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Comparative Study of Two Systems for the Assessment of Static Balance in Veterans with Mild Traumatic Brain Injury

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ABSTRACT

Background: Traditionally, the diagnosis of postural instability relies on the clinical examination of static balance. In recent years, computerized technologies have provided a new approach for the accurate detection of positional changes during functional balance. **Aim:** The aim of this study was to investigate the similarities and differences between two electronic systems, *NeuroCom* and *BioSensics*, and their application in the clinical assessment of impaired balance in American veterans. **Materials and Methods:** We examined the sway around the center of mass during static balance conditions in 25 veterans with mild traumatic brain injury, using the two electronic systems. These patients met the inclusion criteria and were assessed for their impaired balance at the District of Columbia Veterans Affair Medical Center, Washington, DC, USA. **Results:** There were six static balance tests conducted on either *NeuroCom* or *BioSensics* system in triplicate. Of the data for 36 sets of statistical data analyses, there were significant correlations among those for eight data sets (22.2%) between the two systems. The strongest positive correlation between the data from the two systems was found during the baseline test, when inputs from visual, vestibular and sensorymotor sources were uninterrupted. The data from the remaining experimental conditions did not correlate significantly with one another. **Conclusions:** Both *NeuroCom* and *BioSensics* provided comparable data in eight out of 36 experimental conditions in the assessment of static balance in patients with mild traumatic brain injury. The findings clarified the ambiguities in the application of *NeuroCom* versus *BioSensics*, provided new knowledge for the field of physical medicine and rehabilitation, and improved the clinical assessment of static balance in patients with mTBI. **Keywords:** Static balance, postural instability, clinical assessment, traumatic brain injury, mTBI.

1. INTRODUCTION

Being able to sustain one's balance while performing functional tasks, such as maintaining postural changes during activities of daily living, is a fundamental ability for humans to function effectively within the community (1). Trunk stability is often overlooked as an essential component of maintaining balance, enabling the coordinated use of extremities to perform higher level motor tasks (2, 3). Veterans with a diagnosis of mild traumatic brain injury (mTBI) may experience disorders of functional balance (4). The disorders and the associated dysfunction increase risk of falls and the resultant loss of confidence can lead to a progressive decline in physical activity and postural balance (5). According to the United States Congressional Research Service report in 2014 (6), approximately 220,000 veterans have sustained TBI in Iraq and Afghanistan wars with 82.4% of them diagnosed with mTBI. Symptoms of subtle balance impairments may be overlooked during the initial examination by a variety of clinicians. These impairments may significantly affect the patient's quality of life (7). Therefore, clinicians must detect these symptoms before they develop an effective treatment plan to address the underlying causes. Currently, few treatment protocols have effectively addressed imbalance in patients with mTBI.

In recent years, mobile technology such as wearable sensors has provided a new approach for detecting bodily motions and postural changes during dynamic tasks (8, 9). Through the use of this technology, clinicians are able to assess the kinematic components of gait in different settings.

This is crucial in developing a suitable tool for the clinical application, particularly enabling physical therapists to better evaluate postural control of veterans with mTBI. The aim of this study was to investigate the similarities and differences between two electronic systems, *NeuroCom* and *BioSensics*, and their applications in the clinical assessment of static balance in American veterans with mTBI. Such an objective study has not been conducted previously. As presented and discussed in this paper, the findings clarified the ambiguities surrounding the application of *NeuroCom* versus *BioSensics*, provided new knowledge to the field of physical medicine and rehabilitation, and improved the clinical assessment of static balance in patients with mTBI.

2. MATERIALS & METHODS

Patients & Setting: We studied the static balance in 25 U.S. veterans, all of whom had a prior history of head trauma and complained of postural stability impairment. Prior to their voluntary participation in the study, they had been medically diagnosed with mTBI and were referred by their physicians from Polytrauma & TBI unit, Rehabilitation Medicine Service, VA Medical Center, Washington, DC, USA. The diagnosis for each patient was established from his/her chart review, which had also been reviewed and confirmed by the referring physician.

Research Ethics: This study was approved by the Institutional Review Board (IRB) obtained from VA Medical Center, Research & Development Service, Washington, DC, USA. Also, the standard forms for consent to participation and Health Insurance Portability and Accountability Act (HIPPA) were signed and obtained from each patient according to the current U.S. Veterans Health Administration policy. The comprehensive evaluation electronic template with medical records for each participant was reviewed following the IRB approval and compliance with patient data collection procedures set by HIPPA.

