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The effects of balance training on gait late after stroke: a randomized controlled trial

Gunes Yavuzer Ankara University Faculty of Medicine, Department of Physical Medicine & Rehabilitation, Ankara, Turkey and Erasmus University Medical Center, Department of Rehabilitation Medicine, Rotterdam, The Netherlands, **Filiz Eser**, **Dilek Karakus**, **Belgin Karaoglan** Ankara Physical Therapy and Rehabilitation Education and Research Hospital, Ankara, Turkey and **Henk J Stam** Erasmus University Medical Center, Department of Rehabilitation Medicine, Rotterdam, The Netherlands

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Objective: To investigate the effects of balance training, using force platform biofeedback, on quantitative gait characteristics of hemiparetic patients late after stroke.
Design: Randomized, controlled, assessor-blinded trial.
Setting: Rehabilitation ward and gait laboratory of a university hospital.
Subjects: Forty-one patients (mean (standard deviation; SD) age of 60.9 (11.7) years) with hemiparesis late after stroke (median time since stroke six months) were randomly assigned to an experimental or a control group.
Interventions: The control group ($n = 19$) participated in a conventional stroke inpatient rehabilitation programme, whereas the experimental group ($n = 22$) received 15 sessions of balance training (using force platform biofeedback) in addition to the conventional programme.
Main outcome measures: Selected paretic side time–distance, kinematic and kinetic gait parameters in sagittal, frontal and transverse planes were measured using a three-dimensional computerized gait analysis system, one week before and after the experimental treatment programme.
Results: The control group did not show any statistically significant difference regarding gait characteristics. Pelvic excursion in frontal plane improved significantly ($P = 0.021$) in the experimental group. The difference between before–after change scores of the groups was significant for pelvic excursion in frontal plane ($P = 0.039$) and vertical ground reaction force ($P = 0.030$) in favour of experimental group.
Conclusion: Balance training using force platform biofeedback in addition to a conventional inpatient stroke rehabilitation programme is beneficial in improving postural control and weight-bearing on the paretic side while walking late after stroke.

Introduction

Balance is a prerequisite for all functional activities and depends on the integrity of the central nervous system. Following stroke, some patients will never be able to stand, whereas those who manage to stand have delayed and disrupted equilibrium reactions, exaggerated postural sway (in both sagittal and frontal planes),[1,2] reduced weight-bearing on the paretic limb[3,4] and increased risk of falling.[5,6] Various therapeutic approaches can be applied after stroke based on, for example,

Address for correspondence: Gunes Yavuzer, Mustafa Kemal Mahallesi, Bariş Sitesi 87. sok No: 24, Ankara 06800, Turkey. e-mail: gunesyavuzer@hotmail.com

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neurophysiological, motor learning or orthopaedic principles. However, they do not specifically target balance, and there is no evidence that any of these approaches is more effective than another in promoting the recovery of postural control.[7]

Balance is an essential part of sitting, sit-to-stand and walking activities. Impaired balance and increased risk of falling toward the paretic side is found to be significantly correlated with locomotor function, functional abilities and length of stay in inpatient rehabilitation facilities.[7–10] Therefore, falls and injury prevention strategies are suggested as an integral part of each person's rehabilitation plan after stroke.[6] The relearning of postural control through external visual and auditory biofeedback is believed to be an effective therapy for improving balance control.[1,11,12] It is thought that by giving patients additional visual information, they will become more aware of the body's displacements and orientation in space.

In a Cochrane review, Barclay-Goddard *et al.*[13] searched the results of seven randomized clinical trials and indicated that providing feedback from a force platform resulted in improved stance symmetry after stroke but did not improve balance during active functional activities, nor did it improve overall independence. In a recent review, van Peppen *et al.*[14] reported that the additional value of visual feedback in bilateral standing compared with conventional therapy shows no statistically significant effects on symmetry of weight distribution between paretic and non-paretic limb while standing, postural sway in bilateral standing, balance and gait performance tests. On the other hand, Matjacic *et al.*[15] presented the effectiveness of balance training by using kinesiological gait analysis on one patient with chronic hemiparesis.

