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The Test- Retest Reliability and Minimal Detectable Change of the Sensory Organization Test and Head- Shake Sensory Organization Test

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Purpose: The assessment of balance deficits following sport- related concussion can be accomplished using computerized dynamic posturography (CDP) testing procedures, including the Sensory Organization Test (SOT) and the Head- Shake Sensory Organization Test (HS- SOT). Although these tests are considered to be important post-concussion balance assessments, the test- retest reliability of the HS- SOT has not been evaluated in a healthy, athletic population. Our purpose was to evaluate the test- retest reliability of the HS-SOT in a non-concussed, athletic sample. **Methods**: A prospective, time series, cohort design was used in a University research laboratory. Twenty (8 F, 12 M) healthy intercollegiate athletes (age 19.95 ± 1.28 years, height 175.55 ± 13.57 cm, weight 74.73 ± 17.59 kg) participated. Postural stability was assessed at two time intervals (9 days apart). Subjects completed all 6 testing conditions of the SOT and the 2 testing conditions for the HS- SOT. **Results**: Excellent test- retest reliability was demonstrated for the SOT composite equilibrium scores (ICC 1,1= .83). Moderate test- retest reliability was observed for the SOT equilibrium scores for conditions 2 (.66) and 5 (.65); somatic (.58), visual (.65), and vestibular sensory analyses (.68); and sensory analysis preference (.66). Moderate reliability was also noted for equilibrium scores on condition 5 for the HS- SOT (.65). The test- retest reliability was poor for the HS- SOT equilibrium scores on condition 2 (ICC= .26, δ^2= .14), HS-SOT equilibrium score ratio for fixed surface (ICC= .37, δ^2 <.001), and HS- SOT equilibrium score ratio for sway- referenced surface (ICC= .16, δ^2= .003). **Conclusions**: Determining the minimal difference in HS-SOT scores (ICC and MDC) representing significant change over time will help clinicians to identify athletes with balance disorders in the acute post- concussion phase.

INTRODUCTION

In the United States, an average of 1.4 million mild traumatic brain injuries (MTBIs) occur each year, including 1.1 million emergency department visits, 235,000 hospitalizations, and 50,000 deaths.[1] An MTBI is a brain injury caused by trauma to the head and is often referred to as a *concussion.* The actual incidence of concussions may be underestimated, however, because these injuries are 'mild' in nature (in contrast to moderate to severe TBI) and many times go undetected or misdiagnosed, especially in athletic populations.[1] A more accurate estimate of sports- related concussions is 1.6 to 3.8 million MTBIs per year, including those for which no medical care is sought.[1] Although there is no universally accepted definition of concussion, the International Concussion in Sport Group defined this injury as, "A complex pathophysiological process affecting the brain, induced by traumatic biomechanical forces."[2] A concussion is a potentially serious medical condition affecting the welfare of athletes in every sport. Safe return to participation following a concussion is one of greatest challenges facing athletic trainers and team physicians.

Critical to an athlete's return to play are subjective symptom reporting, neurocognitive testing, neurological examination, and balance assessment. These aspects of concussion assessment address the current approaches to the evaluation and management of the concussed athlete.[3] Unfortunately, because *subjective* symptom reporting is athlete- dependent, symptoms may not always be reported accurately. Athletes may not reveal the presence or severity of symptoms, making the athlete's return to play much more dangerous. The evaluation of the athlete with a suspected concussion must rely on available, evidence-based objective assessment tools. Standard neuorimaging techniques (e.g. CT, MRI) are able to identify structural injuries to the brain, including injuries such as skull fractures and intracranial hemorrhage, but are generally considered not helpful in the diagnosis of concussion.[4] Additionally, standard CT or MRI examination does explain the functional disturbances seen following concussion, which can include neurocognitive deficits and altered balance.[4]

