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Research Article

Sensory Organization Test: Normative Data in Athletes with and without Concussion History

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Abstract

Introduction: The human body balance system is a complex system of organs and mechanisms, which generate postural reactions to counter the displacement from the equilibrium position of the body center of gravity, and which control eye movement to maintain a stable image of the environment. Computerized Dynamic Posturography (CDP) allows for a quantitative and objective assessment of the sensory and motor components of the body balance control system as well as of the integration and adaptive mechanisms in the central nervous system.

Objective: To present a normative database for SOT scores from an athlete population.

Methods: University-level Athletes were categorized into the concussion-history group if they reported sustaining 2 or more concussions in the context of their university period experiences. Participants with one concussion were not included in the study. University-level Athletes with no concussion history were selected for the control group. Sensory Organization Test (SOT) protocol, with six conditions, was applied using the NeuroCom SMART EquiTest® Clinical Research System (CRS) (Natus Medical International, version 9.3, Clackamas, OR).

Results: There was no statistical difference within the demographic findings between the two group's age, height, or weight. All conditions, except condition 1 presented a statistically significant difference comparing the values from one group to another, as well as for the four sensory organization ratios ($p < .001$).

Conclusion: Comparing the post-concussion scores to normative values can be used after injury as part of a multifaceted evaluation to identify postural control impairments. SOT could assist in the return to play decision even if the athlete has normal values for the test, decreasing the risk of another concussion.

INTRODUCTION

Balance is defined as the ability to control upright posture under different conditions, and the ability of an individual to sense their limitations of stability [1]. The central nervous system interprets, integrates and selects information from various sensory inputs (somatosensory, visual and vestibular) to provide the necessary information for this performance to produce required motor outputs to maintain static and dynamic balance [1-3].

Balance has been shown to play a fundamental role in many athletic activities [4]. Sensory organization and balance performance are important for sport participation and safety, and it may contribute to a successful performance [5].

Concussions occur in many different sports and is estimated to effect as many as 3.8 million athletes in the USA, per year, during competitive sports and recreational activities. However, as many as 50% of the concussions may go unreported [6,7].

Symptoms that can be reported after a concussion include, but are not limited to headache, fatigue, visual problems, vestibular-related symptoms of dizziness, and balance problems in general. To address any balance related concerns and symptoms, several tools of assessment are available [8-10].

The Computerized Dynamic Posturography is a predominant assessment tool and is considered the gold standard for the assessment of sensory and motor contributions. The Sensory Organization Test (SOT), presented in this equipment, is considered a gold standard and reliable testing protocol, and is sensitive to deficits in postural control [11-13]. The SOT is the most widely used CDP test and measures an individual's functional ability to coordinate and maintain balance under varying sensory conditions, and to suppress incorrect information. It is a functional test (not a site of lesion test) of how the body integrates sensory cues to maintain postural stability when the visual and/or somatosensory inputs are conflicted and when the head is static [12-14].

Sports medicine professionals are faced with the challenging task of evaluating and managing sport-related concussion. Evaluation of concussion should involve a multifaceted approach including a thorough clinical evaluation, a self-reported symptom checklist, postural control assessment, and computerized neurocognitive testing [8-10].

Health professionals in general rely on normative values to diagnose a wide variety of pathological conditions because individualized baseline values are not always available for their patient populations. Baseline scores are thought to account for individual preinjury differences in neurocognition, symptoms, and postural control abilities, thereby providing a valid comparison for post-concussion outcomes is important [8-10,15]. In the absence of an individualized baseline, normative data are valuable as assessment tool. It is important to highlight those normative values created utilizing general population controls are likely not representative of functional balance for high-performing personnel, for example athletes, which may provide a limitation to the sports medicine professionals [14-16].

It is important to have measurements of postural stability in athletes, which lead rigorous physical demands. The purpose of our study was to present a normative database for SOT scores from an athlete population. Furthermore, since no research exists regarding long-term balance performance post-concussion, the secondary purpose was to compare postural-control performance between athletes who had concussion history with those of who maintain a high level of conditioning and training as well but do not have any episode of concussion.

METHODOLOGY

Subjects

University-level Athletes were categorized into the concussion-history group if they reported sustaining 2 or more concussions in the context of their university period experiences. Participants with one concussion were not included in the study. University-level Athletes with no concussion history were selected for the control group.