Other than this case report, all reviewed studies measured postural sway and weight-shifting ability while the patients were standing on the forceplates (posturography), and used only gait velocity to assess gait performance. Posturographic data has been used both for therapeutic purposes, enabling visual and auditory feedback to patients, and as an outcome parameter to assess the effectiveness of the treatment. However, in controlled trials, if the control group does not receive balance training by posturography, the experimental group gets the advantage of the experience with the system. In order to avoid this 'learning effect' the same system should not be used for both treatment and assessment. Quantitative gait analysis is effective for monitoring gait performance in stroke patients, as well as guiding therapy and documenting improvement.[16–20]

The present study was designed to evaluate the effects of task-oriented force platform biofeedback balance training on the gait pattern of hemiparetic patients with stroke using quantitative kinematic and kinetic gait analysis.

Methods

The trial included a sample of 41 (25 men, 16 women) inpatients with hemiparesis after stroke, with a mean (standard deviation; SD) age of 60.9 (11.7) years and a median time since stroke of six months. Stroke was defined as an acute event of cerebrovascular origin causing focal or global neurological dysfunction lasting > 24 h, and diagnosed by a neurologist and confirmed by computed tomography or magnetic resonance imaging. Patients recruited in this study were referred from all over Turkey for inpatient rehabilitation. Generally, in Turkey, an estimated 50% of the stroke population is referred to a rehabilitation centre if they cannot return home directly after discharge from the hospital.

Patients were required to meet the following criteria for inclusion in the study: (1) first episode of unilateral stroke with hemiparesis, in the territory of the internal carotid artery, (2) ability to understand and follow simple verbal instructions, (3) ambulatory before stroke, (4) ability to stand with or without assistance and to take at least one or more steps with or without assistance, (5) no medical contraindication to walking. They were excluded if they had a history of any other neurological pathology, conditions affecting balance, neglect, dementia, impaired vision or conscious levels or concomitant medical illness or musculoskeletal conditions affecting lower limbs (Figure 1).

The stage of motor recovery of the lower limbs was determined by Brunnstrom's Motor Recovery Stage (BMRS).[21] The Functional Independence Measure (FIM) was used to assess activity limitation.[22] The reliability and validity of the Turkish

