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A Comparison of Inertial Motion Capture Systems: DorsaVi and Xsens

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ABSTRACT

Background: dorsaVi Professional Suite, founded in 2018, is a 3D wearable sensor technology system that monitors the kinematic data of the lower extremity and lumbar spine. The dorsaVi system is used in the clinical setting to assist with clinical rehabilitation and preventive measures. **Objective:** The purpose of this study was to compare the inertial motion capture systems: the dorsaVi Professional Suite and Xsens to determine validity and reliability. **Methods:** This study utilized nine participants (7 female, 2 male) with data collected on two separate sessions. Each subject performed 15 repetitions each of double leg squats, left single leg squat, and right single leg squat during session one and then repeated the same testing procedure 7-10 days later. Kinematic variables measured were tibial inclination, knee varus, and knee valgus. Pearson product moment correlation coefficients were used to demonstrate the relationship within and between the motion capture systems across the knee positions and squat trials. **Results:** Within system reliability measurements demonstrated strong correlations ($r>0.90$) of the lower extremity kinematic data between testing sessions. Between system validity measurements also demonstrated strong correlations ($r>0.90$) across all lower extremity movements. **Conclusions:** The dorsaVi Professional Suite knee module kinematic data showed strong correlations to the validated motion capture system (Xsens). Thus, a clinician should be confident in using the dorsaVi in the evaluation, diagnosis, and treatment of patients.

Key words: Inertial Motion Unit (IMU), Movement, Lower Extremity, Physical Therapy, Dorsavi, Biomechanical Phenomena

INTRODUCTION

Assessment of movement patterns is an integral piece of physical therapy practice. Typically, the physical examination involves visual observation of gross and segmental movement by the clinician. While a skilled clinician can complete a rigorous musculoskeletal evaluation, objectively quantifying multi-planar human movement is very difficult, especially at speed. Recently, there have been several 3D systems that have been developed to analyze both healthy and injured adults (Lanovaz, Musselman, Oates, Treen, & Unger, 2017). Several systems have been created that utilize accelerometers, inertial sensors, and gyroscopes to capture detailed kinematic and kinetic data on gross or segmental movement (Lanovaz et al., 2017). IMU (inertial measurement units) have been utilized to quantify gross movement patterns by subjects wearing the 3D technology, therefore decreasing the clinician subjectivity of movement during an exam (Garner, Parish, Shaw, Wilson, & Donahue, 2020).

Three-dimensional optoelectronic motion capture systems can be used to quantify these complex movements, but specific 3D systems are not practical in an outpatient rehabilitation setting. Several types of motion capture systems have been examined to provide quality data to the clinician. For example, Eltoukhy et al. (2017) investigated the correlations across hip, knee, and ankle joint angles between the Microsoft Kinect system and an optoelectronic motion capture system. Results demonstrated that the Kinect system was an acceptable device to measure hip and knee kinematics, however the Kinect system demonstrated poor correlation with the optoelectronic motion capture system in ankle joint kinematics (Eltoukhy et al., 2017).

The dorsaVi Professional Suite is a relatively new wearable inertial motion capture system, utilized primarily in physical therapy clinics, to assist with evaluating general lower extremity biomechanical abnormalities and gait mechanics (Charry, Hu, Ronchi, Taylor & Umer 2013). The dorsaVi Professional Suite has the capability of analyzing knee, low back, and running kinetic and kinematic variables (https://www.dorsavi.com/us/en/professional-suite/). In addition, these systems have progressively been used in the clinic to assist with treatment planning, diagnosing, and overall movement assessment. However, it is reported that there is a significant need for developing strong validity and reliability amongst movement analysis systems and

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utilizing consistent measurement techniques (Baker, 2006). Khurelbaatar, Kim, Kim, and Lee (2015) determined that inertial sensors demonstrate reliability measuring inter-segmental angles by comparing the Xsens and Pedar-X force plate system. Feasibility was determined within this study that joint forces and moments measured by inertial motion sensors and in-shoe pressure sensors mimicked normal full body motions of walking (Khurelbaatar et al., 2015). In addition, the strongest correlation existed with the lower extremity (LE) joint motions to include: hip, knee, and ankle motions, whereas the corresponding joint moments demonstrated smaller correlation coefficients.

Mjosund et al. (2017) found clinically acceptable agreement of lumbar motions between an optoelectronic system (Vicon) and the dorsaVi ViMove IMU system. Hughes, Jones, Starbuck, Sergeant & Callaghan (2019) studied the differences in initial peak accelerations as measured by the dorsaVi ViPerform system and the Delsys IMU system. Good to excellent in-session reliability was demonstrated between the two systems (Hughes et al., 2019). Furthermore, Mohammed et al. (2018) examined reliability and validity of the Xsens IMU motion capture system and concluded that the Xsens hardware and software can be used by a clinician to quantify lower-limb joint angles in clinically relevant movements. In addition, the Xsens has been shown to be a valid and reliable tool to track human movement in ergonomic applications (Robert-Lachaine, Mecheri, Larue, & Plamondon, 2017).