Inclusion & Exclusion Criteria: Medically stable veteran referrals, aged 30-65 years old with a medical diagnosis of mTBI and the ability to comprehend and communicate in English at 6th grade level were included in the study. Each patient was required to provide an informed consent before being included in the study. Patients with any of the following conditions were excluded from the study:

- Inability to provide informed consent due to severe language or memory impairment based on a cognitive screening test.
- Life expectancy of less than 36 months.
- Assessed by the attending physician as not being appropriate to participate in the study due to multiple trauma, such as severe burns, serious organ damage, amputations, multiple fractures, FGA of 15/30, and being non-ambulatory.
- History of substance abuse and/or alcoholism, resulting in neurological damage.
- Past medical history of peripheral nerve injury and severe cardiac condition.

- Not cleared by the attending physician to perform physical activities due to upper or lower motor neuron disease, such as Parkinson's, multiple sclerosis and alcoholism.
- History of severe psychiatric illnesses, such as bipolar depression and schizophrenia.

Testing Conditions and Positions: Patients were tested for 20 seconds each in three positions: *a)* standing on both feet together, *b)* standing on dominant foot only, and *c)* standing in tandem (dominant foot [right] placed behind the non-dominant [left]). Each test was performed with the patients' eyes either open or closed (to eliminate the visual input for postural control), accounting for six testing situations in total for either NeuroCom or BioSensics system.

Outcome Measures: During each of the six testing positions, the patients' area of sway around the body's center of mass was assessed, using NeuroCom and BioSensics consecutively, with a 15-minute rest interval between the two systems.

Data Analyses: Data collected for the six testing situations, as described above, were analyzed statistically, using SPSS program, version 22. We obtained intraclass correlation coefficient (ICC) to assess the sway of the center of mass, based on two-way mixed effects model, where people effects are random and measures effects are fixed (14). The extent of sway was determined by multiplying the medial-lateral and anterior-posterior motions of the hip (5 and 95 percentile of data). We calculated Pearson's product correlation coefficients to determine the strength of the relationship between the data obtained from NeuroCom and BioSensics systems, and the patients' postural control. Reciprocal compensatory index (RCI) was used to assess the patients' postural strategy for sustaining balance, and how postural strategy reduced variance in the center of mass. It was concluded that an RCI value near zero represented a good postural control strategy while an RCI value of greater than 1 represented inappropriate postural control. In other words, a positive correlation between hip and ankle movements led to a greater variation in the center of mass thus resulted in an increased risk of fall. For the *T*-test, we considered 95% confident interval with an alpha value of 0.05 as being acceptable levels.

3. RESULTS

Participants: The demographic characteristics of the study's participants are shown in Table 1. There were 19 males and 6 females at the ages of 30 to 65 years old, all of whom were right handed with the dominant foot being the right one.

Correlation Data: Details of the positive and negative correlation among the data obtained for the six sets of balance tests, using either NeuroCom or BioSensics system, are shown in Table 2. The bold numbers in Table 2 represent those with moderate to fairly strong correlation at 0.01 and 0.05 significance levels. Also, there was good test-retest reliability for the data sets derived from either system, with the ICC being ≤ 0.75 (14).

Subject #	Gender ([a]M/[b]F)	Age (year)	Weight (Lb)	Height (ft, inch)
1	M	46	200	5'10"
2	M	43	231	5'7"
3	F	50	155	5'9"
4	M	39	254	5' 9"
5	M	44	220	5'7"
6	M	37	250	5'7"
7	F	45	137	5'5"
8	M	48	185	5'7"
9	M	57	180	6'2"
10	M	33	220	5'11"
11	M	65	235	6'0"
12	M	41	160	5'7"
13	M	48	185	5'7"
14	M	34	170	5'9"
15	F	59	151	5'5"
16	M	33	230	6'0 "
17	F	45	130	5'2"
18	F	60	155	5'0"
19	M	43	190	5'7"
20	F	47	155	5'8"
21	M	65	235	5'11"
22	M	30	170	5'7"
23	M	45	188	5'5"
24	M	40	170	5'7"
25	M	44	192	5'6"
Average	M:19, F: 6	44	189.9	5'6"

Table 1. Participants' Demographics. [a] M = Male, [b] F = Female

Condition 1 on NeuroCom Vs Position 1 on BioSensics: The data for the condition 1 on NeuroCom, where the subjects stood on both feet with eyes open, correlated positively and strongly with similar data for the wearable electrodes of BioSensics obtained under the same condition, i.e., double stance with eyes open ($r^2 = 0.645$; $p = 0.01$).