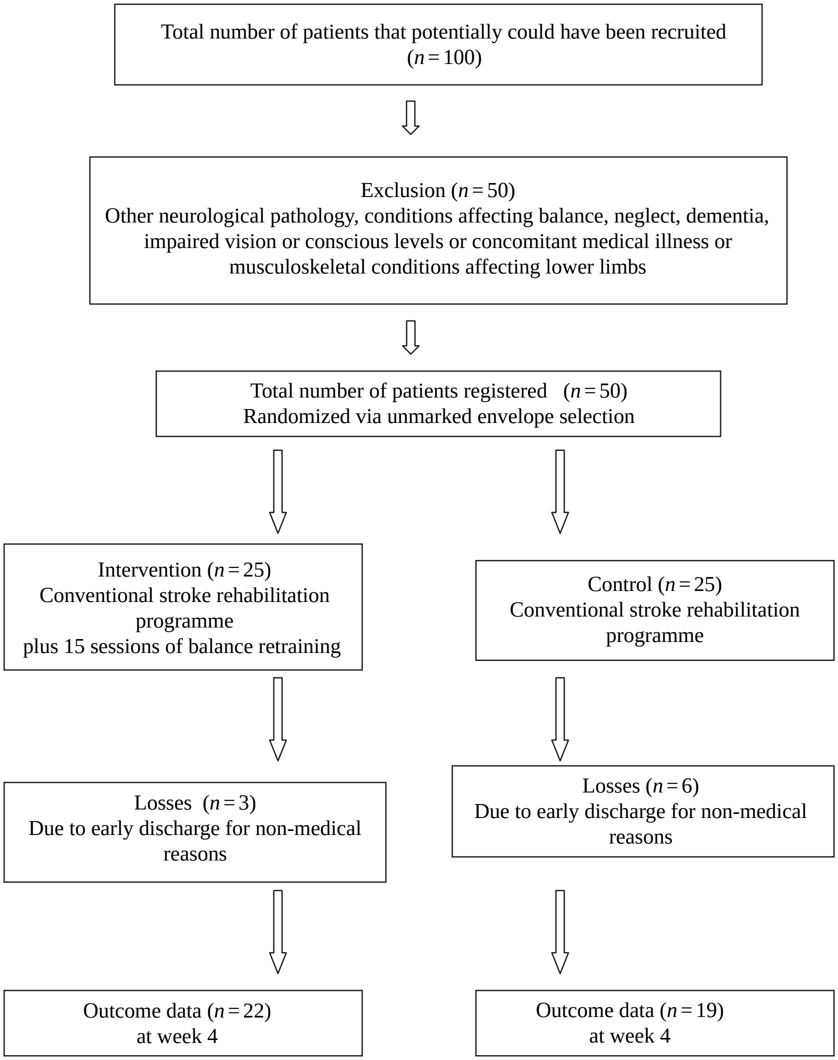

Figure 1 Flow diagram for randomized subject assignment in this study.

version of the FIM has been previously well documented in our clinic.[23] The protocol was approved by the Ankara Physical Therapy and Rehabilitation Education and Research Hospital Ethics Committee in Ankara, Turkey, and all subjects provided written informed consent prior to data collection.

Design

An assessor-blinded, randomized controlled design was used. The physician who performed the gait analysis was blinded to the use of the balance training programme; however, neither the patients nor the physiotherapists who deliver the intervention were blinded, because it was impossible to do so.

Patients were randomly assigned to one of the two groups after initial evaluation. We used the block randomization method in order to ensure an equal number of patients in each group. Blocks were numbered, and then a random-number generator programme was used to select numbers that established the sequence in which blocks were allocated to one or the other group. A resident who was blinded to the research protocol and was not otherwise involved in the trial operated the random-number programme. After randomization, 25 patients were assigned to the control group (conventional rehabilitation programme) and the remaining 25 were assigned to the experimental group (conventional rehabilitation programme plus balance training). Three patients from the experimental group and six patients from the control group dropped out of the study because they discharged themselves early from our rehabilitation clinic, due to non-medical problems. Hence, outcome data were obtained from the remaining 41 patients (Figure 1). The control group did not receive placebo intervention because it would not be logical to ask the patients to stand in front of a dark screen, doing nothing. None of the patients missed more than two scheduled therapies during the study.

Intervention

Subjects in both the experimental ($n = 22$) and the control group ($n = 19$) participated in our conventional stroke rehabilitation programme, 5 days a week, 2–5 h/day, for eight weeks. The conventional programme is patient-specific and consists of neurodevelopmental facilitation techniques, physiotherapy, occupational therapy and speech therapy (if needed). Physiotherapy focused on positioning, range of motion and progressive resistive exercises, together with training in endurance, walking and activities of daily living. Postural control exercises include maintenance of standing and shift of the weight loads to the paretic side. Therapists combine elements of Brunnstrom's movement therapy, Bobath neurodevelopmental treatment and proprioceptive neuromuscular facilitation techniques according to the patients' needs and performance. This personalized rehabilitative care is designed to help the patient regain the ability to function as independently as possible at home, work, and in the community. It involves learning to perform the daily activities of living in order to achieve the best possible quality of life.

