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Effects of balance training with stroboscopic glasses on postural control in chronic ankle instability patients

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Individuals with chronic ankle instability (CAI) are believed to rely more on visual information during postural control due to impaired proprioceptive function, which may increase the risk of injury when their vision is limited during sports activities.

Objectives: To compare (1) the effects of balance training with and without stroboscopic glasses on postural control and (2) the effects of the training on visual reliance in patients with CAI.

Design: A randomized controlled clinical trial.

Methods: Twenty-eight CAI patients were equally assigned to one of 2 groups: strobe or control group. The strobe group wore stroboscopic glasses during a 4-week balance training. Static postural control, a single-leg hop balance test calculated by Dynamic Postural Stability Index (DPSI), and the Y-Balance test (YBT) were measured. During the tests, there were different visual conditions: eyes-open (EO), eyes-closed (EC), and strobe vision (SV). Romberg ratios were then calculated as SV/EO, and EC/EO and used for statistical analysis.

Results: The strobe group showed a higher pretest-posttest difference in velocity in the medial-lateral direction and vertical stability index under SV compared with the control group ($p < .05$). The strobe group showed higher differences in EC/EO for velocity in the medial-lateral and anterior-posterior directions, and 95% confidence ellipse area ($p < .05$), and in SV/EO for velocity in the medial-lateral, 95% confidence ellipse area, and YBT-anterior direction ($p < .05$).

Conclusion: The 4-week balance training with stroboscopic glasses appeared to be effective in improving postural control and altering visual reliance in patients with CAI.

KEYWORDS
sensorimotor system, visual reliance, visual-motor training

1 | INTRODUCTION

Chronic ankle instability (CAI) is a condition characterized by residual symptoms including pain, swelling, loss of function, joint instability, a feeling of "giving way," and/or recurrent ankle sprains.[1] Delahunt et al.[2] characterized CAI as an encompassing term used to classify a subject with both mechanical and functional instability. CAI patients show pathomechanical, sensory-perceptual, and motor behavioral impairments.[3] Despite previous research concerning the topic, it is still unclear exactly how sensory-perceptual impairment affects CAI patients.

CAI patients have shown higher reliance on visual information during a single-legged stance when compared with uninjured controls to compensate for loss of information from the somatosensory system due to recurrent ankle sprains.[4] Reliance on sensory information might be altered by sensory reweighting which is a process of adjusting sensory input.[5] Previous studies found that people with an ACL injury showed a cascade of neuroplastic and neuromuscular alternations that lead to reliance on visual input and cortical motor planning.[6] In addition, the disrupted sensory feedback fundamentally alters the CNS mechanisms for motor control, which increases reliance on visual feedback which is a more reliable sensory system. Furthermore, Song et al.[4] demonstrated that CAI patients appear to increase their use of visual information during postural control. This reweighting occurs not only in CAI patients, but also in patients with knee injuries[6] and the elderly.[7] Alternations in processing sensory information may cause further injuries due to overloaded visual feedback and motor planning in the athletic environment.[6] One study stated that CAI patients with higher reliance on visual feedback may increase re-injury rates when their vision is disrupted during activities.[8] Therefore, it is important to rehabilitate CAI patients to integrate visual and somatosensory information effectively by reducing reliance on visual information.

Traditional rehabilitation programs have tried to improve the ability to reweight sensory information through an eyes-closed condition,[9,10] which was successful in restoring motor control. However, it may stimulate the CNS to compensate for the impaired somatosensory system by increasing the use of visual contribution, which may cause an adaptation of the impaired proprioceptive afferent input from the damaged tissue and related noxious stimuli.[6] Accordingly, the sensory deficits remain. In addition, the traditional rehabilitation programs could not alter visual reliance.[10] In order to accommodate for the limitations, this study used stroboscopic glasses for two reasons: (1) to disrupt visual information during rehabilitation programs and (2) to utilize them in dynamic tasks that might have a greater effect on neuromuscular control if we can modify the visual input during more challenging movements.[6]

Stroboscopic glasses may provide an effective mechanism, during physical rehabilitation, to disrupt visual stimuli during dynamic training tasks.[8] Using liquid crystal technology, a stroboscopic lens flickers intermittently between the clear and opaque parts of the lens, removing the visual information intermittently.[11] Stroboscopic glasses have been widely used for training purposes in various sports such as baseball and football[11,12]; however, they have not been used yet for rehabilitation purposes to improve postural control. We assumed that proprioceptive exercises with the glasses would force the CNS to engage in an adaptive strategy by increasing weighting of the remaining proprioceptive inputs, which may lead to improved use of somatosensory afferent information for managing motor control. If the rehabilitation program with stroboscopic glasses is more effective in restoring the impaired somatosensory system than programs without the glasses, it might provide clinicians with a new tool that may enhance current rehabilitation programs.

The overall purpose of this study was to investigate the effectiveness of dynamic balance training with stroboscopic glasses on postural control in CAI patients. Specifically, we sought to (1) determine whether training with the glasses would show greater improvements in postural control compared with training without the glasses and (2) identify the effects of this training on visual reliance during postural control. We hypothesized that the strobe group (training with stroboscopic glasses) would show more improvements in postural control than the control group (training without the glasses). We also hypothesized that the strobe group would show decreased visual reliance during postural control after the training.

