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Research article

QUANTITATIVE ANALYSIS OF THE RESULTS OBTAINED BY THE FUNCTIONAL TESTING WITH THE SWAY^{TM} BALANCE APPLICATION IN RELATION TO NORMS FOR APPROPRIATE GENDER AND AGE

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Nenad Nedović[1], Milosav Adamović[2], Ivana Sretenović[2]

[1]Medical College of Professional Studies, Belgrade, Serbia
[2]Faculty of Special Education and Rehabilitation, Belgrade, Serbia

Abstract. *The Balance Error Scoring System (BESS) is a common balance test relying on assessment tools such as the Sway^{TM} Balance application for IOS mobile, encompassing the tri-axial accelerometers and movement sensors to measure bodily sway. Given that age and gender are important factors when using this methodology, suitable normative score sets were determined. The main aim of this study was a quantitative analysis of the ability of healthy, 21-year-old participants of both genders to maintain postural balance using the aforementioned normative values. The postural balance scoring was done by the co-application of the modified BESS test and Sway^{TM} Balance software during a protocol organized in three-week double-scoring sessions. In order to assess the participants' age- and gender-dependent abilities, the average balance score medians were contextualized with the appropriate normative values. All of the participants showed average results, with scores ameliorating during the procedure, and the female participants showed generally better results than the males. Focusing solely on the first-session scores revealed, however, that men had scored at the low average cut-off point, while women scored below average age- and sex-dependent cut-off points. However, in the last session both genders scored deeply within the average. This study showed average abilities of the studied participants according to the normative values, as well as a generally better performance of the women compared to the men, but it has also pointed out that, due to subject adaptation, the chosen combination of protocol and technology is of limited usefulness for balance assessment in the general population, indicating the need for protocol adjustments in future studies.*

Key words: *BESS, Sway^{TM}, normative scores, balance*

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Corresponding author: Nenad Nedović
Medical College of Professional Studies, Cara Dušana 254, 11000 Belgrade, Serbia
Phone: +381 11 2618120 • E-mail: nedovicn@gmail.com

INTRODUCTION

The ability to maintain body balance plays a key role in human locomotion, enabling the performance of fundamental motor activities that are important for daily functioning, such as sitting, standing, walking, running, and jumping. Maintaining body balance is a dynamic process, which can be defined as the ability to keep the body in a stable position in stance – static balance, or in gait – dynamic balance (Brauer, Woollacott, & Shumway-Cook, 2001). The physiology of maintaining body balance is a multilayered and complex activity in humans. This activity requires the synergistic collaboration of multiple body systems and organs, primarily the visual, vestibular, and somatosensory system (Adamović, 2018). Hence, balance in conjunction with other motor abilities and perceptual abilities enables precise muscular efforts and successful sport performance (Purenović-Ivanović, Popović, Stanković, & Bubanj, 2016).

A wide variety of different methods is used for balance assessment in everyday clinical practice, as well as for research purposes, including functional tests (Romberg Test, Timed Up and Go Test, Berg Balance Scale, One Leg Test, etc.), force platforms, a path sensor, kinematic or electromyography gait analysis. The advantage of functional tests is reflected in their wide availability, and in their simple implementation and interpretation of results. At the same time, the lack of objectivity is listed as their main disadvantage in contrast to other methods that are more precise, but also very expensive and less accessible (Mancini & Horak, 2010). The Balance Error Scoring System (BESS) is one of the functional tests that can be found in different variants in a wide range of clinical use for static balance assessment. In classical medicine, this test is performed on a firm and/or on a foam surface in sports medicine (Onate, Beck & Van Lunen, 2007; Jeremy, Amick, Thummar, & Rogers, 2014). As with other functional tests, BESS scores are subjective measures of maintaining body balance, which are based on the number of errors across trials. Errors made during the implementation of the protocol include movement of the hips, arms, stepping, stumbling, falling, lifting the forefoot (the anterior aspect of the foot) or heel off the testing surface, or losing position for more than five seconds (Dabbs, Sauls, Zayer, & Chander, 2017). The obvious subjectivity of this scoring system (Chang, Levy, Seay, & Goble, 2014; Finnoff, Peterson, Hollman, & Smith, 2009) has led to the need to develop and use objective assessment tools in order to increase the reliability of the BESS test. One of them is the Biodex Balance System SD (Watson, Chambers, Hobbs, Doherty, & Graham, 2008), which evaluates balance based on the postural sway of the participants during the BESS test. This combination has shown high reliability and validity, but the equipment that is necessary for its performance is large and it is difficult to perform this testing in out-of-hospital and non-laboratory conditions (Dabbs et al., 2017).

