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ARTICLE

Balance, Lateropulsion, and Gait Disorders in Subacute Stroke

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Neurology® 2021;96:1-13. doi:10.1212/WNL.0000000000011152

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Lateropulsion: An Overlooked Driver of Balance and Gait Deficits in Stroke?

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Abstract

Objective

To test the hypothesis that impaired body orientation with respect to gravity (lateropulsion) would play a key role in poststroke balance and gait disorders.

Methods

Cohort study of 220 individuals consecutively admitted to a neurorehabilitation ward after a first hemisphere stroke (DOBRAS cohort [Determinants of Balance Recovery After Stroke] 2012–2018, ClinicalTrials.gov: NCT03203109), with clinical data systematically collected at 1 month, then at discharge. Primary outcomes were balance and gait disorders, quantified by the Postural Assessment Scale for Stroke and the modified Fugl-Meyer Gait Assessment, to be explained by all deficits on day 30, including lateropulsion assessed with the Scale for Contraversive Pushing. Statistics comprised linear regression analysis, univariate and multivariate analyses, and receiver operating characteristic curves.

Results

Lateropulsion was frequent, especially after right hemisphere stroke (RHS, D30, 48%; discharge 24%), almost always in right-handers. Among all deficits, impaired body orientation (lateropulsion) had the most detrimental effect on balance and gait. After RHS, balance disorders were proportional to lateropulsion severity, which alone explained almost all balance disorders at initial assessment (90%; 95% confidence interval [CI] [86–94], $p < 0.001$) and at discharge (92%; 95% CI 89–95, $p < 0.001$) and also the greatest part of gait disorders at initial assessment (66%; 95% CI 56–77, $p < 0.001$) and at discharge (68%; 95% CI 57–78, $p < 0.001$).

Conclusion

Lateropulsion is the primary factor altering poststroke balance and gait at the subacute stage and therefore should be systematically assessed. Poststroke balance and gait rehabilitation should incorporate techniques devoted to misorientation with respect to gravity.

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Go to Neurology.org/N for full disclosures. Funding information and disclosures deemed relevant by the authors, if any, are provided at the end of the article.

Glossary

AUC = area under the receiver operating characteristic curve; **BLS** = Burke Lateropulsion Scale; **CI** = confidence interval; **D30** = day 30 after stroke; **DOBRAS** = Determinants of Balance Recovery After Stroke; **GLM** = generalized linear model; **LHS** = left hemisphere stroke; **Lw/oP** = lateropulsion without pushing; **mFMA** = modified Fugl-Meyer Assessment; **mRS** = modified Rankin Scale; **NPV** = negative predictive value; **PASS** = Postural Assessment Scale for Stroke; **PPV** = positive predictive value; **RHS** = right hemisphere stroke; **ROC** = receiver operating characteristic; **SCP** = Scale for Contraversive Pushing.

The current theoretical model of balance control involves 2 domains devoted to body orientation with respect to gravity and to body stabilization with respect to the base of support.[1,2] This model might help in better understanding balance disorders in the clinic, in order to guide their rehabilitation. It could be especially useful after stroke[3,4] owing to the devastating sequelae induced by balance disorders,[5] which may be explained in terms of impaired body orientation or stabilization.

As early as 1900, cases of brainstem[6] or hemisphere[7] stroke showing a lateral body tilt with fall tendency were described and initially termed lateropulsion,[6] then variously according to authors' consideration for additional postural signs and lesion location. Most known terms are listing phenomenon,[8] thalamic astasia,[9,10] ease of falling,[11,12] pusher/pushing syndrome/behavior,[3,10,13–17] and biased behavioral vertical.[18] Here we adopt lateropulsion, the most frequently used.[3,6,19–25]

Lateropulsion interpretation has long erred across mechanisms involving cerebellar and motor pathways. Today, lateropulsion is considered to have a vestibular origin with different mechanisms depending on lesion location.[3,10,26] After low-brainstem lesions, lateropulsion is ipsilesional and mainly secondary to vestibulospinal disorders, inducing an asymmetric tone with a co-occurrence of vestibulo-ocular signs.[3,25,27] After hemispheric lesion, lateropulsion is contralesional, owing to an internal model of verticality tilted to the contralesional side (opposite the stroke).[3,28] Individuals align their body onto this erroneous reference of verticality,[3,18,28] possibly in relation to a damaged multimodal network.[26] At the beginning, individuals are unaware of the lateropulsion,[11,12] which strengthens the interpretation of a biased internal model of verticality.[3,29]

Severe cases of lateropulsion jeopardize the ability to walk, stand, or sit,[9,13,16,25,30] with poor recovery.[14,17,20,31] Beyond these extreme forms, which represent only 10%,[14,31] the effect of lateropulsion on balance abilities has been little investigated. A few cross-sectional studies of limited sample size have ancillarily reported a moderate correlation between lateropulsion indices and balance abilities.[30,32] To our knowledge, the effect of lateropulsion on balance capacity after stroke has never been investigated longitudinally in a large series. Our main hypothesis was that even mild forms of lateropulsion represent a key determinant of poststroke balance disorders. Indeed, any lateral body tilt generates a destabilizing effect of gravity, with a projection of the center of mass on the ground moving toward the limit of the base of support, which alters balance capacities.

For poststroke gait disorders, a common view is that they are mostly caused by sensorimotor deficits such as weakness,[33] muscular overactivity, and neuro-orthopedic complication of spasticity,[33,34] with an additional detrimental role of balance disorders.[35,36] We hypothesized that mild forms of lateropulsion also greatly affect gait abilities.

Methods

Study design

This was a monocentric observational study of the DOBRAS cohort (Determinants of Balance Recovery After Stroke; NCT03203109). Participants were comprehensively assessed twice in routine care: initially in the first weeks after entry in the rehabilitation ward, then at discharge.

We assessed balance and gait abilities as well as sensory, motor, and cognitive deficits. Assessments were performed by trained and multidisciplinary examiners, with blinding to the study hypothesis. The sample size was planned to conduct multivariate analyses in a large series of individuals (≥200 observations).

