Stroboscopic Vision as a Dynamic Sensory Reweighting Alternative to the Sensory Organization Test

Kyung-Min Kim, Joo-Sung Kim, Jeonghoon Oh, and Dustin R. Grooms

Context: The sensory organization test (SOT) is a standard for quantifying sensory dependence via sway-referenced conditions (sway-referenced support and sway-referenced vision [SRV]). However, the SOT is limited to expensive equipment. Thus, a practical version of the SOT is more commonly employed—the clinical test for sensory integration in balance; however, it fails to induce postural instability to the level of SRV. **Objective:** Determine if Stroboscopic vision (SV), characterized by intermittent visual blocking, may provide an alternative to the SRV for assessing postural stability. **Design:** Descriptive laboratory study. **Setting:** Research laboratory. **Participants:** Eighteen participants (9 males, 9 females; age = 22.1 [2.1] y, height = 169.8 [8.5] cm, weight = 66.5 [10.6] kg). **Intervention:** Participants completed the SOT conditions, and then repeated SOT conditions 2 and 5 with SV created by specialized eyewear. **Main Outcome Measures:** A repeated-measures analysis of variance was completed on the time-to-boundary metrics of center-of-pressure excursion in the anteroposterior and mediolateral directions in order to determine the difference between the full-vision, SV, and SRV conditions. **Results:** Postural stability with either SRV or SV was significantly worse than with full vision ($P < .05$), with no significant difference between SV and SRV ($P > .05$). Limits of agreement analysis revealed similar effects of SV and SRV except for unstable surface mediolateral time-to-boundary. **Conclusions:** In general, SV was found to induce a degree of postural instability similar to that induced by SRV, indicating that SV could be a portable and relatively inexpensive alternative for the assessment of sensory dependence and reweighting.

Keywords: balance/posture, biomechanics, instrument-assisted interventions, sensory integration

Sensory dependence is the preferential contribution of visual, vestibular, and somatosensory feedback for completing a motor task or maintaining stability and can be modified by pathologies, task conditions, or training.^{1,2} The sensory organization test (SOT) is the gold standard for quantifying sensory dependence by utilizing sway-referenced conditions. Specifically, the SOT engages a sway-referenced support condition to knockdown the somatosensory system and a sway-referenced vision (SRV) condition to knockdown the visual system. The SOT provides a standardized assessment of sensory contributions to postural stability and has been used extensively to evaluate concussion and fall risk and patients with balance disorders in order to inform targeted therapies for specific sensory deficits.^{1,3,4}

However, the SOT is limited to expensive equipment; thus, the clinical test for sensory integration in balance (CTSIB) was developed.⁵ In the CTSIB, the sway-referenced condition of the SOT is imitated using a foam pad, and SRV is imitated using a white dome over the head.⁵ The foam-induced postural instability is comparable to the sway-referenced support condition, but the dome is unable to induce instability to the level of the SRV.⁶⁻⁸ Thus, there remains a need to develop an adequate surrogate for SRV conditions for the CTSIB.

Stroboscopic vision (SV) may provide an alternative to SRV and is characterized by intermittent visual blocking via glasses or goggles. SV has recently been shown to modify visual dependence and postural instability in both stable and unstable surface conditions.⁹ However, a comparison to the gold standard sensory dependence for vision SRV condition has yet to be examined. If SV induces postural instability similar to that induced by SRV, then it may offer a viable option for a visually perturbed sensory dependence assessment. Thus, the purpose of this study was to compare the postural instability effects of SV against SRV on both stable and unstable surfaces. We hypothesized that both SV and SRV would significantly increase postural instability relative to full vision, but postural instability between SV and SRV would not be different and have high agreement.

Methods

Eighteen young adults (9 males, 9 females; age = 22.1 [2.1] y, height = 169.8 [8.5] cm, weight = 66.5 [10.6] kg) without any history of musculoskeletal injury in the past 6 months or of vision or balance disorders participated. The University of Miami Institutional Review Board approved the study protocol requiring informed consent.

