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CONCURRENT VALIDITY AND RELIABILITY OF THREE RADAR-BASED BASEBALL VELOCITY TRACKING DEVICES

(Research article)

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Abstract

Radar devices are often used by sports performance practitioners to obtain objective ball flight and speed information. In order to make effective coaching decisions, the radar devices used must be reliable and valid. The purpose of the present study was to examine the concurrent validity of the three commercially available radar devicesusing ball velocity. Three radar devices, Pocket Radar, Trackman, and Stalker Radar, were used to track 100 pitches out of a ball machine across 5 different speeds (80.5 km/h, 96.6 km/h, 112.7 km/h, ICC=0.82 at 128.8 km/h, 144.9 km/h). Between all the devices, the radar devices showed moderate to good reliability at each of the 5 different speeds (ICC=0.53 at 80.5 km, ICC=0.77 at 96.6 km/h, ICC=0.82 at 112.7 km/h , ICC=0.77 at 128.8 km/h, ICC=0.83 at 144.9 km/h). Based upon the good reliability for ball velocity measurements, whenusing a pitching machine withbaseball players, the present findings suggest any of the devices to provide accurate readings for appropriate feedback to coaches and athletes.

Keywords: Consistency, ball, speed, technology, baseball.

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1. Introduction

Quantifying ball flight metrics in the sport of baseball has become a commonly used piece of training, monitoring, and scouting. When assessing relationships in lower extremity power, baseball spin rate, and BV, Wong et al. (2023) concluded that greater fastball spin rates and BV were associated with greater lower extremity power during a countermovement vertical jump in a cohort of professional baseball athletes. In order to capture such ball flight related metrics, the researchers had to use a radar-based ball optical tracking device. The researchers used publicly available data that was captured through TrackMan/StatCast technology (TrackMan, Inc. Stamford, CT), a radar-based ball optical tracking device that captures ball flight-related metrics, installed in all Major League Baseball (MLB) and Minor League Baseball stadiums. Trackman (TM) (TrackMan, Vedbaek, Denmark) has also developed a more commonly used three-dimensional (3D) radar system that is portable and more commonly used in practical settings. The TM-B1, like the stadium version, provides advanced batting performance metrics including more commonly known metrics such as ball exit speed and angle (Liu et al., 2020; Trackman Radar Measurement Glossary of Terms, 2021). In practical settings, handheld radar based devices are also used to capture ball velocity.

Radar guns used in both practical and research settings have been found to have high accuracy (Brechbuhl et al., 2018; Delgado-García et al., 2019; González-González et al., 2018). It is pertinent that a radar gun is both valid and reliable in both settings as coaches, scouts, and researchers alike rely on accurate readings to assess performance of athletes and subjects, respectively (Hopkins et al., 2000). Radar guns calculate ball velocity through the Doppler effect, by which the radar gun analyzes the changes in the signal frequency emitted by the radar and reflected by the ball. Thus, a decrease in the reflected frequency means that the ball is moving away, whereas an increase in this frequency indicates the ball is coming towards the radar gun (Robinson and Robinson, 2016). As sports performance monitoring technology continues to advance, the integration of wearable sensors, video analysis systems, and other advanced tracking technologies can help coaches and athletes improve their performance more effectively (Pekgor et al., 2024: Sekeroglu et al., 2025; Gulgosteren et al., 2025). These technological integrations aid radar-based speed measurements by obtaining objective data to enhance performance and potentially mitigate injury risks (De Fazio et al., 2023). Radar guns and other technological tools remain a tool often used in sports settings, such as youth and community sports programs, along with rehabilitation centers, where they are cost-effective and provide objective performance data that can aid in the programming of training and recovery plans. (Li et al., 2016).

