

Original Article

Efficacy of sitting balance training with delayed visual feedback among patients with stroke: a randomized crossover clinical trial

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Abstract. [Purpose] This study aimed to determine the effect of delayed visual feedback on the center of pressure and sitting balance in patients with stroke. [Participants and Methods] This was a single-blinded, randomized crossover trial. The duration of each intervention in real-time visual feedback and delayed visual feedback conditions while sitting on the platform was five days. We measured the center of pressure, function in sitting test, and functional independence measure for physiotherapy assessment. [Results] Twenty patients with stroke were included in this study. The delayed visual feedback condition improved the center of pressure for lateral distance, function in sitting test, and functional independence measure. The lateral center of pressure deviation increased significantly after 500 ms of intervention. The function in sitting test evaluated the interaction between pre- and post-training, and these conditions revealed that timing and condition factors contributed to the improvement. Sitting balance training affected the functional independence measure. [Conclusion] Sensory-motor and cognitive learning was facilitated through balance training with delayed visual feedback, and the internal model was updated with the efference copy of error correction. Sensory-motor feedback to visual stimulation can improve postural control, balance, and activities of daily living.

Key words: Balance, Delayed visual feedback, Sensory-motor

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INTRODUCTION

Sitting balance is known to contribute to the subsequent acquisition of standing and walking performance in patients with stroke. It has been repeatedly identified as an important predictor of motor and functional recovery after stroke, considering the importance of the trunk in sitting¹⁻³).

Real-time visual feedback (RVF) is useful for sitting balance in patients with stroke. The integration of vision helps somatosensory and vestibular senses to stabilize sitting balance, enhances body image, and contributes to postural control through its coordination with somatosensory perception. A study by Pellegrino et al.⁴), evaluated the effects of RVF in patients with stroke. Participants were seated on a stool positioned on top of a custom-built force platform, and their center of pressure (CoP) positions were mapped according to the coordinates of a cursor on a computer monitor. During training, the cursor position was always displayed, and subjects were instructed to reach the targets by shifting their CoP by moving their trunk. Most stroke survivors were able to perform the required task and improve their performance in terms of duration,

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smoothness, and extent of movement, although not in terms of movement direction. However, when the RVF was removed, most of the patients did not show any improvement in their pretraining performance. The results would have improved if their experience included special somatosensory input rather than only visual input. In contrast, delayed visual feedback (DVF) training has been reported to improve balance skills among healthy participants⁵⁻⁷). Normally, the eye moves at a rate of 50 ms and perception at 150 ms⁸). DVF is considered as a means to delay the cognitive process by ≥ 200 ms, and consequently, load process to lag behind retinal recognition. Farshchiansadegh et al. reported a significant reduction in processing errors in motor learning for spatial recognition in a 300 ms delayed condition in goal targeting and the adapting to reaching task⁹). A study by Rougier et al. reported decreased variability in the center of pressure-center of mass (CoP-CoM) motions under the influence of delay, while CoM movements increased⁷). Furthermore, Van den Heuvel et al.⁵) reported that the mean normalized variability for the high-pass filtered data was much higher for feedback conditions than for RVF; however, it did not increase monotonically with delay. Alternatively, although a clear explanation for the reduced values at 500–750 ms and increasing values for both shorter and longer delays could not be readily formulated, the authors believed that the coupling strength between the different sources of feedback and central corrective processes was influenced by the temporal disparity between these sources⁵).

These observations are related to standing balance in healthy participants. There have been no previous reports analyzing the effects of DVF on sitting balance in patients with stroke. DVF may improve body cognition and sensory-motor function, contributing to more predictive learning⁸). Although this may be useful for rehabilitating patients with stroke, it is not sufficiently clear how DVF affects CoP and sitting balance among these patients.

This randomized, crossover, controlled trial aims to determine the effects of DVF on CoP, sitting balance, and activities of daily living (ADL) in patients with stroke.

