VALIDATION OF A TWO-SENSOR IMU SYSTEM FOR MEASURING JUMP HEIGHT AND WRIST SPEED IN VOLLEYBALL PLAYERS

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INTRODUCTION

The ability to jump high is critical for success in volleyball and many coaches believe it is an essential skill contributing to higher performance. Jumping is involved in a jump set, jump serve, blocking, and spiking. Additionally, producing high-velocity serves and spikes gives the player an advantage on offense. Three-dimensional motion analysis is currently used as the gold standard for measuring vertical jump and swing speed, as cameras track markers on the player and the data is processed later. This process is time intensive and requires the use of expensive equipment. New technologies have provided the capabilities to capture the same data on the court, allowing for more applicable findings. One of the most commonly used inertial measurement units (IMUs) to calculate jump height is Vert™. This commercially used product has been reported to under estimate jump height by 4.1 cm (1). A new system, motusVB, provides jump count, jump height, and wrist speed. motusVB consists of two sensors, one placed on the wrist of the swing arm and the other placed on the pelvis. Through Bluetooth connection to an iOS application, metrics can be monitored in real-time on the court. The purpose of this study was to validate the motusVB measures by comparing data outputs to measures captured with a 16-camera, gold-standard motion capture system. Additionally, a pilot study was also conducted comparing jump height measured by both the motusVB and Vert sensors.

METHODS

Eight healthy, recreational volleyball players (173 ± 16 cm; 80 ± 14 kg) reported to the Motus Biomechanics Laboratory for testing. Players were outfitted with 49 retro-reflective markers on anatomical landmarks as well as motusVB sensors (Motus Global, Rockville Centre, NY, USA) attached on the forearm and waist band (**Figure 1**). Kinematic data were simultaneously collected using a sixteen-camera 3D motion capture system (Motion Analysis Corp., Santa Rosa, CA, USA) at 480 Hz, as well the two sensors at 1000 Hz. Prior to testing, the subject was permitted unlimited time to warm-up. Players were then asked to perform 5-10 maximum jumps mimicking a block at the net. After the blocking task, players were then asked to perform 5-10 jump serves. For the pilot study, the players were outfitted with both the motusVB system and the Vert sensor. Players were asked to jump as high as they could for five trials.

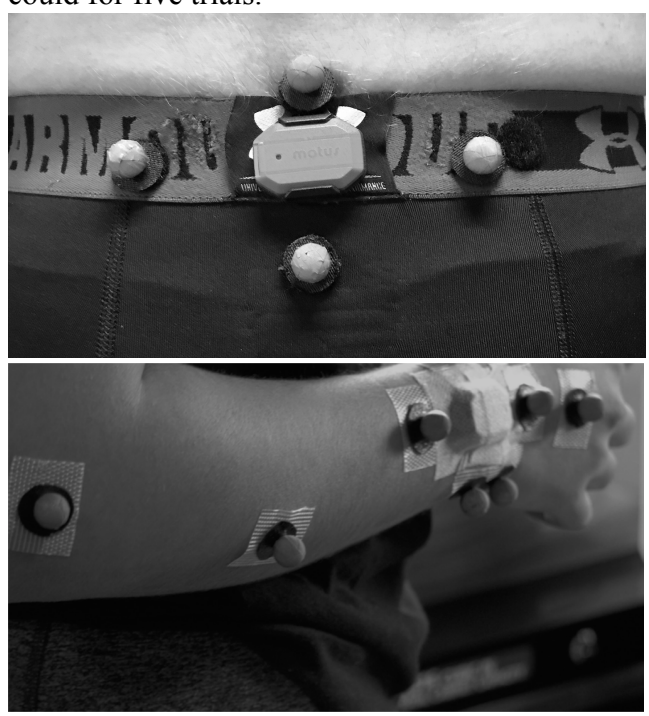

Figure 1. Experimental setup of marker and sensor placement.

Marker motion data were first filtered through a low-pass 14 Hz Butterworth filter then used to calculate kinematics for the forearm and pelvis segments. Gyroscope and accelerometer data simultaneously collected from the motusVB sensors were used to calculate the same kinematics for all trials throughout testing. To determine the validity of the pelvis and wrist-worn motusVB sensors against the currently accepted gold-standard for kinematic measurements, 3D motion capture, RMSE values

and descriptive statistics were calculated for jump height and swing speed of the hand.

The takeoff velocity (TOV) method was used to calculate jump height from the motusVB sensor. By first measuring the maximum TOV of the pelvis sensor, jump height is computed with Equation 1.

$$Jump\ Height = \frac{TOV^2}{2*g} \quad (1)$$

To compute wrist speed, the velocity of the hand at impact was estimated using sensor velocity and angular rate data, as well as forearm length of the athlete, Equation 2.

$$Wrist\ Speed = velocity_{IMU} + \overrightarrow{\omega_{IMU}}\ x\ \overrightarrow{length_{forearm}} \quad (2)$$

Conservation of momentum principles were applied to the change in velocity of the hand during impact in order to estimate ball exit velocity. The following equations (3) and (4) were applied:

$$mass_{HAND} * \Delta V_{HAND} = mass_{VB} * \Delta V_{VB} \quad (3)$$

$$V_{VB} = \frac{mass_{HAND}}{mass_{VB}} * \Delta V_{HAND} \quad (4)$$

RESULTS AND DISCUSSION

Results indicate that the motusVB sensors have strong validity in measuring jump height and wrist speed in volleyball players. Compared to gold-standard motion analysis, the motusVB hip sensor measured jump height with an error of ± 3.80 cm and had a strong correlation between both measurement systems (r = 0.96). The motusVB wrist sensor measured wrist speed with an error of 0.57 m/s and a strong correlation between both measurement systems (r = 0.98).

