# Restoration of Weight-Shifting Capacity in Patients With Postacute Stroke: A Rehabilitation Cohort Study

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**Objectives:** To identify and interrelate recovery characteristics of voluntary weight shifting after stroke and to examine whether the assessment of weight shifting adds information about balance recovery compared with the assessment of quiet standing.

**Design:** Exploratory study using an inception cohort with findings related to reference values from healthy elderly persons.

**Setting:** Dutch rehabilitation center.

**Participants:** Thirty-six inpatients (mean age, 61.8y; mean time poststroke, 10wk) with a first hemispheric intracerebral infarction or hematoma who were admitted to retrain standing balance and walking.

**Intervention:** Individualized therapy.

**Main Outcome Measures:** Center of pressure (COP) displacements were registered during voluntary frontal-plane weight shifting guided by visual COP feedback using a dual-plate force platform. Besides the speed (number of weight shifts) and imprecision (normalized average lateral COP displacement per weight shift), the weight-transfer time asymmetry and the spatiotemporal distribution were determined. Assessments took place as soon as patients could stand unassisted for at least 30 seconds and at 2, 4, 8, and 12 weeks later.

**Results:** During the 12-week training period, the stroke patients increased both their speed (2.3 hits/30s; 95% confidence interval [CI], 1.1–3.4) and precision (37.7mm/hit; 95% CI, 10.4–65.0) of weight shifting. Although the speed appeared to stabilize at a suboptimal level after 8 weeks, precision reached normal reference values after 12 weeks. Both older age (≥65y) and the presence of visuospatial hemineglect negatively affected weight-shifting speed but not its relative improvement in time. During the training period, a small degree of weight-transfer time asymmetry persisted (mean change, .07; 95% CI, –.21 to .36), with an average of 23% slower weight shifts toward the paretic leg, but the spatiotemporal distribution remained symmetrical. The correlations between weight-shifting and quiet-standing control at the end of training were moderate (Spearman $\rho$ range, .50–.77).

**Conclusions:** Even subjects with severe stroke who are selected for inpatient rehabilitation are able to improve their speed and precision of weight shifting by reducing the weight-transfer time toward both legs in a proportionate manner. The observed correlations between weight shifting and quiet standing indicate that the assessment of weight-shifting capacity provides unique information about balance recovery after stroke.

**Key Words:** Cerebrovascular accident; Posture; Recovery of function; Rehabilitation; Stroke.



STROKE IS A MAJOR CAUSE of postural imbalance in terms of static (eg, weight distribution,[1-6] foot-pressure distribution[1,6]) and dynamic (eg, equilibrium reactions,[7,8] weight shifting[2,4,5,9-14]) control. Although stroke patients may suffer from postural instability in all planes,[2,3,15] several studies have shown that frontal plane balance is disproportionally affected.[6,16] Because the ability to initiate and control voluntary weight shifts toward either leg is a prerequisite for independent walking, learning to load and unload the affected leg while standing is an important step in the balance and gait training of stroke patients.[17] Hence, making self-generated weight shifts in the frontal plane within the base of support seems an essential ability to train and monitor in these patients.[4,5,9,12,14] Indeed, the potential validity of such dynamic balance tasks with regard to functional balance and gait has been emphasized.[18]

Studies have shown that when leaning their body as far as possible in a specific direction without adjusting foot position, stroke patients have difficulties in all planes but mostly in the direction of their paretic leg.[2,4,9,11,12] Also, when shifting from a 2-legged to a 1-legged stance[10,13] or when stepping on stairs of various heights,[5] stroke patients show the greatest difficulties with transferring weight toward their paretic leg. On the other hand, loading the nonparetic leg may be troublesome as well,[4,5,10-12] which could be due either to subtle neuromuscular impairments ipsilateral to the brain lesion or to a reduced ability to control weight shifts toward the nonparetic side using the leg and hip muscles of the paretic body side. When stroke patients are required to make cyclic bilateral weight shifts in the frontal plane, they clearly make smaller displacements than do healthy elderly people, which has been referred to as a "stabilization" strategy.[19] This stabilization appears somewhat more evident during externally imposed perturbations than when making voluntarily controlled weight shifts, and it coincides with a lack of modulation of the gluteus medius and medial gastrocnemius muscle activity between the paretic and the nonparetic leg.[19] Hence, when assessing weight-shifting capacity after stroke, it seems essential to investigate self-controlled weight displacements toward both the paretic and the nonparetic leg. Such weight shifting should be analyzed not only in terms of overall speed,[9,14] sway trajectory,[19] or preci-

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sion,[14,18] but also with regard to temporal and spatial asymmetry. As yet, however, no such data are available.

Although there have been studies of dynamic balance training,[20-22] none have reported on weight-shifting capacity as an outcome measure. To our knowledge, no observational studies of the recovery of weight-shifting capacity during the rehabilitation of stroke patients have been reported.

