(±3.06)	(±25.85)	(±15.47)	(±3.82)	(±17.84)	(±10.76)	(±3.95)	(±15.93)	(±9.62)	(±15.54)	(±31.16)	(±24.03)
R/L mean inclination displacement* (°)	3.05$_R$	12.17$_R$	9.12	2.08$_L$	0.70$_L$	1.38	9.89$_R$	0.87$_R$	9.02	3.58$_R$	24.46$_R$	20.88
	(±2.15)	(±26.33)	(±15.73)	(±7.25)	(±13.99)	(±8.88)	(±5.58)	(±11.45)	(±7.29)	(±4.36)	(±25.93)	(±19.47)
Flexion velocity* (°/s)	32.56	29.37	6.71	41.72	27.41	14.31	50.44	20.03	20.43	20.91	31.79	17.45
	(±20.35)	(±29.93)	(±19.81)	(±25.29)	(±24.97)	(±18.32)	(±52.02)	(±5.87)	(±17.48)	(±1.33)	(±8.09)	(±21.05)
Extension velocity* (°/s)	36.73	30.72	6.00	34.74	29.23	5.51	29.42	20.55	24.91	30.81	27.72	13.32
	(±25.62)	(±12.67)	(±12.18)	(±34.18)	(±24.85)	(±20.68)	(±10.58)	(±5.59)	(±19.07)	(±11.75)	(±5.16)	(±34.19)
Left rotation velocity† (°/s)	36.52	27.88	8.64	41.06	21.98	19.07	40.82	20.38	30.41	32.19	49.64	10.88
	(±24.96)	(±11.86)	(±12.68)	(±22.51)	(±30.47)	(±20.50)	(±34.54)	(±8.81)	(±25.36)	(±8.23)	(±22.66)	(±6.09)
Right rotation velocity† (°/s)	27.73	26.47	1.26	62.69	19.21	43.48	44.52	19.61	8.87	62.29	48.96	3.09
	(±16.13)	(±9.60)	(±8.89)	(±25.36)	(±30.91)	(±21.31)	(±38.84)	(±5.73)	(±6.09)	(±50.55)	(±35.02)	(±6.40)
Right inclination velocity† (°/s)	37.25	26.77	10.47	38.22	22.21	16.02	50.93	21.37	29.56	48.19	26.77	21.42
	(±14.21)	(±9.56)	(±8.27)	(±25.45)	(±14.03)	(±13.61)	(±20.39)	(±9.61)	(±11.37)	(±23.41)	(±11.63)	(±13.37)
Left inclination velocity† (°/s)	36.06	25.61	10.45	41.13	25.70	15.43	36.39	25.23	11.46	55.82	37.31	18.52
	(±13.47)	(±12.81)	(±9.52)	(±22.62)	(±17.24)	(±14.02)	(±10.83)	(±16.54)	(±11.09)	(±4.50)	(±10.08)	(±7.81)
Resultant velocity (°/s), right side*	63.13	58.18	4.95	77.77	46.82	30.94	11.04	23.15	12.11	62.15	52.44	9.71
	(±30.55)	(±27.09)	(±20.66)	(±7.39)	(±34.18)	(±20.62)	(±42.30)	(±19.10)	(±6.54)	(±21.96)	(±38.44)	(±29.92)
Resultant velocity (°/s), left side*	61.71	75.45	13.74	88.76	51.05	37.71	66.33	31.06	35.27	93.22	56.25	36.97
	(±22.64)	(±31.59)	(±10.23)	(±23.96)	(±31.11)	(±21.12)	(±34.11)	(±22.16)	(±19.53)	(±34.96)	(±40.23)	(±32.83)

Abbreviations: Diff., difference; E, extension; F, flexion; L, left; R, right; SD, standard deviation.

*Parametric variables.

†Nonparametric variables.

‡Less than .05.