Neuropsychological testing has become a critical aspect of the assessment and management of the concussed athlete[5] and provides an objective, evidence- based assessment of neurocognitive function. These neuropsychological tests can take the form of computerized assessment batteries [e.g. Immediate Post- Concussion Assessment and Testing (ImPACT)], or traditional paper and pencil tests (e.g. Trail- Making Test A and B, Wechsler Digit Span Test, Stroop Color Word Test, Hopkins Verbal Learning Test, etc). Neurocognitive deficits occur primarily during the acute post- concussion phase, ranging from 1-3 days up to about 7 days depending on severity of injury and history of prior concussions.[5] Neurocognitive testing is an essential portion of concussion assessment, but it is only "one piece of the puzzle."[6] Other aspects of the athletes' functional level, such as balance and postural stability, must also be assessed.

Postural stability and balance are other aspects of concussion assessment that provide valuable, objective information to the clinician. Balance can be assessed in a variety of ways in athletic populations; for example, balance can be assessed on the sideline using the Balance Error Scoring System (BESS).[3,6,7] The BESS is a simple and efficient way of determining balance deficits in the acute post- concussion phase. Computerized dynamic posturography (CDP) can also be used to identify decrements in an athlete's balance, and has been used both clinically and for research purposes. The Sensory Organization Test (SOT) is a commonly used CDP balance assessment and is considered to be the "gold- standard" for assessing deficits in postural stability post-concussion.[3,5,7-10] The SOT was developed to isolate and identify which sensory system (somatosensory, visual or vestibular) is involved in regulating posture and to determine how the interaction between these systems affects postural stability.[3,5,7-10] Researchers have identified 'good' concurrent validity between the BESS and CDP (using the SOT).[3,6,7] Acutely concussed subjects demonstrate a significant decrease in postural stability on the SOT when comparing baseline measures to control subjects.[11] This decrease in postural control following concussion is evident for 3 to 10 days[5,8,12] and is believed to be the result of sensory interaction problems during the first few days following injury.[13] The interaction between the three primary sensory systems contributing to balance appears to be disrupted following concussion injuries, but the exact cause(s) remains unclear.

Head trauma incurred during contact sports participation may produce a variety of vestibular- related symptoms, including 'imbalance' that affects an individual's ability to maintain upright stability.[14] Concussive trauma may injure or damage the peripheral vestibular components (e.g. the labyrinth of the inner ear or the vestibular nerve), or central components (e.g. brainstem or vestibulocerebellum).[15] Whereas the SOT can be used to assess upright postural control and the interaction of the three sensory systems, it is not capable of specifically identifying vestibular system dysfunction. The Head- Shake Sensory Organization Test (HS- SOT) is an extension of the standard SOT which is used to measure an athlete's ability to effectively use

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vestibular inputs to maintain balance while simultaneously moving the head. The ability to detect vestibular dysfunction caused by concussion using the HS- SOT has not been previously reported.

Vestibular system dysfunction may contribute to balance deficits among athletes in the acute post- concussive phase; assessment for disruption of normal vestibular function requires a reliable and systematic approach to testing. The HS- SOT demonstrates good to excellent test- retest reliability among healthy subjects ranging in age from 28.3 years to 60.3 years, with better reliability ($ICC_{3,2}$ = .78 to .85) for younger adults compared to older subjects ($ICC_{3,2}$ = .55 to .64).[16] There is no published evidence for the test- retest reliability of the HS- SOT in a healthy, athletic population. Establishing the test- retest reliability of the HS- SOT among a healthy sample would permit clinicians and researchers to apply the HS- SOT to patient populations, including patients with sport- related concussion. The purpose of this study, therefore, is to establish the test- retest reliability of the HS- SOT in a healthy, athletic sample.

METHODS

A prospective, mixed model (time series), cohort study design was used. Postural stability was assessed in the healthy, athletic sample at two time intervals (9 days apart) in a university research laboratory setting. This time point was chosen to follow typical concussion recovery pattern of 10 days. Two testing procedures were completed: (1) the Sensory Organization Test (SOT) and (2) the Head Shake-SOT (HS- SOT). The dependent variables which were collected and analyzed consisted of data derived from SOT Report [composite equilibrium score and sensory strategy analysis (the preferred sensory system used to maintain balance)] and data derived from HS- SOT Report [equilibrium score, equilibrium score ratio on a fixed surface and on a sway- referenced surface, and the movement axis velocity].

