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Recovery of quiet standing balance and lower limb motor impairment early poststroke – how are they related?

Running title: Quiet standing balance recovery poststroke

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Abstract

Background. Recovery of quiet standing balance early poststroke has been poorly investigated using repeated measurements.

Objective. To investigate (1) the time course of steady-state balance in terms of postural stability and inter-limb symmetry, and (2) longitudinal associations with lower limb motor recovery in the first 3 months poststroke.

Methods. Forty-eight hemiparetic subjects (age: 58.9±16.1 years) were evaluated at weeks 3, 5, 8 and 12 poststroke. Motor impairments concerned the Fugl-Meyer assessment (FM-LE) and Motricity Index total score (MI-LE) or ankle item separately (MI-ankle). Postural stability during quiet two-legged stance was calculated as the net center-of-pressure area (COP_{Area}) and direction-dependent velocities (COP_{Vel-ML}, COP_{Vel-AP}). Dynamic control asymmetry (DCA) and weight-bearing asymmetry (WBA) estimated inter-limb symmetries in balance control and loading. Linear mixed models determined (1) time-dependent change and (2) the *between*- and *within*-subject associations between motor impairments and postural stability or inter-limb symmetry.

Results. Time-dependent improvements were significant for FM-LE, MI-LE, MI-ankle, COP_{Area}, COP_{Vel-ML} and COP_{Vel-AP}, and tended to plateau by week 8. In contrast, DCA and WBA did not exhibit change. *Between*-subject analyses yielded significant regression coefficients for FM-LE, MI-LE and MI-ankle scores with COP_{Area}, COP_{Vel-ML} and COP_{Vel-AP} up until week 8, and with WBA until week 12. *Within*-subject regression coefficients of motor recovery with change in COP_{Area}, COP_{Vel-ML}, COP_{Vel-AP}, DCA or WBA were generally non-significant.

Conclusions. Postural stability improved significantly in the first 8 weeks poststroke, independent of lower limb motor recovery at the most affected side *within* subjects. Our findings suggest that subjects preferred to compensate with the less affected side, making inter-limb asymmetries in balance control and weight-bearing invariant for change in the first 3 months poststroke.

Clinical Trial Registration: Clinicaltrials.gov. unique identifier NCT03728036

Keywords: Stroke, Longitudinal study, Posturography, Standing balance, Recovery, Postural sway

Introduction

Regaining steady-state balance during quiet standing is mainly achieved within the first 3 months poststroke[1,2] and is a prerequisite for accomplishing independent gait and most activities of daily life.[2-4] Despite its clinical importance, a limited number of observational studies have investigated how lower limb motor recovery associates longitudinally with steady-state balance improvements within this time window.

A few longitudinal studies[5-9] have suggested that lower limb motor recovery follows a proportional and predictable time course in the first 3 to 6 months poststroke. This includes clinical improvements in synergistic independent motor control,[5,7-9] as measured with the Fugl-Meyer lower extremity motor score (FM-LE), and strength,[6,7] as measured for example with the Motricity Index (MI-LE). These findings corroborate observations of the upper limb[5,7,10] as significant improvements occur in most patients up until week 5[5,6] to 8[7] poststroke, and a small proportion (10 to 15%) fail to show any motor recovery.[8]

At the same time, steady-state balance control remains deficient after independent stance is regained, with stroke patients exhibiting greater postural sway of the net center-of-pressure (COP) than healthy controls and loading more body weight on the less affected leg.[11-13] More recent posturographic studies[14-16] examined the individual-limb COP trajectories to show that this weight-bearing asymmetry (WBA) is further characterized by an asymmetric exertion of stabilizing ankle torques. This so-called dynamic control asymmetry (DCA) reflects the most affected leg's contribution to balance control in the sagittal plane, relative to the less affected side.[14,16] It has been suggested that the DCA is associated with impairment severity,[17] although Roelofs and colleagues[16] have recently shown that even patients with (almost) complete FM-LE recovery may still exhibit significant balance control asymmetries favoring the less affected leg. How this relationship develops *within* subjects over the first weeks after stroke is currently unclear.

To investigate the quality of movement regarding steady-state balance poststroke, the literature[15,17] recommends complementing conventional instability measures, such as the net COP sway area (COP_{Area})[12,13,17] and velocities in frontal ($COP_{Vel\text{-}ML}$) and sagittal planes ($COP_{Vel\text{-}AP}$),[14,16] with metrics that reflect asymmetries, such as DCA and WBA. These metrics may yield different, yet complementary information about how an improved postural stability is achieved in patients with hemiparesis, by distinguishing "normalization" of inter-limb symmetry from persistent compensatory stabilization through the less affected leg, in reference to a control population of healthy adults. So far, very few attempts have been made to implement such metrics in stroke recovery studies[11,18,19] and an earlier study by De Haart and colleagues[14,17] investigated recovery using repeated measurements at arbitrary time-points, often beyond the period in which the recovery of muscle synergies and strength plateaus. According to this knowledge gap, the overall aim of the present observational study was to prospectively investigate the time course of quiet standing balance in terms of posture stabilization and recovery from inter-limb asymmetries early after stroke onset. Subsequently, we aimed to relate these fine-grained task performance changes to motor recovery at the level of the entire lower limb (i.e., FM-LE and MI-LE) and ankle separately (by using the dorsiflexion item of the Motricity Index [MI-ankle]), considering that steady-state balance is mainly controlled through ankle torques.[20] The following research questions were addressed:

1. What is the time course of muscle synergies (i.e., FM-LE) and strength (i.e., MI-LE and MI-ankle) in the most affected leg within the first 3 months poststroke?

2. What is the time course of postural stability (i.e., COP_{Area}, COP_{Vel-ML} and COP_{Vel-AP}) and inter-limb symmetry (i.e., DCA and WBA) during quiet stance within the first 3 months poststroke?
3. How is the severity of motor impairments (i.e., FM-LE, MI-LE and MI-ankle) associated with postural instability (i.e., COP_{Area}, COP_{Vel-ML} and COP_{Vel-AP}) and inter-limb asymmetry (i.e., DCA and WBA) during quiet stance *between* subjects within the first 3 months poststroke?
4. How are improvements in motor impairments (i.e., FM-LE, MI-LE and MI-ankle) associated with change in postural instability (i.e., COP_{Area}, COP_{Vel-ML} and COP_{Vel-AP}) and inter-limb asymmetry (i.e., DCA and WBA) during quiet stance *within* subjects over the first 3 months poststroke?