PARTICIPANTS AND METHODS

This study included patients with stroke in the recovery phase following a stroke who met the inclusion and exclusion criteria. The inclusion criteria were as follows: 1) ability to understand the issue being investigated through verbal explanation; 2) ability to sit for 2 min; and 3) the presence of a unilateral lesion on computed tomography and magnetic resonance imaging between sub-acute and chronic phases. Exclusion criteria included patients having a history of orthopedic surgery, brainstem lesions, cerebellar lesions, multiple cerebral infarctions, subarachnoid hemorrhage, hydrocephalus, unilateral spatial neglect, disability of eye tracking, and severe higher brain dysfunction.

This study was conducted in accordance with the Declaration of Helsinki, International Committee of Medical Journal Editors guidelines, and Consolidated Standards of Reporting Trials guidelines. Written informed consent was obtained from all individual participants included in this study and from the Sonodakai ethics committee (approval No. 71), Tokyo Metropolitan University (approval No. 19102), and the study was registered in the University Hospital Medical Information Network (<http://www.umin.ac.jp/ctr>, UMIN000045146).

An originally developed SR soft vision device (SVZB 4525 L, Sumitomo Riko Co., Ltd. Komaki, Japan; Fig. 1) was used to measure the CoP, and this device was used to provide DVF training.

The task of the participants, subsequent measurement order, and assessment items were randomly assigned to a random number table, and the raters were blinded by a single-blind, randomized crossover design. Participants took part in the standard rehabilitation during the study process. Standard rehabilitation included functional training (such as facilitation and sitting to standing) and ADL training (such as communication and talking, transfer, toilet, and ambulation) for a total of 180 min/day.

The duration of the intervention in RVF and DVF while sitting on the platform was 60 times/day for 5 days, consisting of 3 periods (baseline, post 1, and post 2 evaluations). The post 1 evaluation was performed in 2–3 days between the intervention protocols (Fig. 1).

Randomization was concealed from the recruiter and assessor using sealed opaque envelopes containing the allocation, which was generated earlier by a person independent of the study using random number tables to ensure equal numbers of RVF and experimental participants. The assessor was blinded to the allocation, and the outcome measures were collected after training. The collection of outcome measures was performed by two blinded assessors. To reduce bias, the two blinded assessors were provided with all the instructions and measured outcomes. Computed random numbers were used to classify the study participants into RVF and experimental groups. We followed the procedure for selecting and allocating cases using the Consolidated Standards of Reporting Trials (CONSORT) protocol.

The starting position was the sitting position under RVF (RVFC) and DVF (DVFC) conditions. Participants performed balance training in the RVFC. DVF training was performed using conditions where a 500 ms delayed target was displayed on the monitor (Fig. 2). The task was to perform a maximal lateral tilt to shift the center of gravity (CoG) to the paretic side. The self-CoP projected onto the monitor was used for DVF. In addition, participants were not permitted to lift their ischium on the non-paretic side. The verbal instructions for both tasks were as follows: “After the signal, check the CoG on the monitor and move the CoG to the paretic side (left or right) to the maximum extent possible”.

Patient data were collected from medical records for age, gender, period of onset, lesion site, and Brunnstrom recovery stage. We measured the CoP, function in sitting test (FIST), and functional independence measure (FIM) as physiotherapy

