ACCURACY OF THE MOTUSBASEBALL™ WEARABLE SENSOR

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The purpose of this study was to assess the accuracy of the motusBASEBALL™ sensor. Trained/developmental male adult baseball pitchers (n = 10) threw ten pitches each from a regulation outdoor mound while kinematic and kinetic data were captured using an optical motion capture system and a motusBASEBALL™ sensor. Absolute and relative agreement were assessed. Outputs from the motusBASEBALL™ sensor were significantly different to the motion capture outputs for elbow varus torque, shoulder rotation, and arm speed ($p < .05$). Data were similar for arm slot ($p = .847$). Correlations (r) between system outputs were not significant ($p > .05$) and ranged from 0.312 to 0.630. The motusBASEBALL™ sensor is not a valid sensor for measuring elbow varus torque, shoulder rotation, and arm speed. Researchers and practitioners should use the device with caution.

KEYWORDS: baseball, pitching, elbow, sensor.

INTRODUCTION: The motusBASEBALL™ sensor (now Driveline PULSE) is a wearable inertial measurement unit that attaches to the arm via either sleeve or strap, and estimates elbow varus torque, arm slot angle, shoulder rotation angle, and forearm rotation speed. The interest and use of the motusBASEBALL™ sensor has grown rapidly in the last few years; it was the first wearable sensor approved for in-game use by Major League Baseball. From a research perspective, there are increasing numbers of publications using the motusBASEBALL™ to compare throwing types and distances (Dowling, McNally, Laughlin, & Onate, 2018; Saito, Tsuchida, Ono, & Okada, 2021; Wight, Dowling, & O'Loughlin, 2019) and the relationship between elbow torque and pitch type (Makhni et al., 2018), fatigue (Okoroha, et al., 2018 and arm kinematics (Camp et al., 2017). The authors of these studies all state their results have an application to injury risk or rehabilitation, however there is little evidence of the accuracy of the motusBASEBALL™ sensor.

The first investigation of the accuracy of the motusBASEBALL™ sensor was conducted by Camp et al. (2017) as a pilot study and found large correlation coefficients between outputs from the sensor when compared with outputs calculated from optical motion capture for elbow torque ($r = 0.93$), arm slot ($r = 0.95$), arm rotation ($r = 0.94$), and arm speed ($r = 0.85$). However, a subsequent Letter to the Editor expressed numerous methodological concerns and encouraged researchers to reconsider using the study as evidence of the motusBASEBALL™ sensor's validity (Driggers, Bignham, & Bailery, 2019). In fact, a Response from the original authors stated that the concerns were reasonable, and the study was not designed as a validation of the sensor (Fleisig et al., 2019). The first full study to assess the agreement between the motusBASEBALL™ sensor and optical motion capture by Boddy et al. (2019) found that the sensor underestimated all variables (mean difference, elbow varus torque: 41 Nm, arm slot: 8°, shoulder rotation: 9°, arm speed: 3891 °/s) across fastballs and off-speed pitches. Most outputs from the sensor and optical motion capture were statistically correlated ($p < .05$), however arm speed ($p = .446$) and elbow varus torque ($p = .077$) in the fastball condition were not. A more recent study by Camp et al. (2021) found similar results, with the motusBASEBALL™ sensor underestimating all variables (mean difference, elbow varus torque: 22.9 Nm, arm slot: 5°, shoulder rotation: 6.3°, arm speed: 29.2 rpm).

The purpose of this study was to add to the limited literature on the accuracy of the motusBASEBALL™ sensor in measuring pitching variables by comparing its outputs to those by a three-dimensional optical motion capture system. It was hypothesised that the motusBASEBALL™ sensor would be statistically different to motion capture for all variables.

METHODS: All procedures were approved by La Trobe University's College of Science, Health, and Engineering Human Ethics Sub-Committee (# HEC20323). Ten

