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Original Article

Immediate effect of adding mirror visual feedback to lateral weight-shifting training on the standing balance control of the unilateral spatial neglect model

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Abstract. [Purpose] This study aimed to clarify the immediate effect of adding mirror visual feedback to lateral weight-shifting training on the standing balance control of the left unilateral spatial neglect model. [Participants and Methods] We included 64 healthy participants to create left unilateral spatial neglect models and divided them into four subgroups. Each subgroup received opposite lateral weight-shifting training with or without mirror visual feedback. We then evaluated the static and dynamic standing balance by measuring the center of pressure point alterations in the medial-lateral and anterior-posterior planes. We further evaluated the center of pressure length and bilateral load ratio. [Results] The center of pressure was significantly stable upon performing the eyes-open static standing balance test in the left weight-shifting training subgroup with mirror visual feedback. When participants performed the left dynamic standing balance test, the center of pressure moved significantly rightward and became significantly stable in the right weight-shifting training subgroup with mirror visual feedback. The left load ratio significantly decreased in the right weight-shifting training of subgroups that either did or did not receive mirror visual feedback upon performing the left dynamic standing balance test. [Conclusion] We concluded that adding mirror visual feedback to lateral weight-shifting training affected some measurements of standing balance control of the left unilateral spatial neglect model.

Key words: Mirror visual feedback, Weight-shifting training, Unilateral spatial neglect

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INTRODUCTION

Unilateral spatial neglect (USN) is a common disabling condition following right brain damage, is typically characterized by a failure to respond to stimuli and realize on the contralateral side and unable to use extremities opposite the lesion[1–3]. This neglect condition caused impaired mobility, decreased long-term functional outcomes, limited ability to complete daily activities, and restricted social participation[4, 5]. Various training modalities and therapeutic interventions have been devel-

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oped to overcome complex USN problems[6, 7]. However, the limited number of participants and functional outcomes that have not been significant is challenging to find more effective formulas in future rehabilitation programs[8, 9].

Several studies indicated that mirror visual feedback (MVF) on neglect conditions has a positive and negative effect. Visual feedback training can improve the postural balance control problems in an upright position and affect visual perception in hemiparesis chronic stroke patients[10–13]. Furthermore, mirror therapy (MT) that increased cognitive function then significantly affected motor function, balance capacity, walking velocity, daily living activities, and pain[14–17]. MT is a simple treatment that improves USN and may positively affect visuospatial neglect[18, 19]. In contrast, the MVF indicated a reverse effect of postural control and behavioral response in severe neglect and confuses some patients, especially in recognizing mirror image in mirror agnosia case[20–23]. Hence, the continuity effect of the MVF was temporal and further investigation for alleviating neglect is needed[24–26].

Moreover, weight-shifting training (WST) was often used clinically to improve balance function in stroke patients. A compelled body weight-shift approach could result in a long-lasting improvement of weight-bearing symmetry in individuals with acute and chronic stroke[27, 28]. However, several studies elucidated that the training was not affected weight distribution[29–32]. Additionally, there is a strong association between postural disorders and spatial neglect in stroke patients[33]. Therefore, we propose combining the MVF and WST approaches to improve postural balance ability in USN patients in further investigation.

On the other hand, head-mounted display (HMD) device modifications and adjustments were introduced as an instrument for clinical evaluation and can be a potential treatment strategy for USN patients[34–36]. In addition, healthy participants have been involved in determining the physiological effects of the training developed[37–39]. Moreover, an increase of postural sway during the eye-opened quiet upright standing task was affected by wearing the HMD for virtual reality (VR)[40–42]. HMD modification as the USN model use procedure was explored in healthy participants. The prism glass, which was substituted by a web camera and HMD modification in healthy participants, can project a more appropriate visual orientation direction and optically shift more to the right emulated the left USN patients[43]. Its use modulated the postural balance control change due to deviations of the web camera's visual direction that resembled an actual USN situation[43, 44]. Thus, the present study applied HMD modification with a tilted web camera on healthy participants as the USN model.

