Effects of a 4-Week Dynamic Balance Training with Stroboscopic Glasses on Postural Control in Patients with Chronic Ankle Instability

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Effects of a 4-Week Dynamic Balance Training with Stroboscopic Glasses on Postural Control in Patients with Chronic Ankle Instability

Hyunwook Lee

A thesis submitted to the faculty of Brigham Young University in partial fulfillment of the requirements for the degree of Master of Science

J. Ty Hopkins, Chair Matthew K. Seeley Dustin A. Bruening

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ABSTRACT

Effects of a 4-Week Dynamic Balance Training with Stroboscopic Glasses on Postural Control in Patients with Chronic Ankle Instability

Hyunwook Lee
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Master of Science

Context: Individuals with chronic ankle instability (CAI) rely more on visual information during postural control due to impaired proprioceptive function. The increased reliance on visual information may increase the risk of injury when their vision is limited during complex sports activities. Stroboscopic glasses may help elicit sensory reweighting during postural control. Therefore, we assumed that the glasses would induce and train CAI patients to reweight sensory information for the somatosensory system during dynamic balance training.

Purpose: (1) to identify the effects of the 4-week dynamic balance training on the reliance of visual information during postural control in patients with CAI and (2) to compare the effects of the 4-week dynamic balance with and without stroboscopic glasses on postural control in patients with CAI.

Methods: This study was a randomized controlled trial. Twenty-eight CAI patients were equally assigned to one of 2 groups: a strobe group (6 males and 8 females) or a control group (8 males and 6 females). The 4-week dynamic balance training consisted of multiple single-legged exercises. The strobe group wore stroboscopic glasses during the training, but the control group did not. The main outcome measures included the following: self-reported function measures, static postural control (center of posture (COP)-based measures), and dynamic postural control including the Dynamic Postural Stability Index (DPSI), and the Star Excursion Balance Test (SEBT). There were 3 visual conditions in the static postural control (eyes-open (EO), strobe vision (SV), and eyes-closed (EC)), and 2 conditions in the dynamic postural control (EO and SV). Two-way randomized block ANOVAs were used to assess changes in postural control in each group and condition by using pretest-posttest mean differences.

Results: The strobe group showed a higher difference in center of pressure COP velocity in medial-lateral direction (VelML) and vertical stability index (VSI) under the SV condition compared with the control group (p = .005 and .004, respectively). In addition, the strobe group had significant decreases in VelML, DPSI, and VSI at the posttest compared with the pretest (p = .0001, .01, and .005, respectively).

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

Keywords: chronic ankle instability, balance training, sensory reweighting, visual reliance
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INTRODUCTION

Lateral ankle sprains (LAS) are one of the most common injuries in athletic and nonathletic populations. Approximately 23,000 ankle sprains occur daily in the United States, and up to 40% of these injuries lead to chronic ankle instability (CAI).\textsuperscript{1} CAI is a condition characterized by chronic residual symptoms including pain, swelling, loss of function, joint instability, a feeling of “giving way,” and/or recurrent ankle sprains.\textsuperscript{2,3} Delahunt et al.\textsuperscript{4} 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.\textsuperscript{5} Despite previous research concerning the topic, it is still unclear exactly how sensory-perceptual impairment affects CAI patients.

Sensory-perceptual impairment likely influences movement patterns in a detrimental way and may be important to reinjury risk for CAI patients. Specifically, CAI patients might rely less on somatosensory information than normal individuals due to altered integration of sensory information.\textsuperscript{6} One study examined the reliability of sensory information in CAI patients and concluded that CAI patients showed higher reliance on visual information during a single-legged stance when compared with healthy controls.\textsuperscript{6} Reliance on sensory information is altered by sensory reweighting that is a process of adjusting sensory input.\textsuperscript{7} Sensory reweighting may occur in several ways including changing movements, environmental conditions, musculoskeletal injuries, and aging. One study found that the central nervous system (CNS) might rely more heavily on somatosensory input during quiet standing, but the reliability of somatosensory input decreases during perturbed standing, when the CNS reweights other input (visual and/or vestibular information) to maintain an upright position.\textsuperscript{8} Song et al.\textsuperscript{6} demonstrated that CAI patients appear to have increased the use of visual information during postural control since they
use reduced somatosensory information due to the impaired proprioceptive function. This reweighting occurs not only in CAI patients, but also in patients with knee injuries and the elderly.

