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Modified Head Shake Computerized Dynamic Posturography

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Purpose: Recent research on head shake posturography has demonstrated a modest increase in sensitivity to identifying peripheral vestibular system asymmetry when horizontal head movements were added to portions of the standard Sensory Organization Test (SOT) battery. However, limitations with respect to the head shake protocol were outlined, and usable data for assessing performance could not be established. The purpose of this study was to test a change in protocol for use of head shake SOT to address the noted limitations.

Method: Forty participants ranging in age from 20 to 79 years with no history of dizziness completed Conditions 2 and 5 of the SOT portion of computerized dynamic posturography on EquiTest equipment, while maintaining head still as well as 4 horizontal head movement velocity tasks.

Results: Slope of a linear regression fit to 6 performance points was used to characterize each participant. Spearman's ranked correlation (*r*) indicated a significant relationship between the slope of the line representing a decline in performance with age ($r = -.52$, $p = .0006$).

Conclusions: The head shake modification showed a trend in increasing the separation of normal individuals across age and eliminated the limitations addressed in earlier research. Future research will investigate the head shake modification for identifying vestibular peripheral system asymmetries.

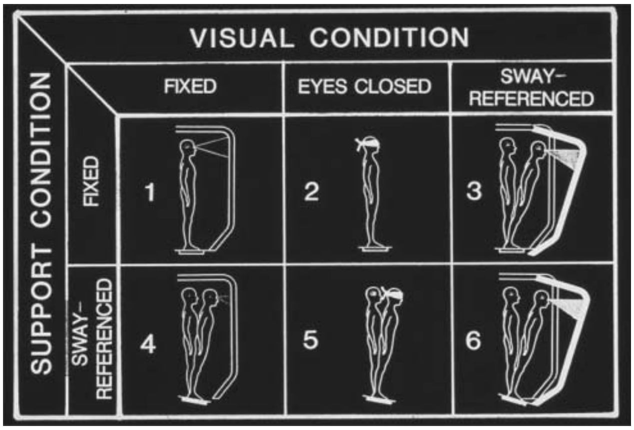
Key Words: head shake, Sensory Organization Test, computerized dynamic posturography, dizziness

Computerized dynamic posturography (CDP) is an assessment of an individual's ability to maintain static and dynamic stance. The assessment is composed of a battery of tests that are analogous to everyday conditions of daily living. There are four primary components to CDP that are used clinically: the Sensory Organization Test (SOT), Motor Control Test, Adaptation Testing, and Postural Evoked Response Test. The SOT is intended to help determine how well an individual can use the visual and proprioceptive systems with the vestibular system or the vestibular system alone. Furthermore, it is the most frequently used component of CDP. SOT is made up of six conditions that assess the individual's balance performance during a sequence of six increasingly difficult subtests. The subtests include combinations of eyes open or eyes closed, and conditions with a moving sway reference (i.e., movement of the visual background and/or movement of the forceplate; see Figure 1). In particular, participants are asked to stand on a forceplate and maintain stable stance while the magnitude of sway in the anterior/posterior dimension is quantified (Shepard, Schulz, Alexander, Gu, & Boismier, 1993).

The information obtained from the various components of CDP is highly valuable when the goal of the assessment is to investigate the functional status of compensation or rehabilitative needs and/or progress (El-Kashlan, Shepard, Asher, Smith-Wheelock, & Telian, 1998; Nashner, 1993). However, CDP (with SOT as the most commonly used protocol) is limited as a tool to screen for site of lesion for possible unilateral peripheral vestibular paresis (Allum & Shepard, 1999; Chandra & Shepard, 1996; El-Kashlan et al., 1998; Nashner, 1993; Shepard et al., 1993).

Prior work by Mishra, Davis, Speers, and Shepard (2009) demonstrated increased sensitivity to the identification of peripheral vestibular system asymmetry (site-of-lesion

Figure 1. Schematic of the Sensory Organization Test portion of computerized dynamic posturography. Reprinted with permission from NeuroCom International, *EquiTest Operator's Manual*, Version 3.0.



diagnostics) when dynamic head movements (head shake) were added to portions of the SOT battery (SOT Conditions 2 and 5). For clarification, during Condition 2 of the SOT protocol, the forceplate is stationary while the individual is instructed to stand quietly with eyes closed for 20 s. During Condition 5 of the SOT protocol, the forceplate rotates forward or backward in the sagittal plane proportionally to the amount of sway by the individual. The individual is again instructed to stand quietly with eyes closed while maintaining upright stance on the forceplate.