Subjects

Twenty (8 females, 12 males) healthy intercollegiate/ intramural athletes ages 18-24 (19.95 ± 1.28 years, height 175.55 ± 13.57 cm, weight 74.73 ± 17.59 kg), from the University of Kentucky and Midway College were included in this study. The variety of subject included men's golf (n=7), women's gymnastics (n=6), men's tennis (n=5), women's tennis (n=1), and softball (n=1). Subjects were excluded if they had a history of a concussion within the past 6 months, any cranial neurosurgery, any neurological or orthopedic condition that may affect their balance, any lower extremity injury still causing current pain or disability, and/ or any implanted biomedical device. Each subject signed an informed consent form prior to participation in the study. Human subject approval was obtained from the Office of Research Integrity at the University of Kentucky prior to beginning the study (IRB# 11-0220-P1H)

Instrumentation

Postural stability testing was conducted using the SOT on the NeuroCom Smart Balance System® (NeuroCom International, Inc. Clackamas, OR). Also, a head tracking device was used to monitor head shakes while conducting the HS- SOT (InVision, NeuroCom International, Clackamas, OR).

Procedures

Subjects were screened for pre- existing balance, vestibular, and/ or neurologic conditions by asking each subject to disclose any previously diagnosed medical conditions. Each subject completed the SOT and HS- SOT as described below. The order of testing was conducted as per the manufacturer's protocol

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specifications for systematic disruption of the sensory systems, therefore randomization was not performed.

The SOT (NeuroCom International, Clackamas, OR) is a postural stability test that causes a systematic disruption of the sensory selection process. This systematic disruption causes an alteration of somatosensory, visual, and vestibular information. The protocol consists of three 20- second trials of 3 different visual conditions (eyes open, eyes closed, sway- referenced) and 2 support surfaces (stable, sway- referenced). The subjects foot placement is standardized to their height as per the manufacture's protocol. Condition 1 requires the subject to stand on a fixed surface with normal visual input (eyes open); condition 2 involves the subject standing on a fixed surface without visual input (eyes closed); in condition 3, the subject is standing on a fixed surface with eyes open and a sway- referenced visual surround. Sway- referencing refers to the tilting of the support surface (force platform) or visual surround, or both.[7] Condition 4 of the SOT is standing on a sway- referenced surface with normal visual input; for condition 5, the subject stands on a sway-referenced surface with eyes closed; and, condition 6 requires the subject to stand on a sway- referenced surface with eyes open but also with a sway- referenced visual surround. After completion of all three trials for each SOT condition, a composite score is automatically computed for each condition and an overall equilibrium score is recorded.

Upon completion of the SOT, each subject completed the HS- SOT. The HS-SOT consists of repeating SOT condition 2 & condition 5 while the subject performs a continuous, rhythmic side-to-side head movement. Each subject was fitted with a head tracking device (InVision, NeuroCom International, Clackamas, OR) which measured the direction and velocity of head movement. The subject is fitted with the head tracker, asked to stand on the NeuroCom force platform and finally instructed to rotate his or her head side-to-side (in a horizontal plane of movement) while maintaining the desired frequency (approximately one turn per second or 85 degrees/ second) and at the desired amplitude (approximately 20 degrees in each direction). For each of the two test conditions, the subject was given one un-scored practice trial followed by five, 15-second scored trials, following manufacture recommendations. Upon completion of both HS- SOT conditions (eyes closed, fixed surface and eyes closed, sway-referenced surface), the subject was removed from the NeuroCom device and the head tracker was removed.

