A Comparison of Balance Performance: Computerized Dynamic Posturography and a Random Motion Platform

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Objective: To establish the clinical utility of the PROPRIO 5000 as a balance assessment device by establishing convergent validity with the NeuroCom sensory organization test (SOT).

Design: Cross-sectional.

Setting: Balance research laboratory.

Participants: Young adults (N = 40; 21.1 ± 1.4 y).

Interventions: Not applicable.

Main Outcome Measures: Performance on each of the 6 NeuroCom SOT testing conditions and PROPRIO 5000 dynamic motion analysis score.

Results: Correlational analyses between output variables yielded significant relationships between the dynamic motion analysis score from the 0 to 10 second (r = - .38), 10 to 20 second (r = - .34), and 20 to 30 second (r = - .35) intervals and the SOT composite balance score.

Conclusions: The initial stages of the PROPRIO 5000 and the NeuroCom SOT battery may evaluate similar aspects of postural control. However, as the magnitude of PROPRIO perturbations increased, the relationship between the devices diverged and the complete PROPRIO assessment is not thought to pair with the SOT assessment. Differences between the 2 devices may be associated with varying degrees of test difficulty and the necessary postural control strategies involved in responding to continual balance perturbations (PROPRIO 5000) or to different sensory inputs (SOT).

Key Words: Posture; Rehabilitation. © 2009 by the American Congress of Rehabilitation Medicine

POSTURAL CONTROL IS a complex process requiring the integration of multiple sensory-motor systems that generate coordinated movements to maintain the COM within the limits of stability. Clinical assessments of postural control have typically focused on static balance whereby the participant is required to maintain the center of gravity over a stationary base of support on a fixed support surface. In some instances visual input is removed, requiring posture to be maintained through visual and support sway referencing during eyes open/closed conditions. By tracking changes in center of pressure motion, an assessment of overall balance, the balance sensory components and the interaction between them is derived. The increased sensitivity to subtle changes in balance has permitted the successful evaluation of deficits that result from a variety of pathologies related to aging, disease, and injury. The PROPRIO 5000 is a novel dynamic balance rehabilitation tool that tracks the patient’s COM movement while standing on a multi-directional platform. The system produces simultaneous motion in both the anterior-posterior and medial-lateral directions that perturb the participant, rather than responding to the participant’s changes in the center of pressure. The ability to track COM motion during a dynamic task presents the possibility of the PROPRIO as a new assessment of postural control. Use of this device, however, is limited because it is not entirely clear what is being measured relative to the balance mechanism. At present no investigations have compared measures obtained by the PROPRIO 5000 with any other postural control measure. Therefore, the overall goal of the present study was to establish the convergent validity, or relationship, of the PROPRIO 5000 as a balance assessment device by comparing performance results with those obtained from the SOT. We hypothesized that the 2 devices would yield correlated measures of postural control emerging from the same underlying balance mechanism.

List of Abbreviations

<table>
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<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>ANOVA</td>
<td>analysis of variance</td>
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<td>COM</td>
<td>center of mass</td>
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<td>CDP</td>
<td>computerized dynamic posturography</td>
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<td>SOT</td>
<td>Sensory Organization Test</td>
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METHODS

Forty young adults (12 men, 28 women) between the ages of 18 and 27 (21.1±1.4y, 169.5±7.9cm, 66.7±13.7kg) participated in this investigation. Exclusion criteria included a diagnosed postural control disability, currently being treated for a lower-extremity injury, or previous exposure to the NeuroCom SOT or the PROPRIO 5000. Each participant completed a single testing session that consisted of a postural control evaluation on the NeuroCom SOT and PROPRIO 5000. Order of test administration was randomized between subjects and all participants completed an institutional review board informed consent before testing.