The increased reliance on visual information in CAI patients may increase a risk of injury when their vision is disrupted during activities. Therefore, if this idea is true, it would be important to rehabilitate CAI patients by reducing reliance on visual input to prevent further injuries. Traditional rehabilitation programs have tried to improve the ability to reweight sensory information through an eyes-closed condition. However, since an eyes-closed condition cannot be utilized in dynamic tasks, previous rehabilitative exercises for sensory reweighting focused only on static exercises. Thus, these balance training programs likely cannot alter the reliance on visual information in CAI patients during postural control. Stroboscopic glasses may provide a mechanism to disrupt visual stimuli during dynamic training tasks. Using liquid crystal technology, a stroboscopic lens flickers intermittently between the clear and opaque parts of the lens, removing the visual information intermittently. Stroboscopic glasses have been widely used for training purposes in various sports; however, they have not been used yet for rehabilitation purposes to improve postural control. We assumed that the glasses would induce and train CAI patients to reweight sensory information for the somatosensory system during dynamic balance training.

The overall purpose of this study was to investigate the effectiveness of training in stroboscopic glasses on postural control in CAI patients. Specifically, we sought to: (1) identify the effects of the dynamic balance training with the glasses on visual reliance during postural control and (2) identify if training with the glasses would show greater improvements in postural control compared with training without the glasses. We hypothesized that the strobe group
(training with stroboscopic glasses) would show altered visual reliance during postural control after the training. We also hypothesized that the strobe group would show more improvements in postural control than the control group (training without the glasses). If the rehabilitation program with stroboscopic glasses is more effective in restoring the impaired somatosensory system than programs without the glasses, it will provide clinicians with a new rehabilitation tool that is convenient to utilize in rehabilitation programs in order to prevent further injuries.

METHODS

Participants

Investigators recruited 28 subjects with CAI (control group: 14, strobe group: 14) (Table 1). Subjects in this study consisted of males and females, a primarily collegiate population, ages 18 to 35 years. All subjects were screened using self-reported disability questionnaires, including a Foot and Ankle Ability Measure Activities of Daily Living (FAAM ADL), FAAM Sports, and Ankle Instability Instrument (AII) (validity: r = 0.84, 0.78, and 0.95, respectively). The combination of these three questionnaires is commonly used to screen subjects with CAI in CAI research. Specific subject inclusion criteria for CAI include (i) a history of ankle sprain injuries that occurred 3 months prior to the time of data collection, (ii) a score of < 90% on the FAAM ADL, (iii) a score of < 80% on the FAAM Sports, (iv) at least 5 “yes” answers including question 1, plus 4 others on the AII, and (v) a history of physical activity at least 3 days/week for a total of 90 min/week in the previous 3 months. Volunteers received the questionnaires above via an online system (Qualtrics, UT, USA).

Procedures (Figure 1)

Prior to data collection, investigators fully reviewed the strobe procedures with each subject, and subjects read and signed informed consents. The study required subjects to
participate in 2 visits for pretraining and posttraining tests. On both days of testing, subjects changed into exercise clothes (spandex shirts and pants) and shoes (T-Lite XI, Nike, USA) provided by the investigators. On the pretest day, they performed 3 different tasks: static postural control, dynamic postural control including Dynamic Postural Stability Index (DPSI) and the Star Excursion Balance Test (SEBT). For the static postural control, subjects stood on a force plate 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 dynamic postural control, there were only 2 conditions (EO and SV). DPSI required subjects to jump 50% of their maximum jump height and land on a force plate and stabilize as soon as possible. For the SEBT, subjects performed the test barefoot with the foot positioned and aligned on a slightly elevated block, and then the subjects were instructed to perform the maximal reach distance with the opposite limb by pushing a sliding block using their toes. Each subject performed 4 practice trials in 3 directions (eg, anterior, posteromedial, and posterolateral) on the tested limb.