In order to understand physiological mechanisms of the affected standing balance control when performing the adding of MVF to lateral WST in low clinical risk, we preliminary investigate the immediate effect of that combined training on the postural balance control changes on the USN model through examining the static standing balance (SSB) and dynamic standing balance (DSB) tests. Accordingly, the present study aimed to clarify the immediate effect of adding MVF training to lateral WST on the standing balance control of the left USN model. We analyzed postural balance responses set on the SSB and DSB tests of the left USN model by measuring the center of pressure (COP) alterations displayed on the monitor in an upright standing position after the WST to the left (L) or right (R) with MVF and without MVF. We hypothesized that this combined training affects COP alterations, stabilizes postural stability, and may affect postural orientation in the standing balance control of the left USN model.

PARTICIPANTS AND METHODS

Sixty-four healthy participants were involved in this study (26 females and 38 males; mean age, 27.9 ± 4.9 years; weight, 59.9 ± 7.9 kg; height, 166.1 ± 6.3 cm). All participants gave written informed consent and provided sufficient explanation before the intervention. The study conforms to the Declaration of Helsinki and obtains approval from the Tokyo Metropolitan University ethical committee (No. 19075). We conducted a non-clinical quasi-experimental design with single-blind allocation concealment. Participants were randomly allocated into two MVF treatment groups and two treatment groups without MVF as control groups consisting of 16 people in each subgroup. The first treatment and control subgroups received the WST to the left with MVF (L-MVF) and without MVF (L-Non-MVF). The second treatment and control subgroups received the WST to the right with MVF (R-MVF) and without MVF (R-Non-MVF). All participants were confirmed without neurological dysfunctions and musculoskeletal disorders history, especially in visual ability, spinal posture, and lower extremities.

During the pre-test, training task, and post-test, all participants wearing the USN model of HMD (Virtual reality headset for mobile phone with 3D glasses) and smartphone (Galaxy S6 edge, SCV31, Samsung Electronics Japan Co., Ltd) with a web camera (SVPro VR 3D camera) mounted on the head and covered the eyes. This USN model procedure is adopted and the same as the previous study protocol[43, 44]. The USN model used a modification of visual direction web camera on HMD of 10 degrees to the right to resemble a mild USN situation (Fig. 1). All participants were not informed about that direction modification in this experiment. A COP platform (SR Vision by Sumitomo Riko Co. Ltd, Nagoya, Japan) was used to quantify variables of the COP point alterations in the medial-lateral (ML) and anterior-posterior (AP) plane, COP-length, and bilateral body load ratio in the SSB and DSB to the left (L) and right (R). These variables indicated postural sway adaptation, postural stability, and postural orientation. During the lateral WST task with MVF, a full standing mirror (210 cm high, 110 cm wide) is positioned in front of the participant at a distance of 150 cm with the symmetrical vertical line attached to the center mirror (Fig. 2). During the task without MVF, the mirror was covered by a black cloth in full.

Two physical therapists administered these trials in a quiet laboratory environmental situation. The experiment begins by assessing COP variables in pre-test before the training. In the first SSB test, participants were asked to stand upright with

