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New Analyses of the Sensory Organization Test Compared to the Clinical Test of Sensory Integration and Balance in Patients with Benign Paroxysmal Positional Vertigo

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Abstract

Objective—To determine whether the Sensory Organization Test (SOT) of the computerized dynamic posturography battery or the Clinical Test of Sensory Integration and Balance (CTSIB) is more likely to indicate balance disorders in people with benign paroxysmal positional vertigo.

Study design—Normal controls were compared to patients with unilateral benign paroxysmal positional vertigo of the posterior semicircular canal (BPPV).

Methods—Subjects performed tests with eyes open or closed on stable and unstable surfaces, with head still or with head moving at 0.33 Hz in pitch or yaw. Dependent variables were the percent time of the standard duration each subject could perform the task, the number of head motions made, and kinematic variables measured with head- and torso-mounted inertial motion units.

Results—Because equilibrium scores of normals improved significantly over repeated trials on SOT patients were given only 1 trial per condition. For percent time between-group differences were found on CTSIB with eyes closed, on foam, head moving in yaw showing significantly reduced performance by BPPV subjects compared to controls. Compared to controls patients made significantly fewer head movements on CTSIB, eyes closed, on foam, head still, pitch and yaw. Kinematic data also differed between the groups on tests with eyes closed, unstable surfaces with different head movement combinations, indicating increased instability in BPPV patients.

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Location of work:

Data were collected at the Bobby R Alford Department of Otolaryngology – Head and Neck Surgery, Baylor College of Medicine.

Financial Disclosure

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Conflict of interest

None

Presented:

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Conclusion—For screening, CTSIB with head movements is more likely than SOT to indicate balance deficits, especially when dependent measures include percent time as well as head movement counts and kinematic measures.

Keywords

balance testing; screening; Romberg; vestibular testing

Introduction

In their seminal paper Nashner et al. reported that patients with vestibular impairments have increased postural sway compared to normals on the standing balance tests of computerized dynamic posturography (CDP) (1). The Sensory Organization Test (SOT) subtest, with its subconditions based on combinations of stable/ unstable support surfaces, vision available/ unavailable, and visual surround stationary/ moving. Performance on conditions using the unstable force platform with eyes closed or sway-referenced visual surround motion are most consistent with vestibular impairments. Dobie (2) expressed reservations about the value of CDP in diagnosing patients with vestibular disorders. Many years later experts are still arguing about that question and the best way to administer the test (3).

Shumway-Cook and Horak described a low-tech, inexpensive balance test based on the same principles of SOT, the Clinical Test of Sensory Integration and Balance (CTSIB) (4). It is easily administered using a stop-watch and a slab of medium density, compliant foam. Norms have been reported for adults (5) and test-retest reliability has been reported for children (6).

Although both SOT and CTSIB are based on the Romberg test (7) they differ in some ways. SOT is performed for 20-second trials; CTSIB is performed for 30-second trials. The dependent measure for SOT is the equilibrium score, based on estimates of postural sway derived from measuring the forces under the feet; the dependent measure for CTSIB is time. SOT is performed on a non-compliant, computer-controlled force platform that moves in phase with the subject's postural sway in the fore-aft direction, i.e. the so-called sway-referenced conditions; CTSIB is performed on foam that is continuously compliant in all directions but does not move. Foot positions are different: for SOT the feet are hip distance apart; for CTSIB feet are usually together. When CTSIB is performed with feet together scores correlate better with SOT scores than when it is performed with feet apart, Although neither test position is strongly correlated with SOT (8).

SOT sway scores and a unique CTSIB score correlated well in one study (9). Another study found no significant differences among tests on sway measures with eyes closed on foam compared to a tilted force platform, in normals, patients with bilateral vestibular loss and patients with cerebellar atrophy (10). Allum et al. compared tests with eyes closed on unstable surfaces, either foam or a moving force platform. They reported that compared to CTSIB, on the fore-aft sway referenced SOT conditions trunk roll angles and velocity were decreased, pitch angles and velocity were increased, and roll frequency spectra amplitudes were decreased (11); they concluded that the two tests yield different trunk sway patterns.

SOT and CTSIB are widely used, although perhaps in different settings. The simplest dependent measure of performance is time although current technology allows for relatively easy measurement of some kinematic variables, too. The goal of this study was to determine if SOT and CTSIB differ on a measure of timed performance and on some kinematic measures of trunk motion in normals and patients with unilateral benign paroxysmal positional vertigo (BPPV).