2 | METERIALS AND METHODS

2.1 | Participants

We recruited 32 participants with CAI and assigned them either to the control ($n = 16$) or strobe group ($n = 16$). However, 28 participants (14 in each group) were used in analysis since four participants (two in each group) discontinued participation in the study due to personal reasons (Figure 1). The sample size was selected by convenience. We followed the International Ankle Consortium's position statement to recruit qualified CAI patients.[13] Specific subject inclusion criteria for CAI include (i) a history of at least 1 significant ankle sprain occurring more than 3 months prior to data collection, (ii) a history of two giving way episodes within the past six months, (iii) a score of <90% on the FAAM ADL, (iv) a score of <80% on the

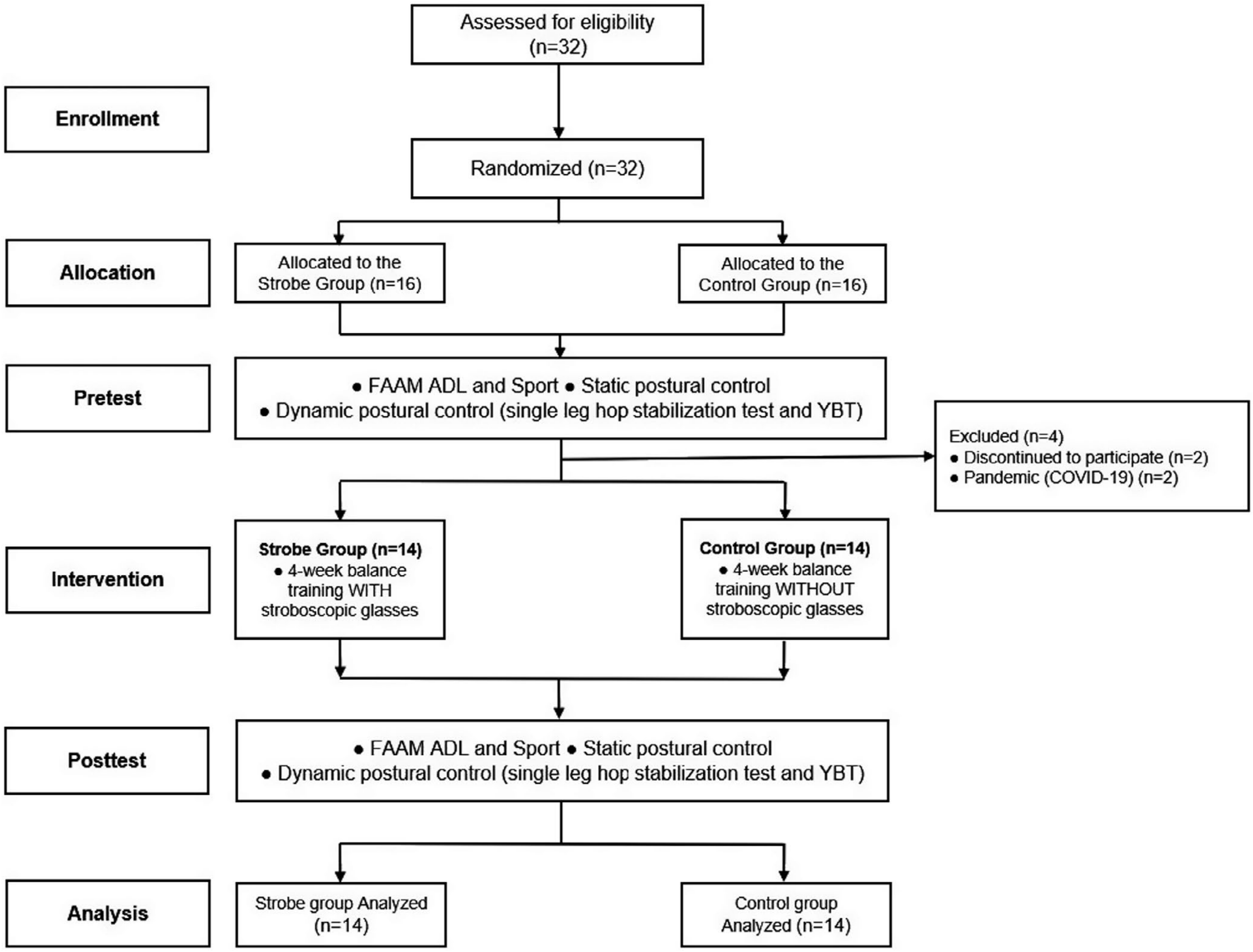

FIGURE 1 Flow chart: All subjects were equally assigned to either strobe or control group. The balance training started within 7 days after the pretest. Within 7 days after the completion of the intervention, subjects performed the posttest in the same manner as the pretest

FAAM Sports, (v) at least 5 "yes" answers including question 1, plus 4 others on the AII, and (vi) a history of physical activity at least 3 days/week for a total of 90 min/week in the previous 3 months.[2]

2.2 | Procedures (Figure 1)