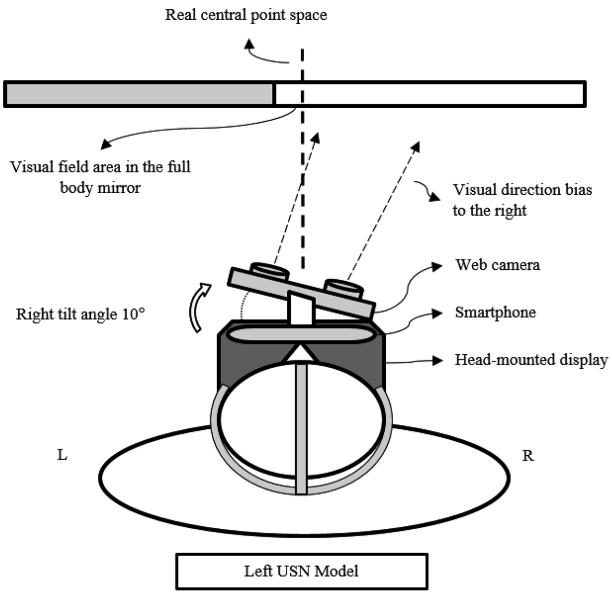

Fig. 1. The left unilateral spatial neglect model condition.

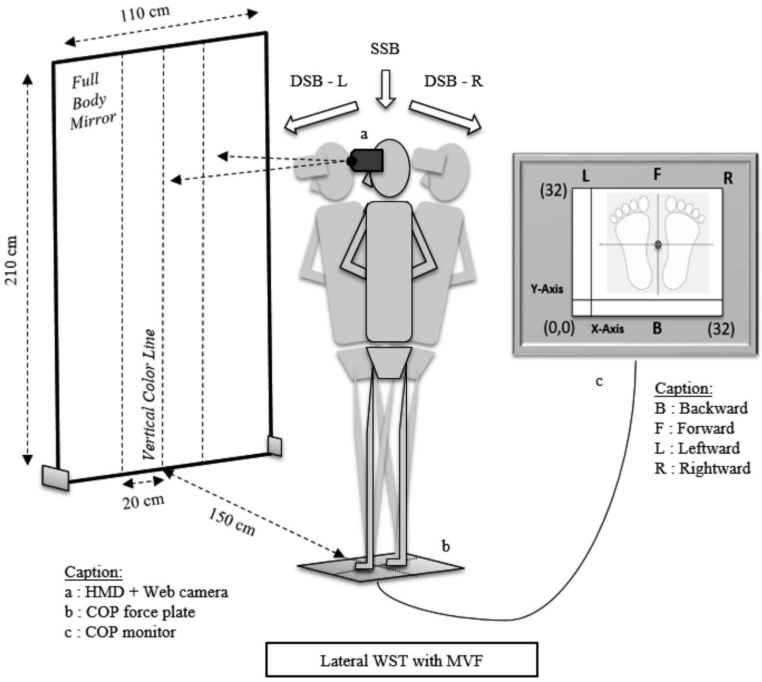

Fig. 2. Experimental setting of lateral WST with MVF.
HMD: Head-mounted display; COP: Center of pressure; WST: Weight-shifting training; MVF: Mirror visual feedback; SSB: Static standing balance; DSB: Dynamic standing balance.

both arms folded across the front of the chest and both feet resting on top of the COP platform with eyes opened (EO) and eyes closed (EC) alternately for 30 seconds each. Then, in the DSB test, participants were requested to sway their posture in the ML plane (leftward and rightward) as possible by keeping an idle position perpendicular and stable alternately for 30 seconds each. All SSB and DSB measurements were then performed in the post-test in the same order as the pre-test (Fig. 2).

In the first two treatment subgroups (L-MVF and R-MVF), the MVF training was performed through WST to the left or to the right of 50 times repetition following a metronome rhythm of 60 bpm in front of an adult-sized mirror set. Participants were asked to stand upright with a sight facing the mirror while observing the body's movements reflected and focusing on the symmetrical vertical line attached to the mirror's center. In the second two control subgroups (L-Non-MVF and R-Non-MVF), participants were asked to stand upright in front of the covered mirror. The same WST was performed without MVF, reflecting the body's movements when participants try to swing laterally with the same number of repetitions. Two physical therapists as observers guided participants during the trial to ensure that motor tasks were executed correctly and synchronously.