As an intervention, we chose a 4-week dynamic balance training that made significant changes in postural control for CAI patients in previous studies. 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. The balance training started within 7 days after the pretest. The progressive balance training program (see Appendix) was designed to challenge a subject’s ability to maintain a single-limb stance while performing various balance activities. During each session, subjects 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 eyes closed.

Within 7 days after the completion of the intervention, subjects performed the posttest in the same manner as the pretest.

Data Reduction

Static Postural Control

Static postural control data was reduced using Matlab software. The standard deviation (SD) of center of pressure (COP) excursions, range of COP excursions, and mean velocity of COP excursions were computed separately for the ML and AP directions based on previously established methods. The COP-based measures have been used to assess postural control in CAI patients. COP-based measures assess postural sway and variability in both frontal and sagittal axes. Lower velocity, range, and standard deviation (SD) of COP are interpreted as indicating better postural control. The range of COP excursions was defined by the distance between the maximum and the minimum COP data points. The mean velocity of COP excursions was defined by dividing the total COP excursion length by the 10 seconds trial time. The area of the 95% confidence ellipse of COP excursions was also calculated, which tells us overall COP range for both directions. The mean of 3 trials for all measures was used for statistical analysis.
**Dynamic Postural Stability Index (DPSI)**

Dynamic postural control data was reduced using Matlab software, which was used to calculate stability indices (SIs) in the 3 principal directions (M-L: MLSI, A-P: APSI, vertical: VSI) and the DPSI. DPSI is a sensitive measure of dynamic postural control used to detect differences between individuals with and without CAI. A higher score represents worse postural control in the DPSI. 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. The following equations were used to calculate the variables. In the calculation, x, y, and z represent data points for ML, AP, and VGRF, respectively.

\[
\text{MLSI} = \sqrt{\frac{\sum (0 - x)^2}{\text{number of data points}}} \\
\text{APSI} = \sqrt{\frac{\sum (0 - y)^2}{\text{number of data points}}} \\
\text{VSI} = \sqrt{\frac{\sum (\text{body weight} - z)^2}{\text{number of data points}}} \\
\text{DPSI} = \sqrt{\frac{\sum (0 - x)^2 + \sum (0 - y)^2 + \sum (\text{body weight} - z)^2}{\text{number of data points}}}
\]

**Star Excursion Balance Test (SEBT)**

SEBT has been used to measure dynamic postural control in patients with CAI and associates it with deficits related to CAI. A longer reach distance generalized by an individual’s leg length represents better postural control. Distances were measured in cm and normalized by dividing by the subject’s lower limb length (anterior superior iliac spine to the distal end of the medial malleolus) and multiplying by 100. Three trials in each of the 3 directions were used for data analysis.
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 dynamic postural control and SEBT). In order to mitigate any assumptions regarding whether the pretest and posttest measurements taken on the same subject were independent or not, we took mean differences between pretest and posttest in each group and condition. Using the differences, we ran 2-way randomized block ANOVA to assess changes in postural control in each group and condition. A Tukey’s Honestly Significant Difference (HSD) post hoc test was performed for pairwise comparisons if they had significant interactions from the ANOVA. An independent t-test was used to assess differences between groups for pretest-to-posttest changes in self-reported function. Furthermore, an independent t-test was also used to assess time main effects in self-reported function and postural control across all groups and conditions. Demographic characteristics were also analyzed by a t-test to compare groups. The alpha level for this study was 0.05 ($\alpha = 0.05$). Cohen’s D effect sizes were calculated in pretest-posttest mean differences to provide the magnitude of differences between conditions within a group.\(^{28}\)

RESULTS

There was no statistical difference in demographics (Table 1). We did not report the condition main effects since they do not correspond to the purpose of this study.