Establishing concurrent validity and agreement between testing tools can be critical, both scientifically and practically, when using multiple types of similar devices to collect similar types of data (Düking et al., 2018). Assessing concurrent validity involves comparing the results obtained from the instrument under study with a referenced standard or established measure, to verify that a new instrument measures what it intends to measure, thus validating its efficacy for what it is to be used for (Kimberlin et al., 2008). In concert with understanding the concurrent validity of devices, evaluating agreement between instruments ensures consistency and reliability in measurement outcomes (Sullivan et al., 2011). By testing concurrent validity and agreement, researchers and practitioners can confidently select appropriate measurement tools, establish data comparability, and create data that is reliable and valid for making better informed decisions. Ensuring the tools used in research produce accurate and consistent results helps not only the researcher but also the practitioner who relies on accurate data and results. In practical applications, such as sports performance analysis, athlete monitoring, and sports rehabilitative settings, having reliable and valid measurements is key for developing effective training programs (Hopkins et al., 2000). The ability to have reliable and valid data from various instruments allows coaches and sports scientists to tailor their approaches based on accurate assessments, ultimately enhancing the effectiveness of interventions in response to assessment and monitoring. All in all, through validation and ensuring agreement between different testing tools, this allows for consistent cross-study comparisons and meta-analyses, thus adding standardization to the current body of knowledge of using such testing tools (Düking et al., 2018).

Advancements in technology have made it so that other, more affordable radar guns, such as the Pocket radar (PR) (Model PR1000-BC, Inc. Santa Rosa, California) and the Stalker Radar (SR) gun (Applied Concepts Inc., Richardson, TX) can be accessed by a broader range of practitioners (Hernández-Belmonte et al., 2021). Both of these devices are commonly used radar devices. The PR has been used by previous studies for different research purposes (Altundag et al., 2019; Rada et al., 2016, 2019). Despite being affordable, both devices displayed good levels of accuracy and reliability for performance monitoring despite the affordable price tag (Abdioglu et al., 2022). Hernández et al. (2021) found a strong correlation and a high level of accuracy and reliability between the PR and the SR (ICC = 0.99, $r \approx 0.98$) when performing both hand-fed forehands in tennis and soccer kicks. When comparing the Speedtrac X (OpticsPlanet, Northbrook, IL) radar gun and the PR, a strong correlation between the devices was found ($r = 0.932$, $p < 0.001$), with a large ICC between the device's measurements (r = 0.964, $p < 0.001$) (Abdioglu et al., 2022). Similar to the study by Hernández-Belmonte et al. (2021), a separate study conducted by Makur et al. (2024) identified excellent agreement between the Bushnell speed radar (Model 101911, Bushnell, Cologne, Germany, accuracy: ±2.0 km/h) and a SR (Model ATS II) for both ball speeds in tennis ball throwing (ICC: 0.989 [95% CI: 0.986; 0.991]) and soccer ball kicking (ICC: 0.986 [95% CI: 0.983; 0.989]).

Despite the good levels of accuracy and reliability between pairs of commercially available and commonly used radar devices in previous research (cite1, cite2, cite3), the results were based on soccer ball kicking and tennis ball throwing. As the quantification of the accuracy and reliability of these devices when measuring speed in highly competitive world-wide sports is of high value, understanding the accuracy of measurements using implements in other world-wide sports, such as baseball, can provide significant value to this growing body of validation of assessment tools across sports. Murata et al. (2021) aimed to determine the accuracy and reliability of the TM device. They concluded that the TM and a proven method using computer vision had goodagreement regarding measurements of speed and spin rate. Despite the TM underestimating the speed if it wasn't able to detect the hitting position, the degree of error was not deemed to be problematic in practical applications.

As radar-based ball tracking devices are commonly used by coaches, scouts, and athletes alike, determining these devices to be valid and reliable will help to justify that these various tools measure what they are intended to measure and how consistent they are in their measurements. To the author's current knowledge, no investigations have identified the validity and reliability between three3 commercially available radar-based devices when tracking velocity using baseballs fed from a pitching machine. Therefore, the purpose of the current study was to examine the concurrent validity of the PR and TM radars for BV measurement by comparing these devices against a reference criterion, SR. The authors hypothesized that there would be good reliability between all three devices

