UNIVERSITY OF CALGARY

Validition of Kinetisense Balance and Kinetisense Advanced Movement Screen clinical assessment tools

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1. Background

Advances in the field of marker-less motion capture have the ability to redefine methods for assessing human motion in various clinical settings. Current protocols for motion or posture assessment in clinic often rely on visual grading scales, sometimes incorporating two-dimensional (2D) video. While these methods are both cost effective and can be performed in a short amount of time, there are concerns regarding their reliability across multiple sessions and between clinicians. For example, the Balance Error Scoring System (BESS), is a popular test used among various populations, from assessing risk of fall in the elderly, to monitoring recovery of an athlete post-concussion. The BESS is made popular in these fields due to the ease in which it can be administered, and the minimal cost associated. However, researchers have raised concerns regarding the validity (Bell, Guskiewicz, Clark, & Padua, 2011; Chang, Levy, Seay, & Goble, 2014), and reliability of the protocol compared to gold standard force plate measures of balance (Finnoff, Peterson, Hollman, & Smith, 2009; Hunt, Ferrara, Bornstein, & Baumgartner, 2009). The same can be said for the use of goniometers, or visual inspection of posture and range of motion in a clinical setting.

For decades, the alternative to visual inspection and 2D video were expensive motion analysis systems using multiple infrared cameras, markers placed on the subjects' skin, and time-consuming software that eventually output precise movement variables in an objective manner. Many clinicians and trainers, however, found the cost of using these systems outweighed the benefit of more valid, and increasingly reliable data. More recently, with refinement of marker-less motion capture, clinicians and trainers now have access to technology that is cost effective, easy to administer, and provides objective, valid movement data.

Current research suggests the Microsoft Kinect 2.0 (Kinect), a commercially available Light Detection and Ranging (LiDAR) camera, provides a valid assessment of human motion for such movements as: reaching tasks (Clark et al., 2012), postural sway during balance trials (Yeung, Cheng, Fong, Lee, & Tong, 2014), and even certain spatiotemporal aspects of walking gait (Clark, Bower, Mentiplay, Paterson, & Pua, 2013; Mentiplay et al., 2015). Using a single LiDAR camera, and appropriate software, anatomical landmarks are identified in three-dimensions (3D) and multi-segment position data are recorded. Marker-less motion capture is faster and more cost effective than traditional 3D motion analysis which requires calibration of expensive camera systems, and precise placement of retroreflective markers on various anatomical landmarks. Of note, the placement of markers by the clinician is a well documented source of error in the calculation of joint angles between days and between clinicians (Gorton, Hebert, & Gannotti, 2009; Osis, Hettinga, Macdonald, & Ferber, 2014; Szczerbik & Kalinowska, 2011)

Kinetisense Inc. has developed a proprietary software package that builds upon the standard algorithm provided by the Microsoft SDK. The Kinetisense algorithm improves the position tracking accuracy of the Kinect and provides joint position information in the sagittal, frontal, and transverse planes. Previous validation of the Kinetisense range of motion algorithm suggests the software can be a viable alternative to expensive motion analysis systems. Consequently, the aim of this study was to build upon prior validation and compare two Kinetisense modules, 3D Balance, and Kinetisense advanced Movement Screen (KAMS) to their respective gold standard measures. (1) The 3D Balance score was compared to centre of pressure (CoP) measurement from a research grade force plate, (2) Components of the 3D Balance score were compared to the same values calculated by a six-camera

motion analysis system, and (3) KAMS anatomical position data and basic joint angles expressed relative to the global coordinate system were compared to the same values calculated using a six-camera high-speed motion analysis system.

2. Methods

2.1 Participants

Fifteen undergraduate and graduate students were recruited from a university campus to take part in the study (age: 27.8 ± 2.97 yrs, height: 170.63 ± 6.11 cm, mass: 71.17 ± 10.17 kg, male = 8). Prior to data collection, participants provided informed written consent according to the University of Calgary Conjoint Health Research Ethics Board (REB17 – 0951). At the time of data collection, participants were healthy, free of injury, and unaffected by any condition that might inhibit their balance or range of motion.