Self-Reported Function (Table 2)

There was no significant difference between groups in pretest-posttest mean differences for all questionnaires. Regardless of the groups and the conditions, there were significant time main effects for FAAM-ADL and Sport, and AII ($p < .0001$, all).
Static Postural Control (Table 3)

There was a significant group x condition interaction in pretest-posttest mean differences for VelML (p = .01). A post hoc test revealed that the strobe group showed a higher difference in the SV condition compared with the control group (p = .01) and only the strobe group under the EC condition showed a higher difference compared with those under the EO condition (p = .00). No other interaction was detected. The strobe group showed higher pretest-posttest mean difference than the control group for VelML (p = .00). Regardless of the groups and the conditions, there were significant time main effects for VelML (p < .0001), VelAP (p = .00), SDAP (p = .01), RangeML (p = .01), RangeAP (p = .01), and Area (p < .0001). The strobe group showed strong Cohen’s D effect sizes (> 0.8) in between EO-SV (1.64) and between EO-EC (1.42) for VelML, between EO-EC (0.96) in VelAP, between EO-SV (0.81) in SDAP, and between EO-SV (1.28) and between EO-EC (1.27) in Area. No strong effect size was detected in the control group. In summary, training with the stroboscopic glasses significantly decreased VelML during static postural control. Furthermore, the strobe group showed strong ES between EO-SV and/or EO-EC in VelML, VelAP, SDAP, and Area.

Dynamic Postural Control

DPSI (Table 4)

There was a significant group x condition interaction in pretest-posttest mean differences for VSI (p = .04). A post hoc test revealed that the strobe group showed a higher difference in the SV condition compared with the control group (p = .00). No other interaction was detected. There were significant differences between groups in pretest-posttest mean difference for DPSI (p = .01) and VSI (p = .01). Regardless of the groups and the conditions, there were significant
time main effects for DPSI and VSI (p < .0001, both). There was no strong effect size in either group. In summary, training with the glasses seemed to decrease DPSI and VSI scores.

**SEBT (Table 5)**

There was no significant interaction and group effect in pretest-posttest mean differences for all directions. Regardless of the groups and the conditions, there were significant time main effects for the PM (p = .00) and PL (p < .0001) directions. There was no strong effect size in either group. In summary, there was no group difference in pretest-posttest mean difference for the SEBT.

**DISCUSSION**

The purpose of this study was to identify the effects of the dynamic balance training with the glasses on visual reliance during postural control. The other purpose was identify if the training with the glasses would show greater improvements in postural control compared with training without the glasses. The primary finding of this study was that the strobe group showed a greater decrease in VelML and VSI when vision was disturbed during postural control when compared with the control group. The strobe group showed a higher pretest-posttest mean difference in VelML, DPSI, and VSI compared with the control group. Regardless of glasses-wearing during the training and different visual conditions, CAI patients showed improvements in 13 out of 17 variables after the training. Overall, our results suggest that the 4-week dynamic balance training improves balance, independent of wearing the glasses; however, training with the glasses was more effective in improving a small number of measures associated with postural control.

In the current study, there were a few significant group effects and group x condition interactions in the pretest-posttest mean difference for the strobe group. Statistically, the results...
demonstrated that the stroboscopic glasses offered no additional benefits, such as improving balance ability and/or altering visual reliance, to those measures without statistical differences. However, we still observed variables that showed statistically significant changes, which give us valuable insights in terms of the effects of balance training with stroboscopic glasses on postural control and visual reliance. In addition, there were strong effect sizes (Cohen’s D > .80) for more variables such as VelML, VelAP, SDAP, and Area.