Prior to data collection, investigators fully reviewed the strobe procedures with each subject, and participants read and signed informed consents. The study required participants to participate in two visits: pre- and post-training tests. The group allocation was evenly randomized before the pretest to avoid any biased decision that might arise from the results of the pretest. On both days of testing, participants changed into standardized spandex shirts and shorts, and athletic shoes. They performed 3 different tasks: static postural control, and dynamic postural control, including a single-leg hop stabilization test, and the Y-balance test (YBT). For the static postural control, participants stood on a force plate (1000 Hz; AMTI, Watertown, MA) with one leg (affected side) and maintained their position for 10-s, repeated 3 times. There were 3 visual conditions: eyes-open (EO), strobe vision (SV), and eyes-closed (EC). For the SV condition, we used stroboscopic glasses (Senaptec, Beaverton, OR) at 3 Hz (0.1-s of clear and 0.233-s of opaque) during the tests. Participants practiced each balance test at least 3 times before testing. In order to eliminate learning effects arising from SV, all practice trials were under the EO condition. In the actual trials, the order of the visual conditions was randomized. For the dynamic postural control, there were only 2 conditions (EO and SV). The single-leg hop stabilization test required participants to jump 50% of their maximum jump height and land on a force plate, stabilize as soon as possible, and stay for 10-s.[14] They performed 3–5 practical trials to get familiar with the task. For the YBT, participants performed the test barefoot with the foot positioned and aligned on a slightly elevated block, and then, the participants were instructed to perform the maximal reach distance with the opposite limb by pushing a sliding block using their toes.[15] Each subject performed 4 practice trials in 3 directions (anterior (ANT), posteromedial (PM), and posterolateral (PL)) on the tested limb. After the posttest, they filled out 3 self-reported function questionnaires again.

As an intervention, we chose a 4-week dynamic balance training that provided significant changes in postural control for CAI patients in previous studies.[16,17] Participants performed the 4-week dynamic balance program and participated in twelve 20-min supervised training sessions with 3 sessions per week. The strobe group wore the stroboscopic glasses during the training sessions, but not during rest time between exercises. The balance training started within 7 days after the pretest. The progressive balance training program (see Appendix A) was designed to challenge a subject's ability to maintain a single-limb stance while performing various balance activities.[16,17] During each session, participants performed dynamic balance activities designed to challenge recovery of single-limb balance after a perturbation and to increase the ability to effectively develop spontaneous strategies to execute movement goals. As a subject developed proficiency within the program, the task and environmental constraints placed on the sensorimotor system were progressively increased. Each activity contained 7 levels of difficulty through which subjects advanced. These activities were intended to promote the restoration of functional variability within the sensorimotor system. Activities included (1) hop to stabilization, (2) hop to stabilization and reach, (3) hop to stabilization box drill, (4) progressive single-limb stance balance activities with eyes open, and (5) progressive single-limb stance activities with the EC condition. For the fifth activity, the strobe group did not wear the glasses.

There were two athletic trainers certified by the National Athletic Trainer's Association in this study. One of them conducted the pre- and posttest, and the other one conducted the balance training.

2.3 | Data reduction

2.3.1 | Static postural control

Static postural control data were reduced using MatLab (MathWorks, Natick, MA, USA). Several center of pressure (COP)-based measures were chosen to assess postural sway and variability in both anterior-posterior (AP) and medial-lateral (ML) axes.[18] The mean velocity of COP excursions was computed separately for the ML and AP directions based on previously established methods.[18] Lower velocity of COP is interpreted as indicating better postural control.[19] The mean velocity of COP excursions was defined by dividing the total COP excursion length by the 10-s trial time. The area of the 95% confidence ellipse of COP excursions (Area) was also calculated, representing overall COP range for both directions. The mean of 3 trials for all measures was used for statistical analysis.

2.3.2 | Single-leg hop stabilization test

Single-leg hop stabilization test data were quantified as dynamic postural stability index (DPSI) that includes stability indices (SIs) in the 3 principal directions (ML: MLSI, AP: APSI, vertical: VSI) as well as a composite score, the DPSI.[20] The MLSI and APSI assess the fluctuations from 0 N for the medial-lateral and anterior-posterior ground reaction forces, respectively. The VSI assesses the fluctuation of the vertical ground reaction force from the subject's body weight. The DPSI is a composite of the MLSI, APSI, and VSI and is sensitive to changes in all 3 directions.[14] Therefore, lower indices represent higher stability. DPSI is a sensitive measure of dynamic postural control used to detect differences between individuals with and without CAI.[21] The following equations were used to calculate the variables.[14] In the calculation, x, y, and z represent data points for ML, AP, and VGRF, respectively.

$$\text{MLSI} = \sqrt{\frac{\sum (0-x)^2}{\#\text{ of data points}}}$$

$$\text{APSI} = \sqrt{\frac{\sum (0-y)^2}{\#\text{ of data points}}}$$

$$\text{VSI} = \sqrt{\frac{\sum (\text{mass}-z)^2}{\#\text{ of data points}}}$$

$$\text{DPSI} = \sqrt{\frac{\sum (0-x)^2 + \sum (0-y)^2 + \sum (\text{mass}-z)^2}{\#\text{ of data points}}}$$

2.3.3 | YBT

The YBT has been used to measure dynamic postural control in patients with CAI and a previous study found the test could detect deficits related to CAI.[22] There were three directions: ANT, PM, and PL. A longer reach distance normalized by an individual's leg length represents better postural control.[22] Reach distances were normalized by true leg length (anterior superior iliac spine to the distal end of the medial malleolus). Three trials in each of the 3 directions were used for data analysis.

