VALIDATION OF A TWO SENSOR IMU SYSTEM FOR BALANCE ASSESSMENTS AND CERVICAL SPINE RANGE OF MOTION MEASUREMENT

Taylor Holt[1], Walter Laughlin[1], Koby Close[1], Brittany Dowling[1], Ben Hansen[1], Glenn Fleisig[1,2]
[1]Motus Global, Rockville Centre, NY, USA
[2]American Sports Medicine Institute, Birmingham, AL, USA
email: ben@motusglobal.com, web: www.motusglobal.com

INTRODUCTION

Current SCAT5 concussion protocol is a standardized tool for evaluating athlete concussions based on eight types of assessments that are done in a healthy state (baseline) and on the side line in the event of a suspected concussion. These include tests of cognitive awareness, neck mobility, memory, reaction time, and balance. Many of these which are subjectively measured could be developed in a mobile device application for more accurate reporting.

The main test of this report is referred to as the Modified Balance Error Scoring System (BESS) test. This testing system involves a series of three stance positions conducted with the eyes closed for 20 seconds: Double leg stance, single leg stance (non-dominant foot), and tandem stance (non-dominant foot behind). Current evaluation protocols involve a subjective judgement system where the rater looks for any errors that occur during this test including; moving the hands off the hips, opening eyes, step, stumble, fall, abduction of flexion of the hip beyond 30º, lifting the forefoot or heel off the testing surface, or remaining out of the proper testing position for greater than 5s. Although this test is quick to administer it suffers from reliability issues and is subject to practice, learning, and fatigue effects. (Doherty, Zhao, Ryan, Komaba, Inomata, & Caulfield, 2017).

Current research using accelerometer and mobile devices for measuring BESS scores or repeatability of BESS error scores shows varying results. In an attempt to identify the best placement for inertial measurement units (IMUs) to replicate the BESS error calculations Brown et al. (2014) attempted to validate a scoring system using a network of sensors and evaluating the linear acceleration data. Although they found that a single IMU on the forehead could predict with some accuracy the BESS score, the reliability and objectivity of this measure has been held in question. However there have been a significant number of studies to show that accelerometer and gyroscope data can be used to accurately reproduce center of pressure (COP) path or postural sway when compared to gold standard measurements such as force plates (Neville, Ludlow, & Reiger, 2015) or motion capture technology (Alberts, et al., 2015) and others which have shown the ability to identified patients who are concussed with 60% sensitivity and 82% specificity (Furnman, Lin, Bellanca, Marchetti, Collins, & Whitney, 2013).

More importantly, it has also been questioned whether the BESS score is even the most accurate method of testing postural stability to determine readiness to play in concussed athletes. Although this test has been shown to accurately predict concussions in acute patients, once these patients have advanced beyond three days subjective tests, such as BESS, lose accuracy in predicting concussed patients (Johnston, Coughlan, & Coulfield, 2017). More recently investigators have been relying on force plates to detect the small changes in postural sway to determine minor changes in COP that cannot be detected in subjective measurements.

Currently the market leader in COP testing is SWAY Medical, which has been shown to have significant relationships from accelerometer data from an iPad to force platform data (Burghar, Craig, Radel, & Huisinga, 2017). However, this system collects data at 10 frames per second which is likely to slow to detect the minor changes postural sway in longer term concussions or concussed athletes with significant balance.

Therefore, there is a need for a more advanced system that can accurately reproduce postural sway data that can be utilized to determine an athlete's concussion status or ability to return to play based on a scoring system comparing to baseline or healthy data.

METHODS

One healthy, collegiate football player (21 years; 193.04 cm; 86.36 kg) reported to the Motus Biomechanics Laboratory for testing and was outfitted with 49 retro-reflective markers on anatomical landmarks as well as a head-band and chest-band instrumented with motusCONCUSSION sensors (Motus Global, Rockville Center, NY, USA). Kinematic data were collected simultaneously using fourteen-camera 3D motion capture system (480 Hz) (Motion Analysis Corp., Santa Rosa, CA, USA) and the sensors. The subject was then instructed through a cervical range of motion protocol: cervical pitch, yaw, and roll. The subject then performed three trials of a double leg stance balance test for 30 s.

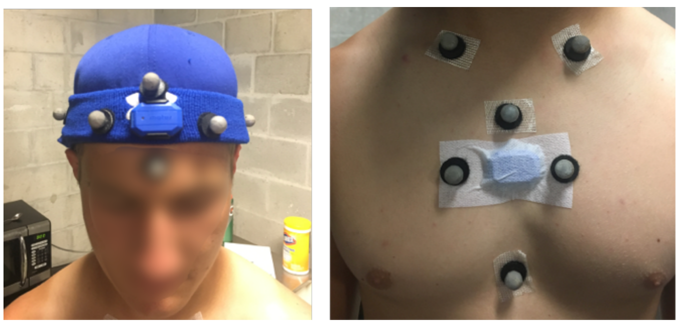

Figure 1. Experimental setup of marker and sensor placement.