Materials and Methods

Subjects

Subjects were 14 normal controls, mean age 34.5, (SD 9.1, range 24.3 to 46.5) and 26 patients with unilateral BPPV of the posterior semicircular canal (BPPVs), mean age 59.2 yrs (SD 11.6, range 34.7 to 78.8), mean length of illness 0.28 yrs (SD 0.45, range 0.03 to 1.63). Control subjects were screened with a health history, Dix-Hallpike maneuvers, left-right (yaw) head shaking, and yaw head thrusts. Patients were all diagnosed by board-certified physicians based on their histories, Dix-Hallpike responses, and any other tests used by their physicians. BPPVs were tested prior to treatment. The Institutional Review Board for Baylor College of Medicine and Affiliated Hospitals approved this study. All subjects gave informed consent prior to participation.

All subjects were ambulatory without canes or other gait aids and wore comfortable clothes and socks without shoes. Every subject wore an inertial motion sensor (IMU; Xsens North America Inc., Los Angeles, CA; fastened on the back at the mid-thoracic level to a standard lightweight safety vest and an IMU on a lightweight, plastic headband atop the head. Each IMU was $5.25 \times 3.75 \times 2$ cm and weighed 28.3 g. These IMU's measure angular motion (deg) as well as calibrated angular velocity (deg/sec) and accelerations (m/s²) about and along the 3 dimensions, respectively. These IMU's have a typical angular resolution of 0.05°; static accuracy of 0.5° in roll/pitch and 1.0° in yaw, with a stated dynamic accuracy of 2° RMS. A single data acquisition program (LabView, National Instruments, Austin, TX, USA) collected time-synchronized data from the IMUs. The IMU data were sampled at 100 Hz.

During SOT dynamic pitch and roll head oscillations at 0.14 Hz, 0.33 Hz and 0.6 Hz, $\pm 30^\circ$, but not static head tilts, have been shown to elicit significantly increased postural sway (12). Yaw head rotations, however, are often easier for patients in rehabilitation to understand and imitate. Roll rotations were not used because some patients undergoing rehabilitation have difficulty understanding the concept of roll. Therefore subjects were asked to make pitch and yaw head rotations. During head motion trials the 0.33 Hz signal to guide head movements was provided via an iPod (Apple, Inc.) portable computerized music player that was clipped to the vest; the subject listened to the sound via an ear bud earphone or via desktop amplifiers. The subject heard a frequency-modulated signal that oscillated between 170 and 450 Hz, at a comfortable intensity level.

Methodology

Both test paradigms had two visual conditions (eyes open, closed), two support surface conditions (stable, unstable) and three head movement conditions (head stationary, moving in pitch, moving in yaw), totaling 12 conditions. Trials were stopped if subjects moved their arms, took steps or, on eyes closed trials, opened their eyes. To avoid learning over trials only one trial per condition per test was used.

SOT was performed on an Equitest (Neurocom International, Clackamas, OR) CDP system, per the manufacturer's instructions with feet hip distance apart, with the safety harness attached to the frame, for up to 20 seconds. CTSIB was performed either on the floor or on Sunmate medium density compliant foam (Dynamic Systems, Leicester, NC), with feet together, for up to 30 seconds (5).

To make performance time equivalent the percentages of maximum trial time (percent time) were compared. For both SOT and CTSIB the kinematic parameters were calculated over the period of motion defined by a defined cycle range, to minimize the startle effect of maintaining balance on the unstable surface while performing head movements and for

obtaining stable measures as determined during pilot studies. For SOT, the range was from cycle 3 – to the maximum number of cycles completed. For CTSIB, the range was from cycles 5 – to the maximum number of cycles completed. Thus, at least 4 cycles were obtained from both tests. For head still conditions, the vector indices for each “ anticipated cycle” of head motion were computed based on an assumed periodicity of 3 sec ($f = 0.33$ Hz). Parameters were calculated to quantify sway in the mediolateral and anterior posterior directions for the trunk segment only. The root mean squares (RMS) of five balance parameters were calculated to characterize the balance performance of subjects: 1) anterior-posterior acceleration (AX), mediolateral acceleration (AY), roll angular velocity (R), pitch angular velocity (P), and yaw angular velocity (Y). Kinematic data were not analyzed from subjects who did not perform SOT or CTSIB tasks for at least 3 and 5 cycles of head movement, respectively. All subjects performed all trials with eyes open for the maximum trial time. SOT is more sensitive to vestibular disorders with eyes closed than open (13) so we report here only the data from trials with eyes closed.