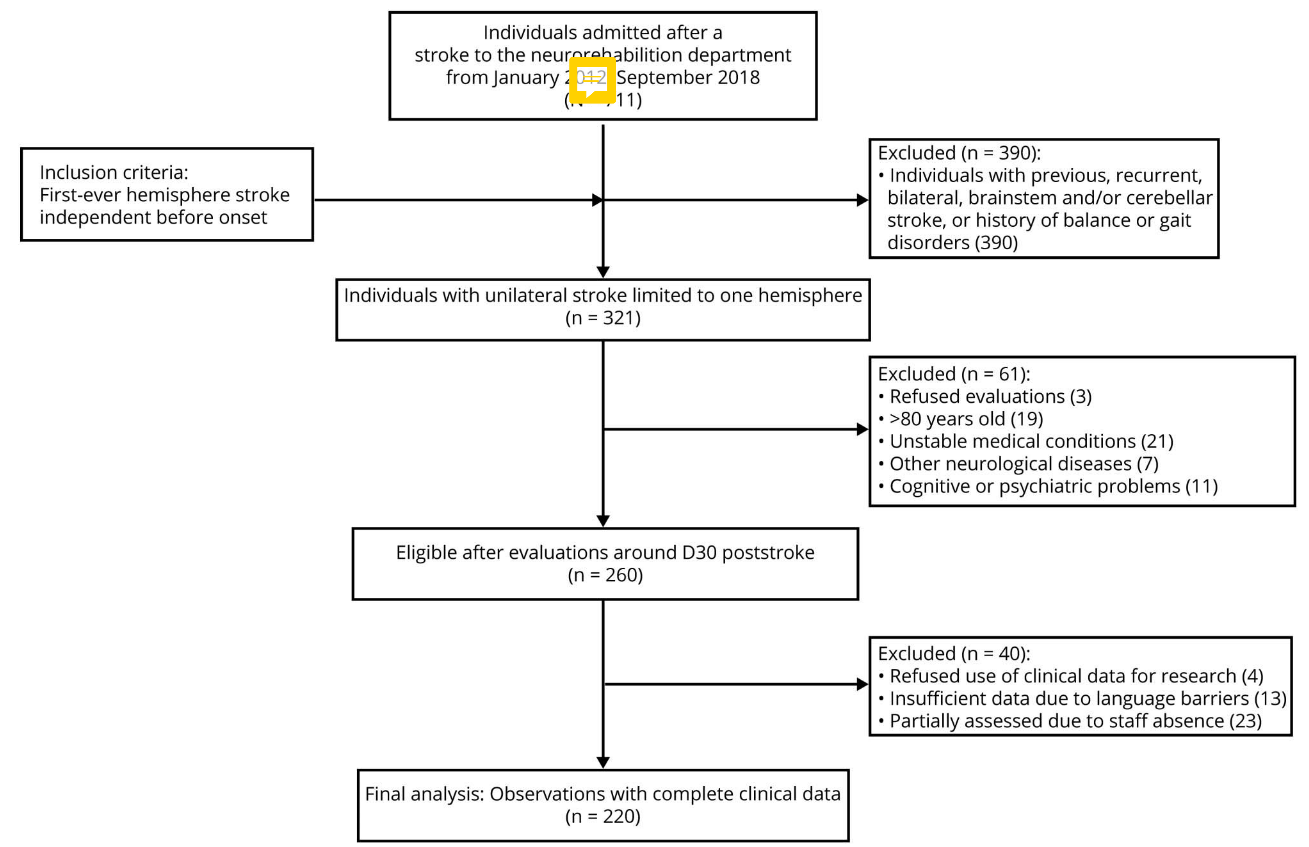
Standard protocol approvals, registrations, and patient consents

The DOBRAS cohort was approved by our institutional review board (CHU Grenoble Alpes) who validated the ClinicalTrials.gov registration (NCT03203109). The study was also registered at the National Committee for Informatics and Freedom (Commission Nationale Informatique et Liberté; CNIL-No.2014874-v1) and was performed in accordance with the Helsinki Declaration. According to French law, observational studies do not require approval by an ethics committee, provided that participants have been informed of the specific research and are not opposed to use of their data. All eligible individuals were informed of the DOBRAS study (orally and in writing) and those who did not want to participate signed an opposition form.

Participants

From January 2012 to September 2018, we included 220 consecutive individuals (figure 1). Inclusion criteria were age ≥18–80 years and a first-ever unilateral stroke limited to one hemisphere (right hemisphere stroke [RHS] or left hemisphere stroke [LHS]). Exclusion criteria were recurrent stroke; complication at the acute stage (malignant infarct, cerebral herniation, subarachnoid hemorrhage, hydrocephalus); dementia; [F1]

Figure 1 Flow of participants in the study



previous disability interfering with balance, gait, or vestibular disorders; unstable medical condition or psychiatric problems; or not French-speaking. These conditions were obtained from the hospital electronic file describing the history of every patient, by interviewing patients and relatives, and by a systematic clinical examination. Patients followed a personalized rehabilitation program, taking into account deficits and activity limitations. According to their abilities, individuals had 2 physiotherapy and 1 occupational therapy sessions per day (total 1 hour 30 minutes), plus, if needed, sessions with a speech therapist, neuropsychologist, psychologist, or orthoptist.

Assessments

We conducted the initial assessments at about day 30 after stroke (D30) with a window of 3 days before and after to start and complete assessments. This date is a compromise between the desire to collect data as early as possible after the stroke and the need for sufficient medical stability and attentional resources to afford a battery of comprehensive assessments performed during several days, at a time when almost all individuals have been admitted to the rehabilitation ward. Among the 220 participants, 207 (94%) were admitted during the first month poststroke and so were assessed on D30. For the 13 others admitted after D30 (6%), the initial assessment was also performed in due time, on day 60 (window of 3 days before and after). These initial assessments collected information about handedness, all deficits, postural and gait disorders, and disability. All variables collected are listed below. The second assessment was performed at discharge and only focused on postural and gait disorders.

Global disability was estimated by the modified Rankin Scale (mRS).

Handedness before stroke was assessed by interview (patient, relatives) by using a French translation of the Edinburgh inventory. Right-handedness was considered with a score >0.4.

To assess body orientation with respect to gravity in the frontal plane, we used the Scale for Contraversive Pushing (SCP).[15] The SCP assesses the 3 components of the pusher syndrome defined by Davies,[13] that is, contralesional lateral body tilt (while sitting and standing), active pushing of the unaffected arm or leg to the contralesional side (while sitting and standing), and resistance to passive correction of posture (while sitting and standing). The total score ranges from 0 to 6. As defined in the original article,[15] individuals who met these 3 criteria with at least 1 point for each were considered pushers. As proposed previously,[3] we also used the SCP to differentiate individuals with an upright posture from those who were mildly tilted. To be conservative, we used the same SCP cut-off >0.5 as in a previous article,[3] which classifies as having a lateropulsion without pushing (Lw/oP) according to the SCP scoring only individuals who showed net lateral body tilt at least in one posture, sitting or standing, but without pushing or resistance. So constituted, the 3 groups corresponded to individuals differently oriented with respect to gravity: individuals upright were correctly oriented, individuals showing Lw/oP presented a moderate deficit in orientation with respect to gravity, and pushers presented a severe deficit in orientation with respect to gravity. We also used SCP scores to test relationships with balance and gait scores. Details on the validity of these approaches are given in the study limitations.

