Validation of a Bat Handle Sensor for Measuring Bat Velocity, Attack Angle, and Vertical Angle

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ABSTRACT

Background: Bat velocity, attack angle, and vertical angle are common variables that coaches and players want to evaluate during their baseball or softball swing. **Objective:** The purpose of this study was to investigate and validate a baseball bat handle sensor against motion capture using recreational baseball and softball athletes for bat velocity, attack angle, and vertical angle. **Methods:** This single visit cross-sectional experimental design study utilized eighteen recreational baseball and softball players (ten males and eight females, age: 20.70 ± 1.69 years, height: 170.74 ± 5.69 cm, weight: 77.97 ± 12.30 kg) were recruited. Bat velocity, attack angle, and vertical angle from the bat handle sensor and 12-camera motion capture system were collected and compared using a two-tailed paired t-test. **Results:** Differences were statistically significant, showing that 95% of the time, the bat handle sensor overestimated the bat velocity by 1.92 to 2.77 m/s, underestimated the attack angle by -3.46 to -1.96º, and overestimated the vertical angle by 1.64 to 3.21º, compared to the motion capture system. **Conclusion:** The bat velocity and vertical angle were overestimated, while the attack angle was underestimated by the bat sensor. The information presented in this study can be viable information for coaches and players when utilizing the baseball bat handle sensor technology for training, practice, or in-game situations.

Key words: Baseball, Softball, Hitting, Accuracy, Technology

INTRODUCTION

Wearable technology is on the rise and is becoming more accurate in the process (Chander et al., 2019; Li et al., 2016; Luczak et al., 2019). In recent years, the rise of technology being utilized in baseball and softball is unprecedented. This can be seen especially in the realm of wearable bat technology. Companies offering solutions to wearable bat sensor technology include: Blast Motion™, Zepp™, and Diamond Kinetics™. While there are many different companies on the market that offer solutions to gaining objective feedback on swings at the plate or in the cage, the data being captured is constant. The types of data being collected and advertised most often include bat velocity (how fast the bat is traveling), attack angle (bat approach on the horizontal plane toward the ball), and vertical bat angle (bat approach on the vertical plane toward the ball). These variables are commonly used by coaches and players to objectively give feedback to swings during training, practice, and games. This data is useful for all swinging athletes and companies are capitalizing on their ability to use the same technology in both baseball and softball to expand their customer and user base. While both sports can utilize this technology, wearable bat sensors are under researched which is why this study is important to the field.

In 2017, Major League Baseball (MLB) approved the baseball bat sensor technology to be used in their instructional league seasons (Gulf Coast League & Arizona League), which are both rookie level affiliate leagues. Following the 2017 season, the use of the bat sensor technology was approved for all Minor League Baseball (MiLB) games. The approval for use in all MiLB games makes the validation of these products even more important as it is being used as a tool to analyze and improve player performance. Technology has become an integral part of player development across baseball and softball with the introduction of sports science departments to many teams from college to professional.

However, validation for bat sensor technologies is limited. The Zepp™ sensor was validated in baseball for the peak velocity and time to contact variables, but not for the angular variables (Bailey, McInnis, & Batcher, 2016). Then when tested in golf, the Zepp™ sensor (same sensor with different variables based on sport played), was found to be inaccurate for velocity on individual shots but would average out to be similar over the course of multiple shots (Lückemann et al., 2018). When the same Zepp™ sensor was applied for use with

a softball player, it was found that the sensor was accurate for bat velocity at moderate velocity but became less accurate as bat velocity increased (Hussain, 2016). The Blast™ and Diamond Kinetics™ sensors have only been tested scientifically in one instance (Aguinaldo, 2016). Aguinaldo's (2016) validation study found that the Blast™ sensor was the most accurate for bat velocity, followed by the Diamond Kinetics™ sensor, and then Zepp™ with 3.4, 6.5, and 8.0 mph of error on average, respectively (Aguinaldo, 2016). An additional study investigating the validation of bat sensors leaving the sensors solutions tested unidentified found the wearable sensors underestimated bat velocity in every swing, and that difference escalated as velocity increased, while also being unreliable when looking at the bat orientation or the angle of the bat (Lyu & Smith, 2018). While previous studies have investigated the bat velocity measurement of the sensors, previous literature is lacking on the validity of the other main measurements of the sensors. The attack angle and vertical angle measurements are common measurements for coaches and athletes to use when trying to obtain objective data on the swing. Therefore, the purpose of this study was to investigate and validate the Blast™ motion baseball sensor to motion capture for recreational baseball and softball athletes for the variables of bat velocity, attack angle, and vertical angle. Although several studies have investigated the validity of sensors, the authors sought to quantify the validity of the Blast™ sensor, as there is no specific validation for this sensor and bat velocity, attack angle, or vertical angle. This study will enable coaches and players to accurately understand the variables of bat velocity, attack angle, and vertical angle for the swing as well as the accuracies and limitations of the Blast™ sensor product as it applies to both baseball and softball athletes. This study aims to improve the ability of baseball and softball coaches as well as swinging athletes to use information from bat sensor technologies to improve in their development and productivity at the plate.