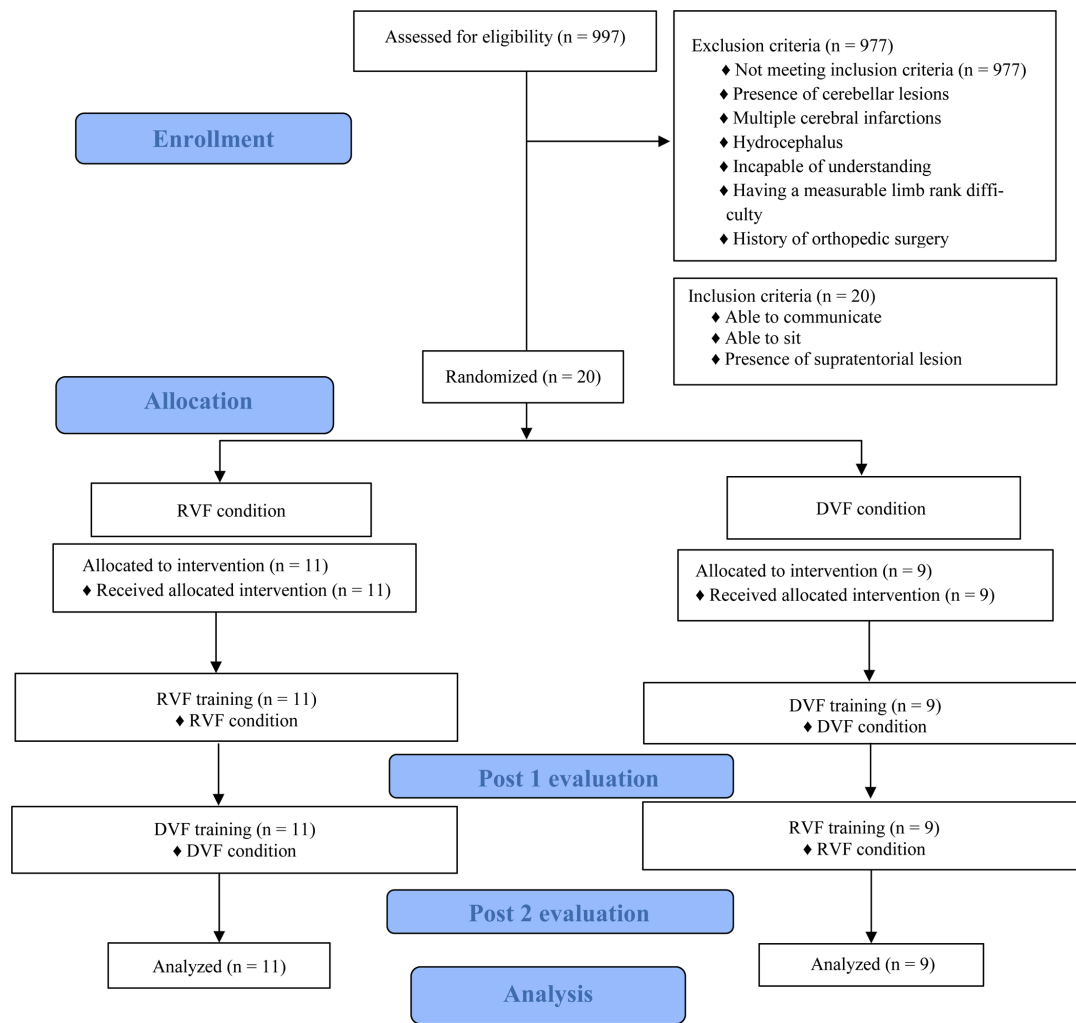


Fig. 1. Study protocol on CONSORT flow diagram.
DVF: delayed visual feedback; RVF: real-time visual feedback.

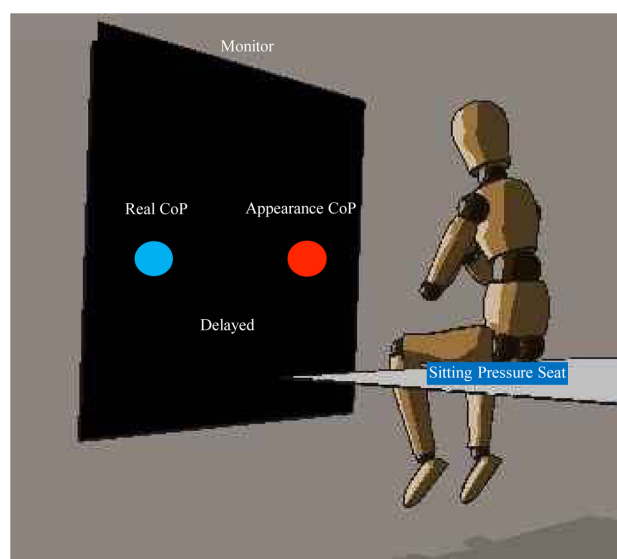


Fig. 2. Delayed visual feedback training. Delayed visual feedback training was performed using conditions where a 500 ms delayed target was displayed on the monitor.

assessments. FIST is a 14-item test investigating several factors involved in the balancing process: sensory, motor, proactive, reactive, and steady-state¹⁰). FIM is a measure of the ability to perform ADL.

