Enhanced Computerized Dynamic Posturography (CDP) System for Clinic and Field Environments

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Introduction

Computerized Dynamic Posturography (CDP) is used clinically [1] to assesses the vestibular, visual, and proprioceptive contributions to balance and the ability of the central nervous system to integrate this sensory information. The Sensory Organization Test (SOT) measures the patient's movements during various sensory conditions [2].

Traditional Computerized Dynamic Posturography (CDP) often faces ceiling effects as the base of support movement is restricted solely to the anterior-posterior (AP) plane and doesn't challenge medial-lateral (ML) sway. Mediolateral (ML) or "roll plane" postural control is an important predictor of fall risk [3].

We describe the development and testing of a new CDP device, the **SK-CDP (Figure 1), which provides somatosensory sway referenced movement in two axes (AP and ML)** and takes advantage of the developments in consumer virtual reality (VR) display and sensors.

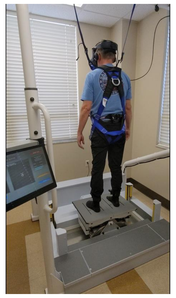

Figure 1. SK-CDP device (left) and participant on the device (right).

The 1D SOT and 2D SK-SOT

The SOT measures the patient's sway while they are standing during various controlled test conditions (Figure 2). The test provides unreliable somatosensory and/or visual information during a standing balance task by moving either the support surface, and/or visual surround, in phase with the participant's postural sway. This approach is called sway-referencing, and it makes the sensory feedback unreliable and therefore not useful for balance[2]. Sway feedback is limited to AP in the conventional 1D SOT (for vision and the support surface).

	Environment		Expected System Response	
Condition	Vision	Surface	Disadvantaged	Using*
1	Stable (Eyes Open)	Stable		Somatosensation
2	Absent (Eyes Closed)	Stable	Vision	Somatosensation
3	Unstable	Stable	Vision	Somatosensation
4	Stable (Eyes Open)	Unstable	Somatosensation	Vision and Vestibular
5	Absent (Eyes Closed)	Unstable	Somatosensation and Vision	Vestibular
6	Unstable	Unstable	Somatosensation and Vision	Vestibular

Figure 2. SOT sensory conditions and their expected system response (from Natus / NeuroCom).

The limits of stability (LOS) for standing balance are larger in the medial-lateral (ML) axis than in the anterior posterior (AP). Specifically, the LOS for the AP axis is 12.5° (8° forward and 4.5° backward). The LOS for ML is 16° in total and is symmetrical (8° for each side).

To achieve **2D sway feedback** with the support platform, the SK-CDP incorporates rotation about the ankle for the AP, and an orthogonal axis of rotation below the base for ML movement (Figure 3). These orthogonal axes and centers of rotation are needed to align with the postural strategies used in controlling the AP and ML components of sway and the LOS.

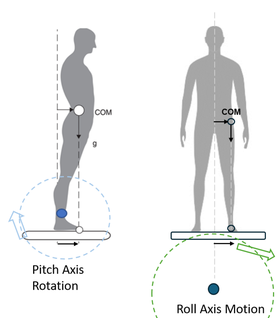

Figure 3. SK-CDP 2D movement axes for pitch (AP) and roll (ML).

The SK-CDP can emulate the 1D SOT and provides a separate new 2D SOT test. The SK-CDP device specifications are summarized in Figure 4.

SK-CDP Specifications

- Anterior-Posterior (AP) motion: Up to +/- 20° around ankle, up to 50°/Sec
- Medio-Lateral (ML): Up to +/- 20° roll, up to 50°/Sec
- Dual Force Plates: Left and right foot, overall size 24" x 18"
- Tracking position sensors (up to 3)
- Head mounted display (Vive Pro) with Eye tracking
- Optional OLED or projection display

Figure 4. SK-CDP Prototype device specifications.

Materials and Methods

Clinical Research Objectives

- Compare 1D SOT scores of healthy participants using the NeuroCom EquiTest and the SK-CDP.
- Compare the 1D SOT scores to the 2D SOT scores of healthy participants using the SK-CDP device.

Eighteen healthy adults between 18–45 years old were recruited for this prospective study.

Exclusion Criteria: pregnant women, postural control disabilities, neuropathy, uncorrected visual impairment, lower extremity injury, orthopedic surgery, weight over 250 pounds, height over 6'2", recent NeuroCom SOT experience.

Testing was conducted on both the SK-CDP and a NeuroCom EquiTest system. Testing was completed over two visits approximately 30 days apart in an outpatient physical therapy clinic (Figure 5). Repeated measures were used to compare 1D and 2D SOT equilibrium score (ES) performance.

We hypothesized that the SK-CDP 1D SOT scores would be similar to the Equitest scores and that the 2D SOT would be significantly more difficult than the 1D SOT.

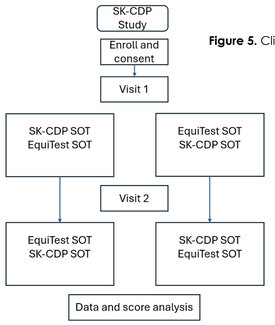

Figure 5. Clinical Research protocol.

Results 1D SOT

The **composite ES scores** across each SOT test condition for each participant for the SK-CDP and the EquiTest were compared. The composite score is an "average" of the component SOT ES scores and gives a broad indication of the overall balance performance.

A **Pearson's correlation** found a significant correlation between the composite ES for the NeuroCom EquiTest 1D SOT and SK-CDP 1D SOT, r = 0.72, p = 0.0004. This indicates that the two tests are similar in their evaluation of composite ES balance (i.e. across all of the SOT conditions).