A detailed description of the SOT protocol (fig 1) has been provided elsewhere. The SOT contains 6 conditions that are each completed with three 20-second trials. The 6 conditions included: (1) eyes open, stable support; (2) eyes closed, stable support; (3) sway-referenced vision, stable support; (4) eyes open, sway-referenced support; (5) eyes closed, sway-referenced support; and (6) eyes open, sway-referenced vision, and sway-referenced support. Sway-referencing involves an anterior/posterior rotation of the platform and/or visual surround that occurs as a response to the person’s shifts in center of pressure. This process serves to render information obtained from the ankle joints (sway-referenced support) or vision (sway-referenced vision) unreliable for balance control. The center of pressure movements occurring throughout the test are used to generate 4 scores associated with postural control: composite balance, somatosensory ratio, visual ratio, and vestibular ratio. The composite balance score is a weighted average calculated from the mean performance of conditions 1 and 2 performances and the average of all trials from conditions 3 through 6. The somatosensory ratio is calculated by dividing the average condition 2 performance by the average condition 1 performance. The visual ratio is calculated by dividing the average condition 4 performance by the average condition 1 performance and the vestibular ratio by dividing the averages of condition 5 by the average of condition 1. Higher composite balance and ratio scores are thought to represent better balance.

The PROPRIO 5000 (fig 2) is a novel dynamic platform capable of tilting in all directions about the vertical axis with a maximum tilt of 25°. The single 120-second assessment generates progressively dynamic platform perturbations beginning at 12.6° per second for the initial 20 seconds of the test. A 12.6° per second increase occurs during each of the subsequent 10-second intervals (20 –30s, 30 – 40s, etc) terminating at 126.4° per second for the final 20 seconds of the test (100 –120s) (table 1). Our participants were instructed on how to perform the balance assessment based on the manufacturer’s guidelines. Each participant stood on the platform with his/her knees slightly bent and were instructed to hold a short piece of rope in both hands to stabilize the arm posture. In addition, we asked participants to focus on a spot on the opposite wall and to remain as still and stable as possible throughout the test. An integrated ultrasonic sensor was affixed to an elastic velcro belt at the participant’s lumbar region (L4/L5 level) and tracked movement during the trial. The sensor has a range of 1.52m and measurement accuracy of ± 0.10mm. The X, Y, and Z coordinates of the sensor were sampled at 4Hz. Each test lasts a maximum of 120 seconds, but may be terminated early if the sensor motion exceeds 0.26m/s. The PROPRIO 5000 generates a composite balance score referred to as the dynamic motion analysis score. The dynamic motion analysis score is calculated by integrated software that uses the sum of the sensor’s vector moments and represents the total 3-dimensional displacement of the participant’s COM that occurred during the test. Other...
computed for the following PROPRIO 5000 dependent variables: dynamic motion analysis score, total time, anterior/posterior score, lateral score, up/down score, flexion/extension score, lateral flexion score, and rotation score. In addition, the raw PROPRIO data were used to calculate the dynamic motion analysis score in 10-second intervals up to 80 seconds (ie, 0–10s, 10–20s, 20–30s). The 10-second interval was selected to coincide with changes in platform perturbation rate (see table 1). Dynamic motion analysis scores were not calculated beyond the 80-second mark due to the precipitous drop in participants able to maintain balance beyond that time.

We calculated Pearson product-moment correlations to estimate the relationship between SOT and full PROPRIO 5000 test variables. Additional Pearson correlations were conducted between the SOT variables and the PROPRIO dynamic motion analysis score at each of the 10-second intervals. Negative correlations between the SOT and PROPRIO variables would indicate a relation between the devices. A repeated measures ANOVA evaluated differences in dynamic motion analysis scores between the 10-second intervals. Post hoc analyses included planned repeated contrasts to verify increased COM motion with each successive PROPRIO interval. All analyses were completed using SPSS version 14.0 and statistical significance was set at $\alpha$ equal to .05.

RESULTS

Means and SDs were calculated for each dependent variable on the SOT and PROPRIO 5000 (table 2). Similar to previous reports, postural control decreased as the SOT condition difficulty increased.\textsuperscript{25,26} A representative dynamic motion analysis score profile is presented in figure 3 and shows a general increase in COM motion throughout the trial. Overall, there was a general decline in balance performance on the PROPRIO as the duration of the test increased (see table 1).