Hence, we conducted a cohort study to provide insight into the restoration of voluntary frontal-plane weight-shifting capacity in postacute stroke patients in terms of speed, precision, and spatiotemporal symmetry. It must be emphasized that the aim of our study was not to evaluate any specific treatment but to identify and interrelate recovery characteristics of weight shifting after stroke (whether or not these characteristics are related to "spontaneous" recovery or to training). To develop effective training strategies, it is important to know what aspects of weight shifting are likely to improve after stroke in terms of speed, precision, and spatiotemporal symmetry and, if so, to what extent compared with healthy elderly persons. A second goal was to assess the relation between weight-shifting and quiet-standing control in the same group of patients, to evaluate the additional information provided by a dynamic balance task compared with static balance tasks.

## METHODS

### Participants

All patients with a first hemispheric intracerebral infarction or hematoma, who were admitted to our rehabilitation clinic for retraining motor skills and self-care abilities during a period of 2 years were eligible. Patients who, on admission, already walked safely and those with medication- or nonstroke-related sensory or motor impairments that could interfere with their postural regulation were excluded. Based on practical assessment, patients with concomitant cognitive or psychiatric problems that impaired their ability to follow simple verbal instructions were also excluded from the study. Thirty-nine stroke patients were included, 2 of whom were lost to follow-up. One patient suffered from severe secondary seizures and another had to be discharged prematurely because of health insurance problems. A third patient had to be omitted from further analysis because of an error in the collection of the weight-shifting data. Thus, an inception cohort of 36 patients was formed.

At a minimum, all patients received 5 weekly 30-minute sessions of individual physiotherapy and 3 weekly 30-minute sessions of occupational therapy. These individual therapies were augmented by small group therapies for improving gross motor skills. These group therapies occupied at least 60 minutes of each working day. This motor rehabilitation was embedded in a more extensive, individualized rehabilitation program with a general emphasis on optimal use of the paretic body side (neurodevelopmental treatment oriented). Age, stroke type (infarction or hematoma), location (left or right hemisphere), and time from stroke at study entry were registered as potentially relevant biologic characteristics, based on the neurologic records including computed tomography or magnetic resonance imaging scanning. As a reference for our stroke patients, we used posturographic data obtained from a study[23] of healthy elderly subjects (N=23; mean age, 63.9±9.3y) who underwent the same procedure as applied in our study. All participants gave their informed consent after receiving both verbal and written information about the study and its potential risks. Approval was obtained from the institutional ethics committee.

### Equipment

Balance registrations were made using a force platform consisting of 2 separate aluminum plates, each placed on 3 force transducers[a] (hysteresis and nonlinearity, <1%) that recorded the vertical ground reaction forces.[24] Signals were processed by 6 direct-current amplifiers[b] (nonlinearity, <0.1%) and first-order low-band pass filters with a cutoff frequency of 30Hz. Data were stored after a 12-bit analog-to-digital conversion, at a sampling rate of 60Hz. By means of digital moment-of-force calculations, the point of application of the resultant of the ground reaction forces in a 2-dimensional transverse plane was determined. The calculations were done for each sample, with a maximum error of ±1mm in the lateral and anteroposterior (AP) directions. The coordinates of this center of pressure (COP) were passed through a digital, low-band pass, 6-Hz Fourier filter to eliminate high-frequency components arising from noise. Two parallel support bars were placed beside the force platform. To provide visual COP feedback, a 15-in (38.1-cm) color monitor was situated slightly below eye level on a height-adjustable table 1m in front of the patient standing on the force platform.

### Procedure

Five posturographic assessments were made during a period of 12 weeks. The first assessment took place as soon as the patient was able to stand without assistance for 30 seconds or more. The same assessments were repeated 2, 4, 8, and 12 weeks later. The timing of each patient's first assessment was indicated by the capability of prolonged active knee and hip extension at the paretic body side, sufficiently strong to prevent limb collapse and abnormal trunk flexion during stance. From this moment, standing balance training could commence without external support (ie, "start" of balance training). The first and last posturographic assessments were accompanied by a clinical evaluation consisting of 2 parts: (1) the principal investigator (MdH) evaluated the subjects' balance and walking skills, rating them according to the 6-point (range, 0–5) Functional Ambulation Categories (FAC)[25,26] and (2) independent qualified members of the rehabilitation team, who were not actively involved in this study, conducted a standardized physical and neuropsychologic examination.