All participants were informed of the testing procedures and signed a written consent form according to the Declaration of Helsinki (2013) and approved by the university's Institutional Review Board, which also approved the study (IRB-FY20-144). All testing was conducted at the human balance research laboratory. Participants with the following conditions were excluded: central vestibular dysfunction, motor impairments, serious or uncompensated visual impairment, neurological disorders, major psychiatric disorders, alcohol ingestion 24 h prior to the tests, and/or the use of drugs that affect the labyrinth or central nervous system. Unable to stand upright with eyes open for at least one minute cannot complete CDP testing [16].

Instrumentation (Equipment)

The NeuroCom SMART EquiTest® Clinical Research System (CRS) (Natus Medical International, version 9.3, Clackamas, OR) consists of a pressure-monitored force platform and dynamic visual surround. During the Sensory Organization Teste (SOT) protocol, the participant's sensory information is altered by calibrated ''sway referencing'' of the support surface or visual surroundings (or both), which tilt to directly follow the patient's anterior-posterior body sway [11,19].

Procedures

During the test, the examiner was positioned in view of the participant and the workstation (computer) to observe COG sway. It was continuous observed of the participant for any signs of anxiety or fatigue, since these can be mitigated with breaks and reassurance about the test procedures. The examiner took notes of any musculoskeletal abnormalities (back, ankle, hip problems, and issues of different leg lengths) that may impact testing and interpretation.

The recommended steps for optimal patient set-up, were applied [19,20]. All the subjects avoid alcohol and medications that may impact balance control upwards of 48 hours before testing.

The six conditions were 1) eyes open, no sway reference; 2) eyes closed, no sway reference; 3) eyes open, visual surround sway reference; 4) eyes open, support platform sway reference; 5) eyes closed, support platform sway reference; 6) eyes open, support platform and visual surround sway reference. Each condition consists of three 20-second trials [13].

The sensory analysis ratio scores for the somatosensory, visual, and vestibular systems express how well a participant can use those specific cues for balance. The preference ratio defines how well a participant can ignore inaccurate visual clues in a situation of visual conflict.

Subjects were instructed, before each trial, to maintain a quiet and natural stance with arms by his or her side, avoiding locking his or her knees while keeping both feet in the pre-designated location throughout testing, to keep their eyes open or closed (mask was provided) depending on which test they were performing according to the SOT protocol. Each wore a harness vest, which was connected to 2 suspension straps on the overhead bar of the machine, to guarantee that they would not fall if they did lose their balance. If a participant lost balance or touched the wall, the trial was marked a fall and not included in analysis [11,13,19,20].

An overall composite equilibrium score was computed using the weighted average of all scores, with the more difficult conditions receiving higher weights. A higher composite score indicates better postural control. Using the average equilibrium score for each condition, ratio pairs were generated to see how well the participants used the specific sensory systems. Outcome measures of the SOT include a final score for each of the six conditions, a total composite score (COMP), and four sensory organization ratios (i.e., somatosensory [SOM], visual [VIS], vestibular [VEST], and preference [PREF]). The final score for each condition is an average of the three trials for said condition, while the composite score is a weighted average of all six individual. Scores are based on the individual's maximum anterior-posterior sway (deg) compared to the theoretical allowable sway (12.5 deg) and expressed as a percentage from 0 to 100. Larger equilibrium scores (ESs) (i.e., near 100%) suggest a greater sense of stability [11,17-20]. The analysis of the results was conducted blinded.

RESULTS

A total of 134 healthy student athletes (normative sample) with no history of a concussion were tested. These healthy student athletes were compared to a sample of 246 student athletes who had experienced a concussion (concussed sample). The descriptive statistics for both samples are found in Table 1.

All participants completed the SOT, and their equilibrium results were used to calculate a composite score, as well as four sensory results: somatosensory (SOM), visual (VIS), vestibular

Table 1: Demographics by gender for the normative and concussed samples at testing.				
	Normative Sample (n = 134)		Concussed Sample (n = 246)	
	Males (n = 102) Mean (SD)	Females (n = 32) Mean (SD)	Males (n = 108) (SD)	Females (n = 138) Mean Mean (SD)
Height (in)	72.58 (3.00)	66.41 (3.50)	71.35 (3.88)	65.73 (3.24)
Weight (lb)	221.96 (46.18)	147.35 (19.20)	197.40 (30.61)	149.14 (19.20)
Age (yr)	19.70 (2.17)	19.84* (2.54)	21.64 (2.86)	20.89 (2.67)

*n = 31

(VEST), and preference (PREF). The descriptive statistics for all the SOT results, and results from independent t-test comparisons of the two samples, are shown in Table 2.