The COP-ML, COP-AP, and COP-length in the SSB and DSB tests were collected in centimeters. The bilateral body-load ratio was obtained in percentage (%). The COP data were composed using Microsoft Excel software after file format conversion from SR Vision platform original software. Pre-and post-test results are shown in Mean ± SD. Difference (Diff) results between pre-and post-test shown in Mean ± SEM. Changing ratio (CR) results showed in percentage (%). Paired sample t-test and Wilcoxon signed ranks test were performed after the data normality test of Shapiro-Wilk test to calculate comparison between pre-and post-test data within-participant effects in each subgroup. The statistical power of the corrected effect size of Cohen's d was estimated for within-participants of each subgroup and calculated with Hedges's g formula[45, 46)]. Statistical software (IBM Corp.; SPSS V. 26, Armonk, NY, USA) was used, and the significance level was set at $p<0.05$.

RESULTS

Participant demographics of each subgroup are shown in Table 1. All participants completed trials and no participant reported fatigue after the training.

The COP-ML, COP-AP, COP-length, and left load ratio results of the MVF and non-MVF subgroup of the SSB and DSB tests in two different WST directions were presented in Tables 2 and 3. CR negative and positive values in the COP-ML indicated that COP point moves further leftward and rightward direction in the frontal plane. CR negative and positive values in the COP-AP indicated that COP point moves further backward and forward direction in the sagittal plane. CR negative and positive values in the COP-length indicated that postural stability is becoming more stable and unstable. The left load ratio's negative and positive values indicated that postural orientation inclined rightward and leftward. The bodyweight ratio to the left and right side of the body is assumed to be opposite and vice versa, so that data displayed on the table is only the left load ratio.

Based on the results, the COP-length became significantly stable (−13.35%) in the L-MVF subgroup on performing the EO-SSB test ($p<0.05$) with an effect size between small to medium (Table 2). When participants were performing the DSB-L test, the COP-ML moved significantly rightward (4.01%) in the R-MVF subgroup ($p<0.05$), the COP-length became significantly stable (−13.64%) in the R-MVF subgroup ($p<0.05$), and the left load ratio significantly decrease (−1.68% and −2.17%) in the R-MVF and R-Non-MVF subgroups ($p<0.05$) with an effect size between small to medium, respectively (Table 3).

DISCUSSION

The present study explored the immediate effect of adding the MVF to lateral WST on the standing balance control of the USN model by comparing the training with MVF and without MVF on each different lateral WST direction. This preliminary investigation is the first study to test an exercise performed in healthy participants conditioned as the USN model. We used the COP monitor to evaluate the standing balance control indicated by the COP-ML, COP-AP, COP-length and left load ratio. A previous study revealed changes in the postural balance control after participants used the USN model. Clinically, the left USN occurs more frequently than the right USN[1–3, 6, 8)], so that the left USN model was chosen in the present study. Moreover, this left USN model situation may differ from the pathophysiological conditions in actual USN patients. However, the USN models' postural response to a designed training may explain at least characteristics and physiological effect mechanisms analogous to the USN patients as an initial consideration in a rehabilitation program with minimal risk.

Mirror training has been implemented clinically for hemiparesis patients[47)]. The mirror was placed vertically in front of the participant in the sideway position to observe upper or lower limb respond to imitate the opposite non-affected limb move-

Table 1. Participant demographics

Subgroup	WST to the left		WST to the right	
	With MVF	Without MVF	With MVF	Without MVF
	(Treatment group 1)	(Control group 1)	(Treatment group 2)	(Control group 2)
Variables	L−MVF (n=16)	L−Non−MVF (n=16)	R−MVF (n=16)	R−Non−MVF (n=16)
Gender	M=9; F=7	M=10; F=6	M=9; F=7	M=10; F=6
Age (years)	27.9 ± 4.2	28.9 ± 5.1	27.1 ± 5.4	27.6 ± 5.2
Weight (kg)	59.5 ± 7.9	60.0 ± 7.5	59.0 ± 8.0	61.1 ± 8.9
Height (cm)	166.9 ± 6.0	165.1 ± 6.5	165.7 ± 6.1	166.8 ± 6.9

MVF: Mirror visual feedback; WST: Weight shifting training; L: Left; R: Right; M: Male; F: Female. Age, weight and height values are presented as mean ± standard deviation.