2.3.4 | Romberg ratio

In order to identify visual contribution during postural control, we calculated the Romberg ratios in each variable. The Romberg ratio has been used to assess visual reliance during postural control in previous studies.[23,24] The ratios were calculated as EC/EO and SV/EO for the static variables and SV/EO for the dynamic variables. A higher ratio represents higher contribution of visual information for the COP-based measures and DPSI, while a lower ratio represents higher contribution of visual information for the reach distances during YBT.

2.3.5 | Statistical analysis

The independent variables were group (strobe and control), time (pretest and posttest), and condition (EO, SV, and EC for the static postural control and EO and SV for the single-leg hop stabilization test and YBT). To simplify the analysis, we removed the time effect by modeling the differences between pretest and posttest. This removed any dependence that might exist among the posttest and pretest measured on the same subject. Additionally, each subject was exposed to all three levels of visual conditions (in a randomized order) after being randomly assigned to a group. To accommodate dependence that may exist between visual conditions measured on the same subject, we fit a repeated measures ANOVA. This was done using a linear mixed model framework and the "lme" function in the R statistical software. Based on this model, we were able to carry out a number of post hoc contrast tests that permitted us to estimate the mean pre − post difference marginally for each level of group and to assess changes in postural control in each group and condition. Tukey's honestly significant difference (HSD) post hoc test was performed for pairwise comparisons if they had significant interactions from the ANOVAs. Repeated measures ANOVAs were used to compare between groups and times in the Romberg ratios. Another repeated measures ANOVA was also used to assess differences in self-reported function. An independent t test was run to analyze demographic characteristics between groups. The alpha level for this study was 0.05.

3 | RESULTS

3.1 | Demographics and self-reported function (Table 1)

There was no statistical difference in demographics between groups (Table 1). There was no significant group ×time interaction in differences for all questionnaires. Regardless of the groups, participants reported improved self-reported function: FAAM ADL and Sport after the training ($p < .0001$, all).

3.2 | Static postural control

Table 2 represents static postural control data. There was a significant group × condition interaction in pretest-posttest mean differences for velocity in the mediolateral direction (VelML) ($p = .01$), while there was no interaction for velocity in the anteroposterior direction (VelAP) and the Area ($p = .04$ and .11, respectively). A post hoc test revealed that the strobe group showed a greater difference in the SV condition compared with the control group ($p = .01$) and only the strobe group under the EC condition showed a greater difference compared with those under the EO condition ($p = .002$). For the group main effect, the strobe group showed greater pretest-posttest mean difference than the control group for VelML ($p = .005$) while there were no significant effects for VelAP and the 95% confidence ellipse area of COP excursion (Area) ($p = .33$ and .20, respectively).

There were significant group ×condition interactions in both EC/EO and SV/EC ratios for VelML ($p = .02$ and .01,

TABLE 1 Participant demographics with self-reported function

Characteristic		Group (mean ± SD) Strobe ($n = 14$)	Control ($n = 14$)
Sex, male/female		6/8	8/6
Age, y		21 ± 3	22 ± 2
Height, cm		175.5 ± 8.0	173.5 ± 8.3
Mass, kg		72 ± 11	71 ± 12
Previous ankle sprains, No.		4 ± 3	5 ± 3
AII (# of Yes)		5.7 ± 0.5	5.1 ± 1.2
FAAM ADL (%)	Pre	86.7 ± 5.7	87.7 ± 8.7
	Post	93.8 ± 5.2	93.9 ± 5.4
FAAM-Sport (%)	Pre	72.5 ± 8.7	72.9 ± 8.7
	Post	88.4 ± 5.6	85.9 ± 8.9

Abbreviations: AII, Ankle Instability Instrument; FAAM ADL, Foot and Ankle Ability Measure for Activities of Daily Living; No., number; SD, standard deviation; y, years.

TABLE 2 Static postural control

Variables	Time	Group	Condition (mean ± SD)			Romberg ratio	
			EO	SV	EC	EC/EO	SV/EO
VelML[†,‡,§,¶] (cm/s)	Pre	Strobe	0.91 ± 0.45	2.23 ± 0.47	2.40 ± 0.59	3.13 ± 2.02	3.06 ± 1.17
		Control	0.77 ± 0.25	1.66 ± 0.30	2.02 ± 0.25	2.36 ± 0.74	2.81 ± 0.67
	Post	Strobe	0.70 ± 0.25	1.25 ± 0.50	1.30 ± 0.51	1.89 ± 0.91	2.19 ± 1.45
		Control	0.70 ± 0.24	1.65 ± 0.29	1.71 ± 0.36	2.59 ± 0.82	2.70 ± 1.02
VelAP[‡] (cm/s)	Pre	Strobe	0.82 ± 0.27	1.83 ± 0.28	2.03 ± 0.29	2.44 ± 0.71	2.72 ± 0.84
		Control	0.83 ± 0.24	1.84 ± 0.26	2.02 ± 0.25	2.58 ± 0.50	2.34 ± 0.41
	Post	Strobe	0.79 ± 0.27	1.46 ± 0.36	1.81 ± 0.31	2.16 ± 1.08	2.89 ± 1.06
		Control	0.79 ± 0.25	1.53 ± 0.50	2.01 ± 0.24	2.76 ± 0.74	2.19 ± 0.93
Area[‡,§] (cm^2)	Pre	Strobe	5.95 ± 2.22	23.33 ± 10.72	25.44 ± 6.72	4.90 ± 2.29	4.54 ± 2.63
		Control	9.95 ± 5.41	22.01 ± 15.72	24.45 ± 13.38	3.40 ± 3.01	2.89 ± 2.46
	Post	Strobe	5.90 ± 1.98	11.97 ± 4.30	14.19 ± 6.30	2.68 ± 1.55	2.15 ± 0.78
		Control	7.10 ± 3.86	16.63 ± 6.22	18.29 ± 8.60	2.91 ± 1.81	2.71 ± 1.18