The physical examination provided data for lower-limb motor selectivity, sensibility, reflex activity, and trunk control. The lower-limb motor selectivity score was based on the 6 motor stages defined by Brunnstrom[27] and further elaborated by Fugl-Meyer[28] from flaccid paralysis through increased muscle tone and selectivity to normal selective muscle control. The lower-limb sensibility score was obtained by testing position sense at the affected ankle joint in 3 different angles of dorsiflexion and plantarflexion by mirroring the nonparetic ankle. The score was recorded as "disturbed" if the patient made more than 1 mirroring error. The lower-limb reflex activity score was obtained by imposing a fast passive dorsiflexion motion at the affected ankle joint. The patient had "ankle clonus" if the number of calf muscle contractions was greater than 1 during sustained dorsiflexion. The patient's trunk control score was determined by the sitting balance item of the trunk control test.[26] Control was rated as "disturbed" if the patient was unable to sit erect on the edge of a bed, feet off the ground, for 30 seconds.

The neuropsychologic examination consisted of a letter cancellation test (the Dutch O-search test), the line bisection test from the Behavioral Inattention Test,[29] and the first 6 items of the block design subtest of the Wechsler Adult Intelligence Scale (WAIS).[30] The patients were considered to have visuospatial hemineglect if they showed abnormal lateralization in at

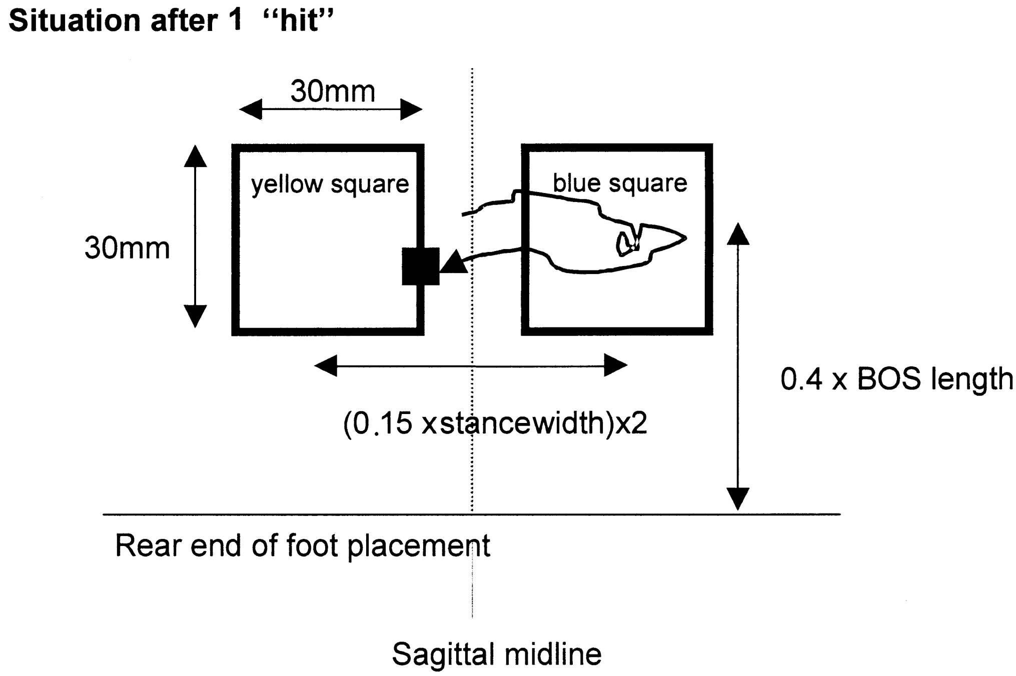


**Fig 1. Size and position of the target squares with regard to the BOS length and stance width. The stance width is the distance between the anterior borders of both tibiae.**

least 2 of the 3 neuropsychologic tests—that is, at least 10% fewer cancellations on the affected side in the O-search test, fewer than 7 of 9 points in the line bisection test, and more than 1 error in the WAIS block design subtest.

**Posturography**

Patients stood barefoot on the force platform with their arms alongside their trunk, if possible. Their feet were positioned against a fixed foot frame with the medial sides of their heels 8.4cm apart and each foot placed with toes outward at a 9° angle from the sagittal midline. Before the first posturographic assessment, the base of support (BOS) was determined in both the lateral (ie, the distance between the heads of the fifth metatarsal bones of both feet) and the AP (ie, the distance from the rear of the heel to the tip of the great toe) directions while standing on the force platform. In addition, the distance between the anterior borders of the distal tibiae was assessed to obtain a measure of the individual stance width. Every balance assessment consisted of 2 consecutive test series. Each test series incorporated four 30-second quiet-standing tasks (standing with the eyes open, with the eyes closed, with a visual vertical midline reference, and while performing a concurrent arithmetic task) and one 30-second weight-shifting task in a fixed sequence, which was repeated in the reversed order to neutralize any time effects. A 1-minute rest was allowed after each balance test, whereas a longer pause was allowed between the 2 test series. The methods and primary results of the quiet-standing tasks have been described in a companion article.[6] Selected data from the quiet standing conditions will be presented in this report to examine the association with weight-shifting capacity.