Table 2. Pre-test, post-test, and difference test comparison between MVF and non-MVF subgroup on the static standing balance (SSB)

Subgroup		WST to the left		WST to the right	
		With MVF	Without MVF	With MVF	Without MVF
		(Treatment group 1)	(Control group 1)	(Treatment group 2)	(Control group 2)
Variables		L−MVF (n=16)	L−Non−MVF (n=16)	R−MVF (n=16)	R−Non−MVF (n=16)
EO−SSB					
COP−ML	Pre	15.87 ± 1.30	16.12 ± 0.60	15.97 ± 0.67	15.88 ± 0.88
	Post	15.74 ± 0.80	15.84 ± 0.74	16.06 ± 0.59	15.84 ± 0.66
	Diff	−0.13 ± 0.36	−0.28 ± 0.24	0.09 ± 0.13	−0.04 ± 0.13
	CR	−0.83%	−1.71%	0.59%	−0.28%
	Hedges’ g	0.117	0.405	−0.138	0.050
COP−AP	Pre	16.92 ± 1.66	16.53 ± 1.31	17.31 ± 1.56	17.34 ± 1.85
	Post	16.68 ± 1.64	16.75 ± 1.33	17.40 ± 1.77	17.31 ± 2.04
	Diff	−0.24 ± 0.17	0.22 ± 0.18	0.09 ± 0.19	−0.03 ± 0.14
	CR	−1.44%	1.32%	0.51%	−0.18%
	Hedges’ g	0.141	−0.162	−0.052	0.015
COP Length	Pre	17.14 ± 5.43	14.09 ± 2.63	14.58 ± 3.21	14.69 ± 4.89
	Post	14.85 ± 6.79	13.61 ± 2.67	14.38 ± 2.97	15.78 ± 4.82
	Diff	−2.29 ± 1.32*	−0.48 ± 0.36	−0.21 ± 0.65	1.08 ± 0.96
	CR	−13.35%	−3.41%	−1.41%	7.36%
	Hedges’ g	0.363	0.176	0.063	−0.218
Left load ratio (%)	Pre	49.69 ± 6.89	49.50 ± 2.41	50.46 ± 3.26	51.08 ± 3.60
	Post	50.97 ± 4.40	50.69 ± 3.54	49.68 ± 2.92	50.86 ± 2.90
	Diff	1.28 ± 1.72	1.19 ± 1.08	−0.78 ± 0.55	−0.22 ± 0.56
	CR	2.57%	2.40%	−1.55%	−0.43%
	Hedges’ g	−0.215	−0.383	0.245	0.065
EC−SSB					
COP−ML	Pre	15.81 ± 0.52	15.93 ± 0.59	16.14 ± 0.61	16.10 ± 0.80
	Post	15.66 ± 0.79	15.91 ± 0.69	15.93 ± 0.67	15.86 ± 0.70
	Diff	−0.14 ± 0.12	−0.03 ± 0.16	−0.21 ± 0.17	−0.24 ± 0.16
	CR	−0.91%	−0.16%	−1.32%	−1.48%
	Hedges’ g	0.218	0.030	0.319	0.311
COP−AP	Pre	16.96 ± 1.51	16.89 ± 1.15	17.69 ± 1.48	17.81 ± 1.76
	Post	16.94 ± 1.64	17.11 ± 1.40	17.63 ± 1.79	17.53 ± 1.97
	Diff	−0.28 ± 0.22	−0.14 ± 0.19	−0.29 ± 0.25	−0.51 ± 0.24
	CR	−0.07%	1.26%	−0.39%	−1.58%
	Hedges’ g	0.012	−0.167	0.035	0.146
COP Length	Pre	13.03 ± 3.26	13.23 ± 3.87	12.80 ± 3.17	15.13 ± 5.12
	Post	13.92 ± 6.12	13.13 ± 4.58	14.01 ± 2.93	14.54 ± 5.88
	Diff	0.89 ± 1.01	−0.11 ± 1.41	1.21 ± 0.74	−0.59 ± 0.83
	CR	6.86%	−0.80%	9.42%	−3.88%
	Hedges’ g	−0.176	0.022	−0.386	0.104
Left load ratio (%)	Pre	50.78 ± 2.91	50.47 ± 2.47	49.71 ± 2.12	50.40 ± 3.31
	Post	51.58 ± 4.62	50.42 ± 3.42	50.39 ± 3.58	50.76 ± 3.21
	Diff	0.80 ± 0.69	−0.05 ± 0.85	0.67 ± 0.97	0.36 ± 0.57
	CR	1.58%	−0.10%	1.36%	0.71%
	Hedges’ g	−0.201	0.016	−0.225	−0.107