The head shake modification to the standard SOT Conditions 2 and 5 proposed by Mishra et al. (2009) incorporated horizontal head movements with a peak head velocity of 60°/s. Their work revealed a limitation to the performance of the head shake SOT protocol for the diagnostic site-of-lesion purpose using the head shake modification to SOT Conditions 2 and 5. The limitation was that the two conditions used to assess postural control performance during head movement—head shake Condition 2 (eyes closed while standing on a stable support surface) at 60°/s and head shake Condition 5 (eyes closed while standing on a sway-referenced support surface) at 60°/s—proved to be restricted in their range. The more difficult of the two (Condition 5 at 60°/s) was too difficult for a number of participants (i.e., yielding fall reactions on the trials), giving a floor effect and not allowing for data usable for assessing performance. The easier of the two conditions (Condition 2 at 60°/s), was not challenging enough and did not differentiate patients in an adequate manner based on head movement sensitivity. Therefore, the current project was proposed to first broaden the range of testing to allow for increased challenge in head shake Condition 2 (the easier of the two test conditions) and decreased challenge in head shake Condition 5 (the more difficult of the two test conditions), with the intent that this information will be used in a future study to improve identification of unilateral peripheral vestibular hypofunction and determine its sensitivity and specificity. Second, we sought to investigate the use of a single outcome variable that incorporated all of the data points acquired during the testing.

Method

Normal participants were recruited from community sources in Omaha, NE, and Rochester, MN. Volunteers signed a written consent form approved by the institutional review board prior to data collection. Forty participants (17 men and 23 women) were included in the statistical analysis. Based on age, each participant was placed into the appropriate age group as follows: Group 1 consisted of 10 participants ranging in age from 20 to 39 years, Group 2 comprised 10 participants age 40 to 59 years, Group 3 comprised 10 participants age 60 to 69 years, and Group 4 consisted of 10 participants ranging in age from 70 to 79 years. The determination of the age grouping was based on prior work investigating the effects of age on postural control as assessed by EquiTest (Nashner, 1993; Shepard et al., 1993). All participants were considered normal based on the following criteria obtained through an interview process: (a) negative history of any form of dizziness (including complaints of lightheadedness, vertigo, or unsteadiness) lasting longer than 1 hr or recurring for greater than 1 day; (b) negative history of any current otologic disease actively involving the middle ear; (c) negative history of perceived, progressive unilateral hearing loss; (d) negative history of current or past neuromuscular disorder; (e) negative history of any disorder interfering with mobility, stance, or neck range of motion; (f) currently not taking any anti-anxiety medications, antiseizure medications, or narcotic-based pain medications; and (g) no use of alcohol within 24 hr of participation in the study.

Study Protocol

After inclusion criteria were met, participants were asked to remove their shoes prior to testing. During all standing conditions, participants wore a safety harness that was fastened to a roll bar on the EquiTest equipment. The standard SOT using three trials of Conditions 2 and 5 was performed on all participants prior to the head shake modification protocol. Analyses of the results were obtained by taking the average equilibrium score from each of the three trials of the condition. The equilibrium score is calculated by the EquiTest based on the maximum excursions of sway in the anterior/posterior plane of 12.5° during the 20 s of recording for each trial within a specific condition (Allum & Shepard, 1999).

Once the SOT Trials 2 and 5 were completed in the traditional manner (as also executed by Mishra et al., 2009), all participants then performed the modified SOT protocol of Conditions 2 and 5 while performing horizontal head movements with a peak head velocity of 60°/s as proposed by Mishra et al. (2009). Participants also completed two additional head shake conditions that consisted of peak head velocity of 120°/s for SOT Condition 2 and a peak head velocity of 15°/s for SOT Condition 5. All horizontal head movements were executed with an excursion of 15° to both sides of center, giving a total excursion of 30° and the head velocities as noted. Therefore, the frequency of horizontal head rotation was 0.16 Hz with a velocity of 15°/s, 0.64 Hz with a velocity of 60°/s, and 1.28 Hz with a velocity of 120°/s. These head shake conditions were randomized, as were the different head shake velocity trials within SOT Conditions 2 and 5. Three trials of each velocity condition were also performed for the head shake protocol. Thus, participants fell into one of eight groups based on order of the four head movement conditions (see Table 1).

During each of the head shake conditions, a three-dimensional rate sensor accelerometer was worn on the participant's head via a comfortable headband. This provided the speed and the excursion of the head movement for the examiner to monitor during the head shake SOT trials. Participants were allowed to practice the task and were cued by an audible signal from a metronome as well as verbal feedback provided by the examiner during the head shake conditions. All participants were instructed to maintain the head-shaking task for 20 s during each trial. To eliminate fatigue, participants were given a 1-min sitting break between each of the head shake conditions. Additional sitting breaks were permitted if indicated by the participant.