The 48 correlational analyses completed between the full duration PROPRIO variables and the SOT scores yielded a single significant finding (SOT condition 2 and the PROPRIO lateral score $\left(r = -0.32, P < 0.05\right)$). The single significant correlation suggests a spurious finding. In contrast, when the PROPRIO data were separated into 10-second intervals, correlational analyses indicated a significant relation between the SOT composite balance and the 0 to 10 second interval ($r = -0.38, P < 0.05$), the 10 to 20 second interval ($r = -0.34, P < 0.05$), and the 20 to 30 second interval ($r = -0.35, P < 0.05$). Correlations between the SOT composite balance score and the lateral dynamic motion analysis interval scores were all nonsignificant ($P > 0.05$). The SOT vestibular ratio was also significantly correlated with the 0 to 10 second interval ($r = -0.31$).

<p>| Table 1: Mean DMA Score and SD for Each Test Interval and the Associated Platform Speed |
|-------------------------------|----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>PROPRIO Test Interval [s]</th>
<th>Mean DMA Score ± SD</th>
<th>Platform Speed (°/s)</th>
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<tbody>
<tr>
<td>0–10</td>
<td>7.96±3.01</td>
<td>12.6</td>
</tr>
<tr>
<td>10–20</td>
<td>8.24±3.37</td>
<td>12.6</td>
</tr>
<tr>
<td>20–30</td>
<td>13.00±8.96</td>
<td>25.2</td>
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<tr>
<td>30–40</td>
<td>16.85±6.50</td>
<td>37.8</td>
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<tr>
<td>40–50</td>
<td>21.22±7.84</td>
<td>50.4</td>
</tr>
<tr>
<td>50–60</td>
<td>24.01±9.61</td>
<td>63.0</td>
</tr>
<tr>
<td>60–70</td>
<td>26.12±13.88</td>
<td>75.6</td>
</tr>
<tr>
<td>70–80</td>
<td>28.21±14.55</td>
<td>88.2</td>
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NOTE. All intervals are significantly greater than the preceding interval ($P < 0.05$), except 0–10 to 10–20 seconds and 50–60 to 60–70 seconds ($P > 0.05$). Abbreviation: DMA, dynamic motion analysis.
DISCUSSION

Postural control is thought to be the end result of multiple afferent and efferent systems integration. A myriad of clinical assessments are available to evaluate these processes, but some may have ceiling effects because of an inability to maximally challenge the patient’s balance mechanism. The PROPRIO 5000 is a novel balance assessment device that may mitigate this obstacle by generating progressively difficult platform perturbations while tracking the participant’s COM motion. The face validity of the PROPRIO as a balance assessment device appears sound, but the convergent validity has yet to be established. Thus, we sought to compare the PROPRIO 5000 with the well established and widely accepted SOT. We hypothesized that the 2 balance assessment devices would generate analogous scores resulting from the mechanism necessary in maintaining postural control.

Our healthy sample failed to yield a significant correlation between the full duration PROPRIO dynamic motion analysis score and any of the SOT variables. However, our results indicated that lower values from primary dynamic motion analysis score generated from the 0 to 10, 10 to 20, and 20 to 30 second intervals were significantly correlated with a higher NeuroCom SOT composite balance score and vestibular ratio. Although it is not entirely clear how this relationship will translate to a clinical population, these findings suggest that the balance demands placed on the participants during the initial stages of the PROPRIO assessment may be similar to those of the SOT. The strength of these correlations, however, do not reach the level of clinical utility, indicating weak convergent validity between the devices. Further, the nonsignificant correlations in the later stages of the PROPRIO test (ie, >30s) suggest that the later phases of the test evoke different balance strategies than the SOT. Contrasting the 2 assessments, the PROPRIO’s late stage platform perturbations elicit a more complex dynamic balance response relative to the SOT’s less demanding motions.