WST: Weight shifting training; MVF: Mirror visual feedback; L: Left; R: Right; Static standing balance (SSB); Eyes opened (EO); Eyes closed (EC); COP: Center of pressure; ML: Medial−Lateral; AP: Anterior−Posterior; Diff: Difference; CR: Changing ratio. The Pre and Post values are presented as mean ± standard deviation (cm). Diff values are presented as mean ± standard error of the mean. *p<0.05 (indicates a significant difference between Pre and Post).

Table 3. Pre-test, post-test, and difference test comparison between MVF and non-MVF subgroup on the dynamic standing balance (DSB)

Subgroup		WST to the left		WST to the right	
		With MVF	Without MVF	With MVF	Without MVF
		(Treatment group 1)	(Control group 1)	(Treatment group 2)	(Control group 2)
Variables		L−MVF (n=16)	L−Non−MVF (n=16)	R−MVF (n=16)	R−Non−MVF (n=16)
DSB−R					
COP−ML	Pre	21.83 ± 1.03	21.75 ± 2.39	22.87 ± 1.48	22.73 ± 1.53
	Post	22.12 ± 1.23	21.85 ± 2.25	22.67 ± 1.90	22.63 ± 1.58
	Diff	0.29 ± 0.19	0.10 ± 0.21	−0.20 ± 0.28	−0.11 ± 0.20
	CR	1.32%	0.43%	−0.93%	−0.49%
	Hedges' g	−0.249	−0.041	0.114	0.062
COP−AP	Pre	16.52 ± 1.83	16.86 ± 1.59	17.01 ± 1.56	16.96 ± 2.01
	Post	16.31 ± 2.15	16.80 ± 1.74	17.16 ± 1.67	16.83 ± 2.09
	Diff	−0.20 ± 0.20	−0.07 ± 0.20	0.14 ± 0.14	−0.13 ± 0.17
	CR	−1.28%	−0.33%	0.92%	−0.81%
	Hedges' g	0.102	0.035	−0.09	0.061
COP Length	Pre	20.98 ± 7.72	21.02 ± 7.17	25.04 ± 10.29	25.29 ± 10.88
	Post	21.52 ± 10.83	21.17 ± 8.66	24.24 ± 8.81	24.86 ± 12.15
	Diff	0.54 ± 1.07	0.14 ± 1.08	−0.80 ± 1.26	−0.43 ± 0.98
	CR	2.53%	0.62%	−3.27%	−1.65%
	Hedges' g	−0.055	−0.018	0.081	0.036
Left load ratio (%)	Pre	20.40 ± 3.61	21.60 ± 10.54	16.61 ± 5.64	18.03 ± 5.14
	Post	20.06 ± 3.79	21.53 ± 10.03	17.97 ± 6.90	17.95 ± 5.98
	Diff	−0.34 ± 0.72	−0.07 ± 0.91	1.37 ± 0.84	−0.08 ± 0.90
	CR	−1.62%	−0.40%	8.15%	−0.42%
	Hedges' g	0.089	0.006	−0.210	0.013
DSB−L					
COP−ML	Pre	9.71 ± 1.60	10.24 ± 2.47	9.02 ± 1.77	9.46 ± 1.81
	Post	9.84 ± 1.62	10.11 ± 2.31	9.38 ± 1.52	9.65 ± 1.95
	Diff	0.13 ± 0.28	−0.13 ± 0.20	0.36 ± 0.15*	0.19 ± 0.17
	CR	1.28%	−1.34%	4.01%	1.84%
	Hedges' g	−0.078	0.052	−0.212	−0.098
COP−AP	Pre	16.96 ± 2.01	17.13 ± 1.73	17.80 ± 1.84	17.65 ± 1.85
	Post	17.05 ± 1.76	17.15 ± 1.77	17.78 ± 2.20	17.58 ± 1.97
	Diff	0.09 ± 0.21	0.02 ± 0.12	−0.02 ± 0.21	−0.06 ± 0.19
	CR	0.52%	0.11%	−0.07%	−0.35%
	Hedges' g	−0.046	−0.011	0.009	0.035
COP Length	Pre	22.80 ± 7.48	21.55 ± 7.84	26.56 ± 9.70	25.39 ± 11.61
	Post	22.13 ± 7.45	20.59 ± 8.20	22.94 ± 7.51	23.65 ± 10.09
	Diff	−0.66 ± 0.94	−0.96 ± 0.83	−3.61 ± 1.65*	−1.73 ± 1.21
	CR	−2.88%	−4.46%	−13.64%	−6.81%
	Hedges' g	0.087	0.116	0.406	0.155
Left load ratio (%)	Pre	80.06 ± 6.49	77.90 ± 10.73	83.89 ± 7.32	82.21 ± 6.76
	Post	79.82 ± 6.72	78.17 ± 9.93	82.49 ± 7.27	80.44 ± 7.79
	Diff	−0.24 ± 1.08	0.27 ± 1.04	−1.40 ± 0.55*	−1.78 ± 0.67*
	CR	−0.29%	0.34%	−1.68%	−2.17%
	Hedges' g	0.035	−0.025	0.187	0.236