Balance disorders were assessed with the Postural Assessment Scale for Stroke (PASS),[32] the most appropriate balance scale at the subacute stage after stroke.[37,38] The total score ranges from 0 to 36 (satisfactory balance), and a score ≥28 indicates the ability to stand independently without any help.[32]

Gait disorders were assessed with the modified chart of the Fugl-Meyer Assessment (mFMA), designed to classify poststroke gait with 7 levels of mobility.[39] The mFMA ranges from 0 (no mobility) to 6 (normal gait), and a score ≥5 indicates the ability to walk independently without a cane (or rollator).

Deficits were assessed by means of a comprehensive battery of tests. Spatial neglect (body and nonbody domains) was assessed with a battery of 6 tests: ecological Catherine Bergego Scale,[40] thumb finding,[40] Fluff (since 2014)[41] and Bells tests,[40] line bisection,[40] and drawing copy.[40] The Catherine Bergego Scale result was considered normal with score <2, moderately altered with score ≥2, and markedly altered with score ≥15. The thumb finding test result was considered abnormal with score >0. The Fluff test result was considered normal with ≥13 targets detached, moderately altered with ≥9 targets detached, and markedly altered with <9 targets detached. The Bells test result was considered normal with ≤6 omissions, moderately altered with ≤15 omissions, and markedly altered with >15 omissions. The line bisection (20 mm) result was considered normal at ≤7 mm, moderately altered at ≤10 mm, and markedly altered at >10 mm. The Gainotti copy result was considered abnormal if >0 omissions. A few individuals with severe comprehension (aphasia) or executive troubles were not able to complete the whole neglect battery but had to perform at least 3 tests to not be considered with missing data. Spatial neglect was considered absent if all test results were normal or slight if only one test result was marginally altered, severe with results of least 2 tests markedly altered (altered if binary categorized), or moderate otherwise.

The presence of aphasia was evaluated by the gravity section of the Boston Diagnostic Aphasia Examination; a score <5 was considered aphasia. Apraxia was assessed by the Apraxia Screen of Tulia[42] and participants with a score <9 had a diagnosis of upper limb apraxia.

Motor weakness was assessed by a standardized examination of muscle strength adapted for participants with central neurologic disorders.[18,32] Eight muscle groups of both the upper and lower limb were tested, and the final score was then adjusted to range from 0 to 80 (normal strength). Light weakness was considered a score >64/80 (every muscle had a motor command of 4/5, on average), severe weakness a score ≤32 (every muscle had a motor command of ≤2/5, on average), and moderate weakness otherwise. Spasticity was assessed with the Ashworth Scale.[18,32] Five muscle groups of both the upper and lower limb were tested, and the final score was adjusted to range from 0 to 40 (extremely severe and diffused spasticity). Participants were classified as follows in terms of spasticity: no or light (0–4), moderate or severe (>4).

Hypoesthesia was manually tested on both contralesional upper and lower limbs by trained physicians who assessed tactile and pain sensibility.[18,32] Participants were classified as having no or light hypoesthesia if errors were seldom, moderate hypoesthesia if detection errors were frequent, and deep hypoesthesia if they did not perceive any stimuli. Hemianopia was manually tested by trained physicians.

Depression was assessed by the Aphasia Depression Rating Scale[43]; participants with scores >8 were considered depressed.

Statistical analysis

Continuous data are presented as median with interquartile range (Q1–Q3) and dichotomized and categorical data as number (%). When useful, 95% confidence intervals (CIs) are given.

Data for upright, Lw/oP, and pusher groups were compared by the Mann-Whitney U test or χ^2 test (Fisher exact test). Effect sizes were calculated by using the Z values of the Mann-Whitney test, $r = Z/\sqrt{n}$, and the X^2 of the χ^2 test, $v = \sqrt{(X^2/n \times \text{degree of freedom})}$. With $p < 0.05$, effect sizes are given; values 0.1, 0.3, and 0.5 represent a small, medium, and large effect for both the Mann-Whitney test and χ^2 test.

The relationship of balance and gait was analyzed by linear regression. Our primary hypothesis was that lateropulsion would be the most detrimental determinant on balance and gait disorders. All the clinical features related to balance and gait disorders were first analyzed by nonparametric univariate analysis (Kruskal-Wallis or Mann-Whitney U test). The significant p values for univariate analyses were adjusted to 0.004 (0.05/12) owing to multiple comparisons. Variables with $p <$ 0.004 on univariate analysis were selected for the multivariate regression model. Because PASS and mFMA scores followed a Poisson distribution, we used a generalized linear model (GLM, Poisson regression).

Then we analyzed the consequences of a misorientation with respect to gravity on balance and gait abilities by using linear regression on initial and discharge data. Owing to the well-known RHS predominance for postural control,[3,4,17,18,31,32] we separately analyzed RHS and LHS.

Table 1 Clinical Data for Participants as a Function of Lateropulsion in 3 Categories

Characteristics	All (n = 220)	Upright (n = 158)	Lw/oP (n = 32)	Pushers (n = 30)	Upright vs Lw/oP	Upright vs pushers	Lw/oP vs pushers
Female	[illegible]	49 (31)	11 (34)	13 (43)	v = 0.03	v = 0.1	v = 0.09
Age, y	66.9 (58–73)	66.2 (54–72)	66 (60–71)	70.4 (64–76)	*r* = −0.03	*r* = −0.21	*r* = −0.28
Right-handers	198 (90)	138 (87)	30 (94)	30 (100)	v = 0.07	v = 0.15	v = 0.18
Stroke features							
Test date, D30	207 (94)	151 (96)	29 (91)	27 (90)	v = 0.08	v = 0.09	v = 0.01
Stroke type, infarct	183 (83)	133 (84)	26 (81)	24 (80)	v = 0.03	v = 0.04	v = 0.02
Stroke side, right hemisphere	94 (43)	49 (31)	20 (63)	25 (83)	v = 0.24	v = 0.39	v = 0.23
Modified Rankin scale score (0–6)	3 (2–4)	3 (2–3)	4 (4–4)	5 (4–5)	*r* = −0.58	*r* = −0.65	*r* = −0.56
Length of hospital stay, d, onset to discharge	81 (51–138)	64 (45–91)	151 (113–180)	169 (143–202)	*r* = −0.47	*r* = −0.55	*r* = −0.19

Abbreviations: D30 = day 30 (others were tested at day 60); Lw/oP = lateropulsion without pushing; pusher = lateropulsion with pusher syndrome; *r* = effect size of the Mann-Whitney test; v = effect size of χ^2 test.
Data are n (%) or median (Q1–Q3), unless stated otherwise.

We further investigated these relationships and tested the value of initial SCP scores to predict the ability to stand (PASS ≥28) or walk independently (mFMA ≥5) at discharge. We plotted receiver operating characteristic (ROC) curves and calculated areas under the ROC curve (AUC). Optimal cutoff values were determined by the Youden Index. From the SCP cutoff values, we calculated sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV).