In line with recovery models of the paretic upper limb,[10] we hypothesized for the first question that significant time-dependent change in FM-LE, MI-LE and MI-ankle would occur within the first 8 weeks poststroke. For the second question, we hypothesized that steady-state balance would parallel motor recovery and follow the same pattern as previously described for upper limb motor performance.[21,22] Recovery of steady-state balance is here defined as posture stabilization reflected by decreases in COP_{Area}, COP_{Vel-ML} and COP_{Vel-AP}. Concomitant reductions in asymmetries in DCA and WBA in the direction of norm values in age-matched healthy controls are seen as an indicator of an improved quality of movement. For the third question, we assumed that patients with lower FM-LE, MI-LE and MI-ankle scores would exhibit greater postural instability (i.e., COP_{Area}, COP_{Vel-ML} and COP_{Vel-AP}) and asymmetries in DCA and WBA, with an increased involvement of the less affected leg. Lastly, we hypothesized concerning the forth question that the *within*-subject associations between recovery of impairments and steady-state balance would be time-dependent. That is, rising FM-LE, MI-LE and MI-ankle scores would associate with reductions in postural instability (i.e., COP_{Area}, $COP_{Vel\text{-}ML}$ and $COP_{Vel\text{-}AP}$) and asymmetries in DCA and WBA mainly within the first 8 weeks poststroke.

Methods

The present longitudinal study is part of the larger TARGEt research project. TARGEt is an acronym for Temporal Analyses and Robustness of hemiplegic Gait and standing balance Early poststroke, and was funded by the Research Foundation - Flanders (FWO, Flanders, Belgium; application no. 1S64819N). This project was approved by the Medical Ethics Committee of the University Hospital Antwerp (No. 18/25/305; Belgian trial registration no. B300201837010) and additional approval was obtained from the ethics committees of other hospitals involved. All procedures were conducted in accordance with the Declaration of Helsinki. The design of the study protocol has been reported elsewhere[23] and the protocol is also registered online (ClinicalTrials.gov identified: NCT03728036). The manuscript was written in conformity with the STROBE statement.[24]

Participants

Patients admitted to one of the three cooperating hospitals and two rehabilitation facilities (Antwerp region, Belgium) after an acute ischemic or hemorrhagic stroke were screened for participation between December 2018 and December 2021. Screening and recruitment were performed by the study coordinator (JS) together with the medical doctors and physiotherapists employed at the stroke units and rehabilitation facilities. All participants met the following inclusion criteria: (1) having experienced a first-ever hemispheric stroke confirmed by CT and/or MRI scan; (2) having been included within the first 3 weeks after stroke; (3) having reduced leg strength, defined as >0 points on item 6a/b of the NIHSS (i.e., at least “drift within 5 seconds”) within 72 hours poststroke and an MI-LE score <91 (i.e., at least “movement against resistance but weaker” for one item) at inclusion; (4) age between

18 and 90 years; (5) premorbid independence in daily life activities (i.e., modified Rankin Scale score of 0-1); (6) no severe orthopedic condition of the lower limbs and trunk or another neurological illness present before stroke; (7) no severe cognitive or communicative deficit that may interfere with understanding instructions and study procedures; and (8) providing written informed consent. These criteria were chosen to recruit a cohort of initially hemiplegic patients with some residual motor impairment requiring inpatient rehabilitation care due to a primary stroke.

Additionally, we recruited age- and sex-matched adult subjects without reported history of neurological and/or orthopedic conditions to obtain healthy reference values of inter-limb symmetry while standing.

Procedures

In line with recommendations from the Stroke Recovery and Rehabilitation Roundtable (SRRR),[25,26] serial measurements were scheduled for each participant at weeks 3, 5, 8 and 12 poststroke. At each time-point, clinical scales were complemented by posturographic measurements of steady-state balance. Two trained assessors (EE, JS) were available to administer clinical scales during face-to-face sessions, while the same observer conducted all serial measurements of individual participants. Posturography was performed by a single assessor (JS) who was trained in operating the measuring instruments. The same measurements were performed once in healthy controls for comparison.

Clinical measurements

During intake, subjects' sex, age, stroke type (i.e., ischemic or hemorrhagic) and most affected body side (i.e., left or right) were recorded. Serial follow-up measurements included, first, the “standing unsupported” item of the Berg Balance Scale (BBS-s) to determine if subjects were eligible for posturography. Second, impairments in synergistic depended motor control and strength were evaluated at the most affected side using the FM-LE[5] and MI-LE,[27] respectively. Synergy was defined as a pathological pattern of muscle co-activation occurring with voluntary movement, referring to the clinical phenomenon of "abnormal muscle synergies".[28,29] The FM-LE (0-34) is valid and highly reliabile,[30] and we used a standardization method developed by See and colleagues.[31] The MI-LE (0-99) was administered by asking subjects to produce a maximum voluntary hip flexion, knee extension and ankle dorsiflexion against resistance. The MI-LE is valid and reliable.[27] We treated the MI-ankle as a separate outcome variable.

Posturographic measurements

The current study investigated steady-state balance defined by Shumway-Cook and Woollacott as "the ability to control the body's center-of-mass (COM) relative to the base of support in fairly predictable conditions and non-changing environments".[32] Accordingly, subjects were instructed to stand quietly on both legs for 40 seconds with their arms alongside their trunk and their eyes fixated on a non-moving visual target. The bare feet were positioned side-by-side in a standardized way (8.4 cm heel-to-heel distance and 9 degrees toe-out angle) and subjects were asked to stand still without further instructions regarding weight-bearing. Measurements started as soon as patients could stand (i.e., BBS-s >0) and, if tolerated, three trials were performed with seated resting breaks in between. The first 10 seconds were removed from each trial.

We used either two laboratory-grade force plates (Type OR6-7 Biomechanics Force Platform, AMTI, MA, US) or a portable plantar pressure plate (0.5m Footscan pressure plate 3D, RS Scan/Materialize, BE) to record ground reaction forces in- or outside the lab environment. The collected raw force data was converted to the net and individual-limb COP trajectories (appendix B, force data acquisition and COP calculations) which were low-pass filtered with a 10 Hz second-order Butterworth filter. Comparability of the two instruments for measuring COP was assessed in advance in healthy controls during vision-deprived stance, yielding high consistency according to Pearson correlation coefficients, yet significant mean differences (appendix A, comparability analyses). To account for these systematic differences, serial *within*-subject measures were always performed with the same type of plate, while *between*-subject variations explained by the choice of measurement instrument were corrected by entering INSTRUMENT as an additional covariate in the final analyses (appendix A, correction method).

To align the individual-limb COP with the anatomical ankle position, the coordinate system was rotated. As subjects may have difficulties with maintaining the standardized position, the actual feet orientation was determined trial-by-trial with an optoelectronic device (Vicon Motion Systems Ltd, Oxford, UK) during force plate measurements, or by the plantar pressure distribution (Footscan, RS Scan/Materialize, BE). The AP axis was defined by a line drawn between the head of the second metatarsal bone and the heel, and the ML axis perpendicular to it.