A two-way ANOVA was performed to evaluate the effects of the SK-CDP and EquiTest for six SOT test conditions on ES balance scores.
The overall results shown in Figure 6 suggest that there are significant differences between tests for Conditions 1 and 4 but not for Conditions 2,3,5 and 6. Results of a 2-way ANOVA show that the two independent variables, test and balance condition and their interaction are significant.

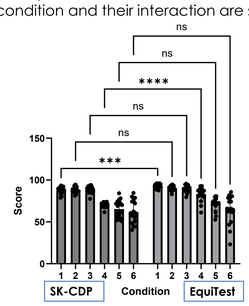

Figure 6. Two-way ANOVA between the NeuroCom EquiTest and the SK-CDP ES for the six SOT conditions.

Results 2D SK-SOT

A one-way ANOVA was used to compare the ES in the anterior-posterior (AP) plane and medial-lateral (ML) plane for the static conditions (conditions 1-3) and dynamic conditions (conditions 4-6) for the SK-CDP 1D SOT and the SK-CDP 2D SOT.

Tukey's multiple comparisons found no significant differences in the scores for the static 1D SOT and static 2D SOT groups for both planes (Table 1 and Figure 7 A & B). There were significant differences in the scores for the dynamic 1D SOT and dynamic 2D SOT groups for both axes (Table 1 and Figure 7A & B).

Table 1. Results of the one-way ANOVA.

Anterior-Posterior Plane Comparisons	Mean Difference	P value
1D static vs 2D static	0.1625	0.9950
1D dynamic vs 2D dynamic	9.881	<0.0001

Medial-Lateral Plane Comparisons	Mean Difference	P value
1D static vs 2D static	1.012	0.4738
1D dynamic vs 2D dynamic	41.46	<0.0001

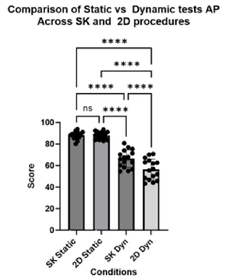

Figure 7A. Comparison between 1D SOT and 2D SOT for static and dynamic conditions in the AP plane.

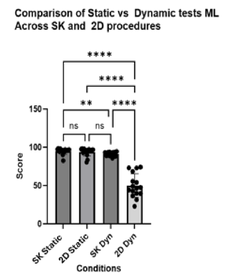

Figure 7B. Comparison between 1D SOT and 2D SOT for static and dynamic conditions in the ML plane.

Figure 7 shows that even for healthy participants **for the 2D SOT, both the ML and AP axes ES scores are significantly lower than the 1D SOT (SK**).

The ES scores for the dynamic conditions in the 2D SOT are significantly lower than the 1D dynamic scores (which trend closer to the maximum theoretical score of 100). This indicates that there is **no ceiling effect in the 2D dynamic test** conditions.

Discussion

An example of a sway result from the SK-CDP data is shown in Figure 8 where the standard SOT (AP somatosensory sway instability) for condition 4 (eyes open sway referenced) is compared against the 2D-SOT (2D AP and ML somatosensory sway instability).

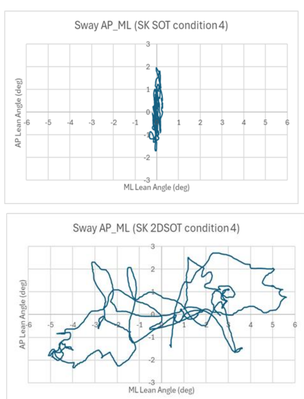

Figure 8. COM sway for the 1D SOT (left) and 2D-SOT (lower). The 1D SOT results in only AP instability, while the 2D-SOT produces greater participant sway in both axes, especially in the ML axis.

Discussion (cont.)

It is known that vestibular roll thresholds show large variations across healthy humans and that larger thresholds correlate with greater imbalance [4].

The standard SOT allows participants to minimize mediolateral sway in a 1D sway-referenced condition as the platform only moves in AP and thus, any off-axis mediolateral sway can use the somatosensory stimulation from receptors in the lower limbs (these provide accurate information about the orientation of the body relative to support surface) [5].

The capacity of the 2D SOT to further degrade proprioceptive inputs represents the primary advantage of this protocol over the standard 1D SOT.

2D sway unstable somatosensory conditions also offers the potential for enhanced testing using dynamic perturbation such as headshake to challenge the vestibular system.

The Head Shake SOT (HS-SOT) is an advanced diagnostic protocol used to identify subtle balance impairments that may not be apparent during a standard, static-head SOT. The HS-SOT typically modifies SOT condition 2 (stable support surface) and condition 5 (unstable support).

The 2D-SOT unstable support offers the potential combining head shake movement perturbations with sway referenced 2D somatosensory unstable motion platform conditions. We expect that this 2D-HS-SOT test will be more challenging than the standard HS-SOT.

Conclusions

- The NeuroCom Equitest 1D SOT and SK-CDP 1D SOT are similar in their assessment of balance.
- When comparing 1D SOT and 2D SOT, participants scored similarly for the static conditions (1-3), but scored significantly lower on the dynamic conditions (4-6), indicating greater difficulty maintaining balance with sway challenged in both the AP and ML planes versus AP plane only.
- The 2D SOT degrades proprioceptive inputs in both the ML and AP planes resulting in greater postural sway during dynamic test conditions, therefore providing a significant enhancement over traditional 1D assessment and potentially addressing ceiling effects in high performing patients.
- Multi-axis sway-referenced somatosensory unstable conditions can likely increase the difficulty of SOT headshake testing.

References

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