Missing data were few, so imputation was not performed. As recommended,[44] *p* values were limited to the main hypothesis, with 2-sided $p < 0.05$ considered statistically significant. Only CIs and effect sizes were given for analyses of secondary endpoints. Statistical analysis involved using SPSS 21.0.

Data availability

Anonymized data that support the findings of this study are available from the corresponding author, upon reasonable request.

Results

[T1] Clinical data for the 220 individuals investigated are presented in table 1. Their median age was 66.9 years (Q1–Q3 58–73), 147 were male (67%), and most were right-handed (90%) and with infarcts (83%). The median mRS score was 3 (2–4); 150 (68%) individuals had moderate or severe disability (mRS score >2). The median hospital stay in the rehabilitation ward was 81 days (range 51–138).

Missing initial data concerned spatial neglect (n = 2), apraxia (n = 5), hemianopia (n = 1), and depression (n = 9). Discharge data could not be collected for 3 (1%) individuals (2 deaths, 1 urgent transfer).

In this series, 158 individuals (72%) were considered upright, with 2 scenarios: 146 (66%) sat and stood perfectly upright (including 1 who exhibited pushing when changing positions in standing), and 12 (6%) showed some degree of isolated body tilt in sitting or standing, without fall tendency. The 62 others (28%) were considered misoriented with respect to gravity in erect posture; among them, 32 (15%) showed Lw/oP and 30 (14%) were pushers. Individuals with lateropulsion were almost all right-handed (97%), and pushers were all right-handed, which indicates that the orientation of the self with respect to gravity relies on a lateralized brain function. Lateropulsion (with or without pushing) prevalence was much greater after RHS than LHS (45/94 [48%] vs 17/126 [13%]; v = 0.38), which indicates a strong right-hemisphere predominance for the upright orientation (lateropulsion 3.7 times more frequent after RHS than LHS).

Relationship between gait and balance disorders

Balance and gait scores were highly correlated, both initially ($r = 0.89$, $p < 0.001$) and at discharge ($r = 0.86$, $p < 0.001$), which indicates that balance capacities highly explained the information contained in gait capacities: 79% (95% CI 75–84) initially (about 1 month) and 74% (95% CI 68–80) at discharge.

Determinants of balance and gait abilities

We sought determinants of balance and gait disorders from initial data. On univariate analyses, only 2 variables did not affect balance or gait (stroke type and aphasia), and 2 did not affect gait (age and stroke side) (table 2). All other variables [T2] were kept in the multivariate analyses (table 2).

For balance disorders, the GLM revealed only 3 deficits with an independent detrimental role: lateropulsion, weakness, and hypoesthesia when severe. The model was sound with

Table 2 Univariate and Multivariate Analysis of Effect of Clinical Features on Balance Disorders and Gait Disorders

	Balance				Gait			
	PASS, median (Q1–Q3)	*p* Value[a] (univariate)	Exp (β) (95% CI)	*p* Value (multivariate)	mFMA, median (Q1–Q3)	*p* Value[a] (univariate)	Exp (β) (95% CI)	*p* Value (multivariate)
Age, y								
≤60 (n = 67)	33 (28–36)	0.003	1		5 (3–6)	0.012		
>60 (n = 153)	32 (19–34)		1 (0.9–1)	0.161	3 (0–6)			
Stroke type								
Infarct (n = 183)	32 (22–35)	0.374			4 (1–6)	0.97		
Hemorrhage (n = 37)	30 (24–34)				3 (2–5)			
Stroke side								
Left (n = 126)	33 (29–36)	<0.001	1		4.5 (3–6)	0.012		
Right (n = 94)	29 (16–34)		1 (1–1.1)	0.831	3 (0–6)			
Lateropulsion								
Upright (n = 158)	34 (31–36)		1		5 (3–6)		1	
Lw/oP (n = 32)	20.5 (18–25)	<0.001	0.9 (0.8–1)	0.037	0.5 (0–2)	<0.001	0.6 (0.3–0.9)	0.014
Pushers (n = 30)	8 (3–15)		0.4 (0.3–0.5)	<0.001	0 (0–0)		0.1 (0–0.2)	<0.001
Spatial neglect								
No or light (n = 120)	34.5 (32–36)		1		5 (4–6)		1	
Moderate (n = 54)	30 (21–33)	<0.001	1 (0.9–1.1)	0.912	3 (1–5)	<0.001	1 (0.8–1.2)	0.942
Severe (n = 44)	14 (6–19)		1 (0.9–1.2)	0.94	0 (0–0)		0.9 (0.5–1.7)	0.838
Aphasia								
No (n = 131)	32 (21–35)	0.801			4 (1–6)	0.951		
Yes (n = 89)	32 (24–35)				4 (2–6)			
Apraxia								
No (n = 169)	33 (26–36)	<0.001	1		5 (2–6)	0.003	1	
Yes (n = 46)	26.5 (13–32)		1 (0.9–1.1)	0.419	3 (0–5)		0.9 (0.7–1.2)	0.484

Continued

Table 2 Univariate and Multivariate Analysis of Effect of Clinical Features on Balance Disorders and Gait Disorders *(continued)*

	Balance				Gait			
	PASS, median (Q1–Q3)	*p* Value[a] (univariate)	Exp (β) (95% CI)	*p* Value (multivariate)	mFMA, median (Q1–Q3)	*p* Value[a] (univariate)	Exp (β) (95% CI)	*p* Value (multivariate)
Weakness								
Light (n = 109)	35 (33–36)		1		6 (5–6)		1	
Moderate (n = 61)	29 (24–33)	<0.001	0.9 (0.8–1)	0.001	3 (2–3)	<0.001	0.6 (0.5–0.8)	<0.001
Severe (n = 50)	13 (7–20)		0.7 (0.6–0.7)	<0.001	0 (0–0)		0.2 (0.1–0.3)	<0.001
Spasticity								
No or light (n = 156)	33.5 (30–36)	<0.001	1		5 (3–6)	<0.001	1	
Moderate or severe (n = 64)	21 (12–30)		1 (0.9–1.1)	0.694	1 (0–3)		1 (0.8–1.2)	0.793
Hypoesthesia								
No or light (n = 57)	35 (34–36)		1		6 (5–6)		1	
Moderate (n = 103)	32 (29–35)	<0.001	1 (0.9–1)	0.404	4 (3–6)	<0.001	0.9 (0.8–1.1)	0.234
Severe (n = 60)	17 (8–26)		0.9 (0.8–1)	0.002	0 (0–3)		0.8 (0.6–1)	0.086
Hemianopia								
No (n = 146)	33 (29–36)	<0.001	1		5 (3–6)	<0.001	1	
Yes (n = 73)	26 (15–33)		1 (0.9–1)	0.257	2 (0–5)		1 (0.8–1.2)	0.983
Depression								
No (n = 87)	34 (30–36)	<0.001	1		5 (3–6)	<0.001	1	
Yes (n = 124)	30 (19–34)		1 (0.9–1)	0.54	3 (0–5)		1 (0.8–1.1)	0.524

Abbreviations: CI = confidence interval; Lw/oP = lateropulsion without pushing; mFMA = modified Fugl-Meyer Assessment gait scale; PASS = Postural Assessment Scale for Stroke.
Data are median (Q1–Q3). Missing data: spatial neglect (n = 2), apraxia (n = 5), hemianopia (n = 1), and depression (n = 9).
[a] Significant *p* value for univariate analyses adjusted as 0.004 (0.05/12) owing to multiple comparisons.