Performance measures of steady-state balance

To quantify postural stability, we first calculated the COP_{Area} by fitting an ellipse in mm^2 that encloses about 85% of the entire signal, using principal component analysis.[33] This metric served as a general stability index by estimating the total amount of postural sway. Second, the root mean square of the AP- and ML-COP velocities ($COP_{Vel\text{-}ML}$, $COP_{Vel\text{-}AP}$; in mm/s) served as estimates of the global balance control efficacy in specific sway directions.[14,16]

Quality of movement was operationally defined by comparing stroke subjects' task performance directly with that of healthy controls.[34] That means, the better they were able to achieve postural stability with equal contributions by both limbs, the higher their movement quality.[23] To estimate how the stabilizing mechanism of ankle torques in each leg contributed to balance control, we calculated the DCA in percentage as a symmetry index of the individual-limb $\mathrm{COP}_{\mathrm{Vel\text{-}AP}}$.[14,16] It is restricted to the sagittal plane, since ankle torques are less relevant to frontal plane balance.[20] A score of 0% estimates symmetry. Positive and negative values reflect greater contribution of the less and most affected leg, respectively. WBA was calculated by dividing the average F_Z below the most affected leg by the total F_Z (i.e., body-weight), to establish a subject's preferred stance. A value of 50% was distracted from WBA, such that 0% means symmetry comparable to DCA. Posturographic outcomes were averaged over three (or at least two) successive trials per session to maximize reliability.[35]

Statistical analyses

To investigate time courses (questions 1 and 2), we first plotted individual time-series of the outcome variables FM-LE, MI-LE, MI-ankle, $\mathrm{COP}_{\mathrm{Area}}$, $\mathrm{COP}_{\mathrm{Vel\text{-}ML}}$, $\mathrm{COP}_{\mathrm{Vel\text{-}AP}}$, DCA and WBA, to observe trends in recovery. Next, for each outcome variable, a multivariable linear mixed model was applied, treating the main fixed effect, that of TIME (week 3, week 5, week 8, week 12), as a categorical predictor variable reflecting progress of time after stroke onset. AGE (years), SEX (female, male), AFFECTED SIDE (left, right) and INSTRUMENT (force plates, pressure plate) were included as covariates. A random intercept per subject was added to account for dependency between repeated measurements. Post-hoc analyses involved Tukey's HSD multiple comparison method, yielding regression coefficients (β) for time-dependent change over the entire period (i.e., weeks 3-12) and across each epoch (i.e., weeks 3–5, weeks 5–8, weeks 8–12). DCA and WBA values were statistically compared between stroke and healthy subjects at each time-point using the non-parametric Steel's test for multiple pair-wise comparisons, with the healthy values treated as control. The significance level was set at <.05.

Question 3 was addressed using linear mixed models, with COP_{Area}, $COP_{Vel\text{-}ML}$, $COP_{Vel\text{-}AP}$, DCA or WBA as the dependent variable, and either FM-LE or MI-LE as the independent variable. TIME, AGE, SEX, AFFECTED SIDE and INSTRUMENT were added as covariates with a subject-specific intercept. Sub-analyses included four separate models at weeks 3, 5, 8 and 12. For question 4, the *within*-subject associations were calculated using the same model architecture but using change scores (i.e., Δ) with sub-analyses across the three different epochs. For questions 3 and 4, the final regression coefficient (β) predicts change in COP_{Area}, $COP_{Vel\text{-}ML}$, $COP_{Vel\text{-}AP}$, DCA or WBA for a one-unit increase in either FM-LE or MI-LE. Multiple testing was accounted for by using Bonferroni-corrected probability values (i.e., P <.05/n).

All models were fitted using JMP Pro (version 16). Histograms and Q-Q plots of residuals were inspected to check model assumptions.

Results

Figure 1 shows a flow chart of the recruitment of subjects and serial measurements. Approximately 250 first-ever stroke survivors were screened during the recruitment period, of which 66 patients were enrolled for this cohort study. Forty-eight of these subjects participated in at least 2 posturographic measurements and were subsequently included in the analyses. Table 1 shows their main baseline characteristics at 3 weeks poststroke. As shown, the included subjects had a mean (SD) age of 58.9 (16.1 years, 19 were female, 36 had suffered an ischemic stroke and 25 had left-sided impairments. Ten healthy control subjects were additionally included with a similar mean age of 46.9 (14.1) years and sex ratio (40% female).

As summarized in Figure 1, four measurements were missed at week 3. Out of the 44 subjects that could be tested, 37 were able to stand independently and participated in the posturographic measurement. At week 5, two measurements were missing and three subjects had too poor balance to perform the posturographic task. At week 8 and 12, five and twelve measurements were missed, respectively. The main reason was unavailability after hospital discharge. As a result, 24 participants could be tested at all four occasions. Fifteen and 9 subjects participated in three and two serial measurements, respectively. The mean time after stroke onset (SD, range) and the number of participants whose data was available at each time-point were as follows: 24.88 (1.79, 22-28) days and N=37 for week 3; 38.61 (2.10, 35-42) days and N=43 for week 5; 59.17 (2.16, 55-63) days and N=43 for week 8; 88.18 (3.66, 84-103) days and N=36 for week 12.

<INSERT FIGURE 1 ABOUT HERE>

<INSERT TABLE 1 ABOUT HERE>

1. Effects of time on recovery of lower limb muscle synergies and strength

Figure 2A depicts individual and mean time-dependent change in FM-LE, MI-LE and MI-ankle. TIME was a significant factor (P<.001) affecting recovery of FM-LE (β=3.84, 95%CI[2.58;5.11],P<.001), MI-LE (β=12.37, 95%CI[7.77;16.97],P<.001) and MI-ankle (β=4.99, 95%CI[2.92;7.05],P<.001) from week 3 to 12. As further shown in Table 2, significant time-dependent change was found between weeks 3 and 5 for FM-LE (β=1.66, 95%CI[0.50;2.82], P=.002), MI-LE (β=5.63, 95%CI[1.43;9.84],P=.004) and MI-ankle (β=2.83, 95%CI[0.92;4.71],P<.001). A significant increase was also seen for FM-LE between weeks 5 and 8 (β=1.49, 95%CI[0.36;2.61],P=.004), whereas a non-significant change was found in MI-LE and MI-ankle scores (*P*>.05, Table 2). TIME was not a significant factor from week 8 onwards.

<INSERT FIGURES 2A-C ABOUT HERE>

2. Effects of time on recovery of steady-state balance during quiet stance

Figures 2B-C show individual and mean time-dependent change in postural stability and symmetry metrics, respectively. As shown in Table 2, TIME was a significant factor for improvements from week 3 to 12 in COP_{Area} (β=-175.0, 95%CI[-263.0;-87.0],*P*<.001), $COP_{Vel\text{-}ML}$ (β=-4.71, 95%CI[-6.73;-2.69],*P*<.001) and $COP_{Vel\text{-}AP}$ (β=-3.14, 95%CI[-5.09;-1.18],*P*<.001), after correction for INSTRUMENT as the only significant covariate for change in COP_{Area} (β=134.3, 95%CI[77.4;191.3],*P*<.001), $COP_{Vel\text{-}ML}$ (β=4.86, 95%CI[2.90;6.83],*P*<.001) and $COP_{Vel\text{-}AP}$ (β=6.28, 95%CI[4.40;8.16],*P*<.001). Further sub-analyses yielded significant reductions in COP_{Area} between weeks 5 and 8 (β=-79.8, 95%CI[-158.4;-1.2],*P*=.045) and in $COP_{Vel\text{-}ML}$ between weeks 3 and 5 (β=-1.90, 95%CI[-3.75;-0.06],*P*=.041).