Statistical Analysis

The mean and standard deviation for each condition within each age group were calculated. In addition, means, standard deviations, and range values were calculated to determine how well each participant was able to match the desired head shake condition velocities. Each participant's change in performance with increasing difficulty of the task was characterized by the slope of a linear regression line fit between condition difficulty rank (Condition 1 = SOT 2, Condition 2 = HS 2-60°/s, Condition 3 = HS 2-120°/s, Condition 4 = SOT 5, Condition 5 = HS 5-15°/s, and Condition 6 = HS 5-60°/s) and equilibrium score; in addition, the scatter plot and corresponding coefficient of correlation were assessed for each individual participant to ensure that the slope was an appropriate summary measure.

The association between individual slopes and age was assessed using Spearman's rank correlation (*r*). The mean slopes were compared between age groups using Wilcoxon rank-sum tests. Mean equilibrium scores were also compared between conditions using Wilcoxon signed-ranks tests for the overall age groups. *P* values < .05 were considered statistically significant. All statistical calculations were performed using JMP software (SAS Institute, 2007).

Results

Average equilibrium scores decreased as condition difficulty increased within each age group, as demonstrated by the means and negative average slope in each age group (see Table 2). The relationship between equilibrium score and condition ranking demonstrated a good correlation for each individual participant, with correlation coefficients ranging from –.70 to –.97 (*Mdn* = –.89). Thus, we used the individual participant slopes to estimate change across conditions. The average mean slope was highest (i.e., lowest decline in performance across the six conditions) for Group 1 followed by Group 2, Group 3, and then Group 4. However, it should be noted that differences between Groups 1, 2, and 3 were not significantly different (Group 1 vs. Group 2, *p* = .31; Group 1 vs. Group 3, *p* = .39, Group 2 vs. Group 3, *p* = .91), while Group 4 demonstrated a significantly higher rate of decline across the six conditions when compared with each of the other three groups (Group 4 vs. Group 1, *p* = .01; Group 4 vs. Group 2, *p* = .002; Group 4 vs. Group 3, *p* = .02; see Figure 2). In addition, there was a significant correlation between slope and age as a continuous variable (*r* = –.52, *p* = .0006). Table 3 provides the mean, standard deviation, and range values of the four head shake conditions by age. Overall, all participants were able to maintain the desired velocity task during the four head shake conditions within a small variance. Of importance, the older groups performed equally as well as the younger participants in the accuracy with which they maintained the task velocity.

Mean equilibrium scores were compared between conditions using the Wilcoxon signed-ranks tests, with all age groups collapsed to evaluate the benefit of the new head shake modifications (i.e., HS 2-120°/s and HS 5-15°/s) in

Table 1. Eight groups based on order of the four head movement conditions.

Group	Order of head movement conditions
1	Condition 2: 3 trials of head shake (HS) 60°/s (HS 2-60°/s) and 3 trials of 120°/s (HS 2-120°/s); Condition 5: 3 trials of 15°/s (HS 5-15°/s) and 3 trials of 60°/s (HS 5-60°/s)
2	Condition 2: 3 trials of 60°/s (HS 2-60°/s) and 3 trials of 120°/s (HS 2-120°/s); Condition 5: 3 trials of 60°/s (HS 5-60°/s) and 3 trials of 15°/s (HS 5-15°/s)
3	Condition 2: 3 trials of 120°/s (HS 2-120°/s) and 3 trials of 60°/s (HS 2-60°/s); Condition 5: 3 trials of 15°/s (HS 5-15°/s) and 3 trials of 60°/s (HS 5-60°/s)
4	Condition 2: 3 trials of 120°/s (HS 2-120°/s) and 3 trials of 60°/s (HS 2-60°/s); Condition 5: 3 trials of 60°/s (HS 5-60°/s) and 3 trials of 15°/s (HS 5-15°/s)
5	Condition 5: 3 trials of 15°/s (HS 5-15°/s) and 3 trials of 60°/s (HS 5-60°/s); Condition 2: 3 trials of 60°/s (HS 2-60°/s) and 3 trials of 120°/s (HS 2-120°/s)
6	Condition 5: 3 trials of 15°/s (HS 5-15°/s) and 3 trials of 60°/s (HS 5-60°/s); Condition 2: 3 trials of 120°/s (HS 2-120°/s) and 3 trials of 60°/s (HS 2-60°/s)
7	Condition 5: 3 trials of 60°/s (HS 5-60°/s) and 3 trials of 15°/s (HS 5-15°/s); Condition 2: 3 trials of 60°/s (HS 2-60°/s) and 3 trials of 120°/s (HS 2-120°/s)
8	Condition 5: 3 trials of 60°/s (HS 5-60°/s) and 3 trials of 15°/s (HS 5-15°/s); Condition 2: 3 trials of 120°/s (HS 2-120°/s) and 3 trials of 60°/s (HS 2-60°/s)