Marker motion data were first filtered through a low-pass 14 Hz Butterworth filter then used to calculate kinematics for thoracic and forehead orientation. Relative cervical spine kinematics were then computed. Gyroscope and accelerometer data simultaneously collected from the motusCONCUSSION sensors were used to calculate the same kinematics for all trials throughout testing. To determine the validity of the head and chest-worn motusCONCUSSION sensors against the currently accepted gold-standard for kinematic measurements, 3D motion capture, RMSE values were calculated for all cervical spine kinematics, and a paired t-test was done for the balance measures of postural sway.

RESULTS AND DISCUSSION

Descriptive statistics are reported in Table 1. There were no statistical differences between balance measures captured with the motusCONCUSSION system and the 3D motion capture ($p<0.001$).

Table 1. Descriptive Statistics for postural sway metrics using motion capture and IMU.

	Motion capture (mean ± SD)	IMU (mean ± SD)
Average radius (cm)	8.76 ± 0.38	9.37 ± 0.46
Max radius (cm)	16.03 ± 0.30	17.27 ± 0.53

Results indicate that the motusCONCUSSION system has strong validity in measuring postural sway. Monitoring balance mechanics for consistency after a baseline can provide valuable information related to the effectiveness of concussion detection for coaches and trainers.

Furthermore, RMSE graphs of cervical spine range of motion are reported below in Figures 2-4. There was a strong correlation between both the motion capture and IMU kinematics in all three planes of motion (pitch, yaw, and roll). Results show that the motusCONCUSSION platform is a valid and reliable means of gathering cervical range of motion data.

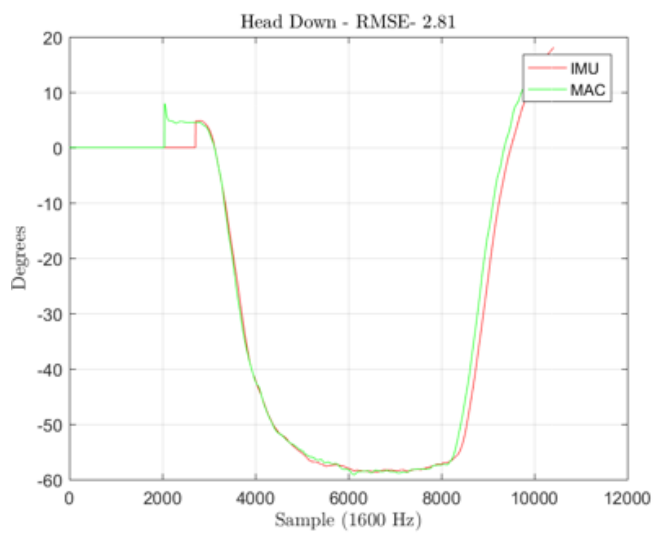

Figure 2. Relationship between motion capture (MAC) data and motusCONCUSSION (IMU) data for neck pitch.

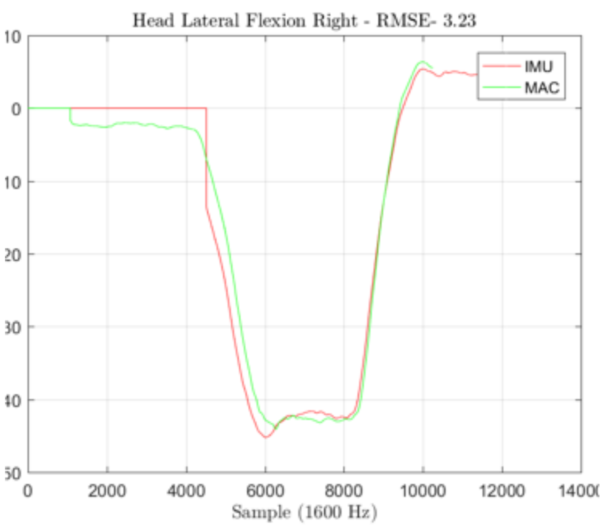

Figure 3. Relationship between motion capture (MAC) data and motusCONCUSSION (IMU) data for neck roll.

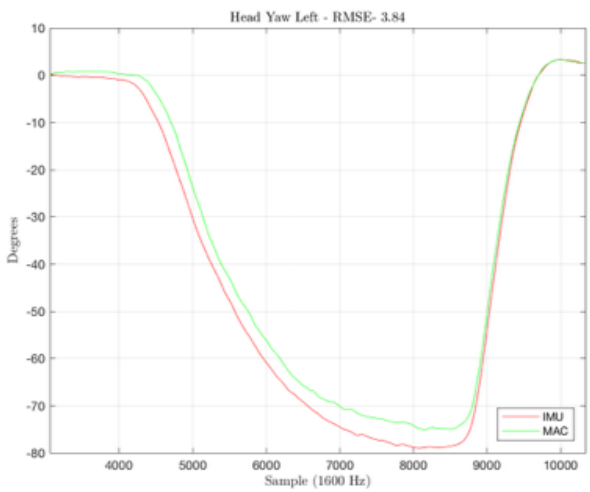

Figure 4. Relationship between motion capture (MAC) data and motusCONCUSSION (IMU) data for neck yaw.

CONCLUSION

The motusCONCUSSION system provides accurate measures of cervical spine range-of-motion associated with standard concussion detection assessments.

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