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Mirror-Based Visual Feedback Versus Conventional Sit-To-Stand Training in Sub-Acute Stroke: A Quasi-Experimental Study

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ABSTRACT: Background: Adults with stroke rise from a chair with more weight on the non-paretic leg and cannot sense the imbalance, so verbal correction may leave it unchanged. A full-length mirror gives a visual signal without instruments. We tested whether mirror feedback added to dose-matched sit-to-stand training improves performance in sub-acute stroke.

Methods: In this quasi-experimental study, 68 adults 1 to 6 months after a first stroke were allocated by alternating enrolment to mirror feedback (n = 34) or identical training with the mirror covered (n = 34), 5 days a week for 4 weeks, with feedback faded in weeks 3 and 4. A blinded assessor measured the Five-Times Sit-to-Stand test (5-STS, primary), a symmetry index, Timed Up and Go (TUG), walking speed and balance confidence at baseline, week 4 and week 8. Analysis used ANCOVA with multiple imputation.

Results: Sixty-three participants (93%) completed follow-up. At week 4 the mirror group was 1.8 s faster on 5-STS (95% CI 0.6 to 3.0; p = 0.003; d = 0.36), below the 3 s clinical threshold, and the benefit grew with baseline slowness (interaction p = 0.001). Symmetry (2.5 percentage points) and TUG (2.6 s) also favoured mirror feedback. These differences were not clear at week 8, whereas balance confidence differed more (5.6 points; p = 0.026). Adverse events were similar (4 versus 5 participants).

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Conclusion: Mirror feedback gave a modest early gain, concentrated in slower participants and mostly gone by week 8. A randomised trial with baseline stratification is needed.

1. INTRODUCTION

Stroke ranks as the second foremost cause of mortality and the third principal cause of death and disability collectively on a global scale (GBD 2019 Stroke Collaborators, 2021). In India, the availability of stroke treatment services is inconsistent, and several rehabilitation departments operate with little equipment (Pandian and Sudhan, 2013). The Stroke Recovery and Rehabilitation Roundtable characterizes the sub-acute phase as occurring between 7 days and 6 months post-onset, seeing it as a period of increased plasticity (Bernhardt et al., 2017), therefore necessitating rigorous evaluation of therapeutic content throughout these months.

Rising from a chair is among the first activities to decline after stroke. People with hemiparesis usually rise with more weight on the non-paretic leg (Rocha et al., 2010), and the quality of the rise relates to falls (Cheng et al., 1998), which are common after stroke (Batchelor et al., 2012). Paretic limb strength and weight-bearing symmetry each relate to sit-to-stand performance (Lomaglio and Eng, 2005), and foot placement and trunk position at seat-off change how asymmetrically the legs are loaded (Lecours et al., 2008; Boukadida et al., 2015).

Task-specific repetition improves function after stroke (French et al., 2016; Veerbeek et al., 2014), and additional sit-to-stand practice improved balance in two randomised trials (Tung et al., 2010; Liu et al., 2016). The best content and dose of that practice remain uncertain.

One reason standard training may leave asymmetry uncorrected is that patients do not perceive how much weight each leg carries during the rise (Briere et al., 2010). An instruction to stand evenly asks them to correct an error they cannot sense. Augmented feedback supplies the missing signal. Ground reaction force feedback has been used to enhance symmetrical weight distribution while rising and sitting (Engardt et al., 1993), and symmetry training has been evaluated for fall prevention (Cheng et al., 2001). Visual feedback has been tested for balance retraining in acute stroke (Walker et al., 2000) and reviewed for standing postural control (Van Peppen et al., 2006). Force-platform feedback has been added to balance training (Srivastava et al., 2009), and in sub-acute stroke sit-to-stand training with real-time force-platform feedback gave larger gains than conventional sit-to-stand training in strength, balance, walking speed and quality of life (Hyun et al., 2021).

Force platforms and monitors are not widely available. A full-length mirror is the simplest form of real-time visual feedback. It lets the patient see trunk alignment, shoulder and pelvic level, and the symmetry of knee and hip extension. A mirror shows posture and not load, so any effect on loading would act through the alignment it reveals. To our knowledge, a mirror has not been tested against the same sit-to-stand training without it after stroke. Hence this study aims to evaluate whether mirror-based visual feedback to dose-matched sit-to-stand training improve sit-to-stand speed and weight-bearing symmetry in adults with sub-acute stroke, and do any differences remain 4 weeks after training stops.

2. MATERIALS AND METHODS

2.1 Design and reporting

This was a prospective, two-group, quasi-experimental study with non-random allocation and a blinded outcome assessor. Participants were allocated to the mirror feedback group (Group A) or the conventional group (Group B) by order of enrolment, alternating between groups. The study is reported according to the TREND statement for non-randomised evaluations (Des Jarlais et al., 2004), and the intervention is described using the TIDieR template (Hoffmann et al., 2014). The comparison group received an active, dose-matched comparator that differed from the experimental programme only in that the mirror was covered, which separates the effect of visual feedback from the effect of extra exercise.

2.2 Setting and participants

The research was conducted at the Neurological physiotherapy unit of a tertiary-care educational hospital that provides both inpatient and outpatient services for stroke patients. Enrollment of participants occurred from February to November 2025. Adults qualified for the study were between 40 and 75 years old, had experienced a first ischemic or haemorrhagic stroke verified by CT or MRI within the preceding 1 to 6 months, were able to stand up from a 45 cm chair without assistance, could maintain

an upright position for a minimum of one minute, and achieved a score of 2 or higher on the Functional Ambulation Category (FAC; Holden et al., 1984) and 24 or above on the Mini-Mental State Examination (MMSE; Folstein et al., 1975). They were in a medically stable condition, authorized for physical activity by the attending physician, and provided written informed permission.

We excluded people with uncorrected visual impairment, homonymous hemianopia or visuospatial neglect, because the experimental intervention depends on the visual channel. Other exclusions were severe lower-limb spasticity (Modified Ashworth Scale grade 3 or above; Bohannon and Smith, 1987) or fixed contracture of the knee or ankle, other neurological or vestibular disorders affecting standing, lower-limb fracture or orthopaedic surgery in the previous six months, unstable cardiac disease or uncontrolled hypertension, and participation in another interventional study. Baseline descriptive data were age, sex, side of hemiparesis, stroke type, days since stroke, FAC, MMSE, Fugl-Meyer Assessment of the lower extremity (FMA-LE; Fugl-Meyer et al., 1975) and minutes per day of usual-care therapy.

2.3 Sample size

The sample size was determined by the 5-STS duration. A between-group disparity of 3 seconds was regarded as the minimal significant difference, consistent with the minimal clinically important difference identified for stroke (Martin-San Agustin et al., 2021), utilizing a standard deviation of 4.0 seconds derived from the parent protocol, a two-tailed alpha of 0.05, and 80% power. This necessitated 28 individuals per group. Permitting a 15% loss, the objective was 34 participants per group (68 overall). A cumulative of 68 individuals (34 from each group) were recruited.