Table 2. Mean, standard deviation, and average slope values for modified head shake conditions by age.

Age group (years)	Condition						Slope
	SOT 2	HS 2-60°/s	HS 2-120°/s	SOT 5	HS 5-15°/s	HS 5-60°/s	
20–39							
M	91.63	91.77	91.00	73.10	68.87	69.40	–5.6507
SD	2.76	4.61	4.79	6.40	13.34	11.50	3.05
40–59							
M	91.47	91.07	89.83	68.50	67.53	65.77	–6.2983
SD	3.54	3.17	2.32	5.25	5.91	4.90	1.28
60–69							
M	89.27	89.63	87.30	66.17	64.43	62.23	–6.6257
SD	2.92	4.12	5.45	11.42	10.9	12.04	2.64
70–79							
M	90.67	90.87	89.60	61.70	54.90	54.50	–9.051
SD	2.48	2.94	2.59	10.35	9.00	8.69	1.87

Note. The slope for each individual participant was estimated across the 6 conditions in order of difficulty; individual participant slopes were then averaged for participants within each age group. SOT = Sensory Organization Test; HS = head shake.

eliminating the ceiling and floor effect noted by Mishra et al. (2009) and to justify the need for all six parameters in future research with patient populations. Specifically, performance on HS 2-120°/s was compared with the standard condition SOT 2, and HS 2-60°/s was compared with standard condition SOT 2, whereas HS 5-15°/s was compared with the standard condition SOT 5, and HS 5-60°/s was compared with standard condition SOT 5.

There was a significant difference in performance between HS 2-120°/s and SOT 2 ($p = .0237$); however, there was not a significant difference in performance between HS 2-60°/s and SOT 2 ($p = .8640$). There was also a significant difference in performance between HS 2-120°/s and HS 2-60°/s conditions ($p = .01$). These findings suggest that HS 2-120°/s was a more challenging condition than HS 2-60°/s for the normal participants to perform than the standard SOT 2 condition, thus eliminating the ceiling effect noted by Mishra et al. (2009). Based on these findings, it may not be necessary to include HS 2-60°/s in a future study with patients.

When comparing the head shake modifications with the standard condition SOT 5, there was a significant difference in performance between HS 5-15°/s and SOT 5 ($p = .018$) and between HS 5-60°/s and SOT 5 ($p = .001$). No statistical difference in performance was noted for HS 5-60°/s or HS 5-15°/s conditions ($p = .41$). It should also be noted that only 2 participants (both from Group 6) presented with fall reactions to the first trial on HS 5-60°/s; no fall reactions were noted for HS 5-15°/s. From a qualitative standpoint, this finding differs from that reported by Mishra et al. (2009), where a majority of their patients had fall reactions on HS 5-60°/s, thus causing the floor effect. Our results

Figure 2. Box plots showing the distribution of estimated slope across six conditions for the four age groups. The line in the middle of the box represents the median, while the ends of the box represent the 25th and 75th percentiles. The lines extending from the box represent the minimum and maximum observed values.

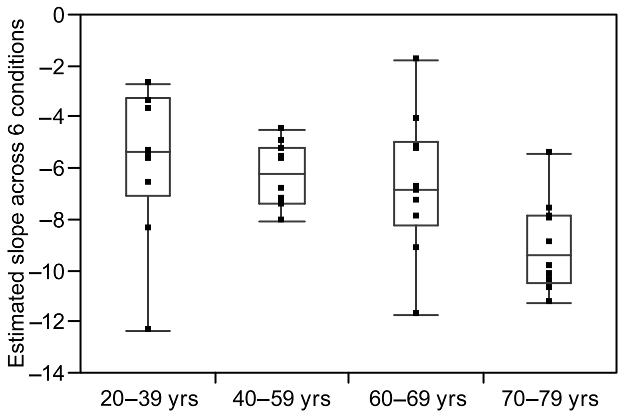


Table 3. Mean, standard deviation, and range values for velocity presentations during the four head shake conditions by age.