The weight-shifting task required voluntary loading and unloading of both the paretic and nonparetic legs using visual COP feedback. The actual COP position was continuously displayed on the monitor as a black cursor moving on a gray background. A real-time (lag time, ≈.016s), real-size visual feedback was provided, in which up-down and left-right cursor movements corresponded to AP and lateral COP displacements, respectively. In addition, 2 stationary squares were presented at either side of the virtual vertical through the middle of the screen, the latter corresponding to the body's sagittal midline. Each square consisted of 4 blue lines 30mm long. The lateral position of the centers of the squares was individually determined at 15% of the stance width at each side of the sagittal midline. In this way, weight bearing of approximately 65% on each leg was required to bring the cursor to the middle of the corresponding square. In the AP direction, the centers of the squares were given fixed positions at a distance of 40% of the length of support from the rear, corresponding to the average COP position in the sagittal plane in healthy subjects.[23] The target square in which direction weight had to be transferred was indicated by the color yellow, whereas the nontarget square was blue. The essence of the required balance task is shown in figure 1.

Subjects were instructed to laterally shift their COP from left to right and vice versa between the 2 squares. They had to maintain their COP for at least 1 second within each target square to make a hit, which was indicated to the subjects by a change in filling color. As soon as a hit was made, the contralateral square became the target and turned into yellow. The start of the weight-shifting registration was preceded by a 5-second anticipation period, which was indicated on the monitor by projecting the numbers 5 to 1. Then, the first target was randomly assigned by the computer. Patients were instructed to start from a comfortable position and to make as many weight shifts as fluently as possible. Because no fixed rhythm was imposed, each subject determined his/her own speed and precision. The weight-shifting task was practiced for several minutes before its first performance, until each subject showed an optimal understanding and individual ability. No physical contact or use of the support bars was allowed during any of the

registrations. This weight-shifting task has already proved to discriminate patients with traumatic brain injury or with a lower-limb amputation from healthy controls and to be sensitive to the effects of recovery and training in these groups, in terms of both speed and precision.[31-33]

### Data Analysis

The number of target hits (*N*) in 30 seconds was selected as a measure of the speed of weight shifting. To assess the precision of weight shifting, an imprecision measure (*P*) was used.[14] First, the total COP displacement in the lateral direction (in millimeters) was divided by the number of full weight shifts (*N*–1) to obtain the average lateral COP displacement per weight shift. Second, because the target distance was related to the individual stance width, this measure was then normalized to the average stance width of all participants according to the following equation:

$$P = \frac{\left(\frac{\sum_{i=1}^{1799} |X_{i+1} - X_i|}{N-1}\right) * \bar{R}}{R_{ind}} \quad (1)$$

where $X_i$ is the lateral COP coordinate, *i* is the time sample, *N* is the number of hits, $\bar{R}$ is the average stance width, and $R_{ind}$ is the individual stance width. In addition, the average time needed to transfer weight from the nonparetic to the paretic leg was divided by the average time needed to shift from the paretic to the nonparetic leg to obtain a measure of weight-transfer time asymmetry (*A*) using the following equation:

$$A = \frac{\bar{t}\,(nonparetic \rightarrow paretic)}{\bar{t}\,(paretic \rightarrow nonparetic)} \quad (2)$$

where $\bar{t}$ is the mean transfer time in a specific direction (ie, the total weight-transfer time divided by the number of full weight shifts in this direction). For the healthy elderly subjects, the mean transfer time from the right to the left leg was divided by the mean transfer time from the left to the right leg. Whereas the speed of weight shifting (number of hits) could be determined for all balance registrations, the imprecision and weight-transfer time asymmetry were calculated only for those registrations with at least 2 full weight shifts in either direction (ie, $N>4$). For each balance task, the comparable parameters derived from the 2 test series were averaged. However, if just 1 of 2 registrations resulted in more than 4 hits, only this registration was used to calculate the imprecision and time asymmetry. To measure the spatiotemporal distribution of the COP trajectory during weight shifting, the percentages of time spent within specific areas inside and outside the target area (ie, the area of and in between the 2 targets; see patterned area in fig 2) were determined.

As for the quiet-standing tasks, the root mean square (RMS) value of the COP velocity (VCOP) in either the lateral or the AP direction was selected as the primary measure of quiet-standing control, because it integrates changes in both amplitude and frequency of the COP fluctuations (see also de Haart et al[6]).

### Statistical Analysis

All posturographic (dependent) parameters were tested in a multivariate analysis of variance[34] (MANOVA), with repeated measures on the factor time (5 follow-up assessments). The influence of various biologic and clinical characteristics was analyzed; these were age (<65y vs ≥65y), type and location of stroke, time poststroke (≤8wk vs >8wk), and initial motor stage (no [Brunnstrom stage ≤IV] vs some [Brunnstrom stage >IV] selective muscle control), disturbed sensibility, ankle clonus, disturbed trunk control, and visuospatial hemineglect. Each characteristic was used as a between-subjects factor in the MANOVA. Selected differences in functional status (ie, Brunnstrom stage, FAC score) before and after the 12-week follow-up period were analyzed using the Wilcoxon matched-pairs signed-rank test. Differences in the time spent within a specific area were analyzed by using either paired or unpaired *t* tests for within- and between-subjects comparisons, respectively. The association between quiet-standing control (VCOP lateral, VCOP AP) and weight-shifting control (speed, imprecision) was assessed by calculating Spearman correlation coefficients.