trained/developmental adult male baseball pitchers (mean ± SD; age 28 ± 6 years, height 184 ± 5 cm, mass 90 ± 6 kg, playing experience 17 ± 6 years) agreed to participate in the study. All testing was completed on an outdoor baseball diamond (La Trobe University, Melbourne, Australia) and the participants were injury free at the time of data collection. The participants were required to throw ten fastball pitches off a regulation mound to a catcher or a marked strike zone on a netted fence behind home plate. Participants were instructed to complete their individualised warm-up before commencing testing.
Twenty-five retro-reflective markers (12 mm in diameter) were attached to the shoulders, upper limbs, and torso of each participant using rigid clusters and single markers (Wells, Donnelly, Elliott, Middleton, & Alderson, 2018). Marker trajectories were captured using a 22-camera Vicon Vantage motion capture system (Vicon Motion Systems Ltd., Oxford, UK; 300 Hz). Simultaneously, a motusBASEBALL™ sensor was placed over the medial side of the pitching forearm, 2-cm distally from the medial epicondyle of the elbow, in a proprietary compression sleeve. The systems were not time-lock synchronised, however, time stamps of each trial on each system were recorded and post-processed matched to the nearest second. Individual marker coordinates were reconstructed with Vicon Nexus software where marker trajectories were filled using spline, pattern, or rigid 'gap filling' functions. Marker trajectories were filtered using a Woltring filter with a mean square error of 0.5 mm. A four-segment linked upper limb kinematic model was applied to the data (Wells et al., 2018) with elbow torque calculated using inverse dynamics. motusBASEBALL™ data was exported directly from the cloud-based Motus dashboard.
The variables assessed were elbow varus torque (Nm; maximum), arm slot angle (°; angle between forearm and ground at release), shoulder rotation angle (°; angle between forearm and ground at maximum external rotation), and arm speed (rpm; maximum rotational speed of the forearm). The mean of each participant's ten trials was used for all variables in the analysis. All statistical tests were performed in jamovi (The jamovi project, V 2.0) with an alpha level of .05. Absolute agreement was assessed using mean absolute error (MAE), Cohen's *d* effects sizes, and two-tailed paired-sampled *t* tests. Normality was assessed using Shapiro-Wilk tests and inspecting Q-Q plots. Bland-Altman plots were also created to assess fixed and proportional bias. Relative agreement was assessed using Pearson's correlation coefficients.

RESULTS: The motusBASEBALL™ sensor underestimated elbow varus torque and shoulder rotation, overestimated arm speed, and was similar for arm slot (Table 1).

Table 1: Descriptive statistics and absolute agreement between the motusBASEBALL™ sensor and motion capture.

Variable	Motion Capture	Motus	*p* value	Effect size (Cohen's *d*)	MAE
Elbow varus torque (Nm)	64.0 ± 10.3	49.5 ± 9.5	.003	1.242	14.5
Arm slot (°)	50.1 ± 12.4	49.1 ± 15.0	.847	.063	10.5
Shoulder rotation (°)	158.0 ± 11.5	146.5 ± 12.4	.007	1.110	12.1
Arm speed (rpm)	770.7 ± 135.8	888.7 ± 60.6	.015	-0.948	128.1

Limits of agreement (95%) were relatively wide and there was evidence of fixed and proportional bias, particularly for elbow varus torque and arm speed (Figure 1). The strength of correlations (r) between the motusBASEBALL™ sensor and the motion capture outputs ranged from 0.312 – 0.630 (Figure 2) across variables with no variable being statistically significant ($p > .05$).

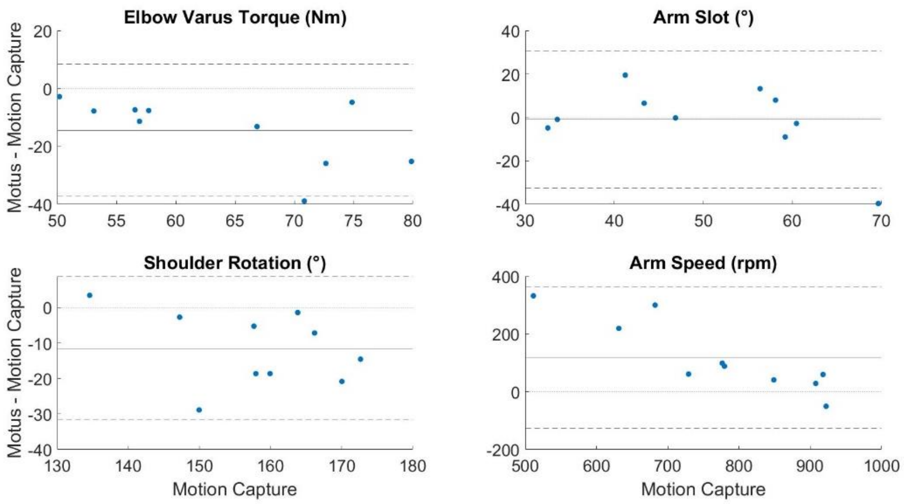

Figure 1: Bland-Altman plots showing fixed and proportional bias of the motusBASEBALL^{TM} sensor.