2.4 Allocation and blinding

Stroke patients in the inpatient ward and those referred for outpatient physiotherapy were screened consecutively. A research coordinator who was independent of outcome assessment checked eligibility and obtained written informed consent in the participant's preferred language before baseline testing, so that eligibility and consent were settled before the group was revealed. The alternating allocation list was held by the coordinator only, and sessions for the two groups were scheduled at different times of day to limit contact between them. Participants and treating physiotherapists could not be blinded. A trained assessor who did not enter the training area and was not told the group carried out all outcome testing, and participants were asked not to reveal their group. At the 4-week assessment the assessor guessed each participant's group. The statistician received coded group labels.

2.5 Interventions

All participants continued usual neurological rehabilitation as prescribed by the treating team, and the minutes per day were recorded. The study intervention was an additional 20-minute supervised sit-to-stand session, 5 days a week for 4 weeks (20 sessions), with identical dose, structure and supervision in both groups.

In both groups the plinth was set so that the knees were at about 90 degrees and the thighs horizontal, and the feet were placed shoulder-width apart on floor-tape outlines. Participants performed up to five sets of ten repetitions with 1 to 2 minutes of seated rest between sets. Each rise was followed by 3 seconds of upright standing and a controlled return to sitting. Seat height was lowered in 2 cm steps once the participant completed a full session without assistance or loss of balance and with a perceived exertion of 5 or below on the Borg CR10 scale (Borg, 1982). A gait belt was worn and the physiotherapist stayed within guarding range. Sessions stopped for pain, dizziness, pallor, undue fatigue, a Borg rating of 7 or above, or resting blood pressure above 180/110 mmHg at the start of the session. The treating physiotherapists had at least 2 years of neurological experience and worked from a written treatment manual. Participants were asked to avoid separate sit-to-stand exercise outside the study.

In Group A a full-length mirror (at least 120 cm tall) stood 1 m in front of the participant with its top at the eye level of the seated participant. A vertical tape line marked the midline of the mirror and horizontal tape marked shoulder level. Participants were asked to keep nose and sternum on the midline, shoulders level and both knees moving together, and the physiotherapist cued them from the mirror image (for example, "look at your shoulders, keep them level"). Constant augmented feedback can make learners depend on it (Salmoni et al., 1984), and reduced feedback frequency can improve retention of motor skill (Winstein and Schmidt, 1990; Schmidt and Bjork, 1992). The mirror was therefore uncovered for all sets in weeks 1 and 2, for alternate sets in week 3 and for every third set in week 4, and it was covered with an opaque sheet in the remaining sets. In

Group B the mirror was covered throughout, and the physiotherapist gave the usual verbal instruction and correction ("stand up evenly through both legs") without reference to any visual or measured feedback.

2.6 Outcome measures and assessment schedule

The main result was the duration of the Five-Times Sit-to-Stand test (5-STS) conducted on a 45 cm chair with arms crossed, with participants doing five rises as quickly as safely possible; the superior result from two attempts was recorded (Mong et al., 2010). Weight-bearing symmetry was assessed using a dual-scale symmetry index. Two identical digital scales were positioned under the participants' feet, and their readings were captured on smartphone video while remaining concealed from the individuals in both groups. The index was calculated by taking the maximum of the paretic side, dividing it by the total of the paretic and non-paretic maxima, multiplying by 100, and averaging across three ascents, indicating that 50% signifies equal distribution of load. The Timed Up and Go (TUG) test measured the duration taken to stand, traverse 3 meters, pivot, return, and sit, averaged over three attempts (Podsiadlo and Richardson, 1991). The comfortable walking pace, a fundamental metric suggested for stroke studies (Kwakkel et al., 2017), was assessed across the central 10 m of a 14 m pathway, averaged over three trials (Flansbjer et al., 2005), and reported in meters per second. The 16-item Activities-specific Balance Confidence (ABC) Scale, which ranges from 0 to 100%, was used to assess balance confidence (Powell and Myers, 1995; Salbach et al., 2006). The Berg Balance Scale was excluded due to its ceiling effect (Blum and Korner-Bitensky, 2008).

Participants rated global change on a single 7-point item from -3 to +3 at 4 and 8 weeks (Kamper et al., 2009) and rated the acceptability of training on a 5-point scale at 4 weeks. Exertion was recorded with the Borg CR10 at the end of each session. Falls, near falls, new pain, dizziness and cardiovascular events were recorded at each session, and attendance was expressed as a percentage of the 20 prescribed sessions. Outcomes were assessed before the first session (T0), at the end of week 4 (T1, primary endpoint) and at week 8 (T2).

2.7 Statistical analysis

Analysis followed the intention-to-treat principle. Missing outcome data (3 participants at T1 and 5 at T2 for 5-STS, symmetry, TUG and walking speed, with one further missing ABC item at T0 and another at T2) were handled by multiple imputation by chained equations with Bayesian ridge regression, giving 50 datasets. The imputation model contained group, age, days since stroke, FAC, MMSE, FMA-LE, usual-care minutes and every outcome at all three time points. Estimates were pooled with Rubin's rules (Rubin, 1987) using the small-sample degrees of freedom of Barnard and Rubin (1999), under the assumption that data were missing at random (Sterne et al., 2009).

The primary analysis was an ANCOVA of 5-STS time at T1 with group as the factor and baseline 5-STS, age, days since stroke and FAC as covariates (Vickers and Altman, 2001). It gave an adjusted mean difference with a 95% confidence interval (CI). Cohen's d was the adjusted difference divided by the pooled within-group standard deviation at that time point, with CI limits scaled in the same way (Lakens, 2013), and was signed so that positive values favour mirror feedback. Residual normality (Shapiro-Wilk), equality of residual variance (Levene) and homogeneity of regression slopes (a group by baseline interaction) were checked for every ANCOVA. Where slopes differed, we report the conditional effect across the observed range of the baseline value with a region-of-significance display (Bauer and Curran, 2005). Mann-Whitney U tests on change scores, with Hodges-Lehmann shifts and percentile bootstrap CIs (2000 resamples), were run for every outcome as the prespecified fallback. The primary result was read against the 3 s threshold, and statistical and clinical significance are reported separately.

The same ANCOVA was applied to each secondary outcome at T1 and at T2. Retention was examined with a linear mixed model on T1 and T2 values with group, time, group by time, baseline value, age, days since stroke and FAC as fixed effects and a random intercept for each participant, estimated by restricted maximum likelihood on all observed data. Ordinal ratings (global change, acceptability) were compared with the Mann-Whitney test. For the four secondary performance outcomes at T1 (symmetry, TUG, walking speed, ABC) we also give Holm-adjusted p values (Holm, 1979); T2 and the remaining analyses are exploratory.