CoP assessment (mean \pm standard deviation) was defined as the maximum lateral movement of the CoP for the lateral distance (LD). It was measured before and after the visual delay or normalized CoP feedback task. Measurements were performed in sitting and non-grounded plantar positions. The LD was calculated using SR soft vision to record the CoP in the left and right directions.

Demographic data were analyzed using the χ^2 test and Mann–Whitney *U* test. The effects of the intervention were measured by repeated two-way analysis of variance with two conditions and two factors for the period (baseline, post 1, and post 2) and after RVFC or DVFC training. We also used the Bonferroni method in the post-hoc test to examine the simple main effect. Statistical analysis was performed using SPSS (version 25.0; SPSS, Inc., Tokyo, Japan) with the level of significance set to 0.05.

We had set 0.14 (large effect size) as the effect size according to η^2 values by multiple classification analysis¹¹), 80% power, and based on inter-group differences in baseline, post 1, and post 2 evaluations with $\alpha=0.05$, in accordance with the crossover study designed using G*power 3.1. (Heinrich Heine University, Dusseldorf, Germany)¹²). Seven participants participated per group to meet the sample size.

RESULTS

This study included 20 patients with stroke in the recovery phase following a stroke. Demographic data of the participants are presented in Table 1.

As shown in Table 2, when the 500 ms DVFC was performed first, LD of CoP increased after the intervention (post 1) ($p<0.05$); however, it did not increase after the subsequent RVFC (post 2). In contrast, when starting with RVFC, there was a small increase in LD of CoP after intervention (post 1) with a significant increase at the subsequent DVFC (post 2) ($p<0.05$). An interaction between time and delayed conditions was observed ($F=53.786$, $\eta^2=0.871$, $p<0.05$). The effect sizes of time and delayed conditions were found to be “large” according to Cohen’s *d* (RVFC<DVFC).

Table 3 shows that when the 500 ms DVFC was performed first, FIST increased after intervention (post 1) ($p<0.05$), but it did not increase after the subsequent RVFC (post 2). In contrast, when starting with RVFC, FIST increased only slightly after intervention (post1) but significantly increased after the subsequent DVFC (post 2) ($p<0.05$). There was an interaction between timing and intervention conditions ($F=655.123$, $\eta^2=0.988$, $p<0.05$) and a simple main effect of timing

Table 1. Demographic data

No	Group	Age (years)	Gender	Post on set (days)	Type of stroke	Region	Damage side
1	RVFC	60	Male	141	CI	MCA	Left
2	RVFC	76	Male	127	CH	Thalamus	Left
3	RVFC	82	Male	131	CH	Putamen	Left
4	RVFC	74	Female	85	CI	ACA	Right
5	RVFC	46	Male	202	CI	MCA	Right
6	RVFC	89	Female	63	CI	MCA	Right
7	RVFC	67	Male	33	CH	Thalamus	Left
8	RVFC	84	Male	90	CI	MCA	Left
9	RVFC	62	Male	57	CI	Corona radiata	Left
10	RVFC	81	Male	141	CI	Internal capsule	Right
11	RVFC	67	Male	61	CI	MCA	Right
12	DVFC	70	Female	93	CI	ACA, MCA	Right
13	DVFC	74	Female	77	CI	ACA	Right
14	DVFC	66	Male	170	CI	MCA	Right
15	DVFC	69	Male	56	CH	Thalamus	Left
16	DVFC	78	Male	88	CI	MCA	Right
17	DVFC	73	Male	130	CH	Putamen	Right
18	DVFC	74	Male	22	CI	Corona radiata	Left
19	DVFC	65	Male	83	CH	Putamen	Left
20	DVFC	41	Male	81	CH	Thalamus	Right
		69.9 \pm 11.7			96.6 \pm 45.9		

RVFC: real-time visual feedback condition; DVFC: delayed visual feedback condition; MCA: middle cerebral artery; ACA: anterior cerebral artery; CI: cerebral infarction; CH: cerebral hemorrhage.