2. Method

The peak BV of each repetition was simultaneously recorded by three radar guns: one TrackMan Portable B1 (TM; TrackMan, Vedbaek, Denmark), one Pocket Radar (PR; Model PR1000-BC, Inc. Santa Rosa, California) and one Stalker Radar (SR; Applied Concepts Inc., Richardson, TX). The SR, with a sampling frequency of 33 Hz, was used as a reference criterion for the validity analysis (Beato et al., 2018; Nagahara et al., 2017; Rampinini et al., 2015). Radar calibration for all three devices was verified with a certified tuning fork (Applied Concepts Inc., Richardson, TX). The tuning fork oscillates at 2,899 ± 5 Hz at 21° C resulting in a calibration signal of 40mph (64km/h). Similar to the setup of Hernández-Belmonte et al. (2021), the

SR was placed on a tripod at a vertical height of 1.20 meters. The PR was held by a member of the research team at the same height to the right of the SR. The TM device was adjacent to the other radar devices, except it stood on a tripod at a height of 8ft (based upon calibration requirements). Twenty pitches were fed one at a time through a 3-wheel pitching machine (I-Hack Attack, Sports Attack LLC., Nevada, USA) for each of the following speeds: 50 mph (80.5 km·h^{-1}), 60 mph (96.6 km·h^{-1}), 70 mph (112.7 km·h^{-1}), 80 mph (128.8 km·h^{-1}), 90 mph (149.9 km·h^{-1}) into a strike zone net placed directly over home plate. The data collection was held inside an indoor facility within a netted batting cage. All of the radar guns were located 5 m behind the target during testing sessions, as the manufacturers recommended. The netted batting cage was directly behind the strike zone; therefore, the radars were behind the netted batting cage. All batteries were charged before the data collection. Data for each device was in an automatic mode (no need to press any button before each pitch). After each pitch was detected by each device, a researcher noted the BV value (in km·h−1) in an excel sheet.

3. Findings

3.1. Statistics Analysis

Concurrent validity and reliability of the three radar devices was measured by an intraclass correlation coefficient (ICC) two-way fixed-effects, absolute agreement model and standard error of the mean (SEM). Interpretations of ICC's are based upon the guidelines described by Koo and Li (2016), in which poor (<0.50), moderate (0.50-0.75), good (0.75-0.90), and excellent(>0.90) ICCs were determined. Based on the sample size (n<20), Hedge's g was used to calculate the measure of effect size (g~0.2 small effect, *g*~0.5 moderate effect, and *g*~0.8 large effect) (Cohen, 1988). A two-way ANOVA was conducted to examine the effects of Device (PR, SR, TM) and Speed (five levels) on measured velocity. Statistical Analysis was performed in RStudio (Posit team (2025). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. URL http://www.posit.co/).

3.1.1. Data Results

The Mean and SEM for each device at each speed is presented in Table 1. The ICC between all three devices was moderate at 80.5 km·h^{-1} (50 mph)(ICC=0.53), at 96.6 km·h^{-1} (60 mph), the ICC was good (ICC=0.77), at 112.7 km·h^{-1} (70 mph), the ICC was good (ICC=0.82), at 128.8 km·h^{-1} (80 mph), the ICC was good (ICC=0.77), and at 149.9 km·h^{-1} (90 mph), the ICC was also good (ICC=0.83) (Table 2). When comparing radar devices against each other, when collapsed across speeds, each ICC between devices were found to be >0.99

(Table 3). The Mean and SEM for each device collapsed across speeds is presented in Table 4. Hedge's g effect sizes are presented in Table 5.

Mauchly's test of sphericity indicated that the assumption of sphericity was violated for Device, $W = 0.44$, $p = 0.001$, and Speed, $W = 0.36$, $p = 0.036$, as well as for the Device × Speed interaction, $W = 0.009$, $p < .001$. Therefore, Greenhouse–Geisser corrections were applied to these effects. After applying the Greenhouse–Geisser corrections, there was a significant main effect of Device, $F(1.28, 24.20) = 70.10$, $p < .0001$, $\eta^2_{(G)} = 0.140$, indicating that mean velocity differed across measurement devices. This is shown in figure 1. There was also a significant main effect of Speed, $F(2.75, 52.82) = 9551.74$, $p < 0.001$, $\eta^2_{(G)} = 0.996$, suggesting that velocity increased as speed conditions changed. However, the Device × Speed interaction was not statistically significant, $F(4.58, 87.33) = 1.66$, $p = 0.158$, $\eta^2_{(G)} = 0.016$, indicating that the pattern of velocity changes across speeds was consistent across devices. This is presented in Figure 2.