WST: Weight shifting training; MVF: Mirror visual feedback; L: Left; R: Right; Dynamic standing balance (DSB); COP: Center of pressure; ML: Medial−Lateral; AP: Anterior−Posterior; Diff: Difference; CR: Changing ratio. The Pre and Post values are presented as mean ± standard deviation (cm). Diff values are presented as mean ± standard error of the mean.

*$p<0.05$ (indicates a significant difference between Pre and Post).

ment[48]. In that procedure, mirror neurons' function in the brain works to improve neuroplasticity performance, hypothesized to restore the impaired brain's function and effectively improve motor function and ADL on stroke survivor[49–51]. In contrast, our study implemented the MVF on the front side to determine whether the participants could rely on their reflected body alignment in the whole-body mirror to maintain their upright postural control. We expected participants might fix their postural balance and shift their visual attention based on that experimental setting. The MVF can enhance the neurophysiological response and increase cognitive activation to be helpful in neuro-rehabilitation and stroke recovery[37, 52–54]. However, our results corroborate a review showing weak evidence and inconsistent studies that mirror training affects healthy individuals' motor performance[14, 39]. These outcomes may be due to participants, unlike patients with neglect who do not use the same clues and cannot modify their procedures to recalibrate their spatial representations[20].

On the other hand, the WST has been investigated to improve balance performance and was often used to encourage the COP transferring stability in stroke patients[27, 29, 30, 32]. Visual feedback effects could be observed in patients presenting weight-bearing asymmetries[38]. Furthermore, the visual feedback rhythmic WST may improve the dynamic balance function for hemiplegic stroke patients[55]. The left USN condition leads COP point to move to the body's right side[33]. Accordingly, our results showed that COP-ML moved laterally following WST to the right once the MVF was added when performing the opposite DSB test.