No significant time-dependent change was found for DCA and WBA. Comparison with mean symmetry values in healthy subjects (DCA: 16.3%, SD=31.8; WBA: -1.1%, SD=3.5) showed significant differences in WBA at week 3 (difference=7.7%, standard error [SE]=3.0,*P*=.001), week 5 (difference=7.2%, SE=2.9,*P*=.005), week 8 (difference=7.5%, SE=2.9,*P*=.009) and week 12 (difference=8.3%, SE=3.0,*P*=.008). Differences in DCA were statistically significant at week 8 (difference=42.5%, SE=20.8,*P*=.029) and week 12 (difference=51.2%, SE=21.2,*P*=.012). Figures 3A-B depict sway profiles measured at each time-point in a single subject.

<INSERT TABLE 2 ABOUT HERE>

<INSERT FIGURES 3A-B ABOUT HERE>

3. Between-subject associations of lower limb impairment severity with steady-state balance

Table 3 shows the *between*-subjects analyses applied cross-sectionally at weeks 3, 5, 8 and 12 for either FM-LE, MI-LE or MI-ankle with COP_{Area}, COP_{Vel-ML}, COP_{Vel-AP}, DCA or WBA. Scatterplots of these associations with their linear regression lines are provided in the supplement (Supplementary figure 3, appendix C). The main effects of FM-LE, MI-LE or MI-ankle were significant for COP_{Area}, COP_{Vel-ML}, and COP_{Vel-AP}, as well as for WBA (*P*<.001). Additional significant covariates were INSTRUMENT (*P*<.001) for the associations with COP_{Area}, COP_{Vel-ML} and COP_{Vel-AP} as the dependent variables; TIME (*P*<.05) for COP_{Area} and COP_{Vel-ML}; and AFFECTED SIDE (*P*<.05) for COP_{Area} (Table 3). *Between*-subject analyses with DCA yielded non-significant results.

Sub-analyses concerning FM-LE, MI-LE and MI-ankle scores yielded significant regression coefficients up until week 8 for COP_{Area}, COP_{Vel-ML}, COP_{Vel-AP} and WBA (*P*<.01, see Table 3 for more detail). At week 12, FM-LE remained a significant predictor of COP_{Vel-ML} (β=-0.49, 95%CI[-0.77;-0.22],*P*<.001) and WBA (β=-0.64, 95%CI:-1.09;-0.21,*P*=.005).

Additionally, a single significant coefficient was identified for MI-LE scores at week 12 concerning WBA (β=-0.20, 95%CI[-0.34;-0.06],*P*=.008).

<INSERT TABLE 3 ABOUT HERE>

4. Within-subject associations of lower limb motor recovery with change in steady-state balance

Regression coefficients between ΔFM-LE, ΔMI-LE or ΔMI-ankle on the one hand, and ΔCOP_{Area}, $\Delta COP_{Vel\text{-}ML}$, $\Delta COP_{Vel\text{-}AP}$, ΔDCA or ΔWBA on the other were estimated for weeks 3–5, weeks 5–8 and weeks 8–12, using 36, 38 and 35 individual change scores, respectively. Scatterplots with their linear regression lines are provided in the supplement (Supplementary figure 4, appendix C). As shown in Table 4, the main effects of ΔFM-LE, ΔMI-LE and ΔMI-ankle were not significant for any dependent variable. Sub-analyses across the three epochs yielded a single significant regression coefficient for ΔMI-LE with $\Delta COP_{Vel\text{-}ML}$ between weeks 8 and 12 (β=-0.12, 95%CI[-0.21;-0.04],*P*=.007).

<INSERT TABLE 4 ABOUT HERE>

Discussion

The present prospective cohort study involving 48 subjects investigated the time course of steady-state balance during quiet stance in relation to lower limb motor recovery within the first 3 months poststroke. Controlling a high-positioned COM above a small base of support while standing is an easily standardized, yet skilled motor task requiring continuous postural corrections by the lower limbs. Unlike other prospective recovery studies in this field,[11,14,17-19] we were interested in how clinically assessed impairments in muscle synergies (i.e., FM-LE) and strength (i.e., MI-LE and MI-ankle) of the most affected leg are associated with postural stability (i.e., COP_{Area}, $COP_{Vel\text{-}ML}$, $COP_{Vel\text{-}AP}$) and asymmetric limb contributions to balance (i.e., DCA, WBA) during quiet two-legged stance. We therefore performed serial measurements in the same subjects and at fixed times poststroke.[25,26] Our main findings are summarized below.

- A restricted time window of recovery concerning motor impairments and postural stability that occurs within the first 8 weeks poststroke. (Table 2)
- Stroke subjects differ significantly from healthy controls with respect to inter-limb asymmetry in DCA and WBA.
- Lack of recovery from asymmetries in DCA and WBA in the first 3 months poststroke, despite significant motor improvements in the most affected leg. (Table 2)
- Significant *between*-subject associations between motor impairment severity and postural instability (i.e., COP_{Area}, $COP_{Vel\text{-}ML}$, $COP_{Vel\text{-}AP}$) as well as a preferred asymmetric stance (i.e., WBA) within the first 3 months poststroke. (Table 3)
- Lack of significant *between*-subject associations of motor impairment severity with DCA. (Table 3)
- An overall lack of significant *within*-subject associations between improved muscle synergies and strength of the lower limb and change in postural stability and symmetry. (Table 4)

In agreement with our first hypothesis, the contribution of the progress of time as a reflection of spontaneous neurobiological recovery[7] was most pronounced for FM-LE, MI-LE and MI-ankle between weeks 3 and 5 poststroke. Approximately half of the total observed change occurred within this relatively short epoch (FM-LE: 43.2%, MI-LE: 45.5%, MI-ankle: 56.7%; Table 2). Recovery rapidly leveled off thereafter, which is in agreement with previous studies.[5-7] In the literature, this restricted time window has also been described for the paretic upper limb[5,10] as well as for other neurological impairments including visuospatial inattention[36] and aphasia,[37] suggesting spontaneous neurological restitution within the first 5 to 8 weeks poststroke.