To obtain norms for the normative sample, it was used separate multiple regression models to predict the composite score and each sensory result. Each regression model included gender (dummy coded), age, weight, height, age^2, and all possible 2-way interactions as predictors. Of the five separate analyses, the models for SOM and PREF did not produce any significant predictors; thus, they are not included in the table of results. The final regression models for the composite score, VIS, and VEST, are shown in Table 3.

Following the multiple regression analyses, it was tested whether the residuals (i.e., actual score– predicted score) from the resulting three models (i.e., for the composite, VIS, & VEST) were normally distributed using a Kolmogorov-Smirnov test. Each test failed to reject the null hypothesis of normality (composite: d = .054, *ns*; VIS: d = .093, *ns*; VEST: d = .066, *ns*). There were no significant predictors for PREF or SOM; therefore, it was calculated residuals using the mean of each distribution. The tests of these two sets of residuals found that the PREF residuals were normally distributed (d = .090, *ns*), but the SOM residuals were not normally distributed (d= .144, p < .01).

It was also tested whether the residuals displayed homoskedasticity using a Breush-Pagan test. With the previously mentioned tests collectively indicating the composite, VIS, VEST, and PREF data met all statistical assumptions; this data could generate a norming procedure for each sensory test result. This percentile rank will indicate whether the subject's SOT measure is sufficiently different from normal to warrant concern. Table 4 lists the necessary equations for obtaining predicted scores and standardizing the residual scores.

As stated previously, the SOM residuals were not normally distributed because the distribution was positively skewed. Therefore, it was determined percentile rank values from the normative sample SOM distribution directly, without referencing a standard normal distribution table. Those percentile ranks (in 10% intervals) and the SOM result each corresponds to from the distribution are presented in Table 5.

DISCUSSION

Computerized Dynamic Posturography (CDP) interprets how the human body integrates vestibular, visual, and somatosensory inputs with neuromuscular systems to maintain balance and is the gold standard to differentiate between sensory, motor, and central adaptive impairments to postural control [19-21]. It is recommended that vestibular clinics establish and utilize specific normative data [22]. Despite the recommendation of the development of normative values, limited published databases are available. Normative SOT scores for children, the elderly, and patients with vestibular disorders have been published, but no such data have been published for athletes, to our knowledge [23-25]. This is the first study presenting normative database of postural stability assessed by the SOT for athletes without concussion history.

Table 2: SOT equilibrium and sensory results for the normative and concussed samples.

	Normative Sample Mean (SD)	Concussed Sample Mean (SD)	t-value	df	p-value	d
SOT #1	96.01 (1.80)	95.65 (1.38)	2.01	220.45*	<.050	0.20
SOT #2	94.83 (2.10)	93.73 (2.58)	4.24	377.00	<.001	0.39
SOT #3	95.25 (2.26)	93.77 (2.62)	5.51	377.00	<.001	0.51
SOT #4	93.25 (3.84)	88.97 (6.27)	8.22	372.35*	<.001	0.66
SOT #5	86.63 (6.19)	77.18 (8.17)	12.65	339.47*	<.001	1.08
SOT #6	87.35 (7.17)	77.42 (10.03)	11.14	350.97*	<.001	0.93
Composite	86.99 (4.59)	79.36 (6.36)	12.25	377.00	<.001	1.13
SOM	98.78 (1.81)	97.99 (2.41)	3.60	341.06*	<.001	0.31
VIS	97.12 (3.39)	93.02 (6.48)	8.08	376.39*	<.001	0.63
VEST	90.22 (5.96)	80.68 (8.36)	12.85	351.24*	<.001	1.08
PREF	100.67 (3.64)	100.27 (5.87)	0.81	371.31*	.417	0.07

*Values for non-equivalent variances; SOM = Somatosensory, VIS = Visual, VEST = Vestibular, PREF = Preference, d = Cohen's-d effect size.

Table 3: Final multiple regression models predicting normative sample's SOT results.

Predictor	b	SE b	B	SE B	*t*	Adj. R^2	MSE
Composite							
Intercept	54.592	6.382					
Height	0.456	0.090	0.405	0.080	5.085*	0.157*	4.217
VIS							
Intercept	79.324	4.914					
Height	0.250	0.069	0.301	0.083	3.627*	0.084*	3.247
VEST							
Intercept	54.715	8.514					
Height	0.499	0.120	0.342	0.082	4.177*	0.110*	5.625

SOT Result+

*p < .05; +Only SOT results with any significant predictors are included; Adj. R^2 = Adjusted R^2; VIS = Visual, VEST = Vestibular, b = unstandardized regression coefficient, SE b = standard error of b; SE B = standard error of B; MSE = mean standard error.