Additionally, when comparing jump height measured by both Vert and the motusVB sensor, there was a weak correlation (r = 0.845), a large bias (-7.4 cm) and a large standard error between both systems (6.2 cm). This inconsistency cannot be explained, as Motus cannot advise on the methods and physics equations used to compute jump height with the Vert sensors. Additionally, others have suggested that making vertical jump comparison between devices is not advised because of discrepancies between results (2).

Table 1. Descriptive Statistics for jump height using motion capture (MAC) and the motusVB sensor (IMU).

Metric	Value	Units
Bias (mean difference)	2.8	cm
Standard error	3.8	cm
Pearson correlation (R value)	0.96	

Table 2. Descriptive Statistics for wrist speed using motion capture (MAC) and the motusVB sensor (IMU).

Metric	Value	Units
Root mean square error (time series)	1.70	m/s
Bias (mean difference)	-0.15	m/s
Standard error	0.57	m/s
Pearson correlation (R value)	0.98	

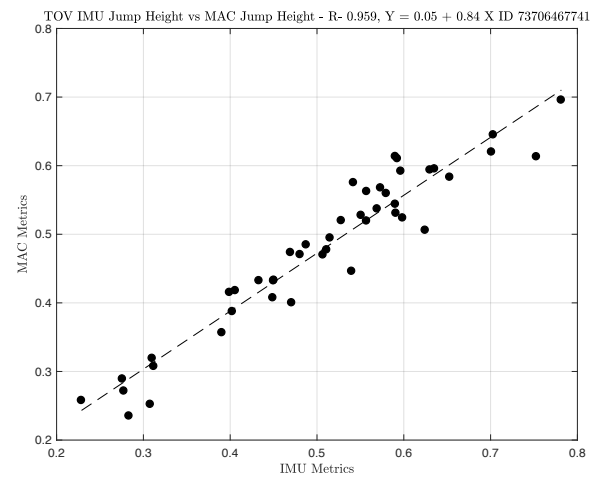

Figure 1. Scatter plot of jump height as measured by motion capture (MAC) and the motusVB hip sensor (IMU)

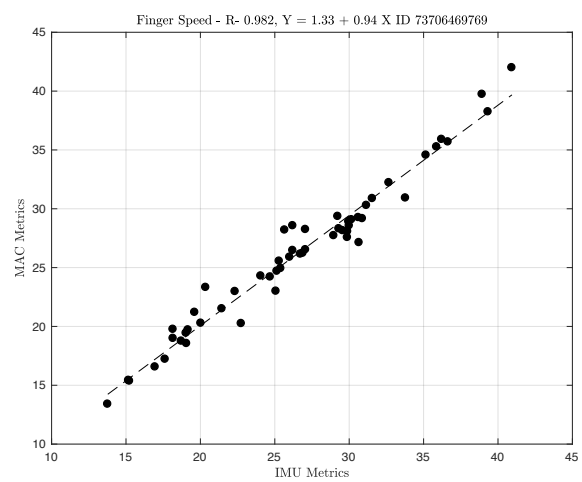

Figure 2. Scatter plot of wrist speed as measured by motion capture (MAC) and the motusVB wrist sensor (IMU)

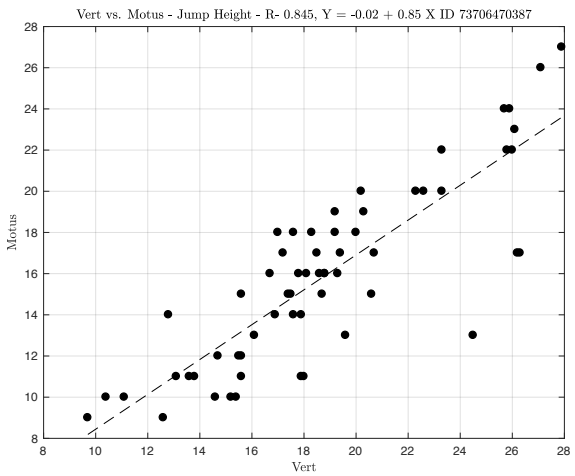

Figure 3. Scatter plot of Jump Height as measured by Vert (Vert) and the motusVB hip sensor (Motus)

Table 3. Descriptive statistics for jump height using Vert and motusVB simultaneously.

Metric	Value	Units
Bias (mean difference)	-7.4	cm
Standard error	6.2	cm
Pearson correlation (R value)	0.85	

CONCLUSION

The ability to accurately measure vertical jump height and wrist speed allows coaches and players to monitor load during training and competition, ensuring athletes are conditioned properly as well as identify potential injury risks. The motusVB system was shown to be valid for measuring both vertical jump height and wrist speed in volleyball athletes. Additionally, this system offers advantages of being relatively inexpensive and commercially available compared to traditional motion capture systems. The ability to obtain instantaneous feedback during training and competition ushers in the possibility to monitor training and competition loads.

References

1. MacDonald K et al. Validation of an inertial measurement unit for the measurement of jump count and height. Phys Ther in Sport, 2017.
2. Isaacs LD. Comparison of the Vertec and Just Jump systems for measuring height of vertical jump by young children. Percept Mot Skills, 1998.