The present study revealed that postural stability was modulated by adding MVF following participants on performing the WST to the left in the EO-SSB test and WST to the right in the DSB-L test. Our results confirm a previous study that indicated postural stability was affected by visual feedback when participants intend to control the movement[13]. Moreover, our result showed that postural balance oriented laterally following the WST to the right with nor without MVF in the DSB-L test. In line with a previous study, these weight-bearing alterations indicated asymmetric loading on both legs modifies the postural control adjustment, and weight distribution on opposite feet supports undisturbed stance upright of healthy participants[28, 29, 56].

As we know, former studies reported that actual USN patients were confused with MFV[20–23]. In comparison, the USN model condition with its HMD interferes and makes it difficult for the individual to process visual information that affected the postural balance[40–44]. Accordingly, the significant difference between the MVF and non-MVF subgroup only showed in some variables. The potential benefits of our findings for the physical therapy clinical setting are that it was necessary to consider whether there is a cognitive load increase resulting from the exercise given that might affect training outcomes. Adding MVF to the lateral WST also requires a specific consideration before implementing it on the USN patients to improve balance control in a standing position. Admittedly, some studies reported that COP in the USN patients tends to rely more on the right leg's non-paretic side[33]. Our results indicated the decreased left load ratio in the DSB-L in the right WST group. We suggested that these results appear to be influenced by the predominance of left-leg stability on standing position in healthy right-handed participants. Hence, we concluded that the over-performing of the right WST on the USN patients seems counterproductive to produce the postural balance stability.

This preliminary study has several limitations. First, the small number of participants in each subgroup may affect the study findings. In theory, the other results of the measurement variables may be significantly different if the number of participants is increased. Second, although there were two control subgroups without adding MVF on lateral WST, we did not have the non-USN and right USN model participants as the other control groups. Thus, it requires further investigation whether participants using the same HMD with and without camera modification had a similar postural response in the trials. Third, since the setup is a USN model in healthy participants, it does not precisely match an actual clinical case accompanied by other neurological symptoms such as hemiparesis and cognitive decline, so that it needs to be careful in construing the outcomes. Hence, further studies are needed to observe the long-term adaptation effect when the training is implemented continuously by involving more participants and control groups with secondary measurements to complement the necessary interpretation in advanced analysis.

In conclusion, indeed, the MVF training is recognized to induce postural adjustment, and lateral WST increases proprioceptive stimulation of the lower extremity to stabilize the postural balance in healthy participants and hemiparesis patients. However, in the present study, the COP-AP did not alter in all subgroups. Our findings revealed that the left WST with MVF affects the postural stability in the EO-SSB test. The Right WST with MVF affects COP-ML, postural stability, and right WST with and without MVF altered left load ratio significantly in the DSB-L test. Our results seem to prove that adding MVF to both lateral WST can immediately affect the standing balance control of the left USN model in some postural balance measurements. The WST in a different lateral direction with MVF or without MVF generally maintains the COP points position, postural stability, postural orientation consistently in both SSB and DSB tests of the left USN model. As a clinical implication, we suggested further study involving actual patients by considering these specific postural responses before applied this combined training to actual hemiparesis and USN patients. Further studies are needed to explore the effects of multimodal treatment on the USN model before implementing it to an actual patient.

Conference presentation

Several parts of our study were presented at three conferences. Firstly, at the 23rd International Society of Electrophysiology and Kinesiology Congress 2020, Nagoya, Japan, abstract number R2-3. Secondly, at the 18th Japanese Society of Neurological Physical Therapy 2020, Kyoto, Japan, abstract number EW-1. Thirdly, at the 25th Japanese Society of Physical Therapy Fundamental Science 2020, Sendai, Japan, abstract number 2G28-03.

Conflict of interest

There are no conflicts of interest to declare.

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