A possible solution to this problem is the use of mobile applications that have been developed lately, useful for the biomedical evaluation of human movements (Dabbs et al., 2017). This group includes Sway™ Balance (Sway Medical, Tulsa, OK, USA), a static balance assessment application that has been used extensively in sports in recent years (Anderson, Gatens, Glatts, & Russo, 2017), as well as medicine in general (Fiems, Dugan, Moore, & Combs-Miller, 2018), with the approval of the Food and Drug Administration (USA) and the European Commission (Sway Medical, 2019). It uses an accelerometer to measure the balance parameters during a series of tests organized in the selected protocol, whereby postural body sway is quantified as a balance indicator using the motion sensors built in a mobile phone with an iOS operating system (iPhone, iPad, iPod Touch). The device is manually fixed to the center of the breastbone, and the tri-axial accelerometers measure the body's acceleration (change of position) in three spatial planes (https://swaymedical.com/ system/balance).

In terms of the validity of the Sway^{TM} Balance application for use in our research, numerous studies are significant. When it comes to the functional analysis of maintaining static balance with the BESS protocol, these studies have shown that in the SwayTMBalance application is a precise, accurate, effective, low-cost, and easy-to-use alternative to the Berg Balance Scale (BBS) (Dabbs et al., 2017; Jeremy et al., 2014).

Age and gender were shown as very important factors in determining balance scores using the BESS protocol and Sway^{TM} Balance technology in previous studies (Brett et al., 2018). Therefore, for these purposes, appropriate normative scores based on these factors were also determined (Brett et al., 2018). They may prove to be very useful in assessing the ability to maintain balance with this application in studies of the human population.

Based on the above, the main aim of this study was to provide a quantitative analysis of the ability to maintain balance in young and healthy participants of both genders during the functional testing, and using the combination of a modified BESS protocol and Sway^{TM} Balance application, according to the previously determined normative values for this variant of functional testing.

METHODS

Sample description

The sample consisted of 37 participants, with an average age of 21.65 ± 1.03 years, average height 173.84 ± 9.91 cm and average body mass 67.35 ± 11.08 kg (expressed as mean ± SD). Of the total number of participants, 13 (35.14%) were males, and 24 (64.86%) were females. The results of the Chi-square test showed no statistically significant difference in relation to gender [$\chi 2$ (1) = 3.270, $p = 0.071$]. All of the participants included in this research were second-year students of basic academic studies at the Faculty of Special Education and Rehabilitation, University of Belgrade. They were tested on the premises of the Faculty during 2018. Those persons who had a condition or disorder affecting their ability to maintain balance were excluded from the study.

Research procedures

Before proceeding with the test, all the participants gave written consent (informed consent) for participation in the study. In our research, a modified Balance Error Scoring System (mBESS) protocol was used. The mBESS represents a modified version of the standard BESS balancing test protocol. It was developed in the following five basic positions: double-leg (DL), tandem-left (TL), tandem-right (TR), single-leg right (SLR), and single-leg left (SLL). All basic positions were held with eyes closed and lasted for 10 seconds, on a firm, static surface without any footwear.

The Sway^{TM} Balance test was applied using the Apple iPhone SE phone (Apple, Computer Inc., Cupertino, CA, USA) with the installed Sway software (version 1.6). At each testing, the participant was asked to hold the phone upright and with both hands pressed the screen of the device into the middle of the breastbone (sternum) so that its upper edge was below the line connecting the collarbones (clavicles). The instruction for each subsequent test was automatically displayed on the iPhone screen immediately after the end of the previous one. After completing the mBESS protocol, the software calculated the total score on a scale from 0 to 100, with a higher score indicating a better balance.