In addition to eight weeks of conventional programme, the experimental group received 15 min of balance training once daily, five days a week for three weeks,[1,24,25] using the Nor-Am Target Balance Training System (Nor-am Patient Care Products, Oakville, Ontario, Canada) in 'standing stability' mode. The Nor-Am device is a portable balance trainer system including a dual forceplate made up of four load cells that detect pressure. Connected to a monitor, it provides visual representation of a person's centre of gravity. Menu-driven exercise tasks depict still or moving targets on the computer monitor. Subjects stood with one bare foot on each forceplate with their eyes open (according to the manufacturer's instructions). Support devices or personal assistance were provided when needed. The subjects were instructed to maintain or shift their weight, in the sagittal and frontal plane as appropriate, to make the representation of their centre of gravity reach the targets presented visually. In this study, because the Nor-Am device was used for intervention purposes only and not for assessment, data obtained from the balance trainer were not analysed statistically.

Quantitative gait analysis

Three-dimensional positions of 15 reflective markers attached to the subjects were tracked using an optical motion measurement system Vicon 370 (Oxford Metrics Limited, Oxford, UK) as each subject walked at a self-selected speed. The Vicon Clinical Manager (VCM) (version 3.2) software was used to calculate joint angles as ordered rotations between anatomically aligned reference frames associated with adjacent body segments. Anthropometric data including height, weight, leg length and joint width of the knee and ankle were collected. Ground reaction forces (GRF) were measured using two Bertec forceplates (Bertec Corp, Colombus, OH, USA). The first trial was regarded as a 'warm-up' and familiarization trial to the laboratory and was not included in the calculations. The best data of three trials were used in the analysis. The trial, in which all the markers were clearly and automatically identified by the system, was designated as the best data. Reliability of our quantitative gait analysis data in healthy subjects[26] and stroke patients[27] has been shown.

Time–distance parameters

Walking velocity, cadence, step length and single support time of all participants were documented for the paretic and non-paretic sides. Asymmetry is a well-known feature of the hemiparetic gait and the restoration of gait symmetry is important in order to regain a physiological gait pattern.[28] To quantify the extent of the temporal and spatial asymmetry of gait pattern, the single-support time asymmetry ratio and the step length asymmetry ratio were calculated, respectively, as follows[29]:

$$\text{Single-support time asymmetry ratio} = 1 - \frac{\text{Single-support time (affected)}}{\text{Single-support time (unaffected)}}$$

$$\text{Step length asymmetry ratio} = 1 - \frac{\text{Step length (affected)}}{\text{Step length (unaffected)}}$$

The greater these ratios, the greater the asymmetry.

Kinematic and kinetic parameters

Pelvic excursions (the difference between peak and valleys of the curve in degrees) in sagittal, frontal and transverse planes were evaluated. Excursions of the paretic hip, knee and ankle were documented only in the sagittal plane. Peak extensor and abductor moments of the hip, peak extensor moment of the knee and peak plantar flexor moment of the ankle at the paretic side during stance were documented. Peak vertical GRFs normalized by bodyweight for each participant were used to evaluate the weight-bearing on the paretic side.

Data analysis

Data analysis was performed using SPSS for Windows version 11.5 (SPSS Inc., Chicago, IL, USA). Mann–Whitney *U*-test and chi-square test were used to compare demographic and baseline characteristics of the two groups. Comparisons between pre- and post-treatment gait data within each group were analysed using Wilcoxon test. In order to investigate whether experimental group changed by more than the control group, we calculated change scores (subtracting the after score from the before score) for each group and compared them by using Mann–Whitney *U*-test. We preferred non-parametric statistics because of the abnormal distribution of the data. Significance was set at 0.05.

Results

Demographic and clinical characteristics of the patients are presented in Table 1. The two groups were similar in terms of age, gender, time since stroke, type of injury, paretic side, lower extremity BMRS and FIM scores. Table 2 presents pre- and post-treatment data on the comparison of the groups in terms of baseline clinical and quantitative gait characteristics.