Post hoc pairwise comparisons using Bonferroni adjustments revealed that all devices differed significantly from each other (all $p < .001$). Specifically, PR recorded significantly lower velocities than both the SR($p < 0.001$) and TM ($p < 0.001$), and SR recorded lower velocities than TM ($p < 0.001$).

Table 1. Mean and Standard Error of the Mean (SEM) for Each Radar Device at Five Speeds

Speed (km·h⁻¹) (mph)	*PR Mean (SEM)*	*SR Mean (SEM)*	*TM Mean (SEM)*
80.5 (50)	80.8 (0.51)	82.4 (0.34)	82.9 (0.33)
96.6 (60)	92.3 (0.45)	93.1 (0.48)	93.3 (0.33)
112.7 (70)	110.6 (0.52)	111.7/0.48	111.9/0.33
128.8 (80)	130.9 (0.55)	131.4 (0.38)	132.1 (0.35)
144.9 (90)	149.2 (0.74)	150.1 (0.59)	150.9 (0.63)
PR = Pocket Radar; SR = Stalker Radar; TM = Trackman.			

Table 2. Intraclass Correlation Coefficients (ICC) Between Three Radar Devices at Five Speeds

PR vs SR vs TM	ICC	F-value	DOF	*p*
80.5 km·h^{-1}	0.53	3.5	19	<0.01*
96.6 km·h^{-1}	0.77	5.2	19	<0.01*
112.7 km·h^{-1}	0.82	9.4	19	<0.01*
128.8 km·h^{-1}	0.77	5.8	19	<0.01*
144.9 km·h^{-1}	0.83	8.6	19	<0.01*
PR vs SR	>.99	1079	99	<0.01*
PR vs TM	>.99	1170	99	<0.01*
SR vs TM	>.99	3846	99	<0.01*
All Devices Speeds	>0.99	2202	99, 198	<0.01*
DOF = Degrees of Freedom (n-1); PR = Pocket Radar; SR = Stalker Radar; TM = Trackman; * denotes p<0.05, All ICCs were two-way fixed-effects, absolute agreement model				

Table 3. Mean and Standard Error of the Mean (SEM) for Three Radar Devices Collapsed Across Five Speeds

Global Speed	PR	SR	TM
Mean (SEM)	112.8 (7.93)	114.7 (7.87)	114.2 (7.91)
PR = Pocket Radar; SR = Stalker Radar; TM = Trackman.			

Table 4. Effect Size (Hedge's g) Between Radar Devices at Five Speeds

Radar Comparison	80.5 km·h^{-1} (50 mph)	96.6 km·h^{-1} (60 mph)	112.7 km·h^{-1} (70 mph)	128.8 km·h^{-1} (80 mph)	144.9 km·h^{-1} (90 mph)
PR vs SR	-1.09	-0.48	-0.65	-0.32	-0.45
PR vs TM	-1.50	-0.73	-0.94	-0.81	-0.77
SR vs TM	-0.51	-0.15	-0.21	-0.61	-0.37
PR = Pocket Radar; SR = Stalker Radar; TM = Trackman.					