Data Reduction

The raw data obtained during the SOT is automatically analyzed through the NeuroCom software to obtain the following outcome measures: (a) a composite equilibrium score, (b) a sensory analysis ratio (indicating which sensory system is the preferred system used by the subject to maintain upright balance), and (c) a strategy analysis (ankle or hip strategy used). The sensory analysis ratios are automatically computed by comparing average scores achieved on various SOT testing conditions, and include a Vestibular Ratio (comparison of condition 5 to condition 1), a Visual Ratio (conditions 4 and 1), and a Somatosensory Ratio (conditions 2 and 1). The raw data obtained during the HS- SOT is also automatically analyzed through the NeuroCom software, yielding the following two outcome measures: (a) an equilibrium score ratio (fixed and sway- referenced), and (b) the movement axis velocity (or average head movement velocity score). The equilibrium score ratios on the HS- SOT are derived by comparing the three- trial average

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equilibrium score on each head- shake condition to the average score achieved on the comparable condition performed with the head fixed (i.e. on the SOT).

Statistical Analysis

Descriptive statistics, measures of central tendency, and variability were calculated to summarize the demographic characteristics of the sample (e.g. age, gender, prior concussion history). Descriptive analyses were also be used to summarize the SOT and HS- SOT data. To determine if there were any significant differences in HS- SOT performance between the two test sessions, a paired (dependent samples) *t* test was used. Intraclass correlation coefficients (ICC 1,1)[17] were calculated to evaluate the test- retest reliability of the HS- SOT equilibrium scores. ICC values were interpreted using Flesiss' criteria: below .4 is considered poor reliability, .4 to .75 is considered moderate to good reliability, and above .75 is considered excellent reliability.[18] On the basis of the reliability coefficients, the minimum detectable change (MDC) for each HS- SOT condition was calculated. MDC was estimated using the following formula:

$$MDC= 1.96 \times SEM \times \sqrt{2}$$ [19]

The standard error of the measurement (SEM) was computed using the following formula:

$$SEM = S_x \sqrt{(1-r_{xx})}$$ [19]

In the formula for calculating the SEM, S_x is the standard deviation of the equilibrium scores and r_{xx} is the reliability coefficient (r). All statistical analyses will be performed with SPSS software (PASW Statistics 18.0, SPSS Inc., Chicago, IL). An *a priori* alpha level of P<.05 was applied to all data to determine significant differences.

RESULTS

Descriptive statistics derived from the SOT and HS- SOT are reported in Tables 1 and 2 respectively. The results of the reliability analyses, including minimal detectable change (MDC) values, are shown in Table 3.

Table 1. Descriptive Statistics for the Sensory Organization Test (SOT)

Descriptive Statistics	Mean	Standard Deviation
Composite equilibrium score, test 1	81.90	4.58
Composite equilibrium score, test 2	84.85	4.57
Sensory analysis, somatic, day 1	1.03	0.03
Sensory analysis, somatic, day 10	1.02	0.02
Sensory analysis, visual, day 1	0.94	0.06
Sensory analysis, visual, day 10	0.95	0.07
Sensory analysis, vestibular, day 1	0.74	0.11
Sensory analysis, vestibular, day 10	0.82	0.06
Sensory analysis, preference, day 1	1.00	0.08
Sensory analysis, preference, day 10	0.99	0.05
Equilibrium score, condition 2 (mean), day 1	91.98	2.44
Equilibrium score, condition 2 (mean), day 10	92.03	2.13
Equilibrium score, condition 5 (mean), day 1	69.55	9.78
Equilibrium score, condition 5 (mean), day 10	77.06	5.74

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Table 2. Descriptive Statistics for the Head Shake Sensory Organization Test (HS-SOT)

Descriptive Statistics	Mean	Standard Deviation
Equilibrium score ratio, fixed surface, day 1	1.00	0.03
Equilibrium score ratio, fixed surface, day 10	1.00	0.03
Equilibrium score ratio, sway-referenced surface, day 1	0.94	0.14
Equilibrium score ratio, sway-referenced surface, day 10	0.86	0.87
Equilibrium score, condition 2 (mean), day 1	91.85	3.56
Equilibrium score, condition 2 (mean), day 10	91.32	6.70
Equilibrium score, condition 5 (mean), day 1	64.95	9.03
Equilibrium score, condition 5 (mean), day 10	67.31	10.12