Conditions 3 & 4 on NeuroCom Vs Position 6 on BioSensics: The test data for the condition 3 on NeuroCom, where the subjects stood on a fixed support with their vision swayed, correlated positively and fairly strongly with the data from BioSensics system, with the subjects in tandem stance and eyes closed ($r^2 = 0.594$; $p = 0.01$). Also, the data collected under identical position for BioSensics (position 6) showed positive and fairly strong correlation with those for the condition 4 on NeuroCom, where the subjects stood with foot support swayed and the eyes open ($r^2 = 0.533$; $p = 0.01$).

Conditions 3 & 4 on NeuroCom Vs Positions 2 & 3 on BioSensics: The data for the condition 3 on NeuroCom (swayed vision, fixed foot support) showed positive and moderate correlation with those for the test positions 2 and 3 on BioSensics system with the subjects in single or tandem stance and the eyes open ($r^2 = 0.328$ & 0.356; $p = 0.05$). Similarly, the data for the condition 4 on NeuroCom (normal vision, swayed foot support) correlated positively and fairly moderately with those for the test positions 2 and 3 on BioSensics system when the subjects were in single or tandem stance position with the eyes open ($r^2 = 0.297$ & 0.309; $p = 0.05$).

Condition 5 on NeuroCom Vs Position 2 on BioSensics: The test data for the condition 5 on NeuroCom (eyes closed, swayed foot support) correlated moderately but negatively with those for the test position 2 on BioSensics system, with the subjects being in single stance and the eyes open ($r^2 = 0.318$; $p = 0.05$).

Conditions 2 & 6 on NeuroCom: The data for the conditions 2 and 6 on NeuroCom, i.e., absent vision and fixed foot support, or swayed for both vision and foot support, did not correlate significantly with the data for any test position on BioSensics system.

Other Test Conditions: The data for the remaining test positions performed on BioSensics, which were not mentioned above under Results, did not correlate significantly with the data for the corresponding NeuroCom test conditions.

4. DISCUSSION

Maintenance of postural stability depends on the integration of the individual's somatosensory, vestibular and visual inputs relating to the body's orientation and position (15). Studies have suggested that BioSensics wearable sensors can provide accurate data for detecting and monitoring postural balance under a variety of functional conditions (16-19). These sensors provide equally reliable data for ankle and hip motions when assessing the

NeuroCom: SOT Condition	BioSensics: BESS Test Position					
	EYES OPEN			EYES CLOSED		
	1. Double Stance	2. Single Stance [c]	3. Tandem Stance [d]	4. Double Stance	5. Single Stance [c]	6. Tandem Stance [d]
1. Normal Vision, Fixed Support	0.645 [a]	0.222	- 0.132	0.163	- 0.053	- 0.019
2. Absent Vision, Fixed Support	- 0.061	0.123	- 0.047	0.233	- 0.061	0.110
3. Sway Vision, Fixed Support	0.016	0.328 [b]	0.356 [b]	0.052	- 0.236	0.594 a
4. Normal Vision, Swayed Support	0.073	0.297 [b]	0.309 [b]	0.019	- 0.139	0.533 a
5. Absent Vision, Swayed Support	- 0.188	- 0.318 [b]	0.015	- 0.029	0.243	- 0.199
6. Sway Vision, Swayed Support	- 0.180	- 0.218	- 0.082	0.070	0.035	- 0.086

Table 2. Correlation of Static Balance Data from SOT Vs BESS Tests. SOT = Sensory Organization Test (10); BESS = Balance Error Scoring System (11). Numbers represent 2-tailed Pearson's correlation coefficient (r^2). [a] Strong correlation significance at 0.01 level ($r^2 \geq 0.500$; $p = 0.01$). [b] Fair to moderate correlation significance at 0.05 level ($r^2 \geq 0.250$; $p = 0.05$). [c] Standing on dominant foot, which was the right foot for all subjects. d Left foot placed in front of the right foot

body's sway around its center of mass during both static and dynamic balance, as compared to those derived from the non-wearable electrodes built into a complex balance system, such as NeuroCom (10).

