BALANCE MEASUREMENTS USING A SMARTPHONE AT THE UPPER ARM COMPARED TO THE BALANCE ERROR SCORING SYSTEM

[1] Peter C. Fino, [2] Matthew D. Weirath, [3]Rahul Soangra, [3]Thurmon E. Lockhart, [4]P. Gunnar Brolinson

[1] Virginia Tech, Blacksburg, VA, USA
[2]Belleville Family Medicine Residency, 375th Medical Group, Scott AFB, IL, USA
[3] Arizona State University, Tempe, AZ, USA
[4] Edward Via College of Osteopathic Medicine, Blacksburg, VA, USA
email: fino@vt.edu

INTRODUCTION

Concussions can affect balance and stability, making balance assessments an important component of concussion test batteries [1]. The balance error scoring system (BESS) has become the standard field test to identify balance deficits following concussions using a trained clinician to count errors [2]. Instrumenting the BESS with inertial measurement units can produce better diagnostic classification than the traditional "error count" which can be challenging for the clinician [3]. Removing the clinician's error count reduces the challenge of administering the BESS. Furthermore, using publicly familiar IMUs will allow more widespread use when a clinician is not readily available (e.g., youth sports, at-home monitoring). This study compared the traditional BESS error count with the sway measurements of a common smartphone attached with a standard sport armband in healthy young adults.

METHODS

Twenty healthy young males (ages 18-22) previously unfamiliar with the BESS gave written consent and were tested two separate times with one week in between sessions. All protocols were approved by the Virginia Tech IRB. A smartphone (iPhone 5, Apple Inc.) was placed laterally on the upper arm, midway between the elbow and shoulder using a standard smartphone sport armband (Belkin Sport-Fit Armband, Belkin). Participants performed three stances (double, single leg, tandem) on firm ground and on a foam Airex balance pad. Participants were instructed to keep their hands on their iliac crests and maintain each stance for 20 seconds with their eyes closed, returning to that position as soon as possible if they moved their hands, feet, opened their eyes, or lost balance.

A trained sports medicine physician counted BESS errors for each stance [2]. The smartphone calculated sway using tri-axial accelerometers, sampled at 31.5 Hz, and computed the angles between the sensitive axes and the direction of gravity using α, β, and γ, the angles of the resultant acceleration with respect to the local reference frame (Figure 1) [4]. The projection's coordinates (d_x, d_y) were calculated using these angles and the height of the smartphone *dz*. The circular sway area was calculated using the mean radius of sway and sway velocity was the sway length over time.

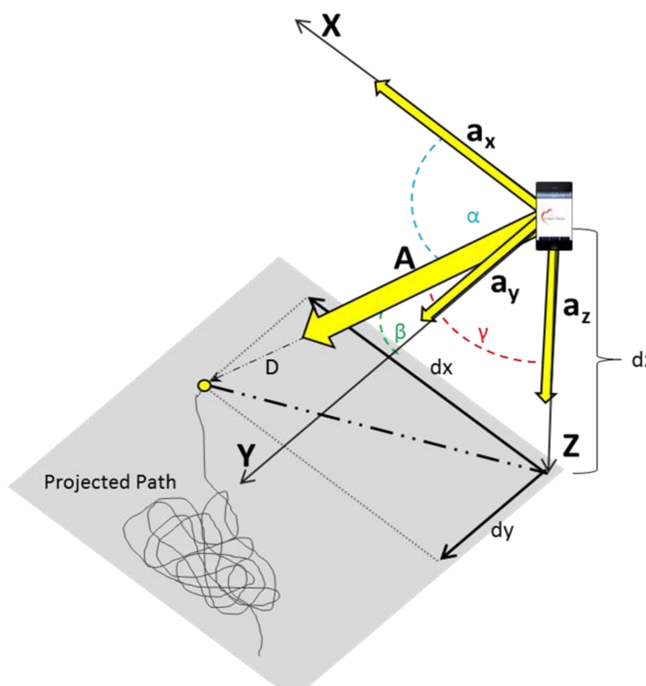

Figure 1: Schematic diagram of projected sway using the iPhone accelerometers. Adapted from [4].

Spearman's rank correlation coefficient (ρ) was used to compare all measurements of sway area and sway velocity to the BESS errors overall and separated by ground (firm vs. foam). Interclass correlation coefficients (ICC (2,1)) compared the repeatability of the BESS and sway measurements on each individual from the first to second weeks.

RESULTS AND DISCUSSION

Spearman's ρ between all BESS scores and sway area was 0.86, and 0.85 between BESS scores and sway velocity. On the firm surface, ρ = 0.76 for sway area and 0.77 for sway velocity. On the firm surface, ρ = 0.83 for sway area and 0.79 for sway velocity. ICC values are given in Table 1. Medians and inter-quartile ranges (IQRs) for each measure are given in Table 2.

Table 1: ICC's comparing between weeks.

ICC	All	Firm	Foam
BESS errors	0.01	0.45	-0.27
Sway area	-0.04	0.40	-0.10
Sway velocity	-0.01	0.08	-0.02

Overall, the smartphone based measures showed good (> 0.80) clinical reliability to the BESS scores, especially for a system located on an upper extremity. While the repeatability was poor, the sway area's repeatability was similar to the BESS, and both showed the highest repeatability on firm ground, the most likely surface for BESS tests without a clinician. Because the BESS errors do not take into account movements of the upper body unless an error is committed, it is possible the smartphone based measures of sway area and sway velocity may more accurately represent the postural control of individuals, with differences between methods attributed to discrepancies in the BESS reliability and repeatability [5]. This discrepancy between methods is evident when examining the single leg stance measurements, where large upper body movements resulted in very large sway amplitudes and velocities, but may have only counted as one error. However, this study is limited because the smartphone based measures were not compared to a ground truth (i.e. force plate) and no concussed individuals were tested, limiting conclusions about the clinical classification ability of the sway area and velocity. By placing the smartphone on the upper arm, the measurements were also biased against arm movements, which resulted in large sway amplitudes and velocities, compared to foot movements or opening eyes, which the BESS treats equal to arm movements but produced small sway amplitudes.

CONCLUSIONS

Overall, a common smartphone and sport armband achieved good reliability and comparable repeatability with the BESS, encouraging further studies in clinical and concussed populations to extend the use of smartphone-based balance testing.

REFERENCES

1. McCrory P, et al. *Br J Sports Med* **45.5**, 250-258, 2013.
2. Guskiewicz KM. *Clin Sports Med* **30.1**, 89-102, 2011
3. King LA, et al. *Arch Phys Med Rehab* **95**, 353-359, 2014.
4. Seimetz C, et al. *Biomed Sci Instrum* **48**, 386-392, 2012.
5. Hunt TN, et al. *Clin J Sport Med* **19.6**, 471-475, 2009

ACKNOWLEDGEMENTS

The first author was supported by an NSF Graduate Research Fellowship (Grant No. DGE 0822220).

Table 2: Medians (IQR) for BESS errors, sway areas, and sway velocities for each stance.

	Firm Ground			Foam Ground		
	Double	**Single Leg**	**Tandem**	**Double**	**Single Leg**	**Tandem**
BESS errors	0 (0)	2.5 (3.5)	1 (2)	0 (0)	8 (3.5)	5 (5)
Sway area (cm^2)	3.0 (1.1)	14.1 (8.8)	8.8 (4.2)	5.5 (1.9)	26.8 (106.8)	22.3 (11.7)
Sway velocity ($cm*s^{-1}$)	1.2 (1.0)	28.0 (47.9)	7.4 (11.1)	4.2 (1.9)	171.8 (1469.3)	70.0 (147.6)