Sensitivity analyses of the primary outcome were a complete-case ANCOVA, a per-protocol analysis of participants who attended at least 16 of 20 sessions, models with usual-care minutes or FMA-LE added, a model on log-transformed 5-STS time, a bootstrap CI for the adjusted difference (2000 resamples) and heteroscedasticity-consistent (HC3) standard errors. The proportion of participants whose 5-STS time fell by 3 s or more was compared with Fisher's exact test, counting missing participants as non-responders in the intention-to-treat version. Post hoc, because some participants crossed 50% at follow-up,

we analysed the absolute deviation of the symmetry index from 50%. Walking speed was grouped using the thresholds of Perry et al. (1995) and read against the minimal clinically important change for gait speed after stroke (Tilson et al., 2010). The proportion of correct assessor guesses was tested against 0.5 with an exact binomial test (Bang et al., 2004). The number of participants with at least one adverse event was compared with Fisher's exact test. Figures show individual data with effect estimates and confidence intervals (Gardner and Altman, 1986; Cumming, 2014; Ho et al., 2019). Analyses were done in Python 3.13 with statsmodels 0.15, SciPy 1.18 and scikit-learn 1.9, with a two-sided significance level of 0.05 and no interim analysis.

2.8 Ethical considerations

The study was approved by the Institutional Review Board of Faculty of Physiotherapy [Ref No: 2679/NEU/PHYSIO/IRB/2025]. It followed the Declaration of Helsinki (World Medical Association, 2013) and the ICMR National Ethical Guidelines (Indian Council of Medical Research, 2017). Written informed consent was obtained in the participant's preferred language. All participants received usual care and an active sit-to-stand programme, and participants could withdraw at any time. Data were coded and stored securely.

3. Results and discussion

3.1 Participants and baseline comparability

Sixty-eight participants were enrolled and 34 were allocated to each group (**Figure 1**). Sixty-five (96%) completed the week 4 assessment and 63 (93%) the week 8 assessment. One participant in the mirror group withdrew consent before week 4, two in the conventional group left before week 4 (relocation, intercurrent illness), and one participant in each group was lost between weeks 4 and 8. Fifty-nine participants (87%) attended at least 16 of 20 sessions. The numbers screened and excluded before enrolment were not recorded in the dataset analysed.

Age, time since stroke, FAC, MMSE and the side and type of stroke were similar across groups (Table 1). The allocation did not produce identical groups, however. The mirror group had more usual-care therapy (mean 41.0 versus 35.3 min/day; standardised mean difference 0.52), a lower FMA-LE score and a slower and more variable baseline 5-STS time (19.4 s, SD 6.7, versus 18.1 s, SD 4.4). Eleven of the 16 participants who needed 22 s or longer at baseline were in the mirror group. At baseline 8 of 34 mirror participants and 3 of 34 conventional participants walked below 0.4 m/s, and 8 and 3 walked faster than 0.8 m/s. Models adjusted for baseline outcome, age, days since stroke and FAC, and usual-care minutes and FMA-LE were added in sensitivity analyses.

Table 1. Baseline characteristics by group

Characteristic	Mirror (n = 34)	Conventional (n = 34)	SMD
Age, years, mean (SD)	58.8 (8.2)	60.2 (9.1)	-0.17
Male sex, n (%)	28 (82)	25 (74)	
Left hemiparesis, n (%)	18 (53)	16 (47)	
Ischaemic stroke, n (%)	26 (76)	26 (76)	
Days since stroke, mean (SD)	71.4 (23.9)	73.6 (26.5)	-0.09
FAC, median (IQR)	4 (2 to 4)	4 (3 to 4)	0.06
MMSE, mean (SD)	28.2 (1.6)	28.1 (1.6)	0.09
FMA-LE, mean (SD)	19.9 (5.4)	21.1 (4.8)	-0.24
Usual-care therapy, min/day, mean (SD)	41.0 (11.9)	35.3 (10.1)	0.52
5-STS time, s, mean (SD)	19.4 (6.7)	18.1 (4.4)	0.23
Symmetry index, %, mean (SD)	40.4 (4.1)	39.5 (4.4)	0.21
TUG, s, mean (SD)	26.5 (10.9)	26.4 (9.5)	0.01
Walking speed, m/s, mean (SD)	0.63 (0.26)	0.61 (0.17)	0.08
ABC score, %, mean (SD)	49.1 (15.3)	52.5 (10.7)	-0.26

SMD, standardised mean difference (mirror minus conventional, divided by the average of the two standard deviations). 5-STS, Five-Times Sit-to-Stand; ABC, Activities-specific Balance Confidence; FAC, Functional Ambulation Category; FMA-LE, Fugl-Meyer Assessment of the lower extremity; IQR, interquartile range; MMSE, Mini-Mental State Examination; TUG, Timed Up and Go. One mirror participant had one missing ABC item at baseline (n = 33).

3.2 Sit-to-stand time

After 4 weeks the mirror group was faster on the 5-STS by 1.82 s (adjusted difference, intention to treat; 95% CI 0.63 to 3.00; p = 0.003; Cohen's d 0.36, 95% CI 0.12 to 0.59; Table 3, **Figure 2**). The unadjusted change from baseline was 3.7 s (SD 3.3) in the mirror group and 1.4 s (SD 1.9) in the conventional group (Table 2). The Mann-Whitney comparison of change scores agreed (Hodges-Lehmann shift -1.79 s, 95% CI -2.87 to -0.56; p = 0.002), and the estimate changed little across sensitivity analyses (Table 5).

Statistical and clinical significance part ways here. The adjusted difference is about 61% of the 3 s threshold used to plan the study, and the lower limit of the interval (3.00 s) just reaches it. A difference of 3 s is therefore compatible with the data, and so is a difference of well under 1 s. A threshold-based view gives a similar result: 15 of 33 mirror participants (45%) and 6 of 32 conventional participants (19%) shortened their 5-STS time by 3 s or more (Fisher p = 0.033; intention to treat p = 0.034; **Figure 6**). Most participants in both groups improved, and the conventional group improved too, by a mean of 1.4 s. The mirror added a further 1.8 s on average, and 18 of 33 mirror participants and 26 of 32 conventional participants fell short of the 3 s threshold.

The planning assumptions also deserve scrutiny. The observed pooled standard deviation of 5-STS time at T1 was 5.05 s against the 4.0 s assumed. At that standard deviation, 28 participants per group give about 59% power for a 3 s difference in an unadjusted comparison, and about 46 per group would give 80%. The study was therefore underpowered for the clinical margin it set, although covariate adjustment narrows the interval (2.37 s wide).