Abbreviations: AP, anterior-posterior; EC, eyes-close; EO, eyes-open; ML, medial-lateral; SD, standard deviation; SV, strobe vision; Vel, velocity.

[†]Significant group × condition interaction in ANOVA for pre-post mean difference ($p < .05$).

[‡]Significant group × time interaction in ANOVA for Romberg ratio in EC/EO ($p < .05$).

[§]Significant group × time interaction in ANOVA for Romberg ratio in SV/EO ($p < .05$).

[¶]Significant group main effects for pre-post mean difference ($p < .05$).

respectively) and Area ($p = .03$ and .02, respectively). For VelAP, only EC/EO ratio showed significant group x condition interaction, while SV/EO did not ($p = .01$ and .90, respectively). Post hoc tests revealed that only the strobe group showed differences in EC/EO and SV/EO ratios for VelML ($p = .04$ and .0002, respectively) and Area ($p = .002$ and .004) and in EC/EO ratio for VelAP ($p = .02$) between times.

3.3 | Dynamic postural control

Table 3 represents DPSI and YBT data.

3.3.1 | DPSI

There was one significant group x condition interaction in pretest-posttest mean differences for VSI ($p = .04$), but not for DPSI, MLSI, and APSI ($p = .17$, .61, and .75, respectively). A post hoc test revealed that the strobe group showed a greater difference in the SV condition compared with the control group ($p = .005$). There were significant differences between groups in pretest-posttest mean difference for DPSI ($p = .01$) and VSI ($p = .01$), but not for MLSI and APSI ($p = .64$ and .65, respectively).

There were no significant group × condition interactions in SV/EO ratio for all variables (DPSI: $p = .17$, MLSI: $p = .36$, APSI = .30, and VSI: $p = .52$).

3.3.2 | YBT

There was no significant interaction or group effect in pretest-posttest mean differences for all directions (ANT: $p = .28$, PM: $p = .61$, and PL: $p = .29$). Regardless of the groups and the conditions, there were significant time main effects for the PM and PL directions ($p = .04$ and .01, respectively) directions.

There was a significant group × condition interaction in SV/EO ratio for ANT ($p = .04$), but not for PM and PL directions ($p = .29$ and .73, respectively). A post hoc test revealed that the strobe group showed a difference in the SV/EO ratio between times ($p = .01$).

4 | DISCUSSION

The purpose of this study was to identify whether training with the strobe glasses would result in greater improvements in postural control compared with training without the glasses. The other purpose was to identify the effects of the dynamic balance training with the glasses on visual reliance during postural control. Overall, the strobe group showed more enhanced postural control than the control group and the training with the glasses was effective in decreasing visual reliance during static postural control, as demonstrated by the results.

As we hypothesized, only the strobe group showed a lower EC/EO and SV/EO ratio in VelML, VelAP, and Area at the posttest compared to the pretest, suggesting