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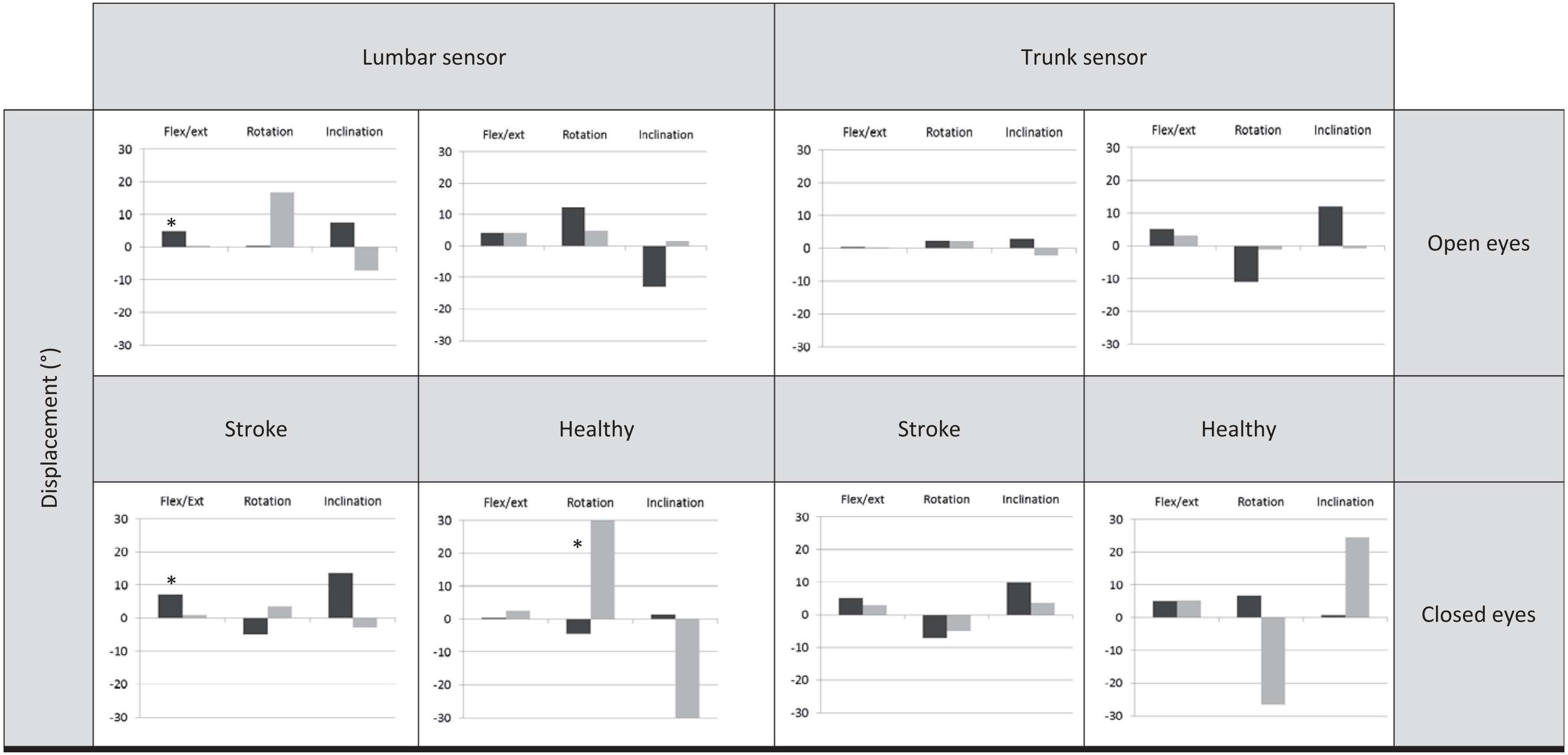

Figure 2. *Differences between legs on displacement (°).*: significant differences were found.*