As we hypothesized in the first purpose, the strobe group showed a greater decrease in VelML under the SV condition compared with the control group. In other words, the stroboscopic glasses affected postural control during visual disturbance. Interestingly, only the strobe group showed a significant change in VelML between EO and EC conditions. Additionally, the strobe group had strong effect sizes between EO and EC for VelML and VelAP and EO and EC for VelML, SDAP, and Area. 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. Peterka et al\(^7\) reported that when one of the sensory inputs is disturbed, people compensate for the lack of information by increasing weight to other inputs. 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. Furthermore, they might have shown an improved ability to more effectively utilize not only limited visual information, but also other sensory information such as 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. Future study is needed to clarify the assumptions.
When looking at the dynamic postural control, stroboscopic glasses could not alter visual reliance as much as static postural control. In this study, there was a significant group x condition interaction only in VSI for the strobe group. However, there was no strong effect size for all stability indices and all directions of the SEBT. Considering DPSI represents a composite of 3 components, MLSI, APSI, and VSI, the difference only in VSI may not represent that there was altered visual reliance during dynamic postural control in general. We assumed that stroboscopic glasses 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 alter their visual reliance. Future studies are needed to identify if 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. Since this is the first study that used the glasses for a rehab purpose to improve postural control in those with musculoskeletal injuries, the results cannot be directly compared with other studies that reported effects of the glasses on those without musculoskeletal injuries. However, the 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.\textsuperscript{29-31} The previous studies explained their results with the effectiveness of the glasses: (1) utilize the limited visual information people receive more effectively and (2) utilize other sensory information, such as kinesthesia awareness and auditory cues, more effectively.\textsuperscript{31} Thus, in this study, training with stroboscopic glasses
might improve the utilization of the sensorimotor system more effectively during postural control. Still, we cannot confirm that those decreased variables can represent improvements in postural control in general due to a weakness in the variables. Therefore, future study would be needed to identify if other variables such as time-to-boundary or the balance error scoring system show significant changes after balance training with stroboscopic glasses.

The improvements in postural control for CAI patients after sensorimotor training have been shown in the literature. In this study, across all groups and conditions, CAI patients demonstrated improvements in 82% of our outcome measures including self-reported functions. The results are in agreement 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). Another study found that a 4-week balance training was effective in improving total distance traveled of the COP during a one-legged stance in those with CAI. Even though previous studies did not measure DPSI, they reported that the training program was effective in improving the dynamic postural control measured by SEBT. Mechanisms behind the improvements were explained in several previous studies. 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. Therefore, presynaptic inhibition is increased or decreased to have adequate reflex responses to meet the requirements of the task. From the spinal adaptation perspective, previous studies reported that increased balance ability goes along with decreased H-reflex after balance training. The balance training may help to avoid joint oscillations as the CNS adapts to adjust to spinal reflex responses. In other words, balance training can 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.\textsuperscript{39} Furthermore, previous studies also reported that the changes in supraspinal structures following balance training were connected to improved balance ability.\textsuperscript{33,35,39} This study, however, cannot ascertain the mechanisms behind the reported changes in balance measures.

Clinical Implication

Overall, 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 more improvements in postural control for CAI patients. The current findings provide useful insights for clinicians in developing rehabilitation programs by applying the stroboscopic glasses. Traditional balance training protocols may be limited in their ability to lower visual reliance for CAI patients who rely on higher amounts of visual information than healthy controls.\textsuperscript{8,12} In addition, CAI patients have a diminished ability to successfully compensate for the removal or alteration of somatosensory inputs from around the foot/ankle complex.\textsuperscript{40,41} As CAI patients improve their postural control by decreasing the reliance on visual information and reweighting sensory information dynamically, the risk of recurrent LAS may be affected since deficits in postural control is a risk factor for recurrent LAS.\textsuperscript{5,42} Even though our data did not show strong effects of the glasses on visual reliance during dynamic postural control, there was relatively strong effects during static postural control, which is a determinant for recurrent LAS.\textsuperscript{42} Therefore, we still 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. Moreover, stroboscopic glasses are relatively affordable and easy to utilize with patients unless they have a history of severe epilepsy.

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. The posttest was scheduled less than a week from the day subjects finished their training. Therefore, we do not know how long the effects of the training on postural control last. Future studies need to identify the long-term effects of training. Furthermore, it would be beneficial to know whether a longer period of training with stroboscopic glasses provides a long-lasting effect. Finally, the current findings can only be generalized to a physically active, young college-aged population.