Comparison with earlier work is limited. Hyun et al. (2021) reported larger gains with force-platform feedback than with conventional sit-to-stand training in sub-acute stroke for strength, balance, walking speed and quality of life. The mirror estimate for sit-to-stand speed is smaller than the 3 s margin, and mirror and force-platform feedback have not been compared head to head. The improvement in the conventional group fits the trials of repetitive and sit-to-stand practice (French et al., 2016; Tung et al., 2010; Liu et al., 2016), which also found gains from dose-matched practice without added feedback.

3.3 The effect depends on how slow participants were at baseline

The assumption of parallel slopes did not hold for 5-STS: the group by baseline interaction had p = 0.001 (interaction coefficient -0.35 s per second of baseline time, 95% CI -0.56 to -0.14). The same pattern appeared for TUG (interaction p < 0.001) and, more weakly, for ABC (p = 0.045), and not for symmetry or walking speed. The conditional effect of mirror feedback on 5-STS at week 4 was close to zero for participants who rose quickly at baseline and grew steadily with baseline slowness (**Figure 3**): -0.1 s (95% CI -1.6 to 1.4) at the 10th percentile of baseline time (13.6 s), -1.2 s (-2.4 to -0.04) at the median (16.7 s), -2.8 s (-4.0 to -1.5) at the 75th percentile (21.2 s) and -4.7 s (-6.7 to -2.7) at the 90th percentile (26.7 s). The interval excluded zero from a baseline time of about 17 s, and the point estimate passed 3 s at about 22 s.

This pattern needs careful reading. Faster participants had little room to improve, which would shrink any difference near the floor of the scale. In addition, the conventional group contained few slow participants (5 of 34 at 22 s or more, against 11 of 34), so the upper end of the curve rests on thin data in the comparison arm. One conventional participant with a baseline time of 34.9 s did not change at all, and removing that person weakened the interaction (p = 0.032) and moved the average effect to 1.6 s (95% CI 0.5 to 2.8). The interaction was not prespecified as a moderator and arises in a non-randomised comparison with unequal baseline spread, so we treat it as a hypothesis. It does fit the premise of the intervention, since patients who are slow and asymmetric have the most to gain from seeing their alignment. It also suggests that a trial should stratify or restrict on baseline 5-STS time.

3.4 Weight-bearing symmetry

The symmetry index rose by 3.8 percentage points in the mirror group and 1.3 in the conventional group, an adjusted difference of 2.5 percentage points (95% CI 0.8 to 4.2) (p = 0.005; Holm-adjusted p = 0.016; d = 0.49). This was the largest standardized effect of the study (**Figure 7**). Twenty-seven of 33 mirror participants (82%) and 21 of 32 conventional participants (66%) moved towards equal loading. The paretic peak load rose by a mean of 2.6 kg in the mirror group and 1.2 kg in the conventional group, while the non-paretic peak load fell by 2.4 kg and 0.5 kg (**Figure 4**). The result is consistent with the mechanism proposed in the introduction, in which the mirror lets patients detect and correct an asymmetry they cannot feel (Briere et al., 2010), and with the earlier use of feedback to shift loading towards the paretic leg (Engardt et al., 1993). The design cannot show that the

mirror worked through this route, because the mirror displays alignment, loading was measured only as an outcome, and no mediation analysis was planned.

The index has limits. It uses separate maxima for each foot, which may occur at different moments of the rise, and 8 participants (5 mirror, 3 conventional) exceeded 50% at week 8, so an increase can mean overshoot. The post hoc analysis of absolute deviation from 50% gave the same conclusion at week 4 (-2.3 percentage points (95% CI -4.0 to -0.7), mirror minus conventional, where negative values mean less asymmetry; p = 0.006). The minimal detectable change for this scale-based method was not available, so the 2.5-point difference cannot yet be judged against measurement error.

3.5 Mobility, walking speed, balance confidence and perceived change

TUG time was shorter in the mirror group by 2.6 s (95% CI 0.9 to 4.3) at week 4 (p = 0.004; Holm-adjusted p = 0.015; d = 0.25), and the nonparametric analysis agreed (Hodges-Lehmann shift -2.2 s; p = 0.009). The standardized effect is small because TUG times varied widely (pooled standard deviation 10.5 s), and, as for 5-STS, the benefit was larger in slower participants. Walking speed rose by 0.11 m/s in the mirror group and 0.06 m/s in the conventional group, an adjusted difference of 0.04 m/s (95% CI -0.01 to 0.09) (p = 0.090). The difference is below the 0.10 m/s that has been described as a small meaningful change after stroke (Tilson et al., 2010). Participants in the community walking category (above 0.8 m/s) increased from 8 to 12 of 33 in the mirror group and from 3 to 8 of 32 in the conventional group, and those walking below 0.4 m/s fell from 8 to 4 and from 3 to 2.

Balance confidence rose by 9.6 points in the mirror group and 4.9 points in the conventional group, an adjusted difference of 4.1 (95% CI -0.3 to 8.5) (p = 0.070; Holm-adjusted p = 0.140). Participants rated their change higher after mirror training (median 2, interquartile range 2 to 3, versus 1, 1 to 2; Mann-Whitney p < 0.001), and 29 of 33 mirror participants and 15 of 32 conventional participants rated themselves at least moderately better (+2 or more). Training was also rated as more acceptable in the mirror group (median 4, interquartile range 4 to 5, versus 4, 4 to 4; p = 0.021). These are self-reports from participants who knew their group, and a mirror that is visible during training may colour them. The patient-level matrix (**Figure 5**) shows that responses were uneven. Twenty of 32 mirror participants with complete data improved on all five outcomes, against 6 of 32 conventional participants, and 3 conventional participants improved on two or fewer outcomes while none of the mirror participants did. Individual responses in each arm ranged from clear deterioration to large gains, so group means describe only part of the response.