TABLE 3 Dynamic postural control scores: DPSI and YBT

Variable	Time	Group	Condition (mean ± SD) EO	Condition (mean ± SD) SV	Romberg ratio SV/EO
DPSI[§]	Pre	Strobe	0.65 ± 0.10	0.71 ± 0.09	1.12 ± 0.27
		Control	0.31 ± 0.15	0.37 ± 0.12	1.13 ± 0.24
	Post	Strobe	0.46 ± 0.12	0.46 ± 0.09	1.08 ± 0.34
		Control	0.50 ± 0.13	0.60 ± 0.09	1.29 ± 0.40
MLSI	Pre	Strobe	0.12 ± 0.03	0.18 ± 0.04	1.57 ± 0.43
		Control	0.14 ± 0.03	0.17 ± 0.24	1.23 ± 0.24
	Post	Strobe	0.12 ± 0.02	0.18 ± 0.05	1.43 ± 0.23
		Control	0.14 ± 0.03	0.17 ± 0.04	1.23 ± 0.32
APSI	Pre	Strobe	0.14 ± 0.02	0.14 ± 0.03	1.08 ± 0.24
		Control	0.16 ± 0.03	0.16 ± 0.03	1.03 ± 0.27
	Post	Strobe	0.15 ± 0.03	0.15 ± 0.03	0.98 ± 0.22
		Control	0.15 ± 0.04	0.16 ± 0.04	1.09 ± 0.29
VSI[†,§]	Pre	Strobe	0.48 ± 0.15	0.49 ± 0.13	1.23 ± 0.49
		Control	0.45 ± 0.16	0.41 ± 0.09	1.07 ± 0.32
	Post	Strobe	0.31 ± 0.09	0.29 ± 0.06	0.10 ± 0.30
		Control	0.36 ± 0.08	0.42 ± 0.09	0.96 ± 0.22
YBT-ANT (%LL)[‡]	Pre	Strobe	0.64 ± 0.07	0.63 ± 0.06	0.98 ± 0.03
		Control	0.67 ± 0.09	0.63 ± 0.09	0.95 ± 0.03
	Post	Strobe	0.64 ± 0.06	0.60 ± 0.05	0.95 ± 0.05
		Control	0.65 ± 0.10	0.62 ± 0.10	0.95 ± 0.05
YBT-PM (%LL)	Pre	Strobe	1.08 ± 0.07	1.06 ± 0.08	0.98 ± 0.03
		Control	1.20 ± 0.12	1.16 ± 0.12	0.97 ± 0.03
	Post	Strobe	1.04 ± 0.08	0.99 ± 0.11	0.96 ± 0.05
		Control	1.13 ± 0.15	1.08 ± 0.13	0.96 ± 0.04
YBT-PL (%LL)	Pre	Strobe	1.07 ± 0.08	1.04 ± 0.09	0.97 ± 0.05
		Control	1.11 ± 0.14	1.10 ± 0.13	1.00 ± 0.09
	Post	Strobe	1.00 ± 0.09	0.95 ± 0.10	0.95 ± 0.04
		Control	1.04 ± 0.15	1.00 ± 0.14	0.96 ± 0.04

Abbreviations: ANT, anterior; APSI, anterior-posterior stability index; DPSI, dynamic postural stability index; EO, eyes-open; LL, leg length; MLSI, medial-lateral stability index; PL, posterolateral; PM, posteromedial; SD, standard deviation; SV, strobe vision; VSI, vertical stability index; YBT, Y-balance test.

[†]Significant group × condition interaction for pre-post mean difference ($p < .05$).

[‡]Significant group × time interaction in ANOVA for Romberg ratio in SV/EO ($p < .05$).

[§]Significant group main effects for pre-post mean difference ($p < .05$).

the presence of balance training. In other words, balance training with the glasses decreased visual reliance during static postural control. The results may indicate that when vision was partially or completely blocked, the strobe group could use other sensory information, such as somatosensory and/or vestibular information, to maintain their static postural control successfully.[5] In the current study, the CNS might weigh somatosensory and/or vestibular information more heavily due to a lack of visual information in the strobe group. A previous study suggested that stroboscopic training might be a method to decrease visual feedback during established exercises to make visual information less important for motor programming.[6] In addition, the training with the glasses may stimulate the CNS to reweight information from vestibular and somatosensory inputs to decrease reliance on visual feedback that was caused by injuries.[6] Furthermore, the strobe group might have shown an improved ability to more effectively utilize not only limited visual information, but also other sensory information such as the somatosensory and/or vestibular system. The results may imply that the strobe group showed less reliance on visual input by reweighting their sensory input to somatosensory and/or vestibular systems during static postural control at the posttest compared with the pretest. As CAI patients improve their postural control by decreasing the reliance on visual information and reweighting sensory information dynamically, the risk of recurrent ankle sprains may be affected since deficits in postural control have been identified as a risk factor for ankle sprains in CAI patients.[4,25]

An analysis of the dynamic postural control measure reveals that stroboscopic glasses may not alter visual reliance. We assume the effects of strobe training are not strong enough to alter visual reliance for all aspects of dynamic movement in patients with CAI. In addition, dynamic movements, such as a jump-landing and reaching task, may be too demanding for CAI patients to rely primarily on other sensory inputs. During the balance training, we progressively increased the level of visual occlusion and exercise as participants completed tasks without failures (see Appendix A). One observation we made during the exercise was that the strobe group could not reach a higher level of exercise as early as the control group, which might be due to the stroboscopic glasses that make it hard to complete the task without errors. As the strobe group progressed slowly, they had less amount of work at higher levels of exercise which involved more dynamic movement than lower-level exercises. Therefore, future studies are needed to identify the optimal level of visual occlusion during exercise and how we can progress the occlusion alongside exercise difficulty. In addition, future studies are needed to identify whether an increased number of repetitions and/or extended period of training with stroboscopic glasses could alter visual reliance during dynamic postural control in patients with CAI.

Regardless of visual conditions, the strobe group showed higher changes in pretest-posttest mean differences for VelML, DPSI, and VSI compared with the control group. In other words, training with stroboscopic glasses might be more effective in improving both static and dynamic postural control than without the glasses. To the best of our knowledge, this is the first study that used the glasses for a rehabilitative purpose to improve postural control in those with musculoskeletal injuries; therefore, the results cannot be directly compared with other studies that reported effects of the glasses on sports activities for individuals without musculoskeletal injuries. However, previous studies reported that the stroboscopic glasses were effective in enhancing visual and perceptual skills, such as catching a ball, passing/shot accuracy, and anticipation timing.[11,26] The previous studies explained their results by referring to the effectiveness of the glasses in (1) utilizing the limited visual information people receive more effectively and (2) utilizing other sensory information, such as kinesthesia awareness and auditory cues, more effectively.[27] Thus, in this study, training with stroboscopic glasses might improve the utilization of the somatosensory system more effectively during postural control. Future research is needed to identify whether other variables such as time-to-boundary or the balance error scoring system show significant changes after balance training with stroboscopic glasses.