The testing was conducted during three sessions with an interval of one week. Trial testing was conducted during the first session, and it was followed by two experimental tests. Each testing involved completing the entire mBESS protocol. Within each session, a pause interval of at least 5 minutes was allowed between the testing. During the second and third session, only two experimental measurements were performed. The procedure was taken from Amick, Chaparro, & Patterson (2015).

Statistical analysis

All of the analyses were performed in the Statistical Package for the Social Sciences (SPSS), version 21.0 (Chicago, IL.), with the level of significance set at $p < 0.05$. The Kolmogorov-Smirnov Test was used to assess the normality of the distribution of the results. As the assumption of normality of distribution was violated, appropriate non-parametric techniques were used in further analysis. For the analysis and determination of changes in the SWAY scores, the Friedman test was used, with a subsequent application of post hoc tests to determine the differences in the measurements. In order to control for Type 1 error, a Bonferroni adjustment was applied. The Mann-Whitney Test was used to examine the differences between two independent groups on a continuous scale. The Chi-square test ($\chi 2$ test) was used to analyze two categorical variables, and the arithmetic means with the corresponding standard deviation for the description of the numerical variables (Palant, 2007).

RESULTS

Statistically significant differences between the results of functional testing in the first, second and third week procedures were found by the Friedman test ($\chi 2$ (5, N=37)=42.79, p=0.071). By examining the medians shown in Table 1, as well as by comparing the values of mean ranks, an increase in the scores determined by specific SWAY™ applications was noted suggesting that there was an improvement in the balance during the procedure.

Table 1 Descriptive statistics of the SWAY scores

Week/Measurement	N	Percentiles			Mean Rank
		25th	Median	75th	
The first week/measurement 1	37	73.48	84.67	91.84	2.57
The first week/measurement 2	37	71.67	88.91	93.12	2.68
The second week/measurement 3	37	79.08	88.56	92.69	3.35
The second week/measurement 4	37	81.34	89.98	95.35	3.68
The third week/measurement 5	37	82.14	88.51	96.70	3.68
The third week/measurement 6	37	83.55	92.33	97.09	5.05

In order to determine precisely the exact sessions in which the change occurred, that is, the measurements between which the differences in the scores had occurred, the Bonferroni post hoc test was used and the Type 1 error was controlled (significance level was set at $p<0.008$). As shown in Table 2, a statistically significant difference was found between the measurements made in the first and third week, more precisely between the first measurement in the first and sixth measurements in the third week, as well as between the second measurement in the first week and the sixth measurement in the third week. There were no statistically significant differences between the other measurements over the three-week period.

Table 2 Differences in scores between measurings

Measurement		Mean difference	SEM	Significance	95% confidence interval	
					Lower limit	Upper limit
1	2	-1.772	1.782	1.000	-7.375	3.832
	3	-5.158	2.183	0.355	-12.021	1.706
	4	-6.491	2.279	0.108	-13.655	0.674
	5	-6.532	2.106	0.056	-13.154	0.090
	6	-8.415*	2.087	***0.004***	-14.977	-1.852
2	1	1.772	1.782	1.000	-3.832	7.375
	3	-3.386	1.938	1.000	-9.478	2.706
	4	-4.719	1.967	0.327	-10.904	1.466
	5	-4.761	1.769	0.161	-10.322	0.801
	6	-6.643*	1.704	***0.006***	-12.000	-1.287
3	1	5.158	2.183	0.355	-1.706	12.021
	2	3.386	1.938	1.000	-2.706	9.478
	4	-1.333	1.315	1.000	-5.467	2.802
	5	-1.374	1.232	1.000	-5.248	2.500
	6	-3.257	1.171	0.128	-6.938	0.424
4	1	6.491	2.279	0.108	-0.674	13.655
	2	4.719	1.967	0.327	-1.466	10.904
	3	1.333	1.315	1.000	-2.802	5.467
	5	-0.042	1.002	1.000	-3.190	3.107
	6	-1.924	.628	0.062	-3.899	0.050
5	1	6.532	2.106	0.056	-0.090	13.154
	2	4.761	1.769	0.161	-0.801	10.322
	3	1.374	1.232	1.000	-2.500	5.248
	4	0.042	1.002	1.000	-3.107	3.190
	6	-1.883	.600	0.051	-3.769	0.004
6	1	8.415*	2.087	***0.004***	1.852	14.977
	2	6.643*	1.704	***0.006***	1.287	12.000
	3	3.257	1.171	0.128	-0.424	6.938
	4	1.924	.628	0.062	-0.050	3.899
	5	1.883	.600	0.051	-0.004	3.769

Table 3 shows a comparison of the achievements of male and female participants during the testing. By comparing the values of mean ranks in each week and each measurement, it was found that the female participants achieved a better performance than the male participants did. However, the results of the Mann-Whitney U Test (Table 4) showed that there were statistically significant differences between the male and female participants in the first week in the first measurement (p=0.045), and in the third week in the fifth measurement (p=0.022).