Confirming our second hypothesis, the present study shows that progress of time is also an independent factor contributing to improved postural stability. Significant reductions in $COP_{Vel\text{-}ML}$ and COP_{Area} were most prominent within the first 8 weeks poststroke, responsible for about 75% of the total observed change (Table 2). Although $COP_{Vel\text{-}AP}$ was not statistically significant within a specific epoch, it displayed a similar pattern of change in the first 12 weeks poststroke (Figure 2B). As such, steady-state balance became increasingly efficient, as reflected by a general COP sway reduction, in approximately the same time window as that seen for lower limb motor recovery.

A shared period of significant recovery has also been found in kinematic studies investigating the quality of upper limb motor performance relative to the Fugl-Meyer arm motor score.[21,22] In contrast, the present study showed that DCA and WBA were, on average, invariant for change over time (Figure 2C). The persistent asymmetry of approximately 45 to 60% greater contribution of the less affected limb in terms of DCA approaches values reported in chronic patients.[16] Moreover, an unchanged asymmetric weight-bearing (about 40% of body-weight on the most affected leg) despite significant COP sway reductions over time, agrees with other longitudinal studies starting their measurements within the first 3 months poststroke.[14,18,19,38] Obviously, subjects preferred to keep and control their balance predominantly with their less affected side to achieve posture stabilization while standing. Figures 3A-B illustrate persistent asymmetries in a typically behaving subject.

In agreement with our third hypothesis, relatively strong *between*-subject associations were found, such that a preferred asymmetric stance appears strongly dependent on the lower limb impairment severity. It was previously shown in healthy subjects that a gradually loaded leg is increasingly involved in balance control.[15,39,40] Thus, persistent loading of the less affected leg may indicate an attempt to actually increase the contribution of this leg's stabilizing ankle torques while standing. Our subsequent finding of a significant time-dependent association of impairment severity with postural instability up until week 8 poststroke (Table 3), furthers point towards an optimization of this compensatory strategy after independent stance is regained. Interestingly, impairment severity was not significantly associated with the DCA when comparing *between* subjects. This dissociation was already shown in the chronic phase poststroke[16] and may involve significant reliance on compensatory stabilization with the less affected leg even in mildly affected subjects (Supplementary figure 3, appendix C).

As shown in Table 4, a dissociation between impairment scales and DCA was also found within subjects over time. A mismatch between motor improvements of the paretic leg on the one hand, and persistent inter-limb asymmetries on the other is a novel finding, as earlier longitudinal studies[14,18,19,38] lacked measurements of change within the window of spontaneous neurobiological recovery. This finding may further explain our subsequent finding that FM-LE, MI-LE and MI-ankle recovery neither explained *within*-subject postural stability improvements (fourth hypothesis), despite a shared recovery time window at the group level. Seemingly, recovery of the most affected leg did not significantly contribute to an improved steady-state balance from 3 weeks poststroke onwards, complementing our finding of persistent asymmetries favoring the less affected side. Our results corroborate findings from electromyography (EMG) studies by Garland and colleagues.[19,38,41] showing that balance reactions with the most affected leg in anticipation of rapid arm movements hardly normalize in the first 3 months poststroke,[19,38,41] even after a mild stroke.[19] Instead, significant anticipatory change was consistently observed on the less affected side.[19,38,41] The same studies[19,38] found an asymmetric control during quiet stance, similar to the present findings, suggesting that this compensatory postural strategy generalizes across tasks.

It should be noted, however, that the present recovery study does not give an answer to *why* patients preferred compensatory strategies despite significant motor improvements at the most affected side. Obviously, steady-state balance while standing is a multifactorial skill. Besides motor impairments, postural deficits have also been linked to stroke-related somatosensory[42] and vestibular[43] impairments, a resultant greater visual dependency[44] and misperception of verticality,[45] as well as reduced balance confidence to prevent falls.[46] To disentangle the relative importance of other impairments, cognition and mood, we should have measured these factors as well in a longitudinal way. Alternatively, one may assume that observed *intra*-limb improvements in FM-LE and MI-LE (Table 2) were too small and incomplete for introducing restitution of *inter*-limb symmetry. Instead, relying on their less affected side may have been perceived as more efficient by patients. Similar to our findings, Roelofs and colleagues also showed that even those with (near) complete FM-LE recovery may show a significant dynamic control asymmetry, suggesting that DCA is a more responsive marker of remaining motor deficits than traditional clinical scales.

In summary, our findings suggest that stroke subjects recover their quiet standing balance mainly in the first 8 weeks poststroke by optimizing, rather than “normalizing” compensatory strategies involving the less affected limb. The independency of steady-state balance improvements and motor recovery of the most affected limb further suggests that only instrumented performance measures reflecting inter-limb asymmetry, such as DCA, are suitable to address the quality of movement in order to improve our understanding of balance recovery mechanisms poststroke.

Limitations

Several limitations of the present study should be considered. First, our sample size is limited and larger epidemiological studies incorporating serial instrumented performance measures are needed to generalize our findings. Second, since we started our assessments at 3 weeks poststroke, we may have missed some early changes in motor performance. Despite this, the study was successful in collecting data serially *within* subjects by applying a postural task with relatively low functional demands. A third limitation is that our results are restricted to quiet two-legged standing, which obviously allows compensation strategies. This may have prevent us from measuring the extend of “true” neurological recovery in the most affected leg for controlling balance. Third, as emphasized, our analyses are restricted to motor impairments in terms of FM-LE and MI-LE. Consequently, we did not investigate recovery in other potentially relevant impairments, such as muscle tone,[47] sensation[44] or visuospatial perception.[48] Additionally, the FM-LE and MI-LE assess distal motor control through movement range and strength in ankle dorsiflexion, whereas quiet standing balance is mainly controlled by plantarflexor activity that resists forwards toppling due to gravity.[49] This “narrow” emphasis of clinical scales on foot elevation alone, may have prevented us from finding significant associations. Fourth, we used two measuring instruments to allow data acquisition in various settings. Since we used the same instrument *within* subjects and added the covariate INSTRUMENT systematically to our final analyses, we believe that the use of two different platform types did not affect our conclusions. Nevertheless, more research is needed for the development and validation of portable instruments to enable even larger longitudinal studies with longer follow-ups beyond hospitalization. Lastly, we did not monitor treatment content and are unable to decide whether our findings were influenced by, for example, therapy dose or focus.

Future directions

An unaddressed key question arising from the current study is: "*Why* do clinical improvements in muscle synergies and strength of the most affected leg hardly generalize to an improved quality of steady-state balance?" Addressing this question requires future studies with serial measurements of sensory and cognitive perception deficits as well as patients' mood (e.g., by using standardized questionnaires of balance confidence[50]). In addition, future studies with serial EMG measurements are needed to show if the actual changes in intra-limb coordination of the paretic leg make a beneficial contribution to posture stabilization or, alternatively, should be seen as "noise" that needs to be suppressed while standing. Unravelling a potential mismatch between the preferred postural strategy and subjects' capacity to normalize their quality of movement by an increased balance contribution from the most affected leg is important to address another unsolved question: "Are therapies aiming to restore symmetry, such as the Bobath approach[51] or visual feedback training,[52] counterproductive if we aim at posture stabilization and avoiding falls?" Building an evidence base for effective rehabilitation strategies is important, as falls remain a major health care problem at all stages of the disease.[53]

To drive the field forward, it is important to reach agreement on a shared language and the metrics applied to assess qualitative aspects of movement. The SRRR mobility task force – a group of experts in the field of balance and gait research – currently gathers intending to build consensus on how future trials should address recovery. This will include standardized recommendations on taxonomy, timing and choice of assessments as well as the metrics used to measure the quality of quiet standing balance and mobility performance within the first 6 months poststroke.