Table 2. Outcomes at baseline, week 4 and week 8, and change from baseline, by group (observed data)

Outcome	Group	T0	T1	T2	Change T0 to T1	Change T0 to T2
5-STS time, s	Mirror	19.4 (6.7)	15.8 (5.2)	15.1 (4.9)	-3.7 (3.3)	-3.9 (3.6)
	Conventional	18.1 (4.4)	16.9 (5.0)	15.8 (5.1)	-1.4 (1.9)	-2.6 (2.4)
Symmetry index, %	Mirror	40.4 (4.1)	43.9 (4.7)	43.3 (5.9)	3.8 (3.5)	3.1 (4.8)
	Conventional	39.5 (4.4)	40.6 (5.4)	41.7 (6.4)	1.3 (3.2)	2.4 (3.7)
TUG, s	Mirror	26.5 (10.9)	22.3 (9.8)	21.2 (9.5)	-4.3 (3.4)	-4.5 (4.4)
	Conventional	26.4 (9.5)	25.3 (11.3)	24.1 (10.8)	-1.6 (3.5)	-3.0 (2.9)
Walking speed, m/s	Mirror	0.63 (0.26)	0.74 (0.27)	0.77 (0.28)	0.11 (0.10)	0.12 (0.13)
	Conventional	0.61 (0.17)	0.67 (0.20)	0.69 (0.21)	0.06 (0.09)	0.09 (0.10)
ABC score, %	Mirror	49.1 (15.3)	58.3 (14.7)	60.0 (16.9)	9.6 (9.0)	10.1 (9.5)
	Conventional	52.5 (10.7)	56.7 (14.6)	55.2 (15.1)	4.9 (8.6)	4.0 (9.7)

Values are mean (SD). Sample sizes at T0, T1 and T2: mirror 34, 33 and 32; conventional 34, 32 and 31. For ABC: mirror 33, 33 and 32; conventional 34, 32 and 30. Lower 5-STS and TUG values and higher symmetry, speed and ABC values indicate better performance. Abbreviations as in Table 1.

Table 3. Adjusted between-group differences at week 4 and week 8 (intention to treat, multiple imputation)

Outcome	Difference at T1 (95% CI)	p	d (95% CI)	Difference at T2 (95% CI)	p	d (95% CI)
5-STS time, s	-1.82 (-3.00 to -0.63)	0.003	0.36 (0.12 to 0.59)	-1.00 (-2.39 to 0.39)	0.155	0.20 (-0.08 to 0.48)
Symmetry index, points	2.51 (0.78 to 4.24)	0.005	0.49 (0.15 to 0.83)	0.57 (-1.62 to 2.76)	0.605	0.09 (-0.26 to 0.45)
TUG, s	-2.59 (-4.31 to -0.87)	0.004	0.25 (0.08 to 0.41)	-1.64 (-3.54 to 0.26)	0.090	0.16 (-0.03 to 0.35)
Walking speed, m/s	0.042 (-0.007 to 0.091)	0.090	0.18 (-0.03 to 0.39)	0.030 (-0.027 to 0.087)	0.302	0.12 (-0.11 to 0.35)
ABC score, points	4.09 (-0.35 to 8.53)	0.070	0.28 (-0.02 to 0.58)	5.55 (0.70 to 10.41)	0.026	0.34 (0.04 to 0.64)

Differences are mirror minus conventional from ANCOVA adjusted for baseline value, age, days since stroke and FAC, pooled over 50 imputed datasets. Cohen's d is signed so that positive values favour mirror feedback. Holm-adjusted p values at T1 for the four secondary outcomes: symmetry 0.016, TUG 0.015, walking speed 0.140, ABC 0.140. Abbreviations as in Table 1.

3.6 Retention at 8 weeks

Four weeks after training ended the 5-STS difference had narrowed to an adjusted difference of -1.00 s (95% CI -2.39 to 0.39) ($p = 0.155$; $d = 0.20$), and the symmetry difference to 0.57 points (95% CI -1.62 to 2.76) ($p = 0.605$). The mixed model agreed (Table 4), with a group by time interaction of -1.76 points (95% CI -3.26 to -0.26) for symmetry ($p = 0.021$) and weaker interactions for 5-STS ($p = 0.075$) and TUG ($p = 0.108$). The narrowing came from further improvement in the conventional group, whose 5-STS time had fallen by 1.4 s at week 4 and by 2.6 s at week 8, while the mirror group held its gain (3.7 s and 3.9 s). In the proportion of participants improving by 3 s or more, the groups were close at week 8 (17 of 32 versus 14 of 31; **Figure 6**). The hypothesis that differences would persist was supported for balance confidence only, where the adjusted difference was 5.6 points (95% CI 0.7 to 10.4) ($p = 0.026$) and the mixed-model interaction was small ($p = 0.461$).

Two readings of the early gain are open. The mirror may speed learning of a symmetric strategy that the conventional group acquires more slowly with verbal cues alone. Alternatively, patients who start from a slower, more asymmetric position may benefit from a visual cue early and then converge with the comparison group as natural recovery continues. The fading schedule was designed to reduce dependence on feedback, and the absence of a late fall in the mirror group's gains argues against dependence (Salmoni et al., 1984), but the study has no arm with constant feedback to test that directly. Reviews of augmented feedback after stroke describe mixed evidence on timing and frequency (van Vliet and Wulf, 2006; Sigrist et al., 2013), and these data add one more setting in which the question is open.

Table 4. Linear mixed model of outcomes at week 4 and week 8 (observed data)

Outcome	Difference at T1 (95% CI)	p	Difference at T2 (95% CI)	p	Group by time (95% CI)	p
5-STS time, s	-1.83 (-3.10 to -0.57)	0.005	-1.09 (-2.36 to 0.19)	0.094	0.75 (-0.08 to 1.57)	0.075
Symmetry index, points	2.44 (0.51 to 4.37)	0.013	0.68 (-1.26 to 2.62)	0.493	-1.76 (-3.26 to -0.26)	0.021
TUG, s	-2.63 (-4.40 to -0.85)	0.004	-1.71 (-3.49 to 0.08)	0.061	0.92 (-0.20 to 2.04)	0.108
Walking speed, m/s	0.040 (-0.012 to 0.092)	0.131	0.033 (-0.019 to 0.085)	0.216	-0.007 (-0.040 to 0.026)	0.671
ABC score, points	4.60 (0.16 to 9.03)	0.042	5.96 (1.46 to 10.45)	0.009	1.36 (-2.26 to 4.98)	0.461

Mirror minus conventional. Each model contained group, time (T2 versus T1), their interaction, baseline value, age, days since stroke and FAC, and a participant-level random intercept. Observations: 128 from 65 participants (125 from 64 for ABC). The group by time term is the change in the between-group difference from T1 to T2. For 5-STS and TUG a positive term means the mirror advantage became smaller. Abbreviations as in Table 1.

Table 5. Sensitivity analyses of the primary outcome (5-STS time at week 4, mirror minus conventional)

Analysis	n	Difference, s (95% CI)	p
Intention to treat, multiple imputation (primary)	68	-1.82 (-3.00 to -0.63)	0.003
Complete case	65	-1.89 (-3.07 to -0.70)	0.002
Per protocol (at least 16 of 20 sessions)	59	-1.37 (-2.44 to -0.29)	0.014
Adjusted additionally for usual-care minutes	65	-1.74 (-2.96 to -0.52)	0.006
Adjusted additionally for FMA-LE	65	-2.06 (-3.23 to -0.89)	<0.001
Bootstrap CI (2000 resamples), complete case	65	-1.89 (-3.02 to -0.80)	
Mann-Whitney on change, Hodges-Lehmann shift	65	-1.79 (-2.87 to -0.56)	0.002
Log-transformed 5-STS, ratio of adjusted geometric means	65	0.90 (0.85 to 0.97)	0.003

Differences are adjusted for baseline 5-STS time, age, days since stroke and FAC unless stated. The model with HC3 heteroscedasticity-consistent standard errors gave an adjusted difference of -1.89 s (95% CI -3.09 to -0.69; p = 0.002). Excluding one conventional participant with a baseline time of 34.9 s and no change gave -1.60 s (95% CI -2.76 to -0.45). The ratio below 1 means shorter times with mirror feedback.