Table 3. Retest Reliability Coefficents (ICC), Minimal Detectable Changes (MDC) Values for Sensory Organization Test (SOT) and Head Shake-Sensory

	Variables	ICC	SEM	p-value	MDC
SOT	Composite equilibrium score	0.83	1.43	<0.001*	3.97
	Equilibrium score, condition 2 (mean)	0.66	1.34	0.012*	3.73
	Equilibrium score, condition 5 (mean)	0.65	4.82	0.013*	13.37
	Sensory analysis, somatic	0.58	0.02	0.033*	0.05
	Sensory analysis, visual	0.65	0.04	0.013*	0.10
	Sensory analysis, vestibular	0.68	0.05	0.0009*	0.14
	Sensroy analysis, preference	0.66	0.04	0.011*	0.11
HS-SOT	Equilibrium score, condition 2 (mean)	0.26	6.03	0.263	16.17
	Equilibrium score, condition 5 (mean)	0.65	5.81	0.015*	16.10
	Equilibrium score ratio, fixed surface	0.37	0.03	0.16	0.09
	Equilibrium score ratio, sway-referenced surface	0.16	0.15	0.359	0.41

***p<.05**

DISCUSSION

The results of the test- retest reliability analysis for SOT composite equilibrium scores demonstrated excellent reliability (ICC= .83). Moderate to good test- retest reliability was observed for the SOT equilibrium scores for condition 2 (ICC= .66), equilibrium scores for condition 5 (ICC= .65), somatic sensory analysis (ICC= .58), visual sensory analysis (ICC= .65), vestibular sensory analysis (ICC= .68), and sensory analysis preference (ICC= .66); moderate to good reliability was also noted for equilibrium scores on condition 5 for the HS-SOT (ICC= .65). The test- retest reliability was poor (<.40) for the HS- SOT equilibrium scores on condition 2 (ICC= .26), HS-SOT equilibrium score ratio for fixed surface (ICC= .37), and HS- SOT equilibrium score ratio for sway- referenced surface (ICC= .16). Although the test- retest reliability for the

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HS- SOT condition 2 appeared to be poor (ICC= .26, p> .05), there was very little variance (δ^2) observed between test sessions 1 and 2 (range = .53, δ^2= .14); a paired t-test demonstrated no significant differences between test sessions (t_{19}= .340, p= .737). Likewise, for the HS- SOT equilibrium score ratio- fixed surface, the reliability was only .37, but the variance (δ^2) was <.0001 and the range was 1.003 to 1.005 (or .002); there was no significant difference between fixed surface score ratios (t_{19}= -.171, p= .331). The test- retest reliability for the HS- SOT equilibrium score ratio- sway referenced surface condition also appeared poor (ICC= .16) but the variance of ratios between test sessions was only .003 (range .864 to .924); there was a statistically significant difference in equilibrium score ratios (sway- referenced surface) between testing sessions (t_{19}= 2.19, p= .042, mean for test 1= .942 ± .142, mean for test 2= .864 ± .087). Therefore, the test- retest reliability of these three conditions (HS- SOT condition 2, HS- SOT equilibrium score ratio fixed and HS- SOT equilibrium score ratio sway- referenced) cannot be determined confidently on the basis of the calculated ICCs in our sample of 20 subjects. Further research using a substantially larger sample size may result in ICC values that are meaningful for these measures.