2.2 Experimental Protocol

Each participant made one visit to the lab and performed a series of six balance trials, according to a modified BESS protocol, followed by seven KAMS trials. The six balance trials consisted of (1) both feet together on firm surface, (2) tandem stance on firm surface with dominant foot forward, (3) one leg stance on firm surface with dominant foot raised, (4) both feet together on unstable foam surface, (5) tandem stance on unstable foam surface with dominant foot forward, and (6) one leg stance on unstable foam surface with dominant foot raised. A foam pad was used for the unstable surface (Airex, 45cm x 38cm x 6cm). All balance trials were performed with eyes closed, hands on iliac crests, and one or both feet flat on the balance surface. Participants were instructed to maintain their static position for 20 seconds. KAMS trials consisted of the following series of basic movements: trunk flexion (sagittal), trunk lateral flexion, trunk rotation (transverse plane), inline lunge, overhead squat, simulated wall angel, and one leg vertical jump off non-dominant leg.

Balance and KAMS trials were recorded using one Microsoft Kinect 2.0 (30 fps) with Kinetisense version 3.6.3 operating on a Microsoft Surface Pro 4 running Windows 10. Marker position data were recorded using a six-camera Vicon MX-3 infrared system (200Hz) with 28 retroreflective markers (14mm) fixed to the participant's skin bilaterally at the following locations: Base of third meta-tarsal phalangeal joint, medial/lateral malleoli, medial/lateral knee joint line, greater trochanter, acromion processes, medial/lateral humeral epicondyles, and radial/ulnar styloid processes. Additional markers were fixed to the sternal notch, right and left forehead, and a cluster of three markers was fixed to the sacrum. Centre of pressure data were recorded using a Bertec force plate (1000 fps). Marker data were tracked, and force plate data were exported using Vicon Nexus software. All data were post-processed using custom written code in MATLAB (v9.1).

2.3 Data Analysis

2.3(a) 3D Balance vs CoP

Lin et al. (2008) showed Mean velocity (MV) to be the most reliable measure of CoP data for within- and between-day balance assessment, therefore the same method was used to compare to the 3D Balance score output by Kinetisense. MV represents CoP displacement by summing each resultant

displacement vector in the xy-plane and dividing by the total duration of the trial. An MV value approaching zero indicates minimal or controlled movement of the CoP, whereas in an increasing value for MV suggests uncontrolled, high velocity movement of the CoP. For 3D Balance, the user receives a score (out of 10) at the end of each trial that accounts for various movement measures of the head, shoulders, hips, and knees as well as ensuring the target pose (ie. tandem stance) is maintained. A high score represents minimal sway and lean of the segments. Because the 3D Balance scores and MV use different scales, the rank of all balance trials was compared between the two methods. In this case, each of the 90 balance trials received a rank from 1 to 90 according to their associated MV score and another rank for their 3D Balance score. Spearman's rank correlation was used to compare the two sets of ranked scores. Spearman's correlation returns a value from 0 to 1 and is evaluated as follows: < 0.5 is weak, 0.5 – 0.7 is moderate, > 0.7 is strong (Craig, Bruetsch, Lynch, Horak, & Huisinga, 2017).

2.3(b) 3D Balance Components vs Vicon

Certain components that make up the 3D Balance score were validated against the same measures as recorded by the Vicon MX-3 cameras. The variables of interest were Average Tilt, Average Displacement, and %Time in Ring. These variables were replicated using Vicon motion data, and compared to the Kinetisense iterations using intraclass correlation coefficient (ICC) (3,1) for absolute agreement. ICC outputs a value *r* ranging from 0 to 1, with 0 representing no correlation and 1 representing perfect correlation. The correlation *r* is interpreted as follows: < 0.4 is poor, 0.4 – 0.59 fair, 0.6 - 0.75 good, and > 0.75 excellent (Cicchetti & Sparrow, 1981).