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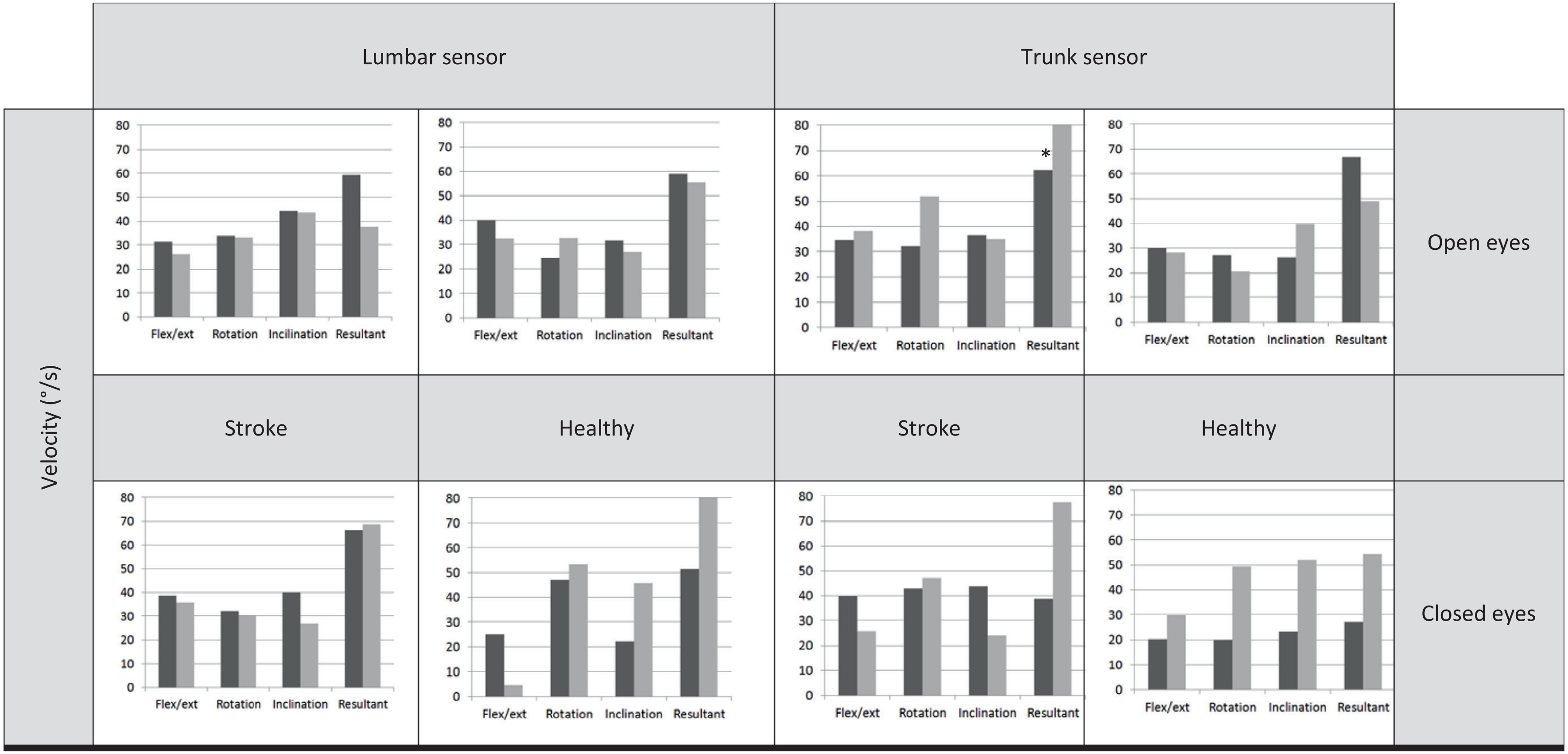

Figure 3. *Differences between legs on velocity (°/s). *: significant differences were found.*

Table 4. *Kinematic variables reliability (intraobserver and interobserver) during single–leg-stance test*

	Trunk						Lumbar					
	Intraobserver			Interobserver			Intraobserver			Interobserver		
		95% CI			95% CI			95% CI			95% CI	
Variable	ICC	Min.	Max.	ICC	Min.	Max.	ICC	Min.	Max.	ICC	Min.	Max.
Left rotation displacement (°)	.935	.911	.958	.918	.904	.934	.947	.929	.968	.927	.900	.951
Right rotation displacement (°)	.895	.874	.908	.890	.877	.913	.932	.914	.953	.914	.904	.927
Rotation mean displacement (°)	.933	.913	.954	.911	.901	.924	.919	.901	.935	.911	.899	.929
Flexion displacement (°)	.906	.897	.923	.888	.852	.906	.919	.897	.941	.901	.889	.913
Extension displacement (°)	.920	.896	.937	.906	.887	.919	.910	.893	.927	.900	.885	.917
F/E mean displacement (°)	.898	.876	.911	.887	.870	.905	.904	.885	.916	.893	.877	.904
Right inclination displacement (°)	.901	.881	.922	.893	.882	.903	.919	.903	.931	.912	.902	.926
Left inclination displacement (°)	.924	.902	9.31	.903	.880	.920	.926	.904	.951	.919	.904	.933
R/L mean inclination displacement (°)	.920	.895	.934	.898	.879	.913	.931	.918	.947	.918	.906	.949
Left rotation velocity (°/s)	.895	.873	.909	.868	.853	.891	.901	.879	.911	.894	.868	.915
Right rotation velocity (°/s)	.880	.862	.898	.872	.853	.894	.894	.877	.908	.883	.872	.897
Flexion velocity (°/s)	.894	.875	.912	.881	.864	.892	.899	.880	.912	.886	.872	.903
Extension velocity (°/s)	.879	.859	.893	.874	.861	.894	.886	.870	.906	.883	.871	.901
Right inclination velocity (°/s)	.866	.843	.887	.859	.851	.872	.879	.863	.892	.870	.853	.884
Left inclination velocity (°/s)	.881	.865	.902	.877	.856	.891	.890	.878	.905	.884	.870	.896
Resultant velocity, right side (°/s)	.869	.847	.888	.859	.846	.870	.886	.875	.895	.873	.852	.891
Resultant velocity, left side (°/s)	.880	.865	.907	.872	.857	.887	.892	.879	.909	.880	.868	.893

Abbreviations: CI, confidence interval; E, extension; F, flexion; ICC, intraclass correlation coefficient; L, left; R, right.

the kinematic data and this tool does not provide data about the third axis.