Table 3 Initial and Discharge Data of Balance and Gait for Participants as a Function of Lateropulsion in 3 Categories

	All (n = 220)	Upright (n = 158)	Lw/oP (n = 32)	Pushers (n = 30)	Upright vs Lw/oP	Upright vs Pushers	Lw/oP vs Pushers
D30							
Body orientation against gravity, SCP (0–6)	0 (0–1.3)	0 (0–0)	1.8 (1.3–2.4)	4.8 (4–6)	r = −0.87 p < 0.001	r = −0.86 p < 0.001	r = −0.86 p < 0.001
Balance, PASS (0–36)	32 (22–35)	34 (31–36)	20.5 (17–24)	8 (3–15)	r = −0.57 p < 0.001	r = −0.63 p < 0.001	r = −0.74 p < 0.001
Gait, mFMA (0–6)	4 (1–6)	5 (3–6)	0.5 (0–2)	0 (0–0)	r = −0.58 p < 0.001	r = −0.64 p < 0.001	r = −0.49 p < 0.001
Discharge							
Body orientation against gravity, SCP (0–6)	0 (0–0)	0 (0–0)	0 (0–0)	1.6 (0.4–3.1)	r = −0.22 p = 0.003	r = −0.79 p < 0.001	r = −0.66 p < 0.001
Balance, PASS (0–36)	34 (32–36)	35 (34–36)	32 (29–33.5)	24.5 (16.5–31)	r = −0.42 p < 0.001	r = −0.57 p < 0.001	r = −0.53 p < 0.001
Gait, mFMA (0–6)	5 (4–6)	6 (5–6)	4 (3–5)	2 (0.5–4)	r = −0.43 p < 0.001	r = −0.53 p < 0.001	r = −0.39 p = 0.003

Abbreviations: Lw/oP = lateropulsion without pushing; mFMA = modified Fugl-Meyer Assessment gait scale; PASS = Postural Assessment Scale for Stroke; pusher = lateropulsion with pusher syndrome; SCP = Scale for Contraversive Pushing. r = effect size of the Mann-Whitney test. Data are median (Q1–Q3).

strong likelihood (X^2 = 806.2, p < 0.001). Lateropulsion was the strongest determinant of balance disorders, with PASS scores multiplied by a β coefficient of 0.4 (95% CI 0.3–0.5, p < 0.001) for pushers or 0.9 (95% CI 0.8–1, p = 0.037) with Lw/oP, everything being equal as compared with upright individuals. Weakness also had a negative effect on balance ability, with PASS scores multiplied by a β coefficient of 0.7 (95% CI 0.6–0.7, p < 0.001) with severe weakness and 0.9 (95% CI 0.8–1, p = 0.001) with moderate weakness. Severe hypoesthesia was an independent factor affecting balance, with PASS scores multiplied by 0.9 (95% CI 0.8–1, p = 0.002).

For gait disorders, the GLM revealed only 2 deficits with an independent detrimental role: lateropulsion and weakness. The model was sound with strong likelihood (X^2 = 390.4, p < 0.001). Gait scores were multiplied by a β coefficient of 0.1 (95% CI 0–0.2, p < 0.001) for pushers, so no participant was able to walk independently, and 0.6 (95% CI 0.3–0.9, p = 0.014) for individuals with Lw/oP. Beyond the pusher feature, gait ability was affected by mild forms of lateropulsion, whereas 92% of upright individuals could walk without human aid. Weakness had also a strong independent effect on gait ability, with a β coefficient of 0.2 (95% CI 0.1–0.3, p < 0.001) with severe weakness and 0.6 (95% CI 0.5–0.8, p < 0.001) with moderate weakness.

Postural, balance and gait recovery

[T3] Table 3 shows that individuals who were initially tilted with respect to gravity were better oriented at discharge, with a large effect size both with Lw/oP (r = −0.62) and for pushers (r = −0.61). The predominance of lateropulsion after RHS was even greater than initially: RHS (22/92 [24%]) vs LHS (2/125 [2%], v = 0.35). At discharge, lateropulsion was 12 times more frequent after RHS than LHS, in which the prevalence became negligible.

At discharge, balance (r = −0.49) and gait (r = −0.46) abilities were both much better in the whole series and in each group (with moderate to large effect sizes).