Statistical Methods

Changes in primary study outcomes (percent time, head movement count, kinematics) were examined using multilevel analysis and mixed effect models (14). Separate models were produced and fitted to each outcome. Within each model we examined the significance of within subject effect (within subject over test, and over various conditions of eyes, surface and head motion) and between subjects (BPPV patients and normal controls) using maximum likelihood estimation techniques. Interaction effects were included in each model and tested for significance. Adjustments were made for multiple comparisons. $P < 0.05$ was considered as statistically significant. Paired comparisons were made for all variables across conditions that changed in only one factor level (meaningful comparisons). The four types of meaningful comparisons were 1) Disease state – controls/BPPVs, 2) Test – CTSIB/ SOT, 3) Support surface – stable/ unstable, and 4) head movement conditions – still/ yaw/ pitch. All analyses were performed in SAS Statistical Software (version 9.3, SAS, Cary, NC).

Results

Normal subjects were given the standard 3 trials on SOT. Without additional head movements, the Equitest Equilibrium score improved significantly from Trial 1 to Trial 2, $p < 0.0009$. With head pitch scores improved significantly from Trial 1 to Trial 3 and between Trials 2 and 3, $p = 0.009$ and $p = 0.014$, respectively. The difference between Trials 1 and 2, however, was not significant. With head yaw scores did not improve significantly over trials, See Table 1.

Time

For percent time, few significant differences were found. With one exception (SOT with head still) controls were significantly more likely than BPPV subjects to complete the tests on unstable surfaces with eyes closed. See Table 2.

Controls did not differ on comparable SOT and CTSIB subtests. BPPVs showed no differences between SOT and CTSIB on head still and head pitch, but the significant difference at head yaw/ unstable surface, $p < 0.0001$, indicated that subjects performed CTSIB for less time than SOT. On CTSIB with unstable surface/ eyes closed/ yaw head movements controls performed the test for significantly greater percent time than BPPVs, $p = 0.009$; the difference between patients and controls remained significant after adjustment for the potential confounding influence of age ($p = 0.025$). BPPVs had significant differences between head still and head yaw conditions, and between head yaw and pitch conditions, on CTSIB/ unstable/ eyes closed, $p < 0.0001$. See Table 3.

Head Movements

On stable support surfaces almost all subjects performed enough head movement cycles. For conditions on unstable surfaces, however, some subjects could not complete enough head movement cycles. Except for one condition, controls were better able to complete enough head movements than BPPVs, especially on CTSIB, where the BPPVs and controls differed significantly at head pitch and yaw ($p < 0.0001$) and approached significance at head still ($p = 0.07$). For SOT/ unstable/ eyes closed/ head still, pitch or yaw, BPPVs and controls did not differ significantly ($p = 0.35$, $p = 0.16$ and $p = 0.14$, respectively). See Table 4.

Kinematic analyses

For all variables, R, P, Y, AX, and AY, the magnitude and variability of measures on the stable surface were generally lower than on the unstable surface. On the stable surface patients and controls had similar responses for all kinematic variables. On the unstable surface, and at most conditions, controls had significantly lower responses than BPPVs; this pattern was observed for all kinematic variables. The kinematic results are shown in Figures 1 and 2.

Discussion

Control subjects demonstrated one-trial learning on SOT head still trials with eyes closed and sway-referenced motion of the force platform. They also demonstrated some learning on head pitch trials. Some controls may also have fatigued over trials, which might have accounted for the lack of change over trials in the head yaw conditions, which were always performed after head still and head pitch trials. Due to this effect of learning over trials, and the potential for fatiguing patient subjects, we used only one trial per condition with all patients.

Controls and BPPVs had equivalent percent time on most comparable subtests, except the unstable surface/ yaw head movements/ eyes closed. SOT percent time did not differ between the groups, but CTSIB percent time with head yaw differed. Therefore, the CTSIB subtest may be more challenging. This idea is further supported by group comparisons that showed significantly fewer subjects could complete a minimum number of head movements for CTSIB rather than SOT. Thus, if the main dependent measure used by the clinician for screening is percent time CTSIB is an adequate test.

Kinematic data should be considered with caution because some subjects could not perform enough head movements on some trials. Differences were significant for CTSIB on foam/ eyes closed/ head pitch or yaw, and approached significance for head still. Thus the mere inability ability to make at least 5 oscillations of the head, reflexively in the head still condition and voluntarily in the head pitch and head yaw conditions may indicate dysfunction. Because BPPVs could make enough head movements on SOT but not on CTSIB, for BPPVs CTSIB may be a more challenging test. Indeed, Allum et al commented that CTSIB may be the more difficult test battery (11).