($F=9.984$, $\eta^2=0.555$). The effect size of time was found to be “large” by Cohen’s effects (time; Pre<Post 2, and condition; RVFC<DVFC).

In Table 4, FIM increased post-intervention (post 1) ($p<0.05$) when the 500 ms DVFC was performed first; however, it showed no increase after the subsequent RVFC (post 2). In contrast, when starting with RVFC, FIM increased only slightly after intervention (post 1) but significantly increased after the subsequent DVFC (post 2) ($p<0.05$). There was an interaction between the timing and intervention conditions ($F=152.552$, $\eta^2=0.956$, $p<0.05$) and a simple main effect for time ($F=8.485$, $\eta^2=0.739$, $p<0.05$). The effect size of time was reported to be “large” by Cohen’s effects (time; post 1<post 2).

DISCUSSION

Recently, CoP excursion of the affected posterior-lateral side was found to be most challenging for patients with stroke; and their reach was lowest in the posterior, lateral, and anterior directions. Patients could move less on the affected side than on the unaffected side²). Therefore, the CoP is more sensitive to the immediate reaction “time” during adaptation in the rehabilitation evaluations. Moreover, the high responsiveness and temporal sensitivity of the balance response are considered important because they can help in rehabilitation therapy. Furthermore, postural control and CoP analysis clarified that CoP control was inhibited by the aging process⁸), and the dependence of postural control on visual cues is greatly influenced by age¹³). In this study, there were no significant differences in RVFC and DVFC with age. We believe that the interaction was significantly different in the DVFC than in the RVFC, and the lateral CoP deviation increased significantly after DVFC. The effect size of the interaction was large in DVFC¹⁴). In other words, the theory suggests that the adaptations of visual and somatosensory information in the DVFC are more useful tools in delaying “time-resisted” visuomotor adaptation in their awareness. This study is the first to report the positive effects of sitting balance training in a patient with stroke with DVFC. The effect of DVFC was sustained afterward, which may have contributed to the sensory facilitation of load and balance learning. According to Lizama et al.¹⁵), additions of somatosensory feedback and VF can correct deviations in the shifts in the CoG, which may contribute to the improvement of balance ability by correcting postural control and deviation of the CoP¹⁶). They reported that the postural control was not the sitting; however, the same was affected by the “time” adaptations in stroke rehabilitation programs. Furthermore, patients with Parkinson’s disease could use VF to improve the tracking performance during the movement because they rely on a restrictive strategy with stiffness and limited movements¹⁷).

DVFC improved the CoP deviation in sitting balance in patients with stroke. In this study, the DVFC corrected the CoP deviation, and the improvement of the LD was the feedback condition with a 500 ms delay. Somatosensory feedback improves error learning because it indicates a strategy in patients with stroke; however, the benefits of DVFC were the difference between DVFC and RVFC of somatosensory perception that resulted in the unconscious amplification of motor sensation. Visual attention and cognitive loading in the DVFC facilitated motor learning between the sensory and motor systems during adaptation following stroke.

Table 2. Results of the center of pressure for real-time visual feedback and delayed visual feedback conditions

	Pre (mm)	Post 1 (mm)	Post 2 (mm)
RVFC	178.5 ± 73.7	182.0 ± 75.3	190.8 ± 77.6*
DVFC†	176.1 ± 81.9	183.1 ± 79.6*	174.4 ± 84.8

RVFC: real-time visual feedback condition; DVFC: delayed visual feedback condition.
†, interaction between time and conditions; *, simple main effects of time.

Table 3. Results of functional sitting test in real-time visual feedback and delayed visual feedback conditions

	Pre (points)	Post 1 (points)	Post 2 (points)
RVFC	45.3 ± 11.4	46.1 ± 10.7	49.4 ± 7.7*
DVFC†	50.5 ± 5.9	53.0 ± 3.6*	53.2 ± 4.5

RVFC: real-time visual feedback condition; DVFC: delayed visual feedback condition.
†, interaction between time and conditions; *, simple main effect of time.