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Tables

Demographics and stroke information (N=48)	
Study subjects	48
Age, years*	58.9 ± 16.1
Sex, female/male	19/29
Body weight, kg*	74.3 ± 13.2
Affected body side, left/right	25/23
Stroke type, ischemic/hemorrhagic	36/12
Measuring instrument, force plates/pressure plate	19/29
Time poststroke, days*	24.9 ± 1.8
Clinical characteristics (N=44)	
FM-LE score (0-34)*	21.9 ± 7.4
MI-LE score (0-99)*	61.2 ± 23.7
MI-ankle score (0-33)*	18.6 ± 8.8
BBS-s score (0-4)*	2.8 ± 1.5
Posturographic characteristics (N=37)	
COP_{Area} (mm²)*	302.7 ± 359.8
$\text{COP}_{\text{Vel-ML}}$ (mm/s)*	10.0 ± 9.5
$\text{COP}_{\text{Vel-AP}}$ (mm/s)*	11.7 ± 9.3
DCA (%)*	44.1 ± 65.8
WBA (%)*	6.6 ± 9.9

Title:

Table 1: Subject characteristics at baseline (i.e., 3 weeks poststroke)

Legend:

Abbreviations: FM-LE, Fugl-Meyer lower extremity motor score; MI-LE, Motricity Index lower extremity score; BBS-s, standing unsupported item of the Berg Balance Scale; COP, center-of-pressure; COP_{Area}, area of the net COP; $\text{COP}_{\text{Vel-ML}}$, rms velocity of the net COP in the frontal plane; $\text{COP}_{\text{Vel-AP}}$, rms velocity of the total COP in the sagittal plane; DCA, dynamic control asymmetry; WBA, weight-bearing asymmetry.

Values are means ± SD if marked (*), otherwise counts are shown. Demographics and stroke information was collected from all included subjects (N=48) at enrollment. Clinical characteristics were obtained in 44 subjects that could be tested at week 3, of which 37 could stand independently to perform the standardized balance task. Their posturographic baseline characteristics are also shown (N=37).

		Week 3 - 12	Week 3 - 5	Week 5 - 8	Week 8 - 12
ΔFM-LE (0-34)	β (SE)	**3.85 (0.46)**	**1.66 (0.44)**	**1.49 (0.43)**	0.70 (0.45)
	95% CI	**2.58; 5.12**	**0.50; 2.82**	**0.36; 2.61**	-0.47; 1.86
	P-value	**<.001**	**.002**	**.004**	.408
	% of total change	**100%**	**43.2%**	**38.8%**	18.2%
ΔMI-LE (0-99)	β (SE)	**12.38 (1.76)**	**5.65 (1.61)**	3.77 (1.57)	2.97 (1.63)
	95% CI	**7.78; 16.99**	**1.44; 9.85**	-0.32; 7.86	-1.27; 7.22
	P-value	**<.001**	**.004**	.083	.266
	% of total change	**100%**	**45.5%**	30.5%	24.0%
ΔMI-ankle (0-33)	β (SE)	**4.99 (0.79)**	**2.83 (0.72)**	1.07 (0.70)	1.09 (0.73)
	95% CI	**2.92; 7.05**	**0.92; 4.71**	-0.77; 2.9	-0.81; 3.00
	P-value	**<.001**	**<.001**	.428	.445
	% of total change	**100%**	**56.7%**	21.4%	21.9%
ΔCOP$_{\text{Area}}$* (mm^2)	β (SE)	**-175.0 (33.7)**	-64.6 (31.1)	**-79.8 (30.1)**	-30.6 (31.3)
	95% CI	**-263.0; -87.0**	-145.6; 16.4	**-158.4; -1.2**	-112.3; 51.2
	P-value	**<.001**	.166	**.045**	.763
	% of total change	**100%**	36.9%	**45.4%**	17.7%
ΔCOP$_{\text{Vel-ML}}$* (mm/s)	β (SE)	**-4.71 (0.77)**	**-1.90 (0.71)**	-1.47 (0.71)	-1.34 (0.71)
	95% CI	**-6.73; -2.69**	**-3.75; -0.06**	-3.26; 0.33	-3.20; 0.52
	P-value	**<.001**	**.041**	.149	.244
	% of total change	**100%**	**40.4%**	31.1%	28.5%
ΔCOP$_{\text{Vel-AP}}$* (mm/s)	β (SE)	**-3.14 (0.75)**	-1.12 (0.69)	-1.31 (0.67)	-0.71 (0.69)
	95% CI	**-5.09; -1.18**	-2.91; 0.68	-3.05; 0.43	-2.52; 1.10
	P-value	**<.001**	.370	.210	.730
	% of total change	**100%**	35.4%	42%	22.9%
ΔDCA* (%)	β (SE)	7.07 (6.23)	5.98 (5.70)	1.57 (5.54)	-0.48 (5.76)
	95% CI	-9.18; 23.33	-8.90; 20.86	-12.88; 16.03	-15.50; 14.54
	P-value	.623	.721	.992	.999
	% of total change	n/a	n/a	n/a	n/a
ΔWBA* (%)	β (SE)	-2.51 (1.13)	-1.98 (1.03)	-0.22 (1.00)	-0.31 (1.04)
	95% CI	-5.45; 0.43	-4.67; 0.72	-2.84; 2.39	-3.03; 2.41
	P-value	.122	.227	.996	.991
	% of total change	n/a	n/a	n/a	n/a

Title:

Table 2: Effects of time on recovery of muscle synergies and strength, and metrics reflecting steady-state balance during quiet stance within the first 12 weeks poststroke.

Legend:

Abbreviations: Δ, change scores; FM-LE, Fugl-Meyer lower extremity motor score; MI-LE, Motricity Index lower extremity score; MI-ankle, Motricity Index ankle item; COP, center-of-pressure; COP$_{\text{Area}}$, area of the net COP; COP$_{\text{Vel-ML}}$, rms velocity of the net COP in the frontal plane; COP$_{\text{Vel-AP}}$, rms velocity of the net COP in the sagittal plane; DCA, dynamic control asymmetry; WBA, weight-bearing asymmetry; n/a, not applicable as the effect of TIME was not significant.