A paired samples t-test was conducted to evaluate the differences in SOT and HS-SOT outcome measures between the 2 testing sessions. The results indicated a significant increase in SOT composite equilibrium score (test 1: 81.90 ± 4.58, test 2: 84.85 ± 4.57, p< .0001), SOT equilibrium score for condition 2 (test 1: 91.98 ± 2.44, test 2: 92.03 ± 2.13 p= .026), SOT equilibrium score for condition 5 (test 1: 69.55 ± 9.78, test 2: 77.07 ± 5.74, p= .011), SOT visual sensory analysis (test 1: .94 ± .06, test 2: .95 ± .07, p= .028), SOT vestibular sensory analysis (test 1: .74 ± .11, test 2: .82 ± .06, p= .006), SOT sensory analysis preference (test 1: 1.00 ± .08, test 2: .99 ± .05, p= .018), and HS- SOT equilibrium score for condition 5 (test 1: 64.95 ± 9.02, test 2: 67.31 ± 10.12, p= .033). In general, the mean scores for each condition increased from day 1 to day 10; this could indicate a possible learning effect between testing sessions 9 days apart on these specific outcome measures.[16] The HS- SOT condition 5 is the most novel and complex of the conditions tested, which increases the task demand on the participants. HS- SOT condition 5, however, was observed to have better (moderate to good) reliability than HS- SOT condition 2 (poor) even though condition 5 is seemingly more difficult for the subject to perform (involving a sway- referenced platform with eyes closed and simultaneous head rotation). This phenomena may be described according to Bernstein's degrees of freedom (DOF) principle.[20] The HS- SOT condition 2 restricts approximately 1.5 DOF by eliminating visual input (through 'eyes closed') and altering the vestibular system with the addition of head rotation. The HS- SOT condition 5 restricts approximately 2.5 DOF by eliminating visual input, altering somatosensory feedback, and altering the vestibular system with the addition of head rotation. According to Bernstein, subjects will "freeze" less DOF when completing HS- SOT 2 than when completing HS- SOT 5; condition 2 of the HS- SOT (eyes closed, fixed platform) allows the extremities to move more independently for greater ability to maintain upright postural stability than condition 5 of the HS- SOT (eyes closed, sway-referenced platform). In other words, the subject has more available DOF, thus they will have more variability in their test results some trials may score high, some trials may score low. Once the subject begins testing on condition 5 of the HS- SOT, they will have to 'freeze' as many DOF as possible to meet the demands of the task

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(because it is more difficult). Thus, the subject will have less variability on HS- SOT condition 5 and the least amount of DOF to move independently; this will make their test results more predictable.[21] Because they have less variability, the test results will be more similar (i.e. more reliable) on condition 5 than condition 2.[20,21]

There were no significant differences in SOT somatic sensory analysis (mean test 1= 1.03 ± .03, mean test 2= 1.02 ± .02, p= .067), HS- SOT equilibrium scores for condition 2 (mean test 1= 91.85 ± 3.56, mean test 2= 91.32 ± 6.70, p= .455), equilibrium score ratio, fixed surface HS- SOT (mean test 1= 1.00 ± .03, mean test 2= 1.00 ± .03, p= .331), or equilibrium score ratio, sway- referenced surface HS- SOT (mean test 1= .94 ± .14, mean test 2= .86 ± .09, p= .693). The lack of any significant differences between testing sessions for these four outcome measures could be attributed to the time which elapsed between testing sessions (i.e. 9 days).

Determining the minimal detectable change (MDC) values for the HS- SOT in a healthy, athletic population was a secondary aim of this study. The MDC represents the amount of real change that occurs with testing.[16] This information is important to clinicians and researchers because it will provide guidelines for interpreting changes in HS-SOT scores over time or among subjects after suffering a concussion.[16] Establishing the MDC for tests such as the HS- SOT will allow clinicians to know the minimum differences in test performance that indicate significant change not due to measurement error or some other confounding effects. The MDC values for the SOT and HS- SOT reported in the current study can be used to identify meaningful clinical changes for these outcome measures. Our reported MDC value for the HS- SOT condition 2 is much higher (16.71) compared to the reported MDC from the Pang et. al. article (2.9). The reason for this is because Pang used a greater variability of age and a larger number of subjects then what was included in our study. Having a smaller MDC value is not necessarily a "good" result because to consider a test score abnormal using Pang's results the differential would have to exceed a value of 2.9. With a higher MDC, the more abnormal a subject would have to score before meaningful results are found. This information would be particularly valuable, for example, in the assessment of balance and vestibular function among a concussed athletic population within this same age range.