Table 3 Achievements according to measurements and gender

Week/Measurement	Gender	N	Mean Rank	Sum of Ranks
The first week/measurement 1	Male	13	14.15	184.00
	Female	24	21.63	519.00
The first week/measurement 2	Male	13	14.69	191.00
	Female	24	21.33	512.00
The second week/measurement 3	Male	13	17.31	225.00
	Female	24	19.92	478.00
The second week/measurement 4	Male	13	16.54	215.00
	Female	24	20.33	488.00
The third week/measurement 5	Male	13	13.46	175.00
	Female	24	22.00	528.00
The third week/measurement 6	Male	13	14.58	189.50
	Female	24	21.40	513.50

Table 4 Differences in measurements between female and male participants

	The First Week Measurement 1	The First Week Measurement 2	The Second Week Measurement 3	The Second Week Measurement 4	The Third Week Measurement 5	The Third Week Measurement 6
Mann-Whitney *U*	93.000	100.000	134.000	124.000	84.000	98.500
p	***0.045***	0.075	0.484	0.309	***0.022***	0.067

Finally, the ability of the participants was evaluated in relation to their gender and age, considering the previously shown pace of changes in maintaining their balance during testing (Table 5). The medians of the average scores achieved during the entire examination, as well as during its first and last week, were placed in the context of the normative limits for the appropriate gender and age.

Table 5 Comparison of the medians of average balance scores of participants of different genders with the norms for corresponding gender and age (normative scores were taken from Brett et al., 2018)

<table>
<tr><td rowspan="5">Men</td><td>Complete procedure</td><td>The first week</td><td>The last week</td></tr>
<tr><td>82.45</td><td>79.03</td><td>85.77</td></tr>
<tr><td colspan="3">Normative scores for the age of 21 years</td></tr>
<tr><td>Below average</td><td>Average</td><td>Above average</td></tr>
<tr><td>69-78</td><td>79-94</td><td>95-96</td></tr>
<tr><td rowspan="5">Women</td><td>Complete procedure</td><td>The first week</td><td>The last week</td></tr>
<tr><td>89.66</td><td>87.67</td><td>92.06</td></tr>
<tr><td colspan="3">Normative scores for the age of 21 years</td></tr>
<tr><td>Below average</td><td>Average</td><td>Above average</td></tr>
<tr><td>71-88</td><td>89-97</td><td>98</td></tr>
</table>

DISCUSSION

In our study, by combining the modified BESS protocol with the scores determined with the specific mobile application SWAY^{TM} Balance, a functional test of maintaining balance was performed on a sample of healthy participants of the average age of 21.65 ± 1.03.

Earlier studies, which included this combination of protocols and tools, have shown improvement in balance during the procedure, as well (Amick et al., 2015). This outcome is consistent with the results of our analyses, suggesting not only the improvement of scores during consecutive weeks of testing but also the largest and statistically significant improvement between the first measurement in the first week and the last measurement in the last week. However, this increase is gradual, since the differences between individual measurements within the same sequences are not statistically significant (Tables 1 and 2).

In line with previous findings (Brett et al., 2018), by comparing the ability of our participants based on the appropriate functional balance test in relation to their gender, it was found that female participants had generally achieved better results than the male participants throughout the study. It is important to note that the female participants were better not only at the beginning but also at the end of the three-week testing (Tables 3 and 4).

By comparing the medians of the mean scores of participants of different genders with the normative values of the balance scores for the corresponding age and gender measured by the Sway^{TM} Balance application in the implementation of the BESS protocol (Table 5), it was noticed that the participants of both genders had achieved the average results for the selected age. However, if the above-mentioned norms were compared only to the medians of scores achieved in the first measurement week, the male participants would have results at the lower limit of the average, while the female participants would have results below the average score. On the other hand, the scores achieved by the participants in the last week of the protocol are higher and within the average for the appropriate age, regardless of their gender (Table 5).