Time–distance and kinematic parameters

Baseline assessments revealed that in spite of randomization, patients in the control group had better pelvic mobility in the frontal plane than experimental group ($P = 0.007$). The experimental group had significant improvement in pelvic

Table 1 Characteristics of the two study groups

Variable	Experimental ($n = 22$)	Control ($n = 19$)	*P*-value
Age (mean (SD) in years)	59.8 (11.6)	62.1 (12)	0.574
Sex (women/men)	10/12	6/13	0.281
Time since stroke (mean (SD) in months)	11.1 (24.6)	5.5 (3.5)	0.305
Time since stroke (median in months)	6	5	0.334
Type of injury (ischaemia/haemorrhage)	15/7	16/3	0.472
Paretic side (right/left)	9/13	6/13	0.755
BMRS lower extremity	4.0(0.9)	4.2(1.0)	0.578
FIM ambulation	8.8(3.0)	9.4(3.2)	0.412
FIM total	81.4(16.0)	85.4(20.3)	0.638

SD, standard deviation, the values are mean (SD) for age, time since stroke; BMRS, Brunnstrom's Motor Recovery Stage; FIM, Functional Independence Measure.

Table 2 Outcome measures in the experimental group and the control group

Outcome measures	Pre-treatment		*P*-value[a]	Post-treatment	
	Experimental	Control		Experimental	Control
Walking velocity (m/s)	0.36 (0.2)	0.44 (0.2)	0.146	0.44 (0.2)	0.45 (0.2)
Cadence (steps/min)	69.9 (17.7)	77.3 (16.1)	0.154	77.8 (16.1)	75.8 (18.7)
Step length (m)	0.30 (0.10)	0.31 (0.10)	0.990	0.34 (0.12)	0.33 (0.09)
Single-support time (s)	0.40 (0.09)	0.44 (0.11)	0.307	0.41 (0.08)	0.45 (0.10)
Step length asymmetry ratio	0.64 (0.45)	0.08 (0.05)	0.097	0.44 (0.27)	0.30 (1.5)
Single-support time asymmetry ratio	0.28 (0.16)	0.11 (0.27)	0.058	0.24 (0.20)	0.14 (0.19)
Pelvic tilt (degrees)	7.7 (4.4)	6.2 (5.3)	0.155	6.8 (3.7)	6.3 (5.4)
Pelvic obliquity (degrees)	7.0 (2.7)	4.7 (2.2)	0.007	5.9 (2.5)	5.0 (3.0)
Pelvic rotation (degrees)	11.1 (5.0)	9.7 (3.6)	0.637	10.3 (5.6)	8.7 (4.5)
Hip[b] (degrees)	24.8 (9.6)	25.4 (9.1)	0.396	25.2 (8.9)	26.4 (9.1)
Knee[b] (degrees)	31.3 (12.5)	34.3 (13.0)	0.229	32.3 (13.6)	35.1 (11.8)
Ankle[b] (degrees)	21.5 (14.5)	18.0 (11.4)	0.512	18.9 (11.0)	20.0 (12.9)
Peak hip extensor moment	−0.13 (0.3)	0.05 (0.5)	0.465	0.06 (0.2)	0.12 (0.4)
Peak hip abductor moment	0.71 (0.2)	0.85 (0.3)	0.157	0.70 (0.3)	0.80 (0.3)
Peak knee extensor moment	0.26 (0.3)	0.40 (0.3)	0.081	0.30 (0.2)	0.38 (0.3)
Peak ankle plantar flexor moment	0.73 (0.3)	0.97 (0.4)	0.088	0.75 (0.4)	0.92 (0.4)
Vertical GRF 1st peak (N% bodyweight)	88.5 (9.5)	92.5 (8.3)	0.329	90.1 (8.4)	90.3 (6.1)

Values are mean (SD), moments are in stance (Nm/kg).
GRF, ground reaction force.
[a]*P*-value is for comparison of the groups in terms of pre-treatment values.
[b]Sagittal plane total excursion in degrees.

excursions in the frontal plane ($P = 0.021$) after treatment and the difference in change scores was significant ($P = 0.039$) in favour of the experimental group (Table 3). Neither group had significant changes in hip, knee and ankle excursions after treatment (Table 2).