METHODS

Participants and Study Design

Ten male recreational baseball players (age: 21.40 ± 2.84 years, height: 177.60 ± 7.26 cm, weight: 84.33 ± 12.65 kg) and eight female recreational softball players (age: 20.00 ± 0.53 years, height: 163.88 ± 4.09 cm, weight: 71.61 ± 11.94 kg) competing in recreational baseball or softball participated in this study. Participants were recruited based on availability of the population on a college campus and sample size determination was based on previous studies investigating other bat sensor technologies (Aguinaldo, 2016; Bailey, McInnis, & Batcher, 2016; Hussain, 2016; Lückemann et al., 2018; Lyu & Smith, 2018). All participants were currently competing in collegiate recreational baseball or softball leagues and were free from injury that would negatively affect their performance. This study utilized a single visit cross-sectional experimental design to evaluate the validity of a bat handle sensor for both baseball and softball recreational athletes. The Mississippi State University Institutional Review Board (IRB) approved this study for the use of

human participants. An IRB-approved consent form defining all procedures and risks was read and signed by all participants prior to data collection procedure initiation. Variables of interest in this study are bat velocity, attack angle, and vertical angle and are compared between the sensor and the motion capture technology for each of the participants.

Protocol

The baseball and softball bats were fitted with a cluster of four retroreflective markers to track the bat's motion during the swing using motion capture. The baseball bat handle sensor was attached to the end of the baseball or softball bat using the provided silicon sensor holder. A ten-swing standardized warm-up was allowed for each participant as they normally would before hitting (Escamilla et al., 2009a, 2009b). Participants were asked by researchers to perform their swing as they would normally during batting practice off a tee. Each participant performed trials of ten swing off a tee during which their swing data was recorded. Data for bat velocity, attack angle, and vertical angle of the bat were recorded by both MotionMonitor™ and bat handle sensor. The swing analysis was completed with 12 Vicon Bonita™ cameras (Vicon™, Oxford, UK) recording at 250 Hz, and the bat handle sensor and Blast Baseball™ (Blast™, Carlsbad, CA, USA) application.

Data Processing

All variables of interest were collected simultaneously using marker trajectory and application data for calculation using MotionMonitor Swing Analysis™ software (Innovative Sports Training™, Chicago, IL, USA) and the Blast Baseball™ application, respectively. Data processing which included filtering of the marker trajectory data, was conducted using the MotionMonitor™ software. Maximum bat velocity was determined by the MotionMonitor™ software. The vertical angle of the bat through motion capture was calculated at ball contact, and the attack angle was calculated using the data from ball contact and the frame before ball contact. Data was then compiled to be compared between each of the swings between the MotionMonitor Swing Analysis™ software and the Blast Baseball™ application.

Statistical Analysis

Descriptive and dependent variables are reported as mean ± standard deviation (SD), along with 95% confidence interval. Differences in the bat velocity, attack angle, and vertical angle were compared using a two-tailed paired t-test to determine which variables were significantly different. Moreover, the data were further analyzed utilizing the concordance correlation coefficient (Lawrence & Lin, 1989; Steichen & Cox, 2002) to determine both accuracy and precision of the sensor against the motion capture data. T-tests were performed using Statistical Package for Social Sciences™ (SPSS) software v. 26.0 (SPSS Inc.™, Chicago, IL) with a significance level of $p < 0.05$. Determination of the concordance correlation coefficient (ρc) (Lawrence & Lin,

1989; Steichen & Cox, 2002; Stewart et al., 2020), Pearson ρ, and bias correction factor (Cb) were performed by Med-Calc Software (MedCalc Software, Belgium).

RESULTS

Bat Velocity

Mean value, standard deviation, *p*-value, and 95% confidence interval for maximum bat velocity for the bat handle sensor and motion capture can be found in Table 1. All data are referenced in meters per second (m/s). Bat velocity was found to be significantly greater for the bat handle sensor when compared to the motion capture. The bat handle sensor overestimates the bat velocity from 1.92 to 2.77 m/s 95% of the time based on the 95% confidence interval. The concordance correlation coefficient found in Table 2 revealed a poor strength of agreement between the sensor and motion capture with a value of 0.542 (McBride, 2005).

Attack Angle

Mean value, standard deviation, *p*-value, and 95% confidence interval for attack angle for the bat handle sensor and motion capture can be found in Table 1. All data are referenced in degrees (º). Attack angle was found to be significantly lower for the bat handle sensor when compared to the motion capture. The bat handle sensor underestimates the bat attack angle from -3.46 to -1.96 º 95% of the time based on the 95% confidence interval. The concordance correlation coefficient revealed found in Table 2 revealed a poor strength of agreement between the sensor and motion capture with a value of 0.663 (McBride, 2005).