Mobility limitation as a function of body orientation with respect to gravity

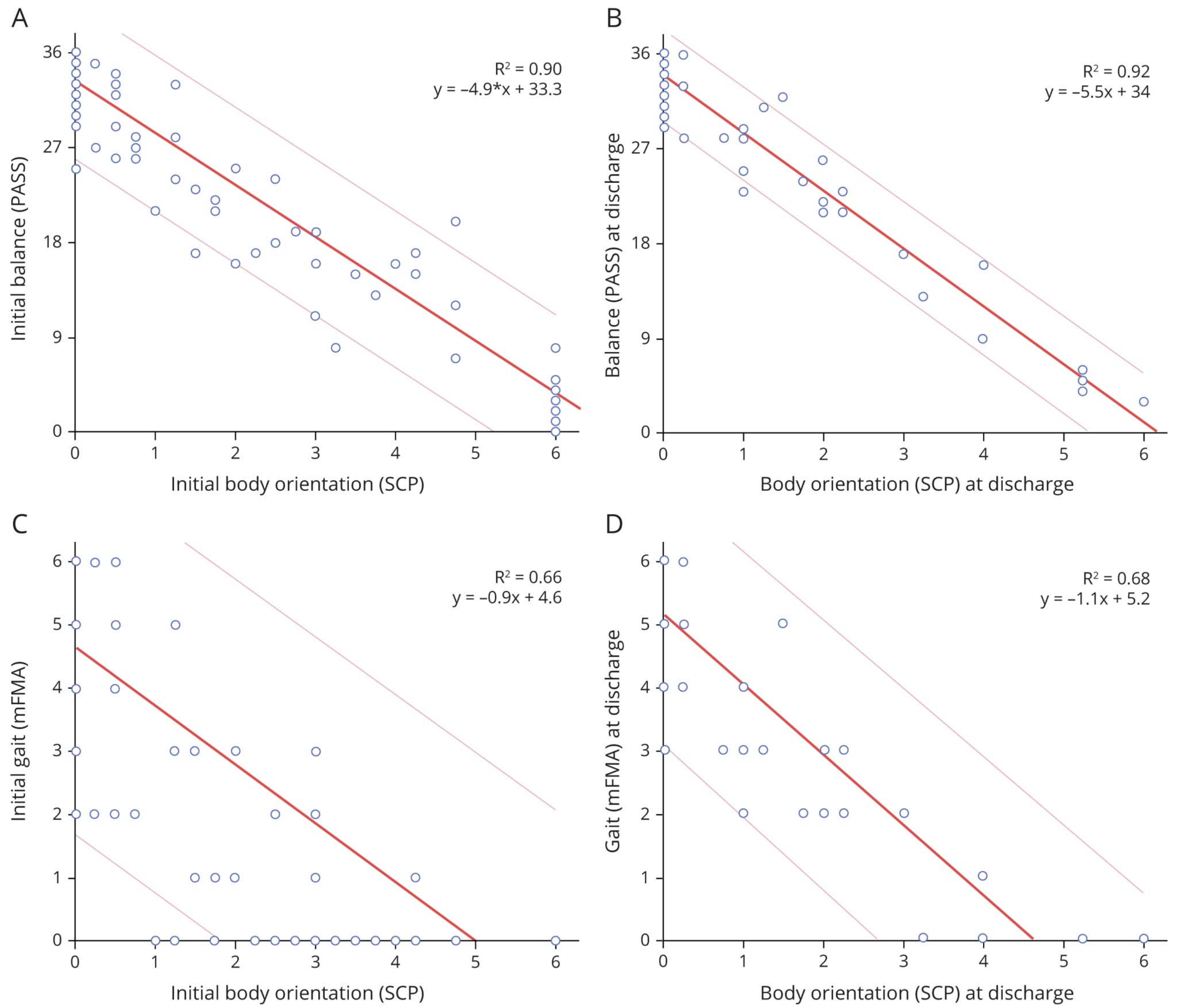
Balance and gait capacities greatly depended on body orientation against gravity (table 3). Upright individuals had much better balance and gait capacities than others. Individuals with Lw/oP had much better balance and gait capacities than pushers. All differences had p values ≤0.003 with moderate to large effect sizes, both initially and at discharge. As a corollary, the length of hospital stay (stroke onset–discharge of the rehabilitation ward) for individuals with lateropulsion was much longer than that of upright individuals (164 days [126–192] vs 64 days [45–91]; r = −0.62).

Body orientation with respect to gravity explains mobility limitation

After RHS, lateropulsion explained almost all the information contained in balance disorders: 90% (95% CI 86–94, p < 0.001) initially (about 1 month after onset) (figure 2A) and [F2] 92% (95% CI 89–95, p < 0.001) at discharge (figure 2B) and also the greatest part of gait disorders: 66% (95% CI 56–77, p < 0.001) initially (figure 2C) and 68% (95% CI 57–78, p < 0.001) at discharge (figure 2D).

After LHS, lateropulsion also explained a substantial part of mobility limitation initially: 59% (95% CI 48–69, p < 0.001) of balance disorders and 43% (95% CI 30–56, p < 0.001) of gait

Figure 2 Relationship between body orientation with respect to gravity and balance/gait capacities after right hemisphere stroke



(A, C) Initial data (about 1 month after onset). (B, D) Data collected at discharge. All the linear regressions were valid because of high R^2 and fit Durbin-Watson statistics ranging from 1.8 to 2.2 (Durbin-Watson A = 2; B = 1.9; C = 2; D = 2.2). mFMA = modified Fugl-Meyer Assessment gait scale; PASS = Postural Assessment Scale for Stroke; SCP = Scale for Contraversive Pushing.

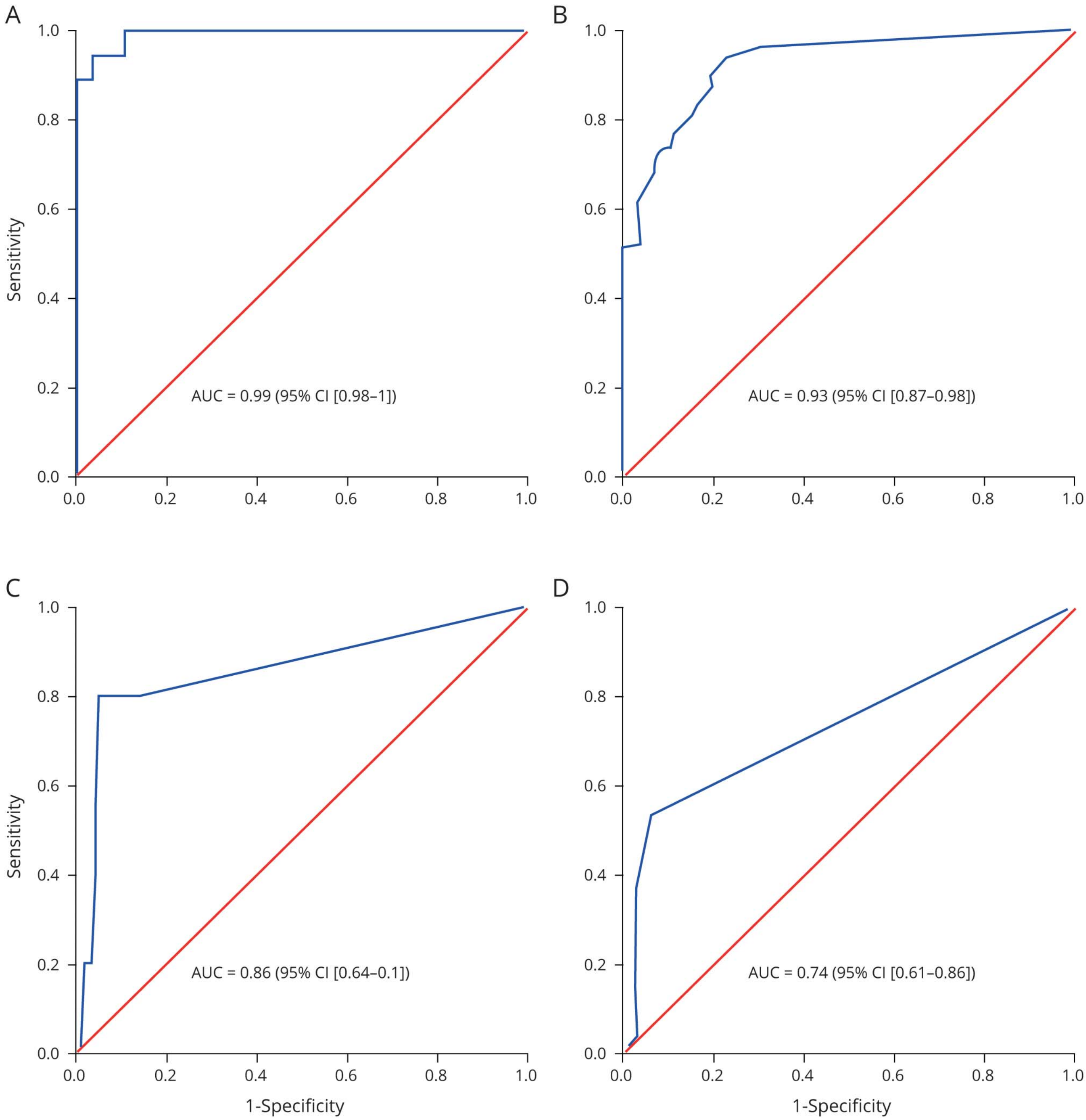
disorders. No analysis was performed at discharge for LHS because only 2/125 (2%) individuals still presented lateropulsion.