Age group (years)	Condition			
	HS 2-60°/s	HS 2-120°/s	HS 5-15°/s	HS 5-60°/s
20–39				
M	63.6	117.2	22.1	64.7
SD	5.89	4.05	3.6	5.18
Range	56–73	112–123	17–27	58–77
40–59				
M	63	122.7	20.5	60.6
SD	5.4	13.78	4.77	4.7
Range	54–69	101–156	14–26	54–67
60–69				
M	61.6	116.8	21.6	61.7
SD	4.06	6.78	4.55	5.95
Range	55–66	111–125	16–31	50–67

suggest that the single outcome variable including HS 5-15°/s eliminated the floor effect reported by Mishra et al.

Discussion

The addition of active head movements to a postural task causes degradation of postural control (Paloski et al., 2006). The advantage of the head shake condition is that it allows for simultaneous stimulation of the peripheral vestibular system while performing a postural control task. The brain must discriminate body sway and head shake stimuli to maintain balance during head shake posturography (Peters, 2007). Prior work by Mishra et al. (2009) stated that modification to Conditions 2 and 5 of SOT that stemmed from previous work by Hain, Fetter, and Zee (1987) and Walker and Zee (2000) incorporates the concept of post-head shake nystagmus. The head shake test produces a buildup of neural activity in the velocity storage integrator, resulting in induced nystagmus in individuals with unilateral peripheral vestibular system hypofunction (Panosian & Paige, 1995). While our head shake procedure is not specifically looking at postvelocity storage integration (post-head shake nystagmus), it presents an analogous protocol. The addition of a head shake task to standard SOT testing disrupts an individual's stance, and we hypothesize that this disruption is likely a combination of the mechanics of moving the head while attempting to maintain quiet stance, in addition to the stimulation of the peripheral vestibular system providing additional sensory cues that need to be integrated into the task of standing. It is also hypothesized that the stimulation of the peripheral vestibular system will cause increased postural control disruption for individuals with asymmetrical peripheral vestibular system functioning, as suggested by Mishra et al. (2009). Of importance, our modifications to the head shake protocol allowing for use of six points and a single outcome parameter (slope of the linear fit line to the six conditions) no longer showed the ceiling and floor effects reported from Mishra et al.

Our results have shown that deterioration in performance on SOT with head shake was acknowledged during the later decades of life, given the statistically significant difference across age. While our results should not be considered normative data, they are consistent with normative values for standard SOT testing (Nashner, 1993) showing a decrease in equilibrium scores with advancing age. However, one may argue that this increased deterioration with age may be the result of older participants performing a harder dual task (i.e., head movements with eyes closed on a fixed forceplate or one that rotates in relation to body sway) and not necessarily implying age-related changes to the stimulated vestibular system. Lundin-Olsson, Nyberg, and Gustafson (1997) have reported that older individuals have difficulty managing attention to simultaneous dual tasks. The addition of the head shake condition places an additional task demand on the participant, and decline in the ability to perform this dual task may be affected by aging (Peters, 2007).

In conclusion, our results suggest that the use of a head shake modification to SOT Conditions 2 and 5 shows a trend in increasing the separation of normal individuals across age. The addition of the head shake conditions that consisted of peak head velocity of 120°/s for Condition 2 and 15°/s for Condition 5 eliminated the ceiling and floor effects reported by Mishra et al. (2009). Future research on the head shake modification needs to be performed in the patient population to retest the hypothesis addressed by Mishra et al. for the identification of peripheral vestibular system asymmetry. This new study will specifically test sensitivity and specificity at predicting patients with unilateral peripheral vestibular system involvement versus gold-standard caloric irrigation testing. The need for all six parameters to be included as part of the single outcome variable to determine sensitivity and specificity for identifying unilateral peripheral vestibular hypofunction will also be addressed in the next phase of study.

While we do not anticipate that knowledge of the sensitivity of the head shake modification protocol will take the place of gold-standard procedures such as caloric irrigations as a tool for identifying peripheral vestibular system hypofunction, it may be used in combination with other clinical tests (e.g., electronystagmography or rotational chair) in the assessment of vestibular pathologies. It may also serve to alert physical therapists who routinely use posturography assessment and see balance disorder patients that the possibility of hypofunction is high and that the patient needs to be referred for more definitive testing. It is also possible that the addition of the head shake protocol with increased sensitivity to peripheral asymmetry may serve as a better indicator of changes over time in the central compensation process because it attempts to link active peripheral vestibular stimulation with postural control.

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