All participants completed the SOT with the NeuroCom EquiTest (Neurocom International Inc, Clackamas, OR), consistent with the testing protocol described previously.⁴ However, SOT conditions 2 and 5, in which participants are asked to close their eyes during testing, were replaced with SV created by specialized eyewear (Nike SPARQ Vapor Strobes; Nike Inc, Beaverton, OR)

K.-M. Kim, J.-S. Kim, and Oh are with the Department of Kinesiology and Sport Sciences, University of Miami, Miami, FL, USA. Grooms is with the Division of Athletic Training, School of Applied Health Sciences and Wellness, College of Health Sciences and Professions; and the Ohio Musculoskeletal & Neurological Institute, Ohio University, Athens, OH, USA. Grooms (groomsd@ohio.edu) is corresponding author.

that intermittently cycles between opaque and transparent for 100 milliseconds at a time.⁹ Participants performed bipedal stances that lasted for 20 seconds and were repeated 3 times. The averages were used for statistical analysis. The study outcomes were time-to-boundary (TTB) parameters of center-of-pressure excursion. We computed TTB measures such as mean and SD of the minima in the anteroposterior (AP) and mediolateral (ML) directions using previously reported methods.¹⁰ A lower TTB value reflects poorer postural stability.

For each of the TTB measures, a repeated-measures analysis of variance was performed to determine if there was a difference in postural stability on the fixed (stable) surface between 3 visual conditions as follows: (1) full vision (SOT condition 1), (2) SV (SOT condition 2), and (3) SRV (SOT condition 3). The same analysis was repeated for these conditions on the sway-referenced (unstable) surface (SOT conditions 4–6). In addition, Cohen *d* effect sizes and associated 95% confidence intervals (CIs) were calculated to provide the magnitude of postural instability with either SV or SRV compared to full vision using pooled SD. Cohen guidelines were used to determine the strength of the effect size as follows: (1) less than 0.2 = trivial, (2) from 0.21 to 0.5 = small, (3) from 0.51 to 0.8 = moderate, and (4) greater than 0.8 = large.¹¹

To assess agreement between SRV and SV, we completed a one-sample *t* test to determine difference from zero for each balance measure, Bland–Altman plots to assess agreement for each measure, and Pearson *r* values with 95% CIs between conditions for all measures. We also calculated R^2 values to determine the variance of SRV performance explained by SV. All statistical analyses were conducted using SPSS statistical software (version 24.0; IBM Corp, Armonk, NY) with the alpha level set a priori at $P \leq .05$.

Results

Descriptive data for the 3 visual conditions with the fixed and sway-referenced surfaces are presented in Tables 1 and 2, respectively. For postural stability on a fixed surface, there were significant differences between the 3 visual conditions for the AP mean and SD measures (Table 1). Postural stability with either SRV or SV in the AP direction was significantly worse than with full vision, but there were no significant differences between SRV and SV. The disruptive effects of SRV were small (close to moderate), and SV effects were moderate, but there was no difference in effect size between SRV and SV relative to FV, because their respective 95% CI overlapped. In contrast to AP postural instability, ML stability was unaffected by SRV or SV on the stable surface.

There were significant differences for all TTB measures for postural stability on the unstable (sway-referenced) surface (Table 2). Postural stability with SRV or SV was significantly worse relative to full vision, but SV again did not significantly differ from SRV. Postural instability with SV or SRV in the AP direction was of large magnitude relative to FV. For ML postural instability, SV also had large effects relative to FV, while SRV had small to moderate effects. Again, relative to FV, the 95% CIs of both SV and SRV overlapped, indicating no effect differences.

The limits of agreement analysis also largely supported a similar effect of SV relative to SRV. On the fixed surface, all TTB metrics had good agreement (Figure 1) and moderate to

high correlation (Table 1, $r = .49$ – $.77$). On the unstable surface, the TTB mean and SD in the AP direction had good agreement (Figure 2), with moderate to high correlation (Table 2, $r = .65$ – $.75$). However, TTB mean and SD in the ML direction had condition differences greater than zero but still had high correlations (Table 2, $r = .79$ – $.82$). The R^2 values for each variable between SRV and SV are reported in Tables 1 and 2.