Values shown are estimated regression coefficients (β), standard error (SE), 95% confidence interval (95% CI), probability estimates (*P*-value) and the percentage of total observed change (% of total change). β-values show time-dependent change corrected for covariates AGE, SEX and SIDE in metrics reflecting lower limb muscle synergies (FM-LE), strength (MI-LE), postural stability (COP_{Area}, $COP_{Vel\text{-}ML}$, $COP_{Vel\text{-}AP}$) and inter-limb symmetry (DCA, WBA). If marked with *, values include an additional correction for INSTRUMENT. A statistically significant (i.e., P <.05) coefficient is highlighted in **bold**.

		FM-LE (0-34)					MI-LE (0-99)					MI-ankle (0-33)				
		Main	W3	W5	W8	W12	Main	W3	W5	W8	W12	Main	W3	W5	W8	W12
COP$_{Area}$ (mm²)	β (SE)	**-16.13^{ab}** **(3.25)**	**-23.30^{a}** **(8.15)**	**-4.99^{a}** **(0.97)**	**-14.52^{a}** **(2.88)**	-7.32^{a} (3.29)	**-4.99^{abc}** **(0.97)**	**-9.00^{a}** **(2.26)**	**-5.93^{a}** **(1.59)**	**-5.04^{a}** **(0.85)**	-1.74^{a} (1.08)	**-11.04^{ab}** **(2.46)**	**-20.98^{a}** **(6.68)**	**-16.59^{a}** **(3.80)**	**-12.78^{ac}** **(2.14)**	-3.05^{a} (2.78)
	95%CI	**-22.60; -9.66**	**-39.91; -6.69**	**-6.92; -3.06**	**-20.36; -8.69**	-14.03; -0.61	**-6.92; -3.06**	**-13.62; -4.38**	**-9.17; -2.71**	**-6.76; -3.33**	-3.95; 0.47	**-15.93; -6.14**	**-34.57; -7.35**	**-24.30; -8.90**	**-17.11; -8.45**	-8.72; 2.63
	P	**<.001**	**.008**	**<.001**	**<.001**	.034	**<.001**	**<.001**	**<.001**	**<.001**	.119	**<.001**	**.004**	**<.001**	**<.001**	.282
COP$_{Vel\text{-}ML}$ (mm/s)	β (SE)	**-0.60^{a}** **(0.09)**	**-0.97^{a}** **(0.14)**	**-0.14^{a}** **(0.03)**	**-0.55^{a}** **(0.13)**	**-0.49^{a}** **(0.13)**	**-0.14^{ab}** **(0.03)**	**-0.27^{a}** **(0.05)**	**-0.19^{a}** **(0.05)**	**-0.18^{a}** **(0.04)**	-0.10^{a} (0.05)	**-0.24^{ab}** **(0.07)**	**-0.69^{ac}** **(0.14)**	**-0.48^{a}** **(0.12)**	**-0.45^{a}** **(0.10)**	-0.17^{a} (0.12)
	95%CI	**-0.78; -0.42**	**-1.25; -0.68**	**-0.20; -0.08**	**-0.79; -0.26**	**-0.77; -0.22**	**-0.20; -0.08**	**-0.37; -0.18**	**-0.29; -0.09**	**-0.26; -0.10**	-0.20; -0.01	**-0.38; -0.09**	**-0.98; -0.41**	**-0.74; -0.22**	**-0.65; -0.24**	-0.43; 0.08
	P	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	**<.001**	.047	**.001**	**<.001**	**<.001**	**<.001**	.170
COP$_{Vel\text{-}AP}$ (mm/s)	β (SE)	**-0.51^{a}** **(0.09)**	**-0.69^{a}** **(0.13)**	**-0.12^{a}** **(0.03)**	**-0.49^{a}** **(0.12)**	-0.40^{a} (0.18)	**-0.12^{a}** **(0.03)**	**-0.18^{a}** **(0.04)**	**-0.18^{a}** **(0.05)**	**-0.16^{a}** **(0.04)**	-0.06^{a} (0.06)	**-0.29^{a}** **(0.07)**	**-0.52^{a}** **(0.11)**	**-0.50^{a}** **(0.12)**	**-0.41^{a}** **(0.10)**	-0.13^{a} (0.16)
	95%CI	**-0.69; -0.33**	**-0.94; -0.43**	**-0.18; -0.07**	**-0.74; -0.24**	-0.77; -0.03	**-0.18; -0.07**	**-0.27; -0.09**	**-0.28; -0.08**	**-0.23; -0.08**	-0.19; 0.06	**-0.43; -0.16**	**-0.75; -0.29**	**-0.74; -0.25**	**-0.60; -0.21**	-0.44; 0.19
	P	**<.001**	**<.001**	**<.001**	**<.001**	.035	**<.001**	**<.001**	**<.001**	**<.001**	.301	**<.001**	**<.001**	**<.001**	**<.001**	.422
DCA (%)	β (SE)	-0.06 (0.89)	-3.27^{d} (1.73)	-0.31 (0.26)	-2.28 (1.40)	-2.30 (1.43)	-0.31 (0.26)	-1.08^{d} (0.52)	-0.65 (0.45)	-1.00 (0.43)	-0.76 (0.45)	-1.01 (0.62)	-3.05^{d} (1.43)	-1.30 (1.41)	**-2.88** **(1.06)**	-2.68 (1.09)
	95%CI	-1.83; 1.72	-6.79; 0.26	-0.83; 0.20	-5.11; 0.54	-5.22; 0.63	-0.83; 0.20	-2.14; -0.01	-1.56; 0.27	-1.86; -0.13	-1.68; 0.16	-2.23; 0.21	-5.96; -0.13	-3.61; 1.02	**-5.02; -0.74**	-4.89; -0.46
	P	.949	.068	.234	.110	.119	.234	.048	.161	.025	.103	.105	.041	.264	**.009**	.020
WBA (%)	β (SE)	**-0.75** **(0.12)**	**-1.19** **(0.20)**	**-0.23** **(0.04)**	**-0.62** **(0.15)**	**-0.64** **(0.22)**	**-0.23** **(0.04)**	**-0.36** **(0.06)**	**-0.26** **(0.05)**	**-0.17** **(0.05)**	**-0.20** **(0.07)**	**-0.37** **(0.10)**	**-0.90** **(0.19)**	**-0.63** **(0.13)**	-0.34 (0.14)	-0.32 (0.19)
	95%CI	**-0.98; -0.51**	**-1.60; -0.78**	**-0.30; 0.15**	**-0.93; -0.31**	**-1.09; -0.21**	**-0.30; -0.15**	**-0.49; -0.24**	**-0.37; -0.16**	**-0.27; -0.06**	**-0.34; -0.06**	**-0.56; -0.17**	**-1.28; -0.51**	**-0.90; -0.36**	-0.61; -0.06	-0.70; -0.07
	P	**<.001**	**<.001**	**<.001**	**<.001**	**.005**	**<.001**	**<.001**	**<.001**	**.002**	**.008**	**<.001**	**<.001**	**<.001**	.018	.103

Title:

Table 3: *Between*-subject associations of lower limb motor impairment severity with steady-state balance during quiet stance at week 3, 5, 8 and 12 poststroke.