Initial Body Orientation Predicts Balance and Gait at Discharge

ROC curves were plotted from initial SCP scores and dichotomized balance (erect stance) and gait (independent [F3] walking) abilities at discharge (figure 3) for RHS and LHS.

For RHS, the AUC was 0.99 (95% CI 0.98–1) for balance (figure 3A) and 0.93 (95% CI 0.87–0.98) for gait (figure 3B). The SCP cutoff values calculated from the Youden Index were 3.5 for balance (sensitivity 0.94, specificity 0.96, PPV 0.86, NPV 0.99) and 1 for gait (sensitivity 0.9, specificity 0.8, PPV 0.67, NPV 0.95). Low values of these indices were satisfactory predictors of good recovery. Specifically, individuals with an initial SCP score <3.5 would be able to stand independently at discharge (probability 99%, 95% CI 92–100), and individuals with an initial SCP score <1 (upright or light lateropulsion) would be able to walk without any help at discharge (probability 95%, 95% CI 87–98). For LHS, the AUC was 0.86 (95% CI 0.64–0.1) for balance and only 0.74 (95% CI 0.61–0.86) for gait. For balance, the SCP cutoff value calculated from the Youden Index was 2 (sensitivity 0.8, specificity 0.95, PPV 0.45, NPV 0.99), so that individuals with an initial SCP score <2 would be able to stand independently at discharge (probability 99%, 95% CI 95–100). No other robust prediction was possible with LHS (figure 3, C and D).

Figure 3 Initial body orientation predicts balance and gait at discharge



Scale for Contraversive Pushing (SCP) score predicts balance and gait abilities in individuals after a right hemisphere stroke (RHS, A [balance] + B [gait]) (n = 92 at discharge) and a left hemisphere stroke (LHS, C [balance] + D [gait]) (n = 125 at discharge). Receiver operating characteristic (ROC) curves predicting, from the initial SCP score, the inability to stand without assistance (Postural Assessment Scale for Stroke [PASS] score <28) at discharge after RHS (A) and LHS (C). ROC curves predicting, from the initial SCP score, the inability to walk independently without a cane or rollator (modified Fugl-Meyer assessment [mFMA] score <5) after RHS (B) and LHS (D). AUC = area under the ROC curve; CI = confidence interval.

Discussion

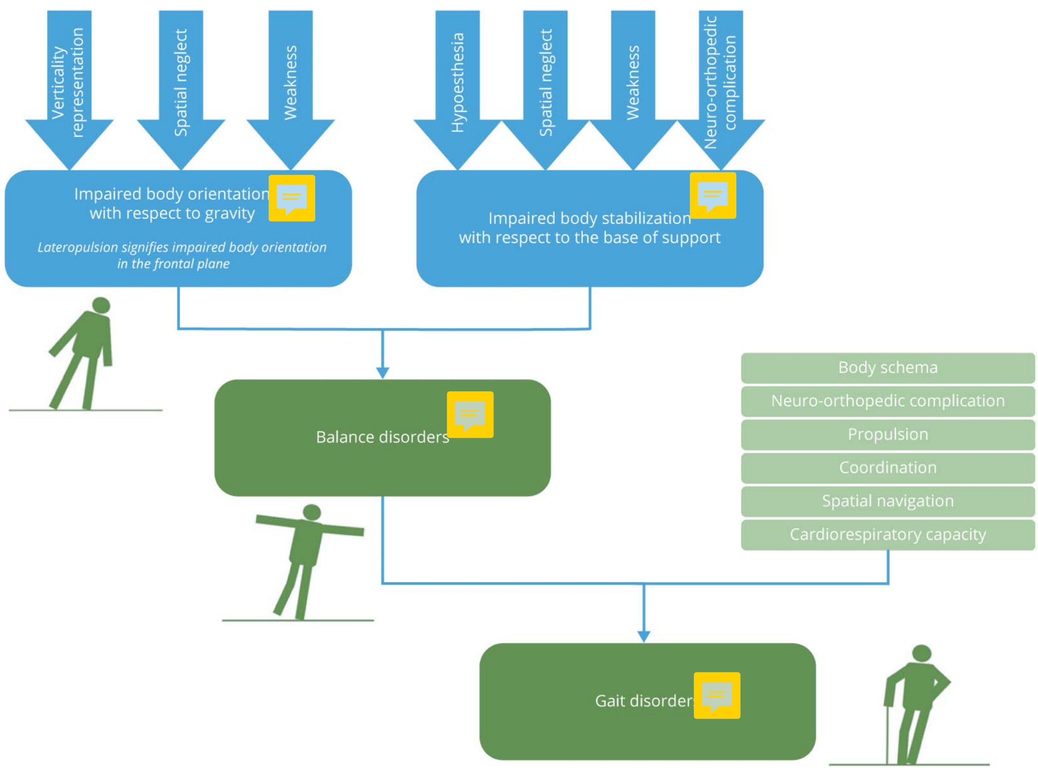
To reduce the destabilizing effect of gravity, the body must be oriented vertical, which corresponds to 1 of the 2 domains of postural control.[1,2] Here we analyzed the contribution of an impaired body orientation in the frontal plane (known as lateropulsion) on daily life balance and gait disorders after stroke. Our findings reveal that lateropulsion is the primary cause of balance and gait disorders at the subacute stage after stroke. This finding contradicts a general feeling that the key problem deals with the stabilization component of balance control. It is of major importance for poststroke balance and gait rehabilitation, which should be rethought.