The dorsaVi IMU Professional Suite is intended to provide clinicians with accurate kinematic data to improve patient evaluation, diagnosis, and treatment. The knee module, a specific component of dorsaVi, has had minimal support to demonstrate validity and reliability due to the newness of the device. Both athletes and clinicians are encouraged to determine the accuracy, value, and validity of 3D wearable devices prior to implementation (Willy, 2018). Since the release of the dorsaVI Professional Suite in 2018, there has been minimal validity and reliability studies completed. Currently, the only validation study that has been conducted is on the ViMove for the low back module. Therefore, the purpose of this study was to investigate the validity and reliability of the dorsaVi Professional Suite knee module relative to the previously validated IMU system, Xsens.

METHODS

Study Design

The study was of a correlational design comparing the sagittal and frontal plane knee kinematics between the two motion capture systems across the independent variable of squat type and dependent variables to include tibial inclination and knee varus (hip external rotation) and valgus (hip internal rotation).

Subject Characteristics

Subjects were recruited from Drake University and included 7 females and 2 males. Ages of the subjects ranged from 22-38 years old and each subject reported a moderate level of physical activity. Subjects also met inclusion criteria if they currently had no lower extremity pathology or injury. Exclusion criteria was outlined to include any individual who was not moderately active or currently had recently undergone a lower extremity surgery or injury. Prior to participation, subjects were verbally informed on the study procedure and signed the informed consent, as approved by the University IRB (#2018-19043).

Materials and Procedures

Initially, subjects underwent anthropometric measurements to include height and weight. Following anthropometric measurements, the subjects were outfitted with both the dorsaVi Professional Suite and Xsens system sensors utilizing elastic straps and also adherent placement stickers. The dorsaVi Professional Suite knee module requires the placement of one IMU sensor on the anterior surface of the mid-shaft of both right and left tibia (Garner, 2020). Tibia sensor placement is based on the anthropometric measurement of height and a ruler is used to measure exact placement, which is the midpoint between the knee and ankle along the anterior surface of the tibia (Wenheng, Charry, Umer, Ronchi, & Taylor, 2014). After placement of bilateral tibia sensors, the dorsaVi Professional suite is calibrated per the professional suite dorsaVi software. The next step was to securely attach the Xsens system onto the subject. The Xsens system utilized seven motion trackers that were applied to the pelvis and lower extremities of the subject and the system was calibrated per manufacturer recommendations for lower extremity motion capture (Xsens Awinda, Xsens Technologies BV, Enschede, Netherlands). Once both motion capture systems were active, the researcher demonstrated the three different functional movements that were to be performed (double leg squat, right single leg squat, and left single leg squat). Subjects verbally agreed to start the data collection and proceeded to complete the following order and repetitions: 15 repetitions of double leg squat, 15 repetitions of right single leg squat, and finally, 15 repetitions of left single leg squat. The researcher instructed each subject to initiate the next repetition to ensure both 3D systems were ready.

Seven to ten days following initial data collections, subjects returned for the second data collection session to complete the same procedure. Prior to the start of the second data collection, all subjects were asked if they had any changes in the initial inclusion criteria and if any residual long-term soreness resulted from initial data collection. All subjects completed the second data collection session.

Kinematic variables (dependent variables) were compared across the three functional movements and between the two systems. The dependent variables included: maximum tibial inclination and knee position in the frontal plane (maximum varus and valgus). These dependent variables were chosen to reflect the similar kinematic variables that could be collected by both the dorsaVi Professional Suite knee module.

Statistical Analysis

Statistical analysis was completed using Stata 15.1 software (StataCorp. 2017. *Stata Statistical Software: Release 15*. College Station, TX: StataCorp LLC). Data collection resulted in 2160 data points between both systems and across all lower extremity movement trials. A Pearson product moment correlation coefficient (Pearson-r) was computed to assess the relationship of lower extremity kinematic measurements between each IMU system and within each IMU system across the two separate testing sessions.

RESULTS

Table 1 presents subject characteristics. As seen in Tables 2 and 3 very high, positive relationships (Mukaka, 2012) were found for each IMU system between testing sessions and across IMU systems. Pearson-r values between the Xsens and dorsaVi systems were as follows (Table 2): double leg squat = 0.93, single leg squat left = 0.92, single leg squat right = 0.93, all variables combined = 0.92. These values indicate agreement in lower extremity kinematic measures between the Xsens and dorsaVi motion capture systems. Pearson-r values within the dorsaVi across both testing sessions were as follows (Table 3): double leg squat = 0.91, single leg squat left = 0.91, single leg squat right = 0.95, all variables combined = 0.92. Pearson-r values within the Xsens across both testing sessions were as follows (Table 3): double leg squat = 0.93, single leg squat left = 0.92, single leg squat right = 0.93, all variables combined = 0.92. These correlation coefficients highlight similar lower extremity kinematic measurements made by both motion capture systems across both testing sessions. This would indicate reliability of measurement of each system.