Table 4: Equations used in norming procedure for each sensory measure.

Sensory Measure	Predicted Score	$Z_{Residual}$
Composite	=0.456(Height) + 54.592	$= \frac{Residual}{4.2}$
VIS	=0.250(Height) + 79.324	$= \frac{Residual}{3.23}$
VEST	=0.499(Height) + 54.715	$= \frac{Residual}{5.6}$
PREF	=100.67+	$= \frac{Residual}{3.64}$

+There were no significant predictors thus the mean PREF score of 100.67 from the normative sample is treated as the predicted score, VIS = Visual, VEST = Vestibular, PREF = Preference.

Table 5: Percentile ranks associated with somatosensory scores/

P. R.	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
SOM	94.79	95.92	96.94	97.94	98.92	98.97	98.98	100	100	101.03	105.43

P.R. = Percentile Rank, SOM = Somatosensory Score

There was no statistical difference within the demographic findings between the two group's age, height, or weight. It was observed in our sample that there was a higher incidence of concussion in female athletes than in male athletes (Table 1). This could be explained due to the evidence that females are more honest in reporting general injuries than males. For this reason, the concussion incidence data is unclear, but is generally consistent in showing a higher risk in females as compared to males in similar sports or is influenced by a reporting bias [8,15,27].

The SOT test's literature confirm that it was the first test performed using the manufacturer's standard protocol. According to several studies, the SOT scores declined with aging, but the variable age did not present a statistically significant difference among our sample, as well as no interaction for gender using a two-way ANOVA [24-25].

All six conditions presented a statistically significant difference comparing the values from one group to another, as well as for the four sensory organization ratios (Table 2) showing that SOT could assist in the return to play decision even if the athlete has normal values for the test, decreasing the risk of another concussion [12,28,29].

Also, this decrease in all values can be explained by an inability of the corporal balance to make effective use of sensory systems. This can have inappropriate adaptive responses during the test, resulting in the use of inaccurate systems as a current finding in subjects after a concussion [24- 26,28]. This demonstrates how important is to have normative data of an individual's performance, so that it can be compared in the absence of an individualized baseline score. With these findings, the SOT scores obtained through the normative group of the athletes could be valuable in helping monitor decisions for return to play [17].

Since the postural control is maintained through the combined afferent information generated by the somatosensory, visual, and vestibular systems, impairment in one or more of these systems leads to balance issue. In relation to sensory organization ratios, a significant reduction especially from Visual (VIS) and vestibular (VEST) values - VIS (97.12 versus 93.02) and VEST (90.22 versus 80.68) was discovered, and both ratios had statistical influence score from height (Table 3). The vestibular and visual inputs are major component of the balance system; therefore, its disturbance or distortion can be a cause of dizziness. If visual limitations prevent a vestibular component from being recognized, affected individuals may not be afforded proper treatment. Thus, these results suggest that the neural circuitry that integrates the vestibular and visual information might be affected due the concussion event. These deficits are interpreted as evidence that previously concussed individuals have difficulty maintaining postural control due an inability to properly integrate sensory the information's to maintaining balance [1-4,9,10,25,26].

A normal performance on CDP requires accurate visual, vestibular, and somatosensory inputs and an intact musculoskeletal system. Thus, comparing the SOT composite score to the normative values could be an appropriate evaluation technique for identifying postural control impairments after concussion [21,25-28].

Considering subjects with abnormal or low values, especially for conditions 5 and 6, where both the visual and somatosensory cues are absent, the subject must rely only on vestibular information to maintain balance. The data can show how individuals are affected, as well as the vestibular component, with the inability to maintain postural control. In our sample, it was observed that the concussion group had lower performance for conditions 5 and 6 comparing to normative sample (Table 4). Some studies suggest that the concussion may alter the central processing of vestibular and visual information [28,30].

Another important finding is the lower SOT scores for concussion compared with normative data which agrees with studies that showed that SOT was sensitive for athletes with concussion [13,26,31].

Limitations within this study included the athletes in the normative group that have suffered from previous concussions. This is because some concussions go unreported and undiagnosed. We also believe that is necessary longitudinal research in concussed individuals.

Overall, the SOT can be a positive additional assessment of concussed athletes. The test information may also provide scientific data to aid in return-to-play and practice. Also, the SOT can assist in indicating to physicians and athletic trainers as to how severe and serious a player's concussion may be with other obtained measures. Comparing the post-concussion scores to normative values can be used after injury as part of a multifaceted evaluation to identify postural control impairments.

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