Improvements in postural control for CAI patients after sensorimotor training have been documented in the literature.[9,17] In the present study, CAI patients, both the strobe and the control groups, demonstrated improvements in most of our outcome measures including self-reported function. These results agree with previous findings. One study reported that CAI patients showed significant improvements in VelML under the EC condition after the same intervention without the glasses (pretest-posttest difference: 0.25 cm/s).[17] Another study found that a 4-week balance training was effective in decreasing total distance traveled of the COP during a one-legged stance in those with CAI (pretest-posttest difference: 11.1 cm).[28] In addition, Anguish et al.[16] reported that the training program was effective in improving the dynamic postural control measured by the star excursion balance test which is considered as an essentially identical task as YBT. Mechanisms behind the improvements were explained in several previous studies.[29,30] Neurophysiological alterations could include reflex responses and/or spinal and brain adaptation after balance training. Basically, reflex response can be either inhibited or facilitated depending on postural complexity.[29] Therefore, presynaptic inhibition is increased or decreased to have adequate reflex responses to meet the requirements of the task.[30] From the spinal adaptation perspective, previous studies reported that increased balance ability goes along with decreased H-reflex after balance training.[29] The balance training may help to avoid unwanted joint movements as the CNS adapts to adjust to spinal reflex responses.[31] In other words, balance training might improve the task-specific reflex modulation. In terms of brain adaptation, one study reported that supraspinal structures, such as the cerebellum, the basal ganglia, and the brainstem, have important roles in improving balance performance.[31] Furthermore, previous studies also reported that the changes in supraspinal structures following balance training were connected to improved balance ability.[30,31] This study, however, cannot ascertain the mechanisms behind the reported changes in balance measures.

4.1 | Limitations

There are several limitations of the current study. One limitation of our study is that we did not have a follow-up test after the posttest. Therefore, we do not know how long the effects of the training on postural control last. Based on a previous study, effects of a 4-week balance and strength training on episodes of 'giving way' decreased in the 6-month follow-up in CAI patients.[32] Future studies need to identify the long-term effects of training with stroboscopic glasses on visual reliance during postural control. Furthermore, the posttest was scheduled less than a week from the day subjects finished their training (strobe group: 4.3 days and control group: 3.9 days. Furthermore, it would be beneficial to know whether a longer period of training with stroboscopic glasses provides an effect on visual reliance during dynamic postural control. Another limitation is that we were unable to determine how the practice effect and familiarity with the glasses impacts the SV condition during balance tests since we did not have a baseline measure to compare with the pretest. However, all groups followed the same procedure, so we can assume the changes that the strobe groups showed were caused by the exercise. Finally, the current findings can only be generalized to a physically active, college-aged population.

5 | CONCLUSION

In conclusion, the 4-week dynamic balance training with stroboscopic glasses effectively decreased visual reliance during static postural control and improved postural control in CAI patients. To the best of our knowledge, this is the first study using stroboscopic glasses in rehabilitative exercises for individuals with an impaired sensorimotor system. More studies are needed to strengthen the ideas discussed in this study.

6 | PERSPECTIVE

The results of this study suggest that wearing stroboscopic glasses during the training may alter visual reliance in those with CAI during static postural control. In addition, training with the glasses may establish greater improvement in both static and dynamic postural control for CAI patients. The current findings provide useful insights for clinicians in developing rehabilitation programs by applying the stroboscopic glasses. Therefore, we encourage clinicians to use stroboscopic glasses in balance training for CAI patients to decrease reliance on visual information during tasks. The glasses can be used to disrupt visual information not only during static postural control, but also for dynamic movements. Stroboscopic glasses are affordable and easy to use with most patients.

CONFLICT OF INTEREST

The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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APPENDIX A

Balance training protocol

1. Single-Limb Hops to Stabilization (10 Repetitions per Direction).

Subject performed 10 hops in each direction. Each repetition consisted of a hop from the starting position to the target position (18, 27, or 36 inches). After stabilizing balance in a single-limb stance, participants hopped in the exact opposite direction back to the starting position and stabilized in the single-limb stance.

Four directions of hops (Figure 1): (1) anterior/posterior, (2) medial/lateral, (3) anterolateral/ posteromedial, and (4) anteromedial/posterolateral. Participants were not able to move to the next level in each category until they demonstrated 10 repetitions error-free. Errors were determined on the basis of the following:

a. Touching down with opposite limb
b. Excessive trunk motion (930-lateral flexion)
c. Removal of hands from hips during hands-on-hips activities
d. Bracing the nonstance limb against the stance limb
e. Missing the target

2. Hop to Stabilization and Reach (Five Repetitions).

Combined with the mentioned exercises, however, after stabilization in the single-limb stance, participants had to reach back to the starting position. Repetitions were counted in the same manner mentioned previously.