Even with the data set limited by the ability of subjects to perform enough head movements, especially for the BPPVs, most kinematic variables indicated significant differences between groups in the unstable conditions on SOT and CTSIB. Controls had minimal differences across most kinematic variables. BPPVs, however, showed similar changes in all kinematic variables for all head movement conditions, in just the unstable conditions, on both SOT and CTSIB. This finding supports previous findings that some BPPVs have normal pre-treatment performance on SOT but some BPPVs have abnormal pre-treatment responses (15, 16). Thus, CTSIB and SOT are also equivalent for most kinematic measures, suggesting that CTSIB is an adequate test for screening.

Fortunately, the literature also shows that BPPV patients who have balance deficits prior to treatment improve to normal levels after treatment with repositioning maneuvers (15, 16). Therefore, treatment with additional balance therapy is not usually necessary. Quite often after successful treatment with repositioning maneuvers patients report subtle but immediate improvements in balance. These findings and comments suggest that in patients with no other vestibular pathology the balance problem is probably caused by the presence of otoconial matter in the semicircular canal and/ or by unweighting the utricle.

The two test populations differed by age. Controls were younger than BPPVs. The age difference might have affected differences between controls and patients but would not necessarily have affected differences between the two test batteries.

In general, these results support the previous evidence that SOT and CTSIB yield similar results. Neither test is diagnostic, but both tests are useful (7). CTSIB is much less expensive than SOT and may continue to be the screening test of choice for small clinics, other environments in which use of relatively large equipment that requires electricity may be impractical, and as part of a battery of tests for studies to screen large groups of people for vestibular disorders rapidly (17, 18).

Conclusions

Both CTSIB and SOT are useful for assessing the standing balance, but they provide different information. CTSIB may be more useful for rapid, inexpensive screening. The standard measure of CTSIB, time, should be augmented with a measure of the ability to make oscillations of the head. Kinematic measures are a third level of analysis that may be informative if the equipment is available.

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Figure 1.

Root mean square torso angular velocity. A. Roll. B. Pitch. C. Yaw. C, CTSIB. S, SOT. N, head still. P, head pitch. Y, head yaw. Center horizontal bars are medians; rectangle ends are interquartile ranges; error bars are 10th and 90th deciles; circles are outliers.

Figure 2.

Root mean square torso accelerations. A. Anteroposterior (A-P). B. Mediolateral (M-L). C, CTSIB. S, SOT. N, head still. P, head pitch. Y, head yaw. Center horizontal bars are medians; rectangle ends are interquartile ranges; error bars are 10th and 90th deciles; circles are outliers.

Table 1

Percent of subjects per group who could complete each test condition.

	CTSIB			SOT		
	N	P	Y	N	P	Y
Controls (N=14) [*] (N=13)	100	86	93	[*] 100	100	100
BPPV (N=26)	35	15	12	73	58	69

N= head still, P= additional pitch head movements, Y= additional yaw head movements.

^{*} One subject's data are missing.

Table 2

Percent of subjects per group who could complete each test condition.

	CTSIB			SOT		
	N	P	Y	N	P	Y
Controls (N=14) * (N=13)	100	86	93	*100	100	100
BPPV (N=26)	35	15	12	73	58	69

N= head still, P= additional pitch head movements, Y= additional yaw head movements.

* One subject's data are missing.

Table 3

Percent time subjects could perform conditions with eyes closed on unstable surfaces, mean (standard deviation, ranges).

	CTSIB			SOT		
	N	P	Y	N	P	Y
Controls	100 (0.08, 99.7–100)	90.3 (23.9, 27.3–100)	* > 100 (0.09, 99.7–100)	100 (0)	100 (0)	100 (0)
BPPV	^ 54.6 (38.5, 7.0–100)	\$ 34.8 (30.5, 11.0–100)	^ # * \$ 38.1 (29.4, 10.2–100)	92.2 (18.2, 44–100)	95.1 (10.2, 60–100)	# 91.7 (18.3, 46–100)

N= head still, P= additional pitch head movements, Y= additional yaw head movements.
^ # *\$ denote paired comparisons that are statistically significantly different. Each symbol indicates a unique paired comparison. \$ indicates a significant difference between rows but within the same column; the other symbols denote differences within the same row across columns.

Table 4

Percent of subjects who were able to perform at least 5 head motions per condition.

	CTSIB			SOT		
	N ⁺	P [*]	Y [^]	N	P	Y
Controls (N=14)	100	86	100	93	86	100
BPPV (N=26)	73	19	19	100	62	81

* and ^ indicate significant differences between groups within columns, at p<0.001, based on Fisher exact tests.

+ indicates a pair that approached significant differences.