Table 1. Bat velocity, attack angle, and vertical angle (Mean ± SD), p value, and 95% confidence interval for bat handle sensor and motion capture

	Bat Handle Sensor	Motion Capture	*p*-value	95% CI
Bat Velocity (m/s)	25.72±3.74	23.37±3.28	< 0.001*	(1.92, 2.77)
Attack Angle (º)	3.98±5.67	6.69±6.21	< 0.001*	(-3.46, -1.96)
Vertical Angle (º)	-24.27±5.54	-26.69±7.56	< 0.001*	(1.64, 3.21)

* Denotes significance between the Bat Handle Sensor and Motion Capture.

Table 2. Concordance correlation coefficient (ρ_c), Pearson correlation coefficient (ρ), and Bias Correction Factor (C_b) for bat velocity, attack angle, and vertical angle

	ρ_c	ρ	C_b
Bat Velocity (m/s)	0.542	0.669	0.810
Attack Angle (º)	0.663	0.723	0.917
Vertical Angle (º)	0.654	0.732	0.893

Vertical Angle

Mean value, standard deviation, *p*-value, and 95% confidence interval for vertical angle for the bat handle sensor and motion capture can be found in Table 1. All data are referenced in degrees (º). Vertical angle was found to be significantly greater for the bat handle sensor when compared to the motion capture. The bat handle sensor overestimates the bat velocity from 1.64 to 3.21º 95% of the time based on the 95% confidence interval. The concordance correlation coefficient found in Table 2 revealed a poor strength of agreement between the sensor and motion capture with a value of 0.654 (McBride, 2005).

DISCUSSION

The main findings of the current study indicate the bat handle sensor significantly overestimates the bat velocity and vertical angle of the bat, while underestimating the attack angle. In each of the three variables tested, the concordance correlation coefficient resulted in a poor strength of agreement (McBride, 2005). This measurement is a combination of the precision (ρ) and the accuracy (C_b) of the bat handle sensor compared to the motion capture. The attack angle and vertical angle have a strong Pearson correlation coefficient with values above 0.70, while the bat velocity has a moderate Pearson correlation coefficient with a value between 0.50 and 0.70. All three variables have a strong bias correction factor of over 0.8, indicating how the two sets of data points for the sensor and motion capture line of best fit are related to the perfect 1:1 ratio (45º angle). This information is valuable as it shows that the sensor is more accurate than it is precise, meaning that over time the values obtained average out to the true number, but each individual data point could hold an error. These findings agree with the results of Lückemann et al. (2018), investigating the sensor validity in measuring the velocity of golf shots.

Bat velocity has been found to be a key variable in determining the skill level of a baseball or softball player (Dowling & Fleisig, 2016; Escamilla et al., 2009a; Inkster, Murphy, Bower, & Watsford, 2011). Therefore, when a bat sensor is being utilized for training, practice, and in-game swings, it is very important for that sensor to be a valid measurement of bat velocity. While the findings from the current study denote significant differences between the bat velocity measured by bat handle sensor and the motion capture technology, it was found that the bat handle sensor overestimates bat velocity 95% of the time between 1.92 and 2.77 m/s. These findings disagree with previous findings comparing other bat sensors to motion capture that found the sensor underestimates bat velocity (King et al., 2012; Lyu & Smith, 2018). While these studies investigated bat velocity sensors, it is important to note that it is unclear which bat velocity sensor was utilized in each. Another possible reason for the disagreement between the current findings and previously published literature is that the participants utilized in this study were recreationally active baseball and softball players and not elite-level athletes. The concordance correlation coefficient between the bat handle sensor and the motion capture was found to be 0.542. While this equates to a poor correlation (McBride, 2005), it is important to note that

the bias correction factor was found to be 0.810, which is the comparison of the line of best fit of the bat handle and motion capture to a perfect 1:1 ratio. This finding suggest that the bat handle sensor will over time estimate the bat velocity more accurately than with a single swing. These findings are significant for coaches and players to understand the variable of bat velocity and how it may be inaccurate in determining bat velocity in a short batting session.