3.7 Adherence, tolerance, adverse events and blinding

Attendance was similar in the two groups (mean 91% of sessions in the mirror group and 88% in the conventional group; p = 0.249), as were Borg CR10 ratings (4.5 and 4.3; p = 0.330). Borg ratings of 7 or more occurred in 8 sessions in total, and 10 sessions were stopped early (Table 6). Nine participants had at least one adverse event (4 mirror, 5 conventional; Fisher p > 0.99), all mild except one episode of marked fatigue in the conventional group (Borg 8), and all resolved. Events were dizziness (1 in each group), near falls (1 in each group), new pain (1 in the mirror group and 2 in the conventional group), one elevated resting blood pressure that deferred a session (mirror) and one episode of marked fatigue (conventional). No fall, injury or

cardiovascular event was recorded beyond these. The hypothesis that the two programmes would have similar rates of adverse events was not contradicted, although nine events cannot exclude a modest difference.

The assessor guessed the group correctly for 40 of 65 participants (61.5%; 95% CI 49.4 to 72.4; exact binomial p = 0.082). The proportion did not differ from chance at the 0.05 level, but the interval reaches 72%, and partial unblinding cannot be ruled out. Walking and sit-to-stand times are objective and were timed by the assessor, which limits the room for expectation to act, whereas the participant ratings are open to it.

Table 6. Adherence, exertion, safety and participant-reported outcomes

Measure	Mirror (n = 34)	Conventional (n = 34)
Sessions attended, mean (SD)	18.2 (2.6)	17.6 (2.5)
Adherence, % of 20 sessions, mean (SD)	90.9 (12.8)	87.8 (12.7)
Attended at least 16 sessions, n (%)	32 (94)	27 (79)
Borg CR10 per session, mean (SD)	4.5 (0.8)	4.3 (0.7)
Sessions with Borg 7 or more, n (participants)	5 (4)	3 (2)
Sessions stopped early, n (participants)	6 (5)	4 (3)
Participants with at least one adverse event, n	4	5
Adverse events judged possibly related, n	3	3
Global rating of change at T1, median (IQR)	2 (2 to 3)	1 (1 to 2)
Global rating of change at T2, median (IQR)	2 (2 to 3)	1 (1 to 2)
Acceptability at T1 (1 to 5), median (IQR)	4 (4 to 5)	4 (4 to 4)
Assessor guessed group correctly, n/N	20/33	20/32

IQR, interquartile range. Global rating of change ranged from -3 to +3. Between-group tests: adherence p = 0.249; Borg p = 0.330; adverse events p > 0.99; global change at T1 p < 0.001 and at T2 p < 0.001; acceptability p = 0.021.

3.8 Strengths and limitations

The study compared a dose-matched active comparator with the same exercise plus a mirror, used a blinded assessor, kept follow-up above 90% and reported results as estimates with intervals. The main weakness is the allocation. Alternating order allows the coordinator to predict the next group, and it produced groups that differed in baseline speed, usual-care therapy and the spread of baseline 5-STS time. Baseline adjustment and sensitivity analyses address measured imbalance and cannot address unmeasured imbalance, so the results are quasi-experimental evidence. Therapists and participants could not be blinded, and the assessor guessed the group more often than chance would predict, though not significantly so. The study had a single centre, a modest sample and short follow-up, and the observed variance was larger than planned, so the primary comparison was underpowered for a 3 s margin. The slope heterogeneity was found after the data were seen. The symmetry index relies on separate foot maxima from two scales. Independent video ratings of treatment fidelity are not part of the dataset analysed here. Finally, the secondary and 8-week analyses were not adjusted for multiplicity.

4. CONCLUSION

Adding a full-length mirror to dose-matched sit-to-stand training gave a statistically clear but small early gain in sit-to-stand speed, weight-bearing symmetry and TUG time in sub-acute stroke, with a mean 5-STS advantage of 1.8 s that did not reach the 3 s threshold set for clinical importance. The benefit was concentrated in participants who were slowest at baseline, it faded by week 8 as the conventional group caught up, and balance confidence was the only outcome with a larger difference at follow-up. Safety and adherence were similar. A mirror costs little and can be used in any department, so it is a reasonable adjunct for slow, asymmetric patients in the first weeks of training, pending better evidence. The next step is a randomised multicentre trial

that stratifies by baseline 5-STS time, includes an arm with force-platform feedback, measures symmetry with simultaneous loading, tests feedback fading against constant feedback, and follows participants beyond 8 weeks.

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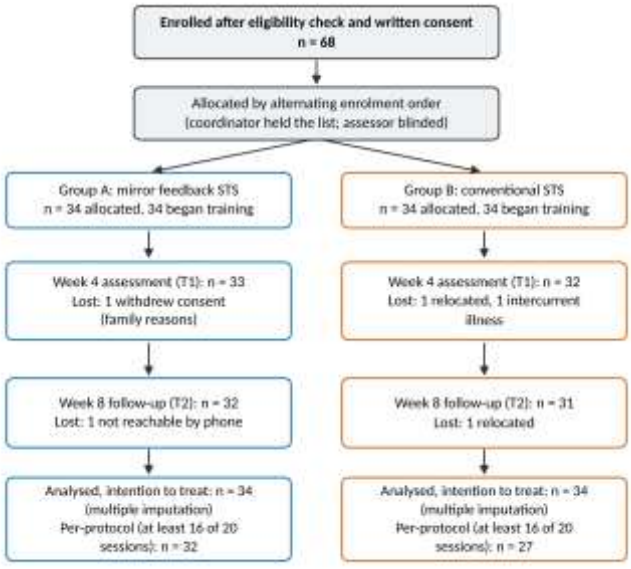


Figure 1. Flow of participants. Participants were allocated by alternating enrolment order. Blue boxes show the mirror feedback group and vermilion boxes the conventional group. Per-protocol analysis included participants who attended at least 16 of 20 sessions. Numbers screened and excluded before enrolment were not recorded in the dataset analysed.