These findings are of clinical significance, proving the practical advantages of wearable systems without losing data accuracy when assessing functional balance in humans. The wearable sensors also provide clinicians with an objective and inexpensive tool to monitor the patients' progress and follow-up. Further, recent evidence suggests that somatosensory inputs are the most important information transmitted from periphery to the brain and are essential for the person's control over postural balance (17). Such information is easily available through the use of BioSensics system, which is a cost effective and portable tool for physical therapists to assess trunk stability, and functional balance not only in clinical settings but also in the community.

The aim of this study was to investigate the similarities and differences between two electronic systems, *NeuroCom* and *BioSensics*, and their applications in the clinical assessment of static balance in American veterans with mTBI. Such an objective study has not been conducted previously. In the following sections, we have compared and contrasted the study results that were generated following the use of the two systems in the assessment of static balance in patients with mTBI.

Baseline Condition: Given the demographic characteristics (Table 1), we feel the participants were reasonably homogeneous for the purpose of this study, as they were all right handed with their right leg being the dominant one. As seen in Table 2, the test data for condition 1 on NeuroCom and those for the position 1 on BioSensics had the highest correlation, indicating that either system may be used to test the subject's baseline data on static balance when inputs from visual, vestibular and sensory-motor sources are uninterrupted and integrated.

Swayed Vision or Foot Support Vs Absent Vision: The results for the conditions 3 and 4 on NeuroCom system correlated fairly strongly with those for test position 6 on BioSensics system. The finding suggests that when either vision or foot support was swayed but the subject's eyes were open, the static balance was disturbed similarly compared to the situation when visual input was absent and the subject's foot support was fixed but in tandem.

Swayed Vision Vs Single or Tandem Stance: The results for test condition 3 on NeuroCom system correlated moderately with those for test positions 2 and 3 on BioSensics system. These results suggest that when vision was swayed but the subject's foot support was fixed, the static balance was not maintained as comparable to when the subject was in single or tandem stance with the eyes open.

Swayed Foot Support Vs Single or Tandem Stance: The data for test condition 4 on NeuroCom system correlated fairly moderately with those for test positions 2 and 3 on BioSensics system. These suggest that when foot support was swayed with stable vision, the static balance was even less comparable to when the subject was in single or tandem stance with the eyes open.

Absent Vision & Swayed Foot Support Vs Single Stance with Eyes Open: The test data for condition 5 on NeuroCom system correlated moderately but negatively with those for test positions 2 on BioSensics system. The negative correlation suggests that the postural stability in a situation that the subject is in single stance with eyes open is not predictive of the balance in a condition where the vision is absent and the foot support is swayed.

Absent or Swayed Vision & Fixed or Swayed Foot Support Vs All BioSensics Positions: There was no correlation among the test data for conditions 2 and 6 on NeuroCom with those for any of the positions on BioSensics system. This suggests that data for these groups of tests from either system are not predictive of each other, likely due to differences in set-up, computer programs, and test positions. This statement also applies to the remaining test conditions on either system that were not discussed above.

Recommendation & Limitations: To further explore the clinical application of NeuroCom and BioSensics systems, we recommend that future research should compare and contrast the application of these systems in the assessment of dynamic balance and gait in a larger population, both in the clinical setting and in the community. This study was conducted in a sample of U.S. veterans with mTBI, therefore, the results may not be generalized to other neurological conditions. Also, our results did not provide intervention strategies in this population, since they were beyond the scope of this study.

5. CONCLUSIONS

The aim of this study was to investigate the similarities and differences between two electronic systems, *NeuroCom* and *BioSensics*, and to clarify their applications in the clinical assessment of static balance in veterans with mTBI, which has not been conducted previously. In summary, the study findings clarified the ambiguities surrounding the applications of the two systems, provided new knowledge for the field of physical medicine and rehabilitation, and improved the objective clinical assessment of static balance in these patients for the first time. Specifically, we can make the following conclusions on the similarities and differences between the two systems:

- The data for condition 1 on NeuroCom had the highest positive correlation with those for test position 1 on BioSensics system.
- The data for conditions 3 and 4 on NeuroCom correlated fairly strongly with those for test position 6 on BioSensics.
- The data for test condition 3 on NeuroCom correlated moderately with those for test positions 2 and 3 on BioSensics.
- The data for test condition 4 on NeuroCom correlated fairly moderately with those for test positions 2 and 3 on BioSensics.
- The data for condition 5 on NeuroCom correlated moderately but negatively with those for test positions 2 on BioSensics.

- • There was no correlation among the data sets for conditions 2 and 6 on NeuroCom with those for any of the test positions on BioSensics.

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