Table 1. Characteristics of Participants

Characteristics	
Sex	7 females, 2 males
Age (years)	22-38 (Range)
Height (cm)	170.84 + 6.86 (M+SD)
Weight (kg)	75.73 + 14.36 (M+SD
BMI	26.2 (M)

Table 2. Pearson-r values across both testing sessions between both Xsens and dorsaVi system

Movements	r-values
Double leg squat	0.93
Single leg squat left	0.92
Single leg squat right	0.93
Combined	0.92

Table 3. Pearson-r values between first and second testing sessions for each IMU system

Movements	DorsaVi r-values	Xsens r-values
Double leg squat	0.91	0.93
Single leg squat left	0.91	0.92
Single leg squat right	0.95	0.93
Combined	0.92	0.92

DISCUSSION

Inertial measurement units (IMU) have become a popular alternative for effective human movement motion capture that offer benefits for utilization in outpatient rehabilitation settings. The purpose of this study was to investigate the validity and reliability of the dorsaVi Professional Suite knee module relative to the Xsens for lower extremity functional movements. The dorsaVi Professional Suite was developed by dorsaVi in 2018 to improve the clinician feasibility for use in the clinic or on the field to capture a kinematic and kinetic evaluation (https://www.dorsavi.com/us/en/professional-suite/). Currently, there are several marker-based motion systems that exist in research, however these are both expensive and difficult to use within a clinical setting (Eltoukhy et al., 2017). To improve the accessibility and feasibility of a 3D wearable sensor system in the clinical setting, dorsaVi developed the Professional Suite (https://www.dorsavi.com/us/en/professional-suite/). With the recent (2018) United States dorsaVi Professional Suite market release, this study was designed to validate the knee module's kinematic measurements with the already validated Xsens system. As demonstrated in the above results section, a very high, positive correlation ($r > 0.9$) existed between all dependent variables when comparing dorsaVi to Xsens. Similar to Lanovaz et al. (2017), r-values were used to demonstrate coefficient correlations between all points of data between Xsens and dorsaVi. The initial data collection (Table 2) demonstrates a very high, positive correlation between the ability to measure specific dependent variables between both software systems.

The dorsaVi Professional Suite system consists of a knee, running, and low back module. Each of these modules measure primarily trunk and lower extremity joint kinematics and kinetic variables (https://www.dorsavi.com/us/en/professional-suite/). Lower extremity joints have been demonstrated to have improved coefficient correlation between software or 3D wearable sensor systems when collecting data on both joint movement and joint moments (Khurelbaatar et al., 2015). In contrast, the overall correlation between upper body joint moments was less (0.65-0.75) between conventional systems and IMU systems, but still defined as acceptable (Khurelbaatar et al., 2015).

The dorsaVi Professional Suite knee module reliability was determined from the consistency that existed between the dependent variables between the initial and second data collections. As shown in Table 2, both software systems demonstrated an r-value greater than 0.90. As described in the Introduction, the Xsens has been shown to be a valid and reliable motion capture system as compared to the current gold standard of optoelectronic motion capture (Luinge et al., 2005; Mohammed et al., 2018; Robert-Lachaine et al., 2017).

The dorsaVi Professional Suite demonstrates the ability to produce consistent results with repetition, which is imperative to clinical practice. Clinically, dorsaVi Professional Suite 3D motion system capture can be used to measure progress from an initial patient evaluation to discharge. As a portable, low expense 3D wearable system, clinicians can utilize the device to capture kinematic data from a patient in a shorten time frame. The dorsaVi Professional Suite knee module software has also demonstrated consistency and accuracy with measuring lower extremity movements when compared to the Xsens. This data supports the utilization of the dorsaVi Professional Suite knee module within the clinic setting for evaluation, diagnosis, and treatment. In addition, clinicians can confidently acknowledge the validity and reliability of 3D kinematic data collected in the clinic. Data generated by the knee module could be utilized to track progress within a patient's rehabilitation plan of care and assist with providing feedback to the physician on return to play.

Study limitations were as follows. The subject sample size was relatively small, therefore making it difficult to generalize results to the entire population. However, the actual number of data points used in the statistical analysis was 2,160. Specific kinematic data was only validated in this study, whereas the dorsaVi Professional Suite has the capability of measuring other kinematic variables. Therefore, these limitations lead to a future research recommendation to validate both the low back and the running modules of the dorsaVi. Future research should also focus on the validity and reliability of the dorsaVi Professional Suite with larger subject populations.

CONCLUSION

The dorsaVi Professional Suite knee module has demonstrated validity and reliability when compared to the validated Xsens system. With the use of an IMU system, clinicians have the capability to objectively assess and reassess kinematic movement patterns of patients recovering from surgery or lower extremity injuries. The dorsaVi system is a reliable, accurate tool for use in clinical evaluation, prevention, and rehabilitation of musculoskeletal injuries. In addition, the dorsaVi Professional Suite can be utilized for future research in clinical and educational settings.

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