Kinetic parameters

Neither group had a significant difference between pre- and post-treatment knee and ankle moments on the paretic side (Table 2). Peak hip extensor moment of the paretic side in stance improved significantly only in the experimental group ($P = 0.023$), but the difference in change score was not significant. There was a statistically significant difference in change scores of vertical GRF first peak (N% bodyweight) ($P = 0.030$) in favour of experimental group (Table 3).

Discussion

Hemiparetic gait is characterized by slow and asymmetric steps with delayed and disrupted equilibrium reactions and reduced weight-bearing on the paretic limb.[16,18,20] Restoration of normal movements of the trunk, pelvis and lower extremity, and improved weight-bearing on the paretic side while walking are some of the most important goals of stroke rehabilitation.[30] This study reveals that a task-oriented balance training with force platform biofeedback in addition to a conventional stroke rehabilitation programme provides more benefit than a conventional stroke rehabilitation programme alone, in terms of pelvic excursions in the frontal plane and weight-bearing on the paretic side, while walking.

Walking velocity is a preferred outcome parameter for hemiparetic gait research as it is easy and reliable to measure.[19] Slow walking velocity has been attributed to a lack of selective motor control and poor balance.[31] However, rehabilitation programmes do not mainly focus on increasing velocity because it may cause a more abnormal gait pattern and result in safety problems. In this study, after treatment, walking velocity improved in the experimental group but the difference was not significant. The majority of patients in both groups showed an asymmetrical gait pattern with less step time on the paretic side than on the non-paretic side. Spatio-temporal asymmetry is a

Table 3 Comparison of the change scores after treatment in the experimental group and the control group

Outcome measures	Experimental	Control	*P*-value
Walking velocity (m/s)	0.08 (0.17)	0.01 (0.14)	0.283
Cadence (steps/min)	7.90 (15.3)	1.47 (10.1)	0.069
Step length (m)	0.03 (0.09)	0.02 (0.09)	0.804
Single-support time (s)	0.01 (0.07)	0.01 (0.09)	0.536
Step length asymmetry ratio	0.19 (1.9)	0.38 (1.5)	0.347
Single-support time asymmetry ratio	0.04 (0.12)	0.03 (0.27)	0.503
Pelvic tilt (degrees)	0.91 (3.10)	0.17 (3.77)	0.527
Pelvic obliquity (degrees)	1.12 (2.06)	0.47 (2.15	0.039
Pelvic rotation (degrees)	0.71 (4.85)	0.68 (4.67)	0.861
Hip[a] (degrees)	0.50 (8.47)	0.35 (6.19)	0.968
Knee[a] (degrees)	1.02 (6.17)	0.15 (10.9)	0.286
Ankle[a] (degrees)	3.24 (11.0)	1.88 (14.5)	0.443
Peak hip extensor moment in stance (Nm/kg)	0.19 (0.29)	0.06 (0.54)	0.538
Peak hip abductor moment in stance (Nm/kg)	0.02 (0.26)	0.05 (0.34)	0.538
Peak knee extensor moment in stance (Nm/kg)	0.03 (0.21)	0.01 (0.29)	0.775
Peak ankle plantar flexor moment in stance (Nm/kg)	0.08 (0.24)	0.11 (0.41)	0.067
Vertical GRF 1st peak (N% bodyweight)	0.50 (3.93)	−3.57 (6.52)	0.030

Values are mean (SD).
GRF, ground reaction force; BMRS, Brunnstrom's Motor Recovery Stage; N, newton.
[a]Sagittal plane total excursion in degrees.

characteristic of poststroke gait and leads to increased energy expenditure and risk of falls.[32,33] Consequently, improvements in gait symmetry provide an important clinical marker of recovery.[28,29] Hesse *et al.*[34] found no significant improvement in gait symmetry after an intensive four-week inpatient rehabilitation programme based on a neurodevelopmental technique. In agreement with their findings, neither group showed a significant improvement after treatment in terms of gait symmetry in our study.