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Figure 2

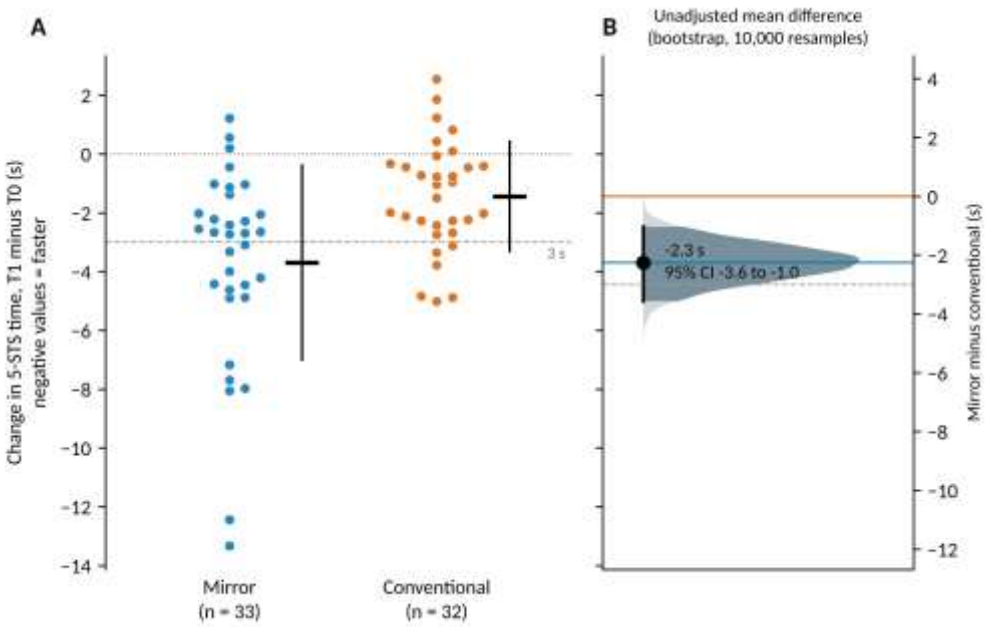


Figure 2. Estimation plot of the change in 5-STS time from baseline to week 4 (observed data). (A) Individual changes (dots) with group mean and standard deviation (black bars); negative values mean faster. (B) Bootstrap distribution (10,000 resamples) of the unadjusted mean difference, mirror minus conventional, with the mean difference (dot) and 95% confidence interval (bar) drawn on a floating axis aligned with the conventional group mean. The dashed line marks a 3 s change.

Figure 3

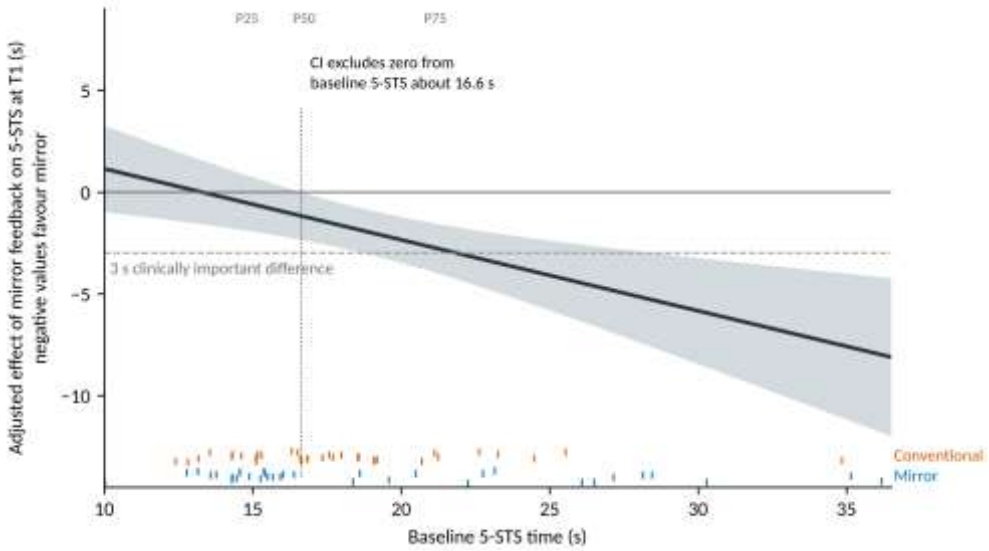


Figure 3. Conditional effect of mirror feedback on 5-STS time at week 4 across baseline 5-STS time (65 participants with week 4 data). The line is the adjusted group difference from a model including the group by baseline interaction, age, days since stroke and FAC, and the band is the 95% confidence interval. Negative values favour mirror feedback. Ticks at the bottom show the baseline values of mirror (blue) and conventional (vermilion) participants. The dashed line marks 3 s.

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Figure 4

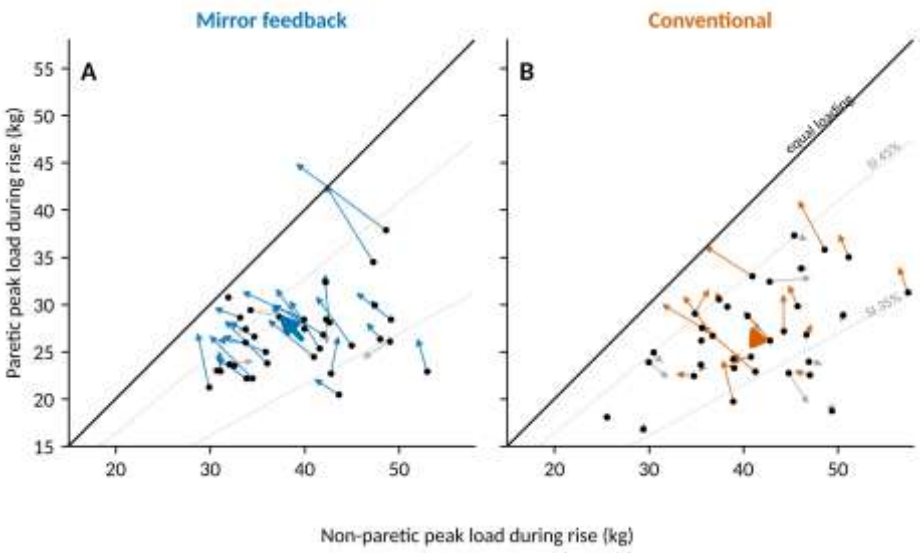


Figure 4. Load-shift plot of peak paretic and non-paretic loads during the rise (mean of three rises, kg). Each arrow runs from baseline (black dot) to week 4 for one participant. Coloured arrows moved towards equal loading (higher symmetry index) and grey arrows moved away. The solid diagonal marks equal loading, the dotted lines mark symmetry indices of 45% and 35%, and the thick arrow is the group mean shift. (A) Mirror feedback. (B) Conventional training.