CONCLUSION

In conclusion, the current results of this study offer that the 4-week progressive dynamic balance training with stroboscopic glasses alter visual reliance during postural control. Furthermore, dynamic balance training with stroboscopic glasses is more effective in improving postural control than training without the glasses. Decreased reliance on visual information may help reduce the risk of recurrent ankle sprains in patients with CAI.
REFERENCES


Table 1. Subject Demographics: t-test for group difference

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<td>Control (n = 14)</td>
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<td>21.8 ± 2.5</td>
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<td>Mass, kg</td>
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<td>Previous ankle sprains, No.</td>
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<td>5.1 ± 3.2</td>
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Abbreviations: No. = number; SD = standard deviation; y = years;
Table 2. Self-Reported Function: t-test for pretest-posttest mean difference and time main effect

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<thead>
<tr>
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<td>± SD</td>
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Abbreviation: FAAM-ADL, Foot and Ankle Ability Measure for Activities of Daily Living; AII, Ankle Instability Instrument; SD, Standard Deviation
Table 3. Static Postural Control: two way ANOVA and Cohen’s D for pretest-posttest mean differences in each visual condition and t-test for time-main effect

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Condition</th>
<th>Pretest-posttest mean difference ± SD</th>
<th>ANOVA</th>
<th>T-test</th>
<th>Cohen’s D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group</td>
<td>Group x</td>
<td>Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VelML (cm/s)</td>
<td>Strobe</td>
<td>EO</td>
<td>0.21 ± 0.39</td>
<td>1.10 ± 0.85</td>
<td>0.98 ± 0.70</td>
<td>P = .00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td>0.45</td>
<td>(0.85, 2.42)</td>
<td>(0.65, 2.19)</td>
<td>(0.52, 0.96)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EC</td>
<td>0.53</td>
<td>(0.21, 1.28)</td>
<td>(0.20, 1.71)</td>
<td>(0.32, 1.17)</td>
</tr>
<tr>
<td>SDML (cm)</td>
<td>Strobe</td>
<td>EO</td>
<td>0.00 ± 0.02</td>
<td>0.01 ± 0.06</td>
<td>0.01 ± 0.03</td>
<td>P = .22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td>0.32</td>
<td>(−0.42, 1.06)</td>
<td>(−0.52, 0.97)</td>
<td>(−0.64, 0.83)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EC</td>
<td>0.81</td>
<td>(−0.35, 1.14)</td>
<td>(−0.35, 1.14)</td>
<td>(−0.33, 1.15)</td>
</tr>
<tr>
<td>RangeML (cm)</td>
<td>Strobe</td>
<td>EO</td>
<td>0.01 ± 0.06</td>
<td>0.05 ± 0.21</td>
<td>0.11 ± 0.14</td>
<td>P = .17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td>0.37</td>
<td>(−0.53, 0.95)</td>
<td>(−0.53, 0.95)</td>
<td>(−0.43, 1.05)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EC</td>
<td>0.79</td>
<td>(−0.37, 1.05)</td>
<td>(−0.37, 1.05)</td>
<td>(−0.60, 0.89)</td>
</tr>
<tr>
<td>RangeAP (cm)</td>
<td>Strobe</td>
<td>EO</td>
<td>0.00 ± 0.05</td>
<td>0.12 ± 0.34</td>
<td>0.03 ± 0.08</td>
<td>P = .65</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td>0.79</td>
<td>(−0.52, 0.97)</td>
<td>(−0.52, 0.97)</td>
<td>(−0.19, 1.30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EC</td>
<td>0.52</td>
<td>(−0.23, 1.26)</td>
<td>(−0.23, 1.26)</td>
<td>(−0.60, 0.89)</td>
</tr>
<tr>
<td>Area (cm²)</td>
<td>Strobe</td>
<td>EO</td>
<td>0.05 ± 1.23</td>
<td>11.36 ± 10.29</td>
<td>11.25 ± 6.22</td>
<td>P = .20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td>1.28</td>
<td>(0.51, 2.04)</td>
<td>(0.50, 2.03)</td>
<td>(−0.73, 0.75)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>EC</td>
<td>0.52</td>
<td>(−0.46, 1.03)</td>
<td>(−0.37, 0.16)</td>
<td>(−0.46, 1.03)</td>
</tr>
</tbody>
</table>