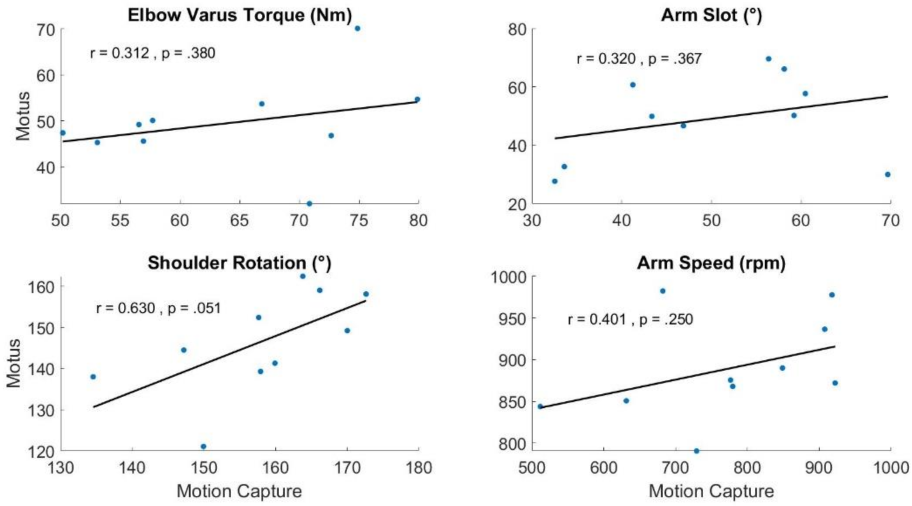

Figure 2: Scatter plots and trendlines showing the correlation between the motusBASEBALL^{TM} sensor and motion capture outputs.

DISCUSSION: The aim of this study was to assess the accuracy of the motusBASEBALL^{TM} sensor in measuring elbow valgus torque, arm slot angle, shoulder rotation angle, and arm speed. The results showed that only arm slot angle was similar between systems, there was evidence of fixed and proportional bias, and there were no significant correlations.

The results of this study are generally in line with previous research. Elbow varus torque was underestimated by the motusBASEBALL^{TM} sensor (14.5 Nm), as was reported previously (Boddy et al., 2019: 41 Nm; Camp et al., 2021: 22.9 Nm). This underestimation has important clinical applications, as pitchers in rehabilitation programs may throw at intensities higher than recorded by the sensor. Shoulder rotation angle was similarly underestimated (current study: 11.5°; Boddy et al., 2019: 9°; Camp et al., 2021: 6.3°). Although arm slot angle has been shown to be underestimated previously (5-8°), there was no difference in the current study. However, the wide limits of agreement show that there was substantial random error across participants. The magnitude of the difference in arm speed is somewhat surprising given the results of the previous validation studies. The proportional bias shown in the Bland-Altman plots suggests that the motusBASEBALL^{TM} sensor overestimates arm speed at lower speeds (e.g., < 800 rpm); speeds that seem to be lower than that achieved by the participants in the Boddy et al. (2017) and Camp et al. (2021) studies.

Interpretation of the results of this study must be done so relative to the following. First, the calculation of the outputs from the motion capture system and the motusBASEBALL™ sensor use different modelling approaches and would therefore result in different outputs. Although Camp et al. (2021) calculated elbow varus torque in a global coordinate system to match the approach of the motusBASEBALL™ sensor, they also calculated it in a local segment reference frame, like the current study (albeit in a joint coordinate system), which provides a more accurate estimation of true elbow varus torque. Second, the data presented in the current study was averaged for each individual, allowing analyses to be conducted on the group level and to easily compare to those reported by Boddy et al. (2019) and Camp et al. (2021). This does not allow the data to be interpreted on the individual level where, for example, limits of agreement might be narrow and correlations higher. Further research using different statistical techniques such as linear mixed models and repeated-measures correlations on the individual level would provide further insight.

CONCLUSION: Based on the results presented in this study and previous research, the motusBASEBALL™ sensor is not a valid sensor for measuring elbow varus torque, arm slot angle, shoulder rotation, or arm speed. It tends to underestimate elbow varus torque, arm slot angle, and shoulder rotation, while arm speed has been variable across studies. If using the sensor, researchers and practitioners should interpret outputs with caution.

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