Consistent with previously reported research by Pang et al., equilibrium scores on the SOT were greater than equilibrium scores on the HS- SOT (conditions 2 and 5) when comparing results from day 1 to day 10.[16] Pang et al. focused on age- related differences in performance on the SOT and HS- SOT and how the addition of head rotation creates additional challenges to maintaining upright postural control.[16] Their study was the first to test the test- retest values of conditions 2 and 5 of the HS- SOT. These researchers compared the intraclass correlation coefficients of a younger adult group (n= 92, ICC= .85, .78) versus an older adult group (n= 73, ICC= .64, .55) for conditions 2 and 5 on the HS-SOT. In comparison to performance on the SOT (which does not involve directional head rotations), head rotations may alter normal upright balance because of the added vestibular stimulation.[10,16] This same challenge seems to be present even in a healthy, athletic population.[16]

There are several limitations that may limit the gernealizability of the results of our study. First, the results can only be generalized to healthy athletes within the age range of 18 to 24 years; younger athletes (e.g. middle/ high school) or older athletes (e.g. semi-professional or professional) may perform differently on the SOT and HS- SOT.

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Sports represented in this sample included men's golf (n= 7), women's gymnastics (n= 6), men's tennis (n= 5), women's tennis (n= 1), and softball (n= 1); these results can only be applied to athletes in these sports. The subjects included in our study represent a homogenous sample within a small age range. Future testing can increase the number of sports included in the study and/ or the age range to achieve a more heterogeneous sample. Third, the estimated effect size (η^2) was small on several variables. The *a priori* sample size estimation indicated that a minimum of 20 subjects was necessary to demonstrate significant differences. For the three conditions that demonstrated poor reliability (i.e. ICCs < .40, which included the HS- SOT condition 2, HS- SOT equilibrium score ratio fixed surface, HS- SOT equilibrium score ratio sway- referenced surface) a very small effect size was observed (η^2= .006, .002, and .201, respectively) along with suboptimal power (1-β= .062, .053, and .546, respectively) probably due to the small number of subjects tested. A higher power would be observed if the variability of the sample was decreased or if the number of subjects was increased for the three measures that demonstrated poor reliability. Fourth, the only head rotation direction used for the head- shake SOT was rotation in the horizontal (yaw) direction. Doing the HS-SOT in a different direction (vertical or side-to-side) may produce different results. An additional limitation was the use of multiple testers involved in giving directions to subjects for the SOT and HS- SOT and, although the directions given to each subject during testing were similar, there was not a standardized set of instructions used. Different testers may have put more emphasis on certain verbal cues, causing some athletes to perform better during testing than others. Establishing and implementing a standardized set of verbal instructions may produce results that demonstrate greater consistency across testing sessions. Lastly, testing was done 9 days apart as determined by the examiners. Balance testing post- concussion has typically been assessed 1, 3, 5, and 10 days post-injury;[5,8] we chose a test- retest interval of 9 days to make the results applicable to balance testing in a concussed athletic population. Accurate interpretation of the test- retest reliability analyses for several of the HS- SOT outcome measures (equilibrium score ratio, fixed and sway- referenced surface) is problematic due to the small variance between testing sessions, and is limited by the 9-day testing interval specified by the researchers.

CONCLUSIONS

The composite equilibrium scores on the SOT demonstrated excellent test- retest reliability (ICC= .83) while the test- retest reliability was moderate to good (ICC= .65) for the HS- SOT equilibrium score, condition 5 (sway- referenced surface). Poor test-retest reliability was noted for the HS- SOT equilibrium score condition 2 (fixed surface, ICC= .26), and the equilibrium score ratios: sway- referenced (ICC= .16) and fixed surface (ICC= .37). Computation of the MDC values for the SOT and HS- SOT may assist in clinical interpretations. Determining the minimal values representing significant change for HS- SOT scores in a healthy, athletic population will help future research aiming to identify athletes with balance disorders in the acute post- concussion phase.

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