In a series of 220 nonselected individuals with a first hemisphere stroke, we found that at initial assessment (D30), most individuals with an LHS remained upright (87%), whereas half with RHS showed lateropulsion (48%), almost always in right-handers (97%). Therefore, the control of uprightness is a highly lateralized brain function, mainly located in the right hemisphere, which justifies our approach to separately analyze RHS and LHS. This analysis requires 4 subgroups of individuals, therefore a large series. Only 2 studies have addressed this question in a large series (>200) of consecutive individuals.[14,31] When individuals were assessed early in the acute stroke unit, no significant RHS predominance was found,[14] whereas an RHS predominance was found when individuals were assessed later at entry in the rehabilitation unit.[31] Together with these 2 studies, ours clearly demonstrates that the gradient RHS/LHS for lateropulsion increases as a function of time after stroke: lateropulsion 1.3 times more frequent after RHS than LHS a few days poststroke,[14] 1.8 times more frequent at admission to rehabilitation,[31] 3.7 times more frequent on D30 (our study), and 12 times more frequent at rehabilitation discharge (our study). We assume that this finding might be related to a possible diaschisis,[45] altering the functioning of both hemispheres during the days following the stroke, whatever the side, because lateropulsion may result from similar lesions of both hemispheres.[22] The release of the diaschisis should increase the predominance of the right hemisphere for processing spatial information, including control of the upright. This suggestion remains to be demonstrated by further studies. Beyond the underlying mechanisms, our findings explain why the recovery of balance and gait disorders is worse after RHS than LHS, a well-known finding.[4]

Lateropulsion plays a primary role in balance and gait disorders during the subacute phase after hemisphere stroke. In RHS, balance disorders were quasi-proportional to lateropulsion severity, which explained them almost entirely in initial and discharge assessments. This novel finding has a major scope because of the high lateropulsion prevalence and the great impact of balance disorders on autonomy.

These results bring new insights into how to conceive post-stroke balance and gait disorders (figure 4), so far considered [F4] to result from motor and tone deficits[4,33] and from spatial neglect,[4,32,46,47] thus leading to impaired postural stabilization and walking propulsion.[36,46,47] An interesting result of our study is that at the subacute stage, gait disorders are mainly due to balance disorders. Overall, from a comprehensive battery of deficits and appropriate multivariate analyses, our study shows that sensory-motor deficits and spatial neglect are less determinant than are deficits in body orientation to generate postural and gait disorders. Thus, lateropulsion is a key determinant of balance and gait disorders at the subacute phase after stroke. Our results advocate for better considering lateropulsion as a rehabilitation target and the need to design

Figure 4 Theoretic model of balance and gait disorders after stroke



We considered the clinical application of the theoretical model of balance control.[1,2] At the subacute stage after stroke, body misorientation (lateropulsion) is the primary cause of balance disorders, which mostly explains gait disorders.

and validate novel techniques and programs partly supported by modulations of the internal model of verticality.[3,29]

Predicting recovery is of great importance for patients and their relatives. It has been repeatedly shown that balance capacity in the first weeks after the stroke is a good indicator of final gait ability and falls occurrence.[35,48] Our study goes further by showing that a satisfactory orientation with respect to gravity (no lateropulsion) predicts a good balance and gait recovery, with very high accuracy. After an RHS, individuals with an initial SCP score <3.5 would be able to stand independently at discharge (probability 99%). In other words, lateropulsion severity at D30 determines the long-term walking prognosis.

Data were collected by a multidisciplinary team that was well-trained and motivated, with few missing data given the large sample size and the study duration. Evaluators were therapists, and blinding was not possible or beneficial in this observational study. To ensure nonbiased assessments, therapists and patients were not informed of the study hypothesis.

How we assessed the orientation with respect to gravity might be viewed as a limitation. Lateropulsion is currently assessed with the Burke Lateropulsion Scale (BLS)[19,23,24] or the SCP.[23,24] The BLS assesses lateropulsion in erect and also recumbent postures. Because we wanted to focus on behaviors against gravity, we used the SCP, which is also reliable,[24,49] despite the lack of cross-cultural validation[24] and several reformulations of items by authors. If we categorized pushers using the seminal cutoff,[15] we also used the SCP beyond its initial objective, to objectively distinguish individuals upright from those showing lateropulsion without being pushers. The appropriateness of this approach, already adopted in some studies,[3,17] was confirmed by the fact that the 3 groups (upright, Lw/oP, pushers) differed in their behavior with respect to gravity (all 3 domains differed, body tilt, pushing, and resistance) and in the severity of other deficits. With an SCP score increment of 0.25 from 0 to 6, the construction of the SCP[15] allows for quantifying the magnitude of the body tilt and the intensity of additional signs (pushing and resistance), thus, lateropulsion severity, which is strongly correlated with magnitudes of biases in the postural perception of the vertical.[3] Therefore, it is appropriate to test relationships between SCP, balance, and gait scores, with good statistical fit. In our care pathways, only one third of individuals admitted to acute stroke units are then referred to rehabilitation units,[50] the others having too slight or too severe disabilities. These criteria, which correspond to those adopted in most European countries,[50] condition the generalizability of our results. However, our findings may be generalized to the rehabilitation context, which is overall important because lateropulsion is a major rehabilitation challenge. One cannot even exclude that the scope of the study might have been reduced by the inclusion criteria (first-ever hemisphere stroke without the cerebral complications listed in Methods) and the time of the initial assessment (D30). Indeed, lateropulsion prevalence and severity are greater earlier after stroke[17,19,49] and likely in cases of preexisting altered brain functions, recurrent strokes, or neurologic complications.

Body misorientation with respect to gravity is the primary factor altering balance and gait during the poststroke subacute stage. Thus, lateropulsion should be systematically assessed. We suggest that poststroke balance and gait rehabilitation incorporate techniques specifically devoted to lateropulsion.

Acknowledgment

The authors thank their colleagues Drs. Patrice Davoine, Anne Chrispin, Marie Jaeger, and Prof. Olivier Detante; and the participants.

Study funding

The DOBRAS study was funded by the French National Clinical Projects from the Health Minister (PHRC-N-VERTICAM-2004 revised 2012; and the PHRIP-15-0594 SCALA), Principal Investigator D. Pérennou. The funder had no role in the conduct of the study or approval of the manuscript.

Disclosure

The authors report no disclosures relevant to the manuscript. Go to Neurology.org/N for full disclosures.

Publication history

Received by *Neurology* December 21, 2019. Accepted in final form April 23, 2020.

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Céline Piscicelli, PhD	Grenoble Alpes University Hospital, France	Acquisition of data, revised the manuscript for intellectual content
Emmanuelle Clarac, PT	Grenoble Alpes University Hospital, France	Acquisition of data, material support
Monica Baciu, MD, PhD	Grenoble Alpes University, France	Revised the manuscript for intellectual content
Marc Hommel, MD, PhD	Grenoble Alpes University, France	Interpreted the data, revised the manuscript for intellectual content
Dominic Pérennou, MD, PhD	Grenoble Alpes University Hospital, France	Designed and conceptualized study, study supervision, interpreted the data, drafted the manuscript for intellectual content, obtained funding

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