Legend:

Abbreviations: FM-LE, Fugl-Meyer lower extremity motor score; MI-LE, Motricity Index lower extremity score; MI-ankle, Motricity Index ankle item; COP, center-of-pressure; COP_{Area}, area of the net COP; $COP_{Vel\text{-}ML}$, rms velocity of the net COP in the frontal plane; $COP_{Vel\text{-}AP}$, rms velocity of the net COP in the sagittal plane; DCA, dynamic control asymmetry; WBA, weight-bearing asymmetry; W, week poststroke.

Values shown are estimated regression coefficients (β), standard error (SE), 95% confidence interval (95% CI), and probability estimates (*P*). β-values predict change in postural stability (COP_{Area}, $COP_{Vel\text{-}ML}$, $COP_{Vel\text{-}AP}$) and symmetry (DCA, WBA) from a one-point difference on the FM-LE, MI-LE or MI-ankle. Models were corrected for significant covariates with ^{a}, INSTRUMENT; ^{b}, TIME; ^{c}, SIDE; and ^{d}, SEX. A Bonferroni correction was applied for declaring significance (i.e., $P < .05/5$) as indicated in **bold**.

		ΔFM-LE (0-34)				ΔMI-LE (0-99)				ΔMI-ankle (0-33)			
		Main	W3-5	W5-8	W8-12	Main	W3-5	W5-8	W8-12	Main	W3-5	W5-8	W8-12
ΔCOP_{Area} (mm^2)	β (SE)	-1.85 (5.59)	-12.52 (11.62)	4.34 (12.38)	-9.73 (8.27)	-0.33 (1.28)	-7.83 (3.47)	3.01 (2.62)	-4.47 (1.80)	-2.24 (2.10)	-8.54 (3.49)	-3.71 (6.57)	-5.58 (4.34)
	95%CI	-12.97; 9.26	-36.29; 11.24	-20.67; 29.34	-26.65; 7.18	-2.88; 2.22	-14.92; -0.73	-2.33; 8.36	-8.14; -0.78	-6.44; 1.95	-15.69; -1.38	-17.10; 9.68	-14.47; 3.30
	P	.741	.290	.726	.249	.799	.032	.259	.019	.289	.021	.577	.209
$\Delta COP_{Vel\text{-}ML}$ (mm/s)	β (SE)	-0.23 (0.13)	-0.55 (0.23)	-0.16 (0.25)	-0.04 (0.21)	<0.01 (0.03)	-0.09[a] (0.08)	0.08 (0.05)	**-0.12 (0.04)**	-0.04 (0.05)	-0.11 (0.08)	0.12 (0.13)	-0.24 (0.10)
	95%CI	-0.49; 0.03	-1.02; -0.07	-0.68; 0.35	-0.46; 0.39	-0.06; 0.06	-0.25; 0.07	-0.03; 0.18	**-0.21; -0.04**	-0.14; 0.05	-0.27; 0.05	-0.16; 0.39	-0.45; -0.04
	P	.084	.026	.517	.864	.927	.281	.164	**.007**	.364	.165	.389	.020
$\Delta COP_{Vel\text{-}AP}$ (mm/s)	β (SE)	-0.11(0.16)	-0.37 (0.22)	0.12 (0.28)	-0.15 (0.33)	-0.01(0.04)	-0.02 (0.07)	0.04 (0.06)	-0.15 (0.07)	-0.04 (0.06)	-0.05 (0.07)	-0.10 (0.15)	-0.34 (0.16)
	95%CI	-0.42; 0.21	-0.82; 0.09	-0.45; 0.69	-0.82; 0.52	-0.08; 0.06	-0.17; 0.13	-0.09; 0.16	-0.29; -0.01	-0.16; 0.07	-0.19; 0.09	-0.41; 0.21	-0.67; -0.01
	P	.500	.109	.678	.659	.786	.780	.563	.049	.429	.487	.509	.047
ΔDCA (%)	β (SE)	2.38 (1.37)	3.52 (2.32)	2.98 (2.04)	-1.30 (2.63)	-0.01 (0.34)	0.05 (0.77)	0.06 (0.46)	-0.57 (0.61)	0.05(0.51)	0.45 (0.66)	-0.30 (1.13)	-2.17 (1.33)
	95%CI	-0.34; 5.09	-1.24; 8.27	-1.17; 7.14	-6.68; 4.08	-0.70; 0.67	-1.52; 1.62	-0.87; 1.00	-1.81; 0.68	-0.95; 1.06	-0.89; 1.79	-2.60; 2.00	-4.90; 0.55
	P	.085	.141	.154	.626	.967	.946	.890	.359	.917	.498	.792	.114
ΔWBA (%)	β (SE)	0.39[a](0.24)	0.55 (0.51)	0.46 (0.42)	-0.72 (0.40)	0.14[a] (0.06)	-0.04 (0.17)	0.20 (0.09)	0.09 (0.10)	0.14[a] (0.07)	0.04 (0.14)	0.19 (0.23)	0.07 (0.22)
	95%CI	-0.08; 0.86	-0.50; 1.59	-0.39; 1.31	-1.55; 0.10	0.02; 0.26	-0.38; 0.29	-0.02; 0.37	-0.11; 0.29	-0.01; 0.29	-0.25; 0.33	-0.27; 0.65	-0.38; 0.53
	P	.102	.292	.279	.082	.026	.794	.030	.345	.061	.775	.415	.741

Title:

Table 4: *Within*-subject associations of lower limb motor recovery and change in steady-state balance during quiet stance within the first 12 weeks poststroke.

Legend:

Abbreviations: Δ, change scores; FM-LE, Fugl-Meyer lower extremity motor score; MI-LE, Motricity Index lower extremity score; MI-ankle, Motricity Index ankle item; COP, center-of-pressure; COP_{Area}, area of the net COP; $COP_{Vel\text{-}ML}$, rms velocity of the net COP in the frontal plane;

$COP_{Vel\text{-}AP}$, rms velocity of the net COP in the sagittal plane; DCA, dynamic control asymmetry; WBA, weight-bearing asymmetry; W, week poststroke.

Values shown are estimated regression coefficients (β), standard error (SE), 95% confidence interval (95% CI), and probability estimates (*P*). β-values predict ΔCOP_{Area}, $\Delta COP_{Vel\text{-}ML}$, $\Delta COP_{Vel\text{-}AP}$, ΔWBA and ΔDCA from a one-point increase on the FM-LE, MI-LE or MI-ankle. Models were corrected for significant covariates with [a], INSTRUMENT. A Bonferroni correction was applied for declaring significance (i.e., $P < .05/4$) as indicated in **bold**.