Discussion

We found both SRV and SV significantly impaired standing balance relative to full vision, with no significant difference between SV and SRV. Specifically, we observed small to moderate effects for AP postural instability on a stable surface, with no ML effect and moderate to large effects for AP and ML postural instability on an unstable surface with both visual conditions. The limits of agreement analysis indicated that SV and SRV induced comparable effects in all conditions for all outcome metrics except for the ML direction during the unstable surface condition. This lack of agreement may have been due to the different mechanisms of visual knockdown. The SV condition reduces visual feedback by 50% (strobe rate of 100-ms transparent/100-ms opaque) and is not specific to an AP or ML corrective strategy, whereas the SRV produces inaccurate visual feedback primarily in the AP direction. Nonetheless, SV accounted for approximately 62% to 67% of the variance in SRV for ML TTB mean and SD; the remaining 33% to 38% can potentially be attributed to differences in the ways in which visual information was manipulated. The different mechanisms of visual perturbation, while resulting in generally similar postural instability, should be considered for SOT in patients with postural instability depending on an origin of postural instability (reduced sensory feedback versus inability to recognize accurate sensory input).

Stroboscopic vision can be utilized dynamically and is portable and relatively inexpensive (\$200 or less), making it an attractive alternative for sensory reweighting assessment. The need for such a tool is especially apparent in settings dealing with highly active patients, such as in sports medicine, with emerging evidence indicating that common musculoskeletal conditions induce sensory reweighting.^{12–15} SOT may not be effective in athletic populations due to its reliance on a static bipedal stance not being challenging enough to discover postural instability that may be manifested during more aggressive athletic maneuvers. Thus, SV could be an alternative for progressive sensory reweighting in more active populations. Of note, our findings are limited to individuals without current injury and to the NeuroCom system. Patients, especially those with disorders affecting balance, may respond to SV differently; this requires future research.

Conclusions

Stroboscopic vision was found to induce a degree of postural instability similar to that induced by SRV and can be used in the assessment of sensory reweighting as part of CTSIB, allowing future investigators and clinicians to engage in more dynamic postural stability assessments.

Table 1 TTB Measures of Center-of-Pressure Excursion During 20-second Bipedal Stance on Fixed (Stable) Surface

TTB parameters	RM ANOVA	Effect size ^a				One-sample <i>t</i> test ^b	Pearson <i>r</i> ^c	<i>R</i> ²
		FV	SRV	SV	FV and SRV	SV and SV		
ML mean (s)	$F_{2,34} = 1.52$; $P = .23$	64.82 (15.15)	62.27 (12.01)	59.45 (12.62)	-0.19 (-0.84 to 0.47)	-0.38 (-1.04 to 0.28)	$t_{17} = 1.24$; $P = .23$	.71 (.36, .88); $P < .01^{**}$
AP mean (s)	$F_{2,34} = 3.73$; $P = .03^{*}$	35.25 (12.60)	30.01 (9.87)	26.86 (13.56)	-0.46 (-1.12 to 0.20)	-0.64 (-1.31 to 0.03)	$t_{17} = 1.56$; $P = .14$	.77 (.47, .91); $P < .01^{**}$
ML SD (s)	$F_{2,34} = 1.47$; $P = .24$	40.14 (9.14)	38.19 (7.46)	36.08 (10.82)	-0.23 (-0.89 to 0.42)	-0.41 (-1.07 to 0.25)	$t_{17} = .92$; $P = .37$	.49 (.30, .78); $P = .04^{**}$
AP SD (s)	$F_{2,34} = 3.63$; $P = .04^{*}$	26.60 (10.68)	22.49 (7.34)	20.04 (9.38)	-0.45 (-1.11 to 0.21)	-0.65 (-1.32 to 0.02)	$t_{17} = 1.69$; $P = .11$	.75 (.44, .90); $P < .01^{**}$
								.50 (.13, .77)
								.59 (.22, .83)
								.24 (.09, .61)
								.56 (.19, .81)

Abbreviations: AP, anteroposterior; FV, full vision; ML, mediolateral; RM ANOVA, repeated-measures analysis of variance; SRV, sway-referenced vision; SV, stroboscopic vision; TTB, time-to-boundary. Note: Bolded *R*² values were calculated from the Pearson correlation coefficients.