Table 4. Functional independence measures in real-time visual feedback and delayed visual feedback conditions

	Pre (points)	Post 1 (points)	Post 2 (points)
RVFC	66.8 ± 21.0	67.7 ± 21.5	71.4 ± 26.8*
DVFC†	75.4 ± 25.6	83.8 ± 19.4*	83.9 ± 19.6

RVFC: real-time visual feedback condition; DVFC: delayed visual feedback condition.
†, interaction between time and conditions, *, simple main effect of time.

The interaction between timing and intervention conditions ($F=655.123$, $\eta^2=0.988$, $p<0.05$) revealed that timing and condition factors contributed to improving the FIST scores for balance ability in patients with stroke. The sensory weighting mechanism of the model scales the gain of sensory cues (proprioceptive, somatosensory, and visual) in terms of relative contributions to the overall feedback gain^{18–20}. Therefore, it is likely that the sensory-motor system of DVFC enhances the effectiveness of the intervention period and the load of balance training.

In motor learning theory, CoP movements performed at low frequencies induced long-lasting transportation (as deduced from the frequency relationship mentioned above that links CoP and CoG amplitudes) and overshoot the expected response⁷. In this study, VF was used at 0.25 Hz with a 500 ms delay; hence, the delayed CoP gradually affected the sensory-motor system. It was also responsible for the coincidence between visual input and balance motion, which resulted in an improvement in the FIST scores. Furthermore, sensory-motor learning improved the postural control on sitting in DVF. On the other hand, Foulkes et al.²⁰ reported that the adaptation observed was consistent with the idea that there was a “delay component” in the internal processes, as proposed in models such as the Smith predictor model. This task not only provided eye-tracking training but their program also included a delayed approach to improve the internal model. The internal model of the reference copy was created using the sensory-motor learning process.

Time was also a factor with a simple main effect before and after the intervention ($F=9.984$, $\eta^2=0.555$, $p<0.05$). This may have been due to the effect of timing because it was a ceiling effect in sensory adaptations for the FIST. Because the ability to be adequately perceived is lower than in young healthy participants, visual and sensorimotor information processes may have been deficient.

Sitting balance training was observed to affect the independence of progressing from sitting to standing and walking. In addition, sitting balance with DVF improved ADL; and it was related to functional prognosis ($F=152.552$, $\eta^2=0.956$, $p<0.05$). Sensory-motor function is loaded into more important motor learning and cognitive errorless learning in prognosis. Dean et al.²¹ reported favorable outcomes from a 2-weeks training period which involved increasing the number of repetitions and cognitive difficulty of cognitive manipulative tasks. However, in this study, each intervention was implemented for 5 days to improve sitting balance and ADL, with a 2–3 day washout period, inferring that this might be an appropriate intervention protocol. These time windows are critical for patients with stroke, as it is essential for adaptation, improvement of sitting balance and ADL, and recovery of visual and perception systems²². We believe that the mechanism can be adapted to the visual somatosensory system in sensory-motor feedback to FIM among patients with stroke.

Finally, we analyzed the balance adjustments due to the instability of the CoP movement during lateral tilting. The reactive balance strategy activates postural control after an external disturbance occurs, thus ensuring balance recovery and leading to ADL^{22, 23}).

The primary mechanism by which the feedback occurred is considered to be somatosensory input due to lateral tilt by sensory stimuli and visual loading of visual delay that generated efferent copies such as premotor planning and planning by images of movement and visual sensation. Furthermore, balance control by the preceding somatosensory senses and the sense of predicted CoG movement by the DVF allowed the CoG movement to be greater than what was initially predicted, increasing the distance of the CoP. This may have enabled the predictive control of DVF rather than merely providing DVFC. In particular, we believe that rewriting of the efferent copy with DVF contributed to the improvement in balance control ability.

The limitations of this study were that it had a relatively small sample size, and the variability in function and the two base conditions had large standard deviations. Long-term effects are unclear, and future studies are required in this field.

Funding and Conflict of interest

All authors declare that they have no conflict of interest.

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