Figure 1. Main Effects on Measured Velocity

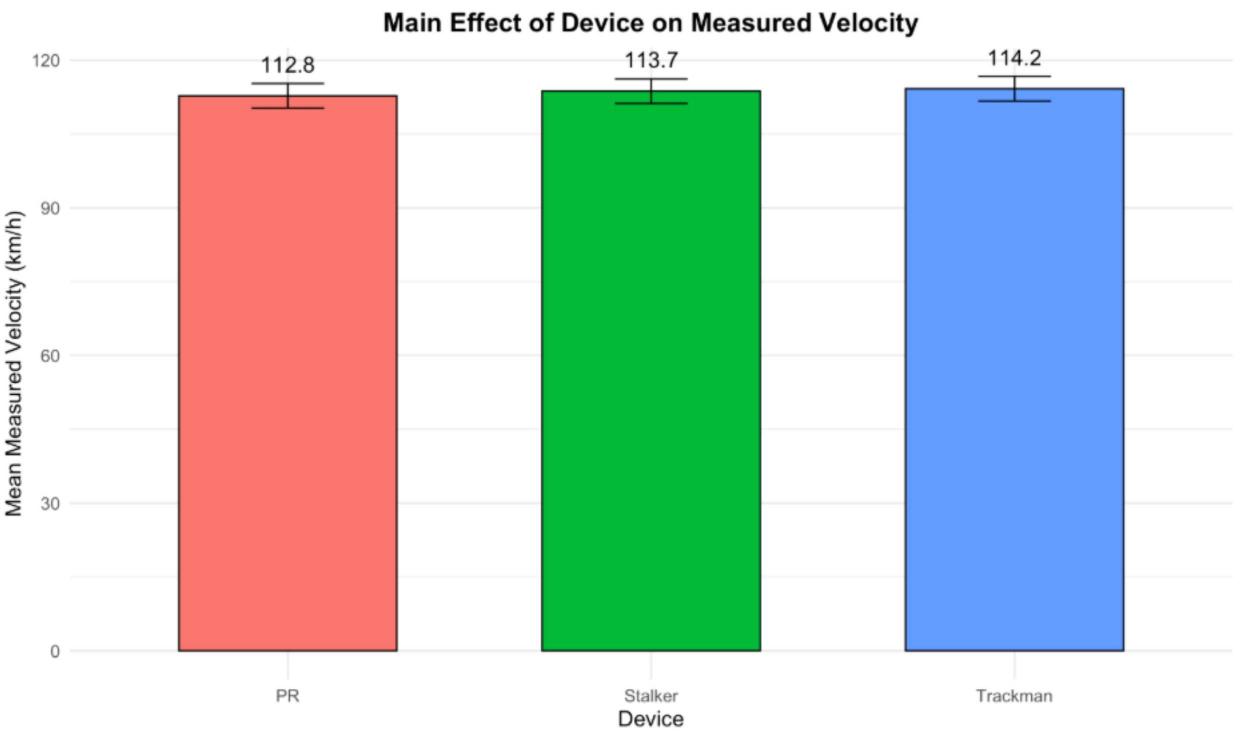
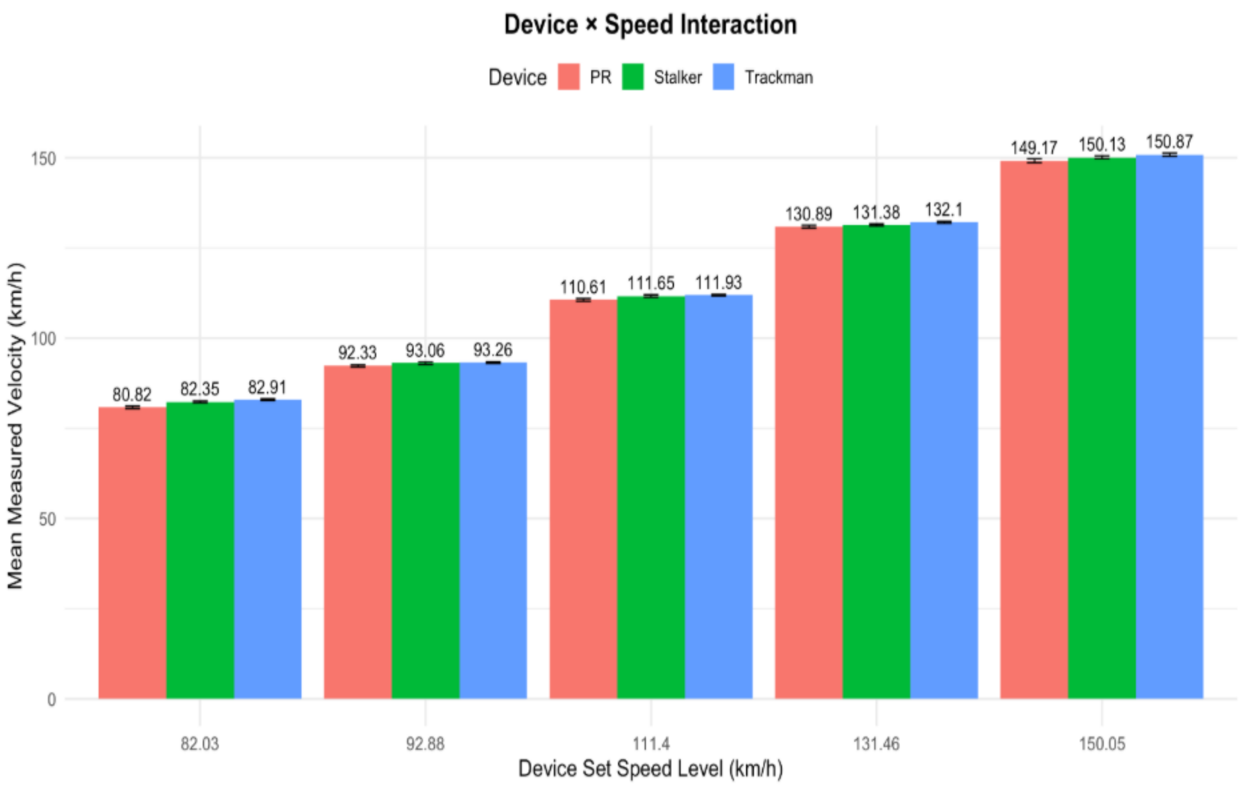