^aCohen's *d* estimate of effect size was calculated between 2 of 3 visual conditions using pooled standard deviation, along with its associated 95% confidence interval. A lower TTB measure indicates poorer balance; a negative value of effect size represents a decline in balance performance. ^bOne-sample *t* tests were performed for each measure to determine the difference between SRV and SV from zero. ^cPearson correlation coefficients (*r*) were estimated between SRV and SV conditions for each measure, along with their 95% confidence intervals.

*AP postural control with SRV or SV was significantly worse than postural control with full vision; SV did not significantly differ from SRV. **Significant correlation between SRV and SV conditions.

Table 2 TTB Measures of Center-of-Pressure Excursion During 20-Second Bipedal Stance on Sway-Referenced (Unstable) Surface

TTB parameters	RM ANOVA	Effect size ^a				One-sample <i>t</i> test ^b	Pearson <i>r</i> ^c	<i>R</i> ²	
		FV	SRV	SV	FV and SRV				FV and SV
ML mean (s)	$F_{2,34} = 7.77$; $P < .01^*$	50.69 (10.18)	44.14 (10.95)	34.99 (17.65)	–0.62 (–1.29 to 0.05)	–1.09 (–1.79 to –0.39)	–0.62 (–1.29 to 0.05)	$t_{17} = 3.44$; $P < .01$	.62 (.26, .85) $P < .01^{**}$
AP mean (s)	$F_{2,34} = 16.56$; $P < .01^*$	17.64 (4.86)	12.17 (3.94)	12.35 (4.43)	–1.24 (–1.97 to –0.50)	–1.14 (–1.86 to –0.41)	0.04 (–0.61 to 0.70)	$t_{17} = -.16$; $P = .88$	.56 (.19, .81) $P < .01^{**}$
ML SD (s)	$F_{2,34} = 5.77$; $P < .01^*$	30.76 (5.92)	28.11 (7.03)	21.98 (10.91)	–0.41 (–1.07 to 0.25)	–1.00 (–1.69 to –0.31)	–0.67 (–1.34 to 0.01)	$t_{17} = 3.95$; $P < .01$	.67 (.32, .86) $P < .01^{**}$
AP SD (s)	$F_{2,34} = 7.34$; $P < .01^*$	15.19 (4.62)	11.14 (3.12)	9.58 (5.70)	–1.03 (–1.72 to –0.33)	–1.08 (–1.78 to –0.38)	–0.34 (–1.00 to 0.32)	$t_{17} = 1.51$; $P = .15$	.65 (.26, .86); $P < .01^{**}$

Abbreviations: AP, anteroposterior; FV, full vision; ML, mediolateral; RM ANOVA, repeated-measures analysis of variance; ML, mediolateral; SRV, sway-referenced vision; SV, stroboscopic vision; TTB, time-to-boundary. Note: Bolded *R*² values were calculated from the Pearson correlation coefficients.

^aCohen's *d* estimate of effect size was calculated between 2 of 3 visual conditions using pooled standard deviation, along with its associated 95% confidence interval. A lower TTB measure indicates poorer balance; a negative value of effect size represents a decline in balance performance. ^bOne-sample *t* tests were performed for each measure to determine the difference between SRV and SV from zero. ^cPearson correlation coefficients (*r*) were estimated between SRV and SV conditions for each measure, along with their 95% confidence intervals.

*AP postural control with SRV or SV was significantly worse than postural control with full vision, while SV did not significantly differ from SRV. **Significant correlation between SRV and SV conditions.

Figure 1 — Bland-Altman plots for time-to-boundary (TTB) measures of center-of-pressure excursion during 20-second bipedal stance on fixed (stable) surface; the dotted line indicates zero, the solid line represents the average difference (bias line), and the dashed lines show the 95% confidence intervals of the average differences. AP indicates anteroposterior; ML, mediolateral; SRV, sway-referenced vision; SV, stroboscopic vision; TTB, time-to-boundary.

Figure 2 — Bland-Altman plots for time-to-boundary (TTB) measures of center-of-pressure excursion during 20-second bipedal stance on sway-referenced (unstable) surface; the dotted line indicates zero, the solid line represents the average difference (bias line), and the dashed lines show the 95% confidence intervals of the average differences. AP indicate anteroposterior; ML, mediolateral; SRV, sway-referenced vision; SV, stroboscopic vision; TTB, time-to-boundary.

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