2.3(c) KAMS vs Vicon

To assess validity of the KAMS protocol, the basic movements described above allowed for the extraction of the following joint angles and segment position data. Each variable was measured using the KAMS protocol and the Vicon system:

- Lateral Hip Tilt (Frontal plane)
- Lateral Shoulder Tilt (Frontal plane)
- Relative Position of Shoulder to Elbow
- Relative Position of Elbow to Wrist
- Relative Position of Knee to Ankle
- Vertical Jump Height

Comparisons between the above measures calculated in KAMS and the same measures replicated in Vicon were made using ICC (3,1) for absolute agreement.

3. Results

A strong correlation was observed for comparison between the 3D Balance score and an established measure of balance performance using mean velocity of CoP ($r_S = 0.762$, $p < 0.001$). Table 1 shows the ICC (3,1) for specific components of the 3D Balance score compared to the Vicon system.

Average tilt and % time in ring 1 showed good reliability (0.69 – 0.74), while travel distance displayed excellent reliability with ICC value of 0.84.

Table 1. Intraclass correlation coefficients (3,1) of 3D Balance components for absolute agreement with the gold standard Vicon system (AP = Anterio-posterior; ML = Medio-lateral; Vert = Vertical).

3D Balance Variable	**ICC (3,1)**
Avg. Tilt	0.69*
Travel Distance	0.84*
%Time in Ring 1	0.74*

^ n = 38. Trials in which both the Kinetisense software and the Vicon system reported 100% of the trial spent within Ring 1 were not included. Including these values would wrongfully increase the ICC value.
* Significant correlation ($\alpha = 0.05$)

ICC values for comparison of a set of KAMS variables compared to the Vicon system are shown in Table 2. Correlation of KAMS joint angles and relative positions between joint centres varied when compared to the Vicon system.

Table 2. Intraclass correlation coefficients (3,1) of KAMS variables for absolute agreement with the gold standard Vicon system (AP = Anterior-posterior; ML = Medial-lateral; Vert = Vertical), n = 15 (unless otherwise stated).

KAMS Variable	**ICC (3,1)**
Lateral Hip Tilt	0.85*
Lateral Shoulder Tilt	0.93*
Shoulder/Elbow Position Vert.	0.96*
Elbow/Wrist Position ML	0.91*
Elbow/Wrist Position AP	0.61*
Knee/Ankle ML	0.69*
Vertical Jump Height	0.98*
* significant correlation ($\alpha = 0.05$)	

4. Conclusion

The Kinetisense 3D Balance and KAMS modules were validated against gold-standard measurements of force plate CoP and multi-camera Vicon motion capture. Overall, the validation of both modules showed promising results.

Kinetisense Inc. has shown great foresight by already taking the necessary steps to ensure that the KAMS scoring system is tailored to the capabilities of the Kinect camera. For instance, the measures of Shoulder Transverse Rotation and Knee/Ankle AP have been modified to only include an "all or nothing" score, as opposed to scoring based off an absolute rotation angle or joint position. By adjusting the scoring criteria for certain KAMS movements, Kinetisense is well positioned to avoid the possible shortcomings of the Kinect camera.

The results of this study suggest the Kinetisense 3D Balance module may be a valid alternative to expensive and cumbersome force plate or multi-camera motion analysis systems for clinical balance assessment and postural sway analysis. The objective scoring provided by the 3D Balance tool improves upon current clinical standards that rely on scoring sheets or subjective interpretation of 2D video. The ease of set-up and the quick turnaround of objective balance data allow the clinician to fully dedicate themselves to interacting with and assessing the patient. Instead of calibrating cameras, placing markers, and processing data the clinician can spend their time working with the patient to interpret the results, discuss their progress, and develop training plans.

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