Velocity

In the present study, we did not find significant differences in velocity variables between the 2 groups except in 1 of the 64 analyzed variables (lumbar sensor, flexion velocity left-nondominant leg, closed eyes, Diff. = 22.34 [±19.36]). The velocity results presented in this study are not consistent with other published studies (Sawacha et al[23] and Wen et al[25]). In other studies, they found significant differences between healthy people and patients with stroke in the SLS, for example, Wen et al[25] (anteroposterior axis: open and closed eyes [$P < .05$], mediolateral axis: open and closed eyes [$P < .01$]) and Sawacha et al[23] (anteroposterior axis: open eyes, $P = .022$; mediolateral axis: open eyes, $P = .031$, closed eyes, $P = .015$). The differences in the results between the present study and the published studies could be explained, on the one hand, by the mean age of the participants, as the mean age of the patients with stroke (72.33 [±3.97]) was higher than the participants in the study by Wen et al[25] (55.0 [±12.8]).

In addition, as previously mentioned, another possible reason that justifies this difference can be found in the exclusion criteria of participants in the study of Sawacha et al,[23] who were excluded if they had taken part in a rehabilitation treatment.

We did not find significant differences regarding velocity data in the longitudinal axis and angular velocity either, nor did we find any study that compared the differences in these variables between patients with stroke and healthy people in dynamic, semistatic, or static balance in the consulted literature. This is because it is necessary to use inertial sensors to obtain these data and the consulted studies used platform pressure as their measurement tool.

Intrasubject Differences between Affected and Nonaffected Legs

Differences were found only in 5 of the 36 analyzed variables. Lumbar sensor differences (extension open eyes, mean flexion-extension open eyes), trunk sensor differences (extension closed eyes, mean flexion-extension closed eyes; right inclination closed eyes) (Table 4). These results are consistent with the results in healthy elderly people where significant differences have not been found in the SLS between the dominant and the nondominant leg measure with either the lumbar or the trunk sensor (Fig 2)

In the velocity results, significant differences were not found in patients with stroke (only found in 1 variable—trunk sensor, negative resultant velocity, open eyes). These results are also consistent with results in healthy elderly people where we did not find differences (Fig 3).

Although there are no previous studies that have evaluated the difference between the affected leg and the nonaffected leg in balance tests in patients with stroke and the small sample included in the present study, it is important to highlight the findings of the present study, because the fact of not showing significant differences between both legs could be a decrease of risk of falls. Even so, the results of the present study should be taken with caution, because the participants were elderly, a group in whom the neuromuscular functions of the healthy leg may be altered and, therefore, no statistically significant differences with the affected leg appear. On the other hand, we must also emphasize the rehabilitating treatment carried out by the patients included in the present study (deep-water running and stretching exercises and strengthening of the leg with 3 weekly sessions, with a total duration of 12 weeks), which could explain why no differences were found between the 2 legs.

Reliability

In the present study, we found an excellent reliability in the kinematic data in the SLS in healthy elderly people and in patients with stroke with inertial sensors located in the lumbar region and in the trunk. The values of reliability of the present study are consistent with those of Gray et al.[26]

The detailed analysis of the data highlights some points of interest. Gray et al reported values of intraobserver reliability in patients with stroke between .45 and .90 95% CI and between .35 and .96 95% CI in healthy people in the SLS. Our results are similar to those of Gray et al—in our study, we found an intraobserver reliability between .895 and .947 95% IC and an interobserver reliability between .887 and .927 95% CI.

In addition, values of reliability of SLS for velocity are shown in this study. Values for velocity reliability in the SLS have not been published previously because in most balance test studies, platform pressure, which cannot obtain velocity values, is used. We found values for intraobserver reliability between .866 and .901 95% CI and for interobserver reliability between .859 and .894 95% CI.

Strengths and Weaknesses

Inertial sensors have been used in other studies to measure kinematic parameters of balance in patients with stroke.[27,28] It is essential to use inertial sensors as they provide more details than the shift pressure platform does, because the sensors can record movement along 3 axes, whereas the pressure platform can only record along 2 axes.

Another highlight of the inertial sensors is that their use can also record the angular velocity of a gesture, which is impossible using a pressure platform, meaning that this tool provides a greater number of kinematic data.

It is important to note that the main finding of the present study is that we did not find significant differences in the SLS between healthy people and patients with stroke who undergo rehabilitation treatment, so it is essential to increase the number of participants to give more strength to these results.

Conclusions

The present study showed the absence of statistically significant differences in displacement and velocity in the SLS balance test between healthy older people and elderly people who had suffered a stroke, evaluating this test with inertial sensors. In addition, differences between the affected-dominant leg and the nonaffected-nondominant leg were analyzed without differences in the variables of displacement and speed either in the group of elderly persons who had suffered a stroke or in the group of healthy adults . Finally, we also evaluated the reliability data of the inertial sensors in the kinematic analysis of the SLS, which showed a high reliability for this purpose.

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