Figure 5

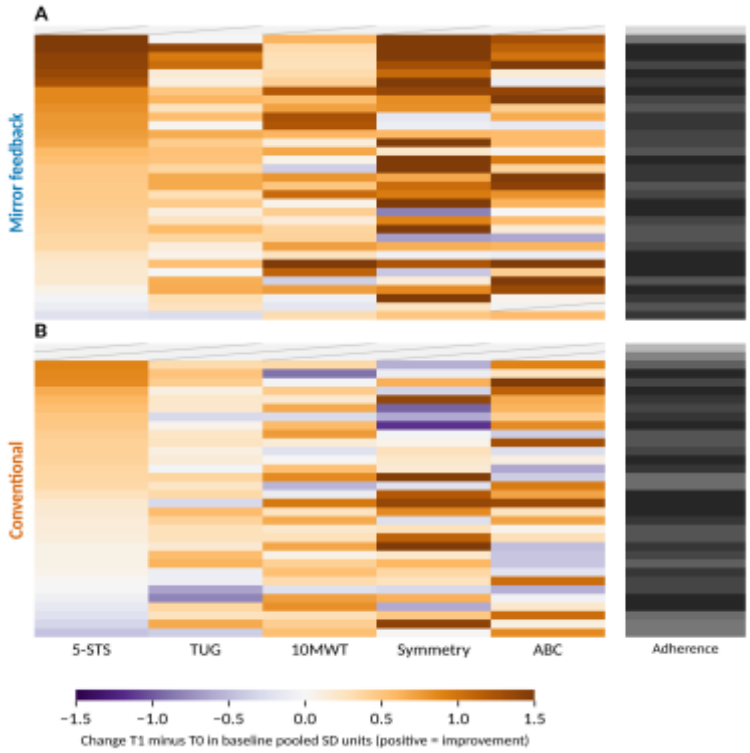


Figure 5. Patient-level response matrix. Rows are participants within each group, sorted by the change in 5-STS time. Colour shows the change from baseline to week 4 in units of the pooled baseline standard deviation, signed so that orange means improvement and purple means deterioration; hatched cells are missing. The grey strip on the right shows adherence (darker means more sessions attended). (A) Mirror feedback. (B) Conventional training.

Figure 6

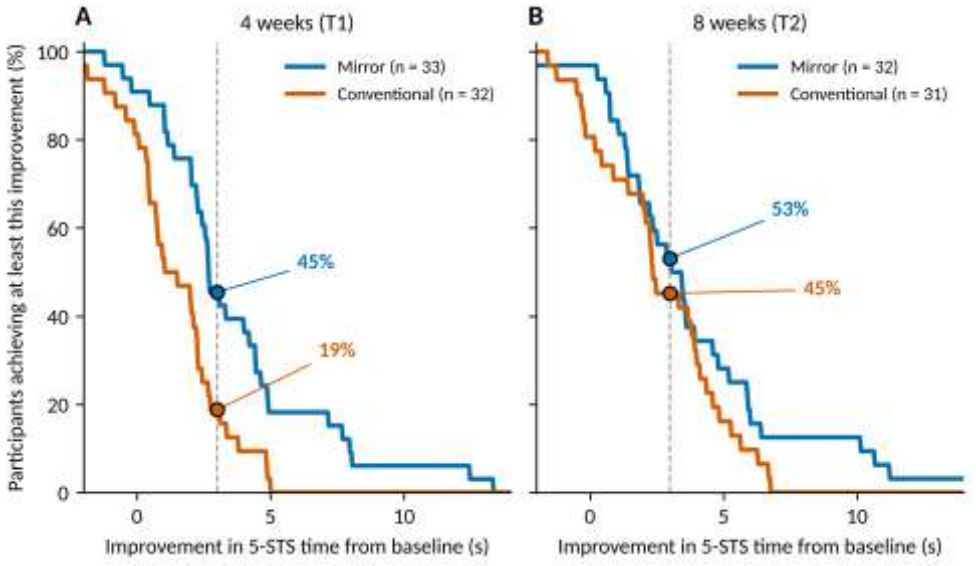


Figure 6. Cumulative responder curves for improvement in 5-STS time. Each curve shows the percentage of participants whose time had fallen by at least the value on the horizontal axis. The dashed line marks 3 s, and dots with labels give the percentage reaching it. (A) Week 4. (B) Week 8.

Figure 7

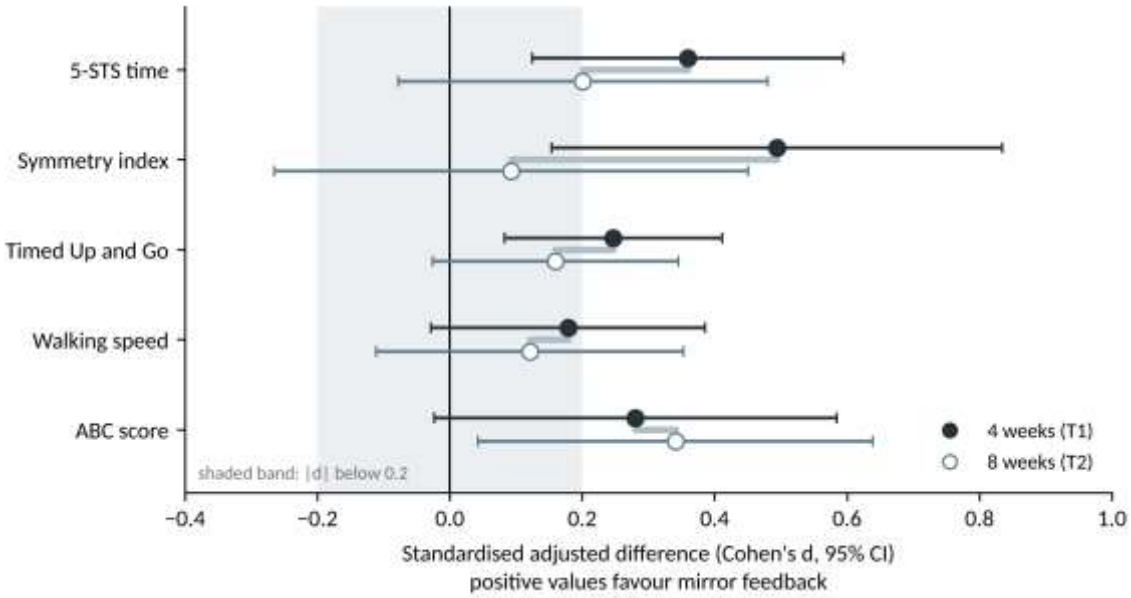


Figure 7. Standardised adjusted differences (Cohen's d with 95% confidence interval) at week 4 (filled circles) and week 8 (open circles) from the intention-to-treat ANCOVA. Positive values favour mirror feedback, and the grey band marks absolute values below 0.2.