All the results obtained in this study indicate the adaptation and learning process of the participants during the functional assessment of body balance with the mBESS protocol, regardless of gender. Moreover, this is the main limitation when using the combination of this functional test and the Sway^{TM} Balance application as a tool for analyzing the ability to maintain postural balance in the general population (Jeremy et al., 2014). Previously proposed solutions to this problem include the use of a moving or slippery surface during testing (Amick et al., 2015). However, it is necessary to point out the possibility of using a standard BESS protocol with an extended stay in BESS positions for 20s for research in the general population. While maintaining a break of 10s between positions, this solution could make the completion of the protocol significantly more difficult. Extending the breaks between individual three-week trials for more than a week and, if possible, repeated application of static/solid and moving/slippery surfaces in consecutive weeks of the selected procedure could also help in slowing the learning process of the participants during the research.

CONCLUSION

Overall, the data presented in this study indicate the gender differences in maintaining the balance and better performance of women, whereby in the selected sample of the general population, both genders had average achievements in the context of age-appropriate normative gender-based scores. However, since the results indicate the participants' adaptation and learning during the testing, the selected methodology showed limited usefulness for assessing the ability of maintaining balance in the general population. Therefore, it is necessary to make some additional adjustments to the BESS protocol and the testing procedures, if the purpose is its use for analyzing the balance of healthy persons in combination with the SWAY™ application.

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KVANTITATIVNA ANALIZA REZULTATA DOBIJENIH FUNKCIONALNIM ISPITIVANJEM UZ POMOĆ SWAY^{TM} APLIKACIJE ZA PROCENU RAVNOTEŽE U ODNOSU NA NORME PREMA ODGOVARAJUĆEM POLU I GODININAMA ŽIVOTA

Sistem za ocenjivanje grešaka u ravnoteži (prema engl. Balance Error Scoring System-BESS) je uobičajen test ravnoteže koji se zasniva na alatima za procenu poput Sway^{TM} Balance aplikacije za IOS mobilne operativne sisteme, koja obuhvata triosne akcelerometre i senzore kretanja za merenje njihanje tela. S obzirom da su uzrast i pol važni faktori prilikom primene ove metodologije, utvrđeni su odgovarajući setovi normativnih skorova. Osnovni cilj ovog istraživanja bio je kvantitativna analiza sposobnosti zdravih, 21-godišnjih učesnika oba pola da održe posturalnu ravnotežu koristeći gore navedene normativne vrednosti. Ocenjivanje posturalne ravnoteže izvršeno je primenom modifikovanog BESS testa i Sway^{TM} Balance softvera tokom protokola organizovanog u tronedeljnim sesijama i sa dvostrukim bodovanjem. Da bi se procenile sposobnosti prema uzrastu i polu, prosečni medijani rezultata ravnoteže su kontekstualizovani odgovarajućim normativnim vrednostima. Svi učesnici su pokazali prosečne rezultate, sa skorovima koji se poboljšavaju tokom procedure, dok su žene pokazale bolje rezultate od muškaraca. Fokusiranjem isključivo na rezultate prve sesije utvrđeno je međutim, da su muškarci zabeležili nisku prosečnu tačku prekida (tzv. cut-off point), dok su žene zabeležile ispod prosečne tačke prekida u odnosu na starost i pol. Međutim, tokom poslednje sesije ispitanici oba pola ostvarili su prosečne rezultate. Ovo istraživanje je pokazalo prosečne sposobnosti ispitivanih učesnika, u odnosu na normativne vrednosti, kao i uopšteno bolje performanse ispitanica u odnosu na ispitanike. Istraživanje je takođe, ukazalo da je zbog adaptacije ispitanika, izabrana kombinacija protokola i tehnologije bila od ograničene koristi u proceni ravnoteže opšte populacije, što ukazuje na potrebu za prilagođavanjem protokola u budućim istraživanjima.

Ključne reči*: BESS, Sway^{TM}, normativni rezultati, ravnoteža*