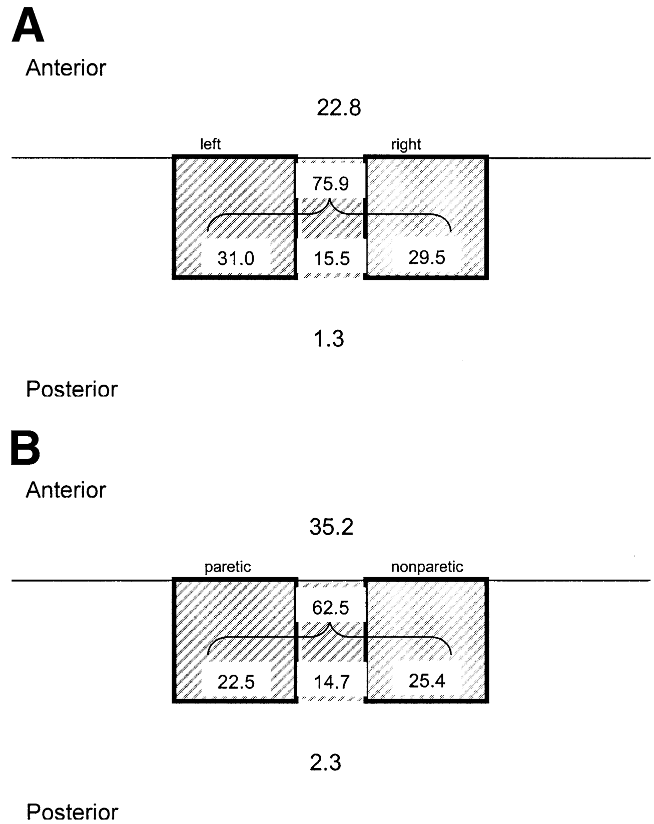


**Fig 2. Percentages of time spent inside and outside the target area for (A) healthy elderly subjects (n=23) and for (B) stroke patients (n=36), averaged over all follow-up assessments (n=5).**

## RESULTS

### Cohort

Five follow-up assessments were completed in 36 stroke patients, whose main biologic and clinical characteristics are listed in table 1. As for their functional capacity, the median Brunnstrom stage was IV (range, II–VI) at the start of the balance training and improved to V (range, III–VI) after 12 weeks ($P<.001$). The median FAC score improved by 2 points from 2 (range, 1–4) at the start to 4 (range, 1–5) at the end of the 12-week period ($P<.001$). Eleven patients failed to make a minimum of 5 weight shifts in at least 1 of the follow-up assessments; therefore, a reduced sample of 25 patients was used to calculate the changes in imprecision and weight-transfer time asymmetry. This subgroup did not show significant

**Table 1: Biologic and Clinical Characteristics of All Stroke Patients and of the Subgroup of Patients With at Least 5 Hits During the Weight-Shifting Task Throughout the Follow-Up Period**

| Characteristics | Stroke Patients (n=36) | Subgroup (n=25) |
|---|---|---|
| Age (y) | 61.8±13.0 (27–82) | 59.8±11.9 (34–82) |
| Time poststroke (wk) | 10.0±5.5 (3.3–24.1) | 10.0±5.7 (3.3–24.1) |
| Sex (male/female) | 19/17 | 14/11 |
| Type of stroke (infarction/hematoma) | 29/7 | 22/3 |
| Hemisphere of stroke (left/right) | 13/23 | 7/18 |
| Sensibility (disturbed/normal) | 23/13 | 16/9 |
| Ankle clonus (present/absent) | 18/18 | 14/11 |
| Trunk control (disturbed/normal) | 22/14 | 16/9 |
| Visuospatial hemineglect (present/absent) | 15/21 | 10/15 |

NOTE. Values are mean ± standard deviation and (range) or N.

differences in Brunnstrom stage or FAC score at the start or at the end of the balance training compared with the total group of stroke patients. The number of hits, the imprecision measure, and the weight-transfer time asymmetry are presented with their 95% confidence intervals (CIs) in table 2 for all the follow-up assessments, together with the reference values obtained from the healthy elderly.