Comparing the attack angle and vertical angle of the bat handle sensor to motion capture is novel in bat wearable research. The current findings demonstrated that the bat handle sensor and motion capture were statistically different for both angles with the attack angle being underestimated and the vertical angle being overestimated. Furthermore, the concordance correlation coefficient demonstrates a poor correlation with 0.663 and 0.654 for the attack angle and vertical angle, respectively. For both variables, however, the 95% confidence interval shows the difference to be under 3.5º with attack angle being -3.46º to -1.96º and the vertical angle being 1.64 to 3.21. In addition, the bias correction factor of 0.917 (attack angle) and 0.893 (vertical angle) shows that the line of best fit between the bat handle sensor and motion capture is relatively close to the perfect 1:1 ratio. This again demonstrates that as more swings are collected, the attack angle and the vertical angle will average out to be closer to the true angle than a single measurement will be. These findings are important for coaches and players to understand the error associated with these readings, but also demonstrate that the error is under 3.5º 97.5% of the time.

APPLICATIONS FOR COACHING PRACTITIONERS

Motion capture systems are the gold standard in human movement because they can accurately and repeatedly quantify human movement if the system is calibrated properly (Luczak et al, 2018). Using the baseline of a gold standard system, researchers found the Blast Motion™ sensor to be repeatable but not accurate. However, because the sensor is consistently inaccurate within a specified range, practitioners can still utilize the data to help their athletes. If each Blast Motion™ sensor is consistently in disagreement with motion capture output, coaches can utilize the results to make the proper adjustments to the player's swing. Since the goal of a batter is to hit the ball with as high a velocity as possible—and not to simply swing the bat with the highest velocity possible—the usefulness of the Blast™ is still valid.

Furthermore, in a dynamic movement pattern such as swinging a bat, variation is unavoidable. Live batting practice and games will require the batter to change their bat speed, attack angle, and vertical bat angle for each pitch type and location to be most successful. Third-party software such as Baseball/ Softball Cloud™ and Traq™ attempt to use the data generated from a bat sensor to determine optimum angles for optimum contact in each pitch location. This information enables a coach to assess data for pitch locations to create attack plans for their athletes. As coaching practitioners, we use an autoethnographic frame (Brown et al., 2020; King et al., 2021; Luczak et al., 2020) to know that the data is consistently inaccurate, comparing the data to batted ball metrics allows a coach to determine optimal bat characteristics for each batter, pitch, and location.

Also, as coaching practitioners we know that, statistically, any assumption made with small sample sizes is dangerous. Data from the current study illustrates that the more data the Blast Motion™ sensor collects, the more accurate those results become compared to motion capture data. Coaches should be encouraged to gather as much data as possible and avoid one-off pitches as they coach their players including each pitch type and pitch location. That would allow coaches, and the software they utilize, to make more accurate and reliable assessments of their athletes.

Moreover, not until the 2020 MLB season were all stadiums outfitted with the Hawkeye camera system, which now provides the capability for teams to assess bat dynamics through motion capture. Therefore, all the standards for bat metrics have been set by the sensors, not motion capture data. Bat sensor data will remain much more prevalent than motion capture data of bat dynamics of the swing until the MLB has collected enough data. However, even after they collect "enough," most of the baseball world will still be utilizing bat sensor data.

The present study illustrates how the Blast™ sensor overestimates bat speed and underestimates both attack angle and vertical bat angle compared to motion capture analysis. However, the Blast™ sensor's accuracy creates a consistent platform from which a coach can still utilize the data. Knowing the difference between the data collected by both platforms will prove to be a key element in analysis moving forward. Coaches should be encouraged to continue to remain fluent in available technology while also ever seeking to understand the limitations and accuracy of all tools available. More studies of this type are needed to create transparency around performance technologies like bat sensors so that coaching practitioners will have a greater understanding around the accuracy of the data collected. Studies like the one presented herein are a necessary step toward creating trust in the technology, something that is currently missing in the wearable technology space (Burch, 2019; Luczak et al., 2018; Luczak et al., 2020).

A key limitation to this study is the combination of both baseball and softball players in the data collection. The combination of both could lead to a greater standard deviation in the variables recorded due to minor swing differences. It is also important to note that all the participants in this study were recreationally active baseball and softball players. The findings of the current study do not necessarily demonstrate the accuracy of the sensor for higher-skilled athletes as their bat velocity would be significantly higher. Therefore, future studies could be directed towards recruiting elite baseball/ softball players.

Also, since the ball was placed on a tee, the variation swing to swing was likely more reliable for research. However, in practice, the location of the pitch will change the bat speed, attack, and vertical bat angles necessary for optimum performance. therefore, interpreting these data in practical applications will look much different.

CONCLUSION

The findings of the current study give insight into how coaches and players should utilize the Blast™ bat handle sensor. While it was found that the bat handle sensor and motion capture data are significantly different for measuring bat velocity,

attack angle, and vertical angle, this study also provides the 95% confidence interval for the error. With knowledge of the error for specific variables of interest within a baseball or softball setting, coaches and players will be able to understand the data being presented to them and the potential measurement error of the readings. With measurement errors under 3 m/s for bat velocity and under 3.5º for the attack and vertical angles, the bat handle sensor can be a useful tool in evaluating both baseball and softball players' swings.

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