Participants hopped, stabilized, and reached back to the starting position. Then they hopped back to the starting position and reached to the target position. Participants were not able to advance to the next level in each direction until they demonstrated five repetitions error-free. Errors were determined on the basis of the following:

a. All errors associated with hop to stabilization
b. Using the reaching leg for a substantial amount of support during reaching component

All directions for Hop to Stabilization and Hop to Stabilization and Reach have seven levels of difficulty to progress:

1. 18-inch hop. Allowed to use arms to aid in stabilizing balance after landing with strobe level 2
2. 18-inch hop with hands on hips while stabilizing balance after landing with strobe level 2
3. 27-inch hop. Allowed to use arms to aid in stabilizing balance after landing with strobe level 3
4. 27-inch hop with hands on hips while stabilizing balance after landing with strobe level 3
5. 36-inch hop. Allowed to use arms to aid in stabilizing balance after landing with strobe level 4
6. 36-inch hop with hands on hips while stabilizing balance after landing with strobe level 4
7. 36-inch hop from a 6-inch platform with strobe level 5

3. Unanticipated Hop to Stabilization.

Participants stood in the middle of a nine-marker grid. A sequence of numbers was displayed on a computer screen in front of the participants. Each number correspond to a target position to which they would hop. As the progression of numbers changed, participants would hop to the new target position. The hop to stabilization rules were applied for this activity; however, in this case, participants were allowed to use any combination of hops (AP, ML, AM/PL, or AL/PM) they desired to accomplish the goal of getting through the sequence error-free. As a participant developed proficiency, the amount of time per move was reduced. In each session, participants performed three sequences of numbers.

Levels of unanticipated hop to stabilization.

Level 1: 5 s per move with strobe level 2
Level 2: 3 s per move with strobe level 2
Level 3: 1 s per move with strobe level 3
Level 4: If subject could progress to completion of all moves within 1 s without error, a foam pad was placed on one of the numbers during the sequence. The subject then continued the progression at the same level of intensity. If he or she could not complete the course error-free, the time constraint was reduced to the level below with strobe level 3.
Level 5: If subject could progress to completion of all moves at Level 3 with the foam pad error-free, a step was added to an additional number with strobe level 4.
Level 6: If a subject progressed error-free, an additional foam pad was added to one of the numbers, resulting in two foam pads and one step with strobe level 4.
Level 7: If a subject progressed error-free, an additional step was included, resulting in two foam pads and two steps with strobe level 5.

Errors were determined on the basis of the following:

a. Touching down with opposite limb
b. Excessive trunk motion (930- lateral flexion)
c. Removal of hands from hips during hands-on-hips activities
d. Bracing the nonstance limb against the stance limb
e. Missing the target

Each sequence of numbers was random such as 9, 7, 1, 6, 4, 5, 3, 8, 2.

4. Single-Limb Stance Activities.

Participants performed three repetitions of single-limb stance activities. Each activity (eyes-open -close) had 7 levels of difficulty. Single-limb stance eyes open or strobe vision.

1. Arms across chest on hard floor for 60 s with strobe level 2
2. Arms across chest for 30 s on foam pad with strobe level 2
3. Arms across chest for 60 s on foam pad with strobe level 3
4. Arms across chest for 90 s on foam pad with strobe level 3

Ball toss on foam.

5. 30 s with arms across chest; 20 throws with a 6-lb medicine ball with strobe level 3
6. 60 s with arms across chest; 20 throws with a 6-lb medicine ball with strobe level 3
7. 90 s with arms across chest; 20 throws with a 6-lb medicine ball with strobe level 5

Single-limb stance eyes-close.

1. Arms out on hard floor for 30 s
2. Arms across chest on hard floor for 30 s
3. Arms across chest on hard floor for 60 s
4. Arms out on foam pad for 30 s
5. Arms across chest for 30 s on foam pad

6. Arms across chest for 60 s on foam pad
7. Arms across chest for 90 s on foam pad

Participants were not able to advance to the next level in each category until they demonstrated three repetitions error-free. Errors were determined on the basis of the following:

a. Subjects touching down with opposite limb
b. Excessive trunk motion (930- lateral flexion)
c. Removal of arms from across chest during specified activities
d. Bracing the nonstance limb against the stance limb

Example of a Typical Session.

1. Hop to stabilization
   Anterior/posterior—Level 2, 10 repetitions
   Medial/lateral—Level 1, 10 repetitions
   Anterolateral/posteromedial—Level 2, 10 repetitions
   Anteromedial/posterolateral—Level 2, 10 repetitions
2. Unanticipated hop to stabilization—Level 1, Sequence 1
3. Hop to stabilization and reach
   Anterior/posterior—Level 2, 5 repetitions
   Medial/lateral—Level 1, 5 repetitions
   Anterolateral/posteromedial—Level 2, 5 repetitions
   Anteromedial/posterolateral—Level 2, 5 repetitions
4. Unanticipated hop to stabilization—Level 1, Sequence 2
5. Single-limb stance eyes-open—Level 4, 3 repetitions
6. Single-limb stance eyes-close—Level 2, 3 repetitions