For the patients with stroke, a mean increase of 2.3 hits/30 seconds (95% CI, 1.1–3.4) in weight-shifting speed across time was found ($F_{4,32}$=5.18, $P$=.002); however, even after 12 weeks, the stroke patients did not reach the same number of hits as did the healthy elderly subjects. Instead, after 8 weeks of training, weight-shifting speed appeared to stabilize. In contrast, the imprecision measure showed a mean decrease of 37.7mm/hit (95% CI, 10.4–65.0) ($F_{4,21}$=1.78, $P$=.17) and, after 12 weeks, reached the same level of precision as did the healthy elderly subjects.

The weight-transfer time toward either leg was equal in the healthy elderly subjects but not in the stroke patients. Whereas the healthy elderly subjects needed an average of 2.6 seconds to make 1 weight shift, the stroke patients needed an average of 4.3 seconds to make a weight shift to the paretic leg and 3.5 seconds to transfer their weight onto the nonparetic leg during the first assessment. The average weight-transfer time asymmetry measure showed a mean change of .07 (95% CI, –.21 to .36) throughout the follow-up period, except for a marked increase in asymmetry ($A$=1.6) during the second assessment ($F_{1,24}$=1.80, $P$=.19).

In the ideal situation, the COP trajectory would move only within the target area (see patterned area in fig 2). Averaged over all assessments, the stroke patients spent less time (62.5%) in the target area than did the healthy elderly subjects (75.9%) ($t_{56}$=–2.67, $P$=.004). Although the stroke patients improved their time spent within the target area from 58.5% at the start to 64.7% at the end of the training period, this improvement did not reach significance ($t_{35}$=–1.69, $P$=.10). Of the time spent outside the target area, the healthy elderly subjects and the stroke patients deviated mainly anteriorly (22.8% and 35.2%, respectively). In the group with stroke, for both the time spent within the target area and outside, there were no significant asymmetries in favor of the paretic or the nonparetic leg.

## Subgroup Analysis

For the biologic characteristics, a main effect was found for age on the speed of weight shifting ($F_{1,34}$=14.78, $P$<.001) (fig 3). Patients 65 years and older were significantly slower (averaged over time, 6.6 hits) than those younger than 65 years (averaged over time, 9.6 hits). Both groups appeared to stabilize their performance after 8 weeks of balance training. No main effects were found for time from stroke nor for the location or type of stroke.

As for the influence of the various clinical characteristics at baseline, the presence of visuospatial hemineglect had a negative (20%) effect on the weight-shifting speed ($F_{1,34}$=4.21, $P$<.05), which is illustrated in figure 4. Both patients with and without hemineglect improved their performance across time but showed stabilization after 8 weeks of balance training. Stroke patients with hemineglect showed a relatively large weight-transfer time asymmetry ($A$=1.4). No significant effects were found for initial motor stage, sensibility, reflex activity, or trunk control.

## Association With Quiet Standing

The association between weight-shifting and quiet-standing control was examined at the start and at the end of the training period by correlating both weight-shifting speed and imprecision with the RMS COP velocity in the frontal (VCOP lateral) and sagittal (VCOP AP) planes averaged over conditions and

**Table 2: Speed, Precision, and Symmetry of Weight Shifting for All Follow-Up Assessments**

| Time (wk) | S | S+2 | S+4 | S+8 | S+12 | HE |
|---|---|---|---|---|---|---|
| No. of hits (N=36) | 6.9 (5.8–8.0) | 7.6 (6.5–8.7) | 8.4 (7.4–9.5) | 9.2 (8.3–10.1) | 9.2 (7.9–10.4) | 11.5 (10.8–12.2) |
| Imprecision (mm)* (n=25) | 154 (124.3–183.7) | 138 (116.3–159.6) | 139.7 (104.1–175.3) | 126.4 (100.0–152.8) | 116.4 (98.6–133.9) | 118.8 (103.5–134.2) |
| Time asymmetry† (n=25) | 1.3 (1.1–1.5) | 1.6 (1.1–2.0) | 1.3 (1.1–1.4) | 1.2 (1.1–1.4) | 1.2 (1.0–1.4) | 1.0 (0.9–1.1) |

NOTE. Values are means and 95% CIs.
Abbreviations: HE, healthy elderly; S, start of balance training.
*Imprecision is the normalized average COP displacement per weight shift in the frontal plane.
†Time asymmetry is the average time needed for weight transfer to the paretic leg divided by the average time needed for weight transfer to the nonparetic leg.