The ability to maintain the COM within the limits of stability is the essence of postural control. Optimum postural control is achieved through different movement strategies used for a variety of conditions. Under quiet standing conditions, and in response to relatively small amplitude and low velocity perturbations, people commonly maintain balance using an ankle strategy. This involves the activation of the plantar and dorsiflexor musculature to respond to slow COM movements. However, as perturbations that may have exceeded the ability of the SOT to accommodate, the increasingly severe platform perturbations...
This proposition is supported by the observation of an association between the dynamic motion analysis and somatosensory ratio in the later stages of the PROPRIO test.

Some researchers have speculated that sensory strategies, orientation in space, control of dynamics, cognitive processing, biomechanical constraints, and movement strategies may all influence the person’s ability to maintain optimal postural control. Deficits to each of these areas has been shown to have a negative impact on balance, but the subject group enrolled here was free from any conditions known to affect balance. Thus, as reflected by the findings, it is reasonable to believe that the movement strategies elicited by the SOT and PROPRIO were similar in the initial stages. However, although the perturbation magnitude of the SOT is limited, the end stages of the PROPRIO test elicited a unique balance demand in response to the sizeable platform perturbations. This difference minimized the relationship between devices.

Study Limitations

Lastly, it is clear that the SOT and PROPRIO evaluate the balance mechanism in different manners. The SOT focuses on the participant’s use of perceptual information by implementing a series of conditions that conflict or remove the somatosensory and visual balance components. Changes in the estimated center of pressure movement are tracked during each condition and compared with the static balance task (condition 1), permitting the systematic evaluation of not only overall balance performance, but of each of the sensory components. In contrast, the PROPRIO 5000 tracks the estimated COM movement resulting from random platform perturbations, influencing the somatosensory and vestibular systems through the platform motion and associated head movement. Thus, as reflected by our findings, those participants relying heavily on the somatosensory mechanism will have an increasingly difficult time maintaining balance. The significant correlations between the initial dynamic motion analysis scores and the vestibular ratio may have resulted from head rotation stimulating the vestibular system and its balance reflex. The PROPRIO manufacturer’s test administration guidelines do not provide a means to isolate the vestibular system by deactivating (ie, eyes closed) or conflicting (ie, sway referencing) the visual system, but it was not our intent to mimic the SOT by influencing these control processes. Future investigations that directly challenge these mechanisms may find differing results than those reported here.

CONCLUSIONS

This study is the first to investigate the PROPRIO 5000 as an evaluative tool for postural control. The PROPRIO has previously been promoted as a balance training tool, but the dynamic platform and COM motion tracking may have potential as a postural control assessment device. Further assessments in a clinical population are needed before the device can be widely adopted. Our intent however, was to establish convergent validity of the PROPRIO with the NeuroCom SOT, a well-established postural control assessment device. Although the full PROPRIO assessment does not correlate with the NeuroCom SOT, the early stages of the PROPRIO test (ie, 0–10, 10–20, and 20–30s) are significantly correlated with the SOT, suggesting that they may evaluate similar aspects of the postural control mechanism. However, weak correlations between the 2 devices (ie, \( r = -0.30 \) to \(-0.34\)) indicate a small portion of shared variance and thus a reduced degree of convergent validity. As the magnitude of perturbations increased in the later stages of the PROPRIO test, the correlation between the 2 devices diverges. The disparity between devices is likely related to the greater dynamic load the PROPRIO places on the balance system. Differences between the 2 tasks in the later stages of the PROPRIO assessment are likely to be linked to differing postural control demands and the adoption of different movement strategies to complete the task. Although we did not use a clinical population in this investigation, use of the PROPRIO 5000 as a postural control measurement device has some merit in a healthy population. Future works should establish the reliability of the PROPRIO and continue to validate the device through comparisons with other established assessments and integrate techniques that manipulate the components of the balance mechanism in both healthy and diseased populations.

References