Abbreviation: Vel, velocity; ML, medial-lateral; AP, anterior-posterior; EO, eyes-open; SV, strobe vision; EC, eyes-closed; CI, Confident Interval

a: A post hoc test revealed that the strobe group showed higher difference in the SV condition compared with the control group (p = .005) and only strobe group under the EC condition showed higher difference compared with under the EO condition (p = .001)
Table 4 DPSI: two way ANOVA and Cohen’s D for pretest-posttest mean differences in each visual condition and t-test for time-main effect

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group</th>
<th>Condition</th>
<th>Pretest-posttest mean difference ± SD</th>
<th>ANOVA</th>
<th>T-test</th>
<th>Cohen’s D (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group</td>
<td>Condition</td>
<td>Time</td>
</tr>
<tr>
<td>DPSI</td>
<td>Strobe</td>
<td>EO</td>
<td>0.19 ± 0.14 0.24 ± 0.13</td>
<td>P = .01</td>
<td>P = .17</td>
<td>P &lt; .00</td>
</tr>
<tr>
<td></td>
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<td>SV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>EO</td>
<td>0.11 ± 0.19 0.07 ± 0.13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MLSI</td>
<td>Strobe</td>
<td>EO</td>
<td>0.00 ± 0.02 0.01 ± 0.05</td>
<td>P = .64</td>
<td>P = .61</td>
<td>P = .97</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>EO</td>
<td>0.00 ± 0.02 0.00 ± 0.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>APSI</td>
<td>Strobe</td>
<td>EO</td>
<td>0.02 ± 0.03 0.01 ± 0.04</td>
<td>P = .65</td>
<td>P = .75</td>
<td>P = .12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>EO</td>
<td>0.01 ± 0.03 0.00 ± 0.04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>VSI</td>
<td>Strobe</td>
<td>EO</td>
<td>0.16 ± 0.17 0.19 ± 0.15</td>
<td>P = .00</td>
<td>P = .04a</td>
<td>P &lt; .00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control</td>
<td>EO</td>
<td>0.08 ± 0.17 0.02 ± 0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a: A post hoc test revealed that the strobe group showed higher difference in the SV condition compared with the control group (p = .004)
Table 5. SEBT: two way ANOVA and Cohen’s D for pretest-posttest mean differences in each visual condition and t-test for time-main effect

<table>
<thead>
<tr>
<th>Variable (reach distance/leg length)</th>
<th>Pretest-posttest mean difference ± SD</th>
<th>ANOVA</th>
<th>T-test</th>
<th>Cohen’s D (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group</td>
<td>Condition</td>
<td>Group</td>
<td>Condition</td>
</tr>
<tr>
<td>Anterior</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strobe</td>
<td>EO</td>
<td>−0.01 ± 0.01</td>
<td>.98</td>
<td>−0.03 ± 0.03</td>
</tr>
<tr>
<td>Control</td>
<td>SV</td>
<td>−0.02 ± 0.03</td>
<td>.98</td>
<td>−0.01 ± 0.03</td>
</tr>
<tr>
<td>PM</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strobe</td>
<td>EO</td>
<td>−0.04 ± 0.05</td>
<td>.39</td>
<td>−0.06 ± 0.06</td>
</tr>
<tr>
<td>Control</td>
<td>SV</td>
<td>−0.07 ± 0.08</td>
<td>.39</td>
<td>−0.08 ± 0.08</td>
</tr>
<tr>
<td>PL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strobe</td>
<td>EO</td>
<td>−0.07 ± 0.06</td>
<td>.61</td>
<td>−0.09 ± 0.06</td>
</tr>
<tr>
<td>Control</td>
<td>SV</td>
<td>−0.07 ± 0.11</td>
<td>.61</td>
<td>−0.10 ± 0.08</td>
</tr>
</tbody>
</table>

Abbreviation: PM, posteromedial; PL, posterolateral
Figure 1. A Flow Chart: all subjects were equally assigned to either strobe or control group. The balance training started within 7 days after the preintervention balance tests. Within 7 days after the completion of the intervention, subjects performed the posttest in the same manner as the pretest.
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 (Fig. 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
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 and eyes closed) 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 closed
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 closed—Level 2, 3 repetitions