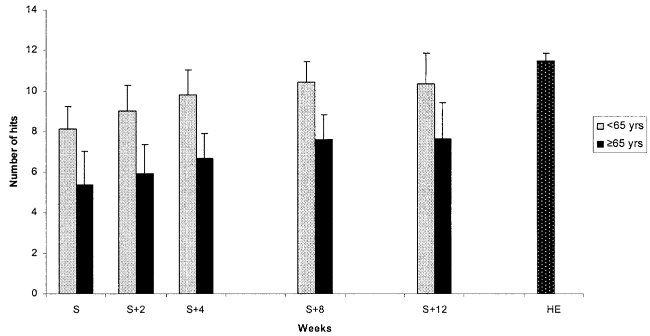


**Fig 3. Speed of weight shifting, expressed as the number of hits, for the stroke patients younger than 65 years (n=20) and for those 65 years and older (n=16) at all follow-up assessments. The 95% CIs are plotted 1-sided. Abbreviations: HE, healthy elderly (n=23); S, start of balance training.**

during each of the standing conditions alone. Table 3 shows significant and substantial associations of both weight-shifting speed (mainly at the end of the training) and imprecision (at the start and at the end of the training) with VCOP lateral and with VCOP AP during all 4 quiet-standing conditions.

## DISCUSSION

The primary goal of this study was to provide insight into several characteristics of the restoration of weight-shifting control in first-ever postacute hemispheric stroke survivors during 12 weeks of inpatient rehabilitation, irrespective of the causal mechanisms. For this purpose, an instrumented dynamic balance task was used that required patients to make voluntary well-controlled weight shifts in the frontal plane while using real-time and real-size visual COP feedback. This task was analyzed in terms of speed and precision and with regard to spatiotemporal symmetry, to identify a possible resymmetrization process. During the training period, balance and walking skills of the stroke group as a whole developed from "dependent on one person" to "fully independent on level ground," whereas leg muscle selectivity improved from "gross alternating muscle synergies" to "some degree of selective muscle control."

### Speed and Precision

The posturographic results showed that, at the start of the training, the selected stroke patients made fewer weight shifts and were less precise than were the healthy elderly subjects, which indicates that both the speed and precision of weight shifting are affected by stroke. During the follow-up period, the stroke patients became significantly faster (33%) and more precise (25%). However, whereas the precision of weight shifting reached normative reference values after 12 weeks, the increase in speed stabilized after 8 weeks without reaching the performance level of the healthy elderly.

Stroke patients 65 years and older were significantly slower than those younger than 65 years at all assessments, yet both age groups showed quite similar recovery profiles. The relatively pronounced slowness in the elderly stroke patients can be understood in view of the fact that the applied balance task requires integration of (artificial) visual feedback with other sources of sensory input to program and execute well-controlled weight shifts under time pressure. Indeed, several studies[14,35-37] have shown aging effects on sensory integration and central processing time related to balance performance. Subgroup analysis also showed a negative effect of visuospatial hemineglect on the speed of weight shifting. Patients with hemineglect showed a relatively large weight-transfer time asymmetry ($A=1.4$) as well. Because patients with hemineglect suffer from deficits in distributing their attention over both sides of their body and action space,[38] they may experience disproportional problems with visually controlled weight shifting, especially to their paretic leg. Neither age nor the presence of visuospatial hemineglect, however, seemed to affect the relative improvement of weight-shifting speed during the rehabilitation. All patient groups gradually improved and tended to stabilize their performance in terms of speed after 8 weeks of training.

### Spatiotemporal Symmetry

On average, the stroke patients needed 23% more time to make a weight shift to their paretic leg than they did when shifting to their nonparetic leg, which remained more or less constant during the training period. On the one hand, this degree of weight-transfer time asymmetry seems rather small, considering the large differences in sensorimotor functions between the paretic and nonparetic legs in most patients. On the other hand, the observed weight-transfer time asymmetry does not tend to diminish. This pattern of results may indicate that stroke patients have difficulties with making weight shifts to both legs—not only the paretic one, which would be in accordance with other studies.[4,5,10-12] This conclusion is supported by analyzing the spatiotemporal distribution of the COP displacements during weight shifting. Both inside and outside the target area, the stroke patients did not show a significant asymmetry with regard to the time spent on their paretic versus nonparetic side, yet they were generally less efficient than the healthy elderly subjects, both at the start and at the end of the training, because they spent more time outside the target area. When outside the target area, both patients and healthy elderly subjects deviated mainly anteriorly, which probably reflects a safety strategy to avoid posterior falls.

### Association With Quiet Standing

Significant correlations were found between the control of quiet standing and the precision of weight shifting among individual patients. Remarkably, weight-shifting precision was as equally associated with sagittal- as with frontal-plane control during quiet standing, yielding shared variances (Spearman $\rho^2$) ranging from 23% to 61% (see table 3). Also, for the speed of weight shifting, there were significant correlations with quiet-standing control in both planes; however, more at the end ($\rho^2$