It has been shown that patients with hemiparesis have asymmetric trunk movements with increased pelvic excursion in frontal plane.[18,33,35] Kinematic and kinetic studies of upper-body motion in the frontal plane have shown that the trunk is precisely controlled and highly dependent upon the motion of the pelvis.[36–38] Control of pelvic motion is critical to the maintenance of total body balance since the weight of the head, arms and trunk acts downward through the pelvis. Dynamic balance of the head, arms and trunk about the supporting hip is dependent upon the control of pelvic motion by the hip musculature (hip muscle moment) and the coupling between the pelvis and upper trunk. Haart *et al.*[33] suggested that stroke patients suffer from severe postural instability and postural asymmetry during quiet standing in the frontal and sagittal planes; however, functional improvements during rehabilitation are most prominent in the frontal plane. Dault *et al.*[39] suggested that sagittal plane imbalance in healthy elderly and stroke patients may be largely due to the effects of ageing, whereas frontal plane imbalance is much more specific for the postural problems associated with stroke. They proposed that visual feedback may help stroke patients to better correct their frontal plane asymmetry and imbalance. The total pelvic excursions in sagittal and frontal planes while walking were investigated in this study and it was found that excessive pelvic excursion in the frontal plane decreased significantly in the experimental group with a significantly higher change score, indicating a better postural control. Bujanda *et al.*[40] found a strong correlation between motor recovery of the lower extremity and frontal plane kinematics of the trunk after stroke. It has been shown that hip abductor and adductor muscles are highly responsible for balance control in the frontal plane by controlling equal weight-shifting between the paretic and non-paretic sides after stroke.[41] These findings support the idea that treatment techniques improving the motor function of the paretic lower limb, particularly those aiming to exercise the hip abductor/adductor muscles, would improve symmetry and balance

Clinical message

- Balance training, using force platform biofeedback, in addition to a conventional inpatient stroke rehabilitation programme is beneficial in improving postural control and weight-bearing on the paretic side while walking late after stroke.

and might consequently reduce the risk of falling after stroke.

Impaired balance in poststroke patients is often related to uneven weight-bearing.[32,40] Haart *et al.*[3] reported that assessment of weight-shifting capacity provides unique information about balance recovery after stroke and can be used as an outcome parameter to develop new rehabilitation strategies. Eng and Chu[42] have shown that weight-bearing ability can be reliably measured by forceplates in terms of vertical GRF and used as an outcome measure in stroke patients. In our trial, patients in the experimental group showed a better increase than control group in weight-bearing ability on the paretic side after treatment.

There are limitations in this study. Precaution must be taken in generalizing the results, as our findings and conclusions are based on a population of subacute stroke inpatients, surviving from first stroke, without severe cognitive deficits and with some ability to walk in the gait analysis laboratory. In spite of randomization, unfortunately, the control group revealed slightly better gait pattern than the experimental group. The difference between the groups in baseline pelvic excursion in the frontal plane was statistically significant. Better initial values of gait characteristics might have caused a ceiling effect in the control group. Another limitation is the lack of long-term follow-up results. When patients are discharged it is not possible to evaluate them by computerized gait analysis, mainly due to socioeconomic difficulties. Another limitation might be the lack of an untreated control group to rule out spontaneous recovery. Because all subjects had been referred to our centre for inpatient stroke rehabilitation, on ethical grounds we could not withhold therapy. Moreover, this is a randomized controlled trial in which we can expect that both experimental and control groups have a similar chance of spontaneous recovery. The control group did not receive a placebo therapy, which may cause a bias as the experimental group received more attention from the therapist – even though it was only 15 min extra.

It has been shown that hip abductor and adductor muscles are highly responsible for balance control in the frontal plane by controlling equal weight-shifting between the paretic and non-paretic sides after stroke.[41] Future studies may investigate the effects of balance training on muscle activation pattern of hip abductor muscles by dynamic electromyographic recordings while walking.

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