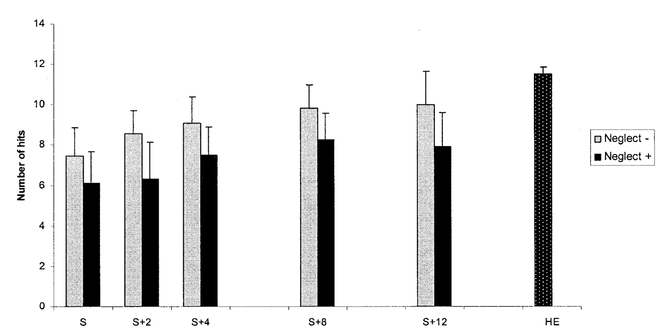


**Fig 4. Speed of weight shifting, expressed as the number of hits, for the stroke patients without a visuospatial hemineglect (n=21) and for those with a visuospatial hemineglect (n=15) at all follow-up assessments (healthy elderly, n=23). The 95% CIs are plotted 1-sided.**

**Table 3: Spearman Correlations Coefficients (ρ) for the Relationship Between Weight-Shifting Capacity (Speed and Precision) and Quiet-Standing Control (RMS COP Velocity or VCOP) at the Start and at the End of the Balance Training (n=25)**

| | | Speed (no. of hits) | | Imprecision* | |
|---|---|---|---|---|---|
| Parameters | Tasks | Start of Balance Training | End of Balance Training | Start of Balance Training | End of Balance Training |
| VCOP lateral | EO | –.23 | –.70† | .64† | .77† |
| | EC | –.06 | –.59† | .48‡ | .66† |
| | DT | –.44‡ | –.74† | .63† | .72† |
| | VR | –.15 | –.67† | .59† | .75† |
| | Average | –.19 | –.67† | .60† | .72† |
| VCOP AP | EO | –.41‡ | –.54† | .78† | .71† |
| | EC | –.31 | –.57† | .66† | .66† |
| | DT | –.51† | –.64† | .78† | .74† |
| | VR | –.26 | –.50‡ | .70† | .64† |
| | Average | –.43‡ | –.60† | .82† | .72† |

Abbreviations: DT, dual task; EC, eyes closed; EO, eyes open; VR, vertical midline reference.
*Imprecision is the normalized averaged COP displacement per weight shift in the frontal plane.
†Significant at $P<.01$.
‡Significant at $P<.05$.

range, 25%–55%) than at the start of the training period. On the one hand, these reasonably fair associations between weight shifting and quiet standing seem to imply that the control of both tasks relies, at least partly, on common physiologic mechanisms. On the other hand, the shared variances of the selected parameters are low enough to conclude that the assessment of voluntary weight-shifting capacity significantly adds information about individual balance performance in stroke patients, compared with the assessment of quiet-standing tasks alone. This general conclusion is supported by the results of other studies.[18,19] Our results suggest that this additional information may be particularly relevant in the case of poor balance skills (ie, at the start of a training program).

### Limitations

The results of our study are representative of weight-shifting restoration only with regard to a specific subgroup of first-ever hemispheric stroke patients, which is commonly selected for inpatient rehabilitation in the Netherlands. From the fact that 61% of the included patients had disturbed trunk control and 44% had an FAC score as low as 1 at study entry, it is evident that the selected patient sample is characterized by relatively severe sensorimotor deficits, which causes dependence in performing most daily activities. Because a functional criterion was applied for the start of the posturographic assessments in individual patients (ie, 30s of independent standing), the time from stroke varied considerably at study entry (see table 1). As a result, the possible influence of various other biologic or clinical characteristics that covary with the time from stroke (eg, leg muscle selectivity) may have been neutralized. Although, to our knowledge, this is the first study that investigates the restoration of weight-shifting capacity over a 12-week period after stroke, the number of patients included was limited, which may have led to a lack of statistical power, especially in those analyses done on subgroups of patients.

## CONCLUSIONS

Even severe stroke patients who are selected for inpatient rehabilitation to retrain gross motor skills can substantially improve their weight-shifting capacity in the frontal plane during a 12-week training period, in terms of both speed and precision. Unlike the speed of weight shifting, precision may even reach the performance level of the healthy elderly. An advanced age (>65y) and the presence of visuospatial hemineglect primarily affect the absolute weight-shifting speed but not its improvement over time. Greater weight-shifting speed is accomplished by a reduction in weight-transfer time to both the paretic and nonparetic legs in a proportionate manner, which is indicated by a persisting small degree of weight-transfer time asymmetry. In addition, the spatiotemporal distribution of the weight-shifting activity appears remarkably symmetric, although more anterior deviation occurs in stroke patients than in the healthy elderly. In addition to static balance assessments, the assessment of weight-shifting capacity provides unique information about balance recovery after stroke. These observational data may guide the development and evaluation of new rehabilitation strategies to improve weight-shifting capacity and related functional activities in stroke patients.

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## Suppliers

a. Load cells, type LM-100KA; Kyowa Electronic Instruments Co Ltd, Chofu-Higashiguchi Bldg 2F, 45-6, Fuda 1-chome, Chofu, Tokyo 182, Japan.
b. RMP DC-amplifier, type MBP 6218; Elan Schaltelemente GmbH, Holzheimer Weg 50, D-4040 Neuss 1, Germany.