Figure 2. Device and Speed Interaction



4. Discussion

The current study aimed at examining the concurrent validity of the PR and TM radars for BV measurement by comparing these devices against a reference criterion, SR. Excellent agreement between each radar collapsed across all speeds was evident by the extremely high (ICC ≥ 0.99). Only one other study has determined the validity of the PR (Hernández-Belmonte et al., 2021). They found in that study that there was good concurrent validity with the SR as well as good inter-unit reliability between two PR's when hitting a tennis ball and kicking a soccer ball. The SEMs were all less than 1.6 km·$^{h-1}$ at each velocity and for each radar, indicating that there was good radar reliability and not much variability away from the mean of each speed set by the pitching machine. When looking at ICCs at each of the respective speeds, the findings present one moderate and four good ICCs between three radar-based ball-velocity tracking devices. This demonstrates that all devices have reliability that both a researcher and practitioner can use with minimal error. When viewing the effects sizes, all effect sizes, either small, moderate, or large, were negative indicating there was minimal effect of each device on the other showing good validity. Depsite being a large effect size, the devices are close together with respect to speed, less than 1 km/hr between devices. Given that the conditions were in a lab under controlled conditions, the results of this data may not be as representative as compared to being in an outdoor environment with live pitches thrown by a real pitcher.

Despite this study being completed without human subjects, this study is not without limitations. First, the study only used baseballs that were fed through a baseball pitching machine. As other studies have used other spherical objects, such as tennis and soccer balls, this study, specifically, only used baseballs. Future research could utilize the methods of this study, and other similar studies, and use other objects commonly used in sports, such as a football or lacrosse ball. The pitching machine allowed for pre-set consistent speeds to be read by each radar device. Adding a live pitcher could have varied the results due to a pitcher not knowing exactly if they are reaching the same speed consistently for multiple pitches. For even more practical purposes, future studies could use a live pitcher to determine how these radar devices track in a live outdoor setting with a batter and catcher. In addition to not using a live pitcher, as the SR and PR were at the same height, the TM was set-up higher, at 8ft, based upon calibration settings. This could have led to possible speed discrepancies between the three devices, however, calibration helps the system to adjust for off-set angles.

Based on the information gathered in the present study, sport coaches, sports performance practitioners, scouts, researchers, and others involved in monitoring performance-based BV measurements, can expect to have accurate data when using any of the three devices tested. As affordability and access to technology can play a role in what data is captured, the present study finds that either device can be used as a practical tool when evaluating BV for testing and monitoring, as well as in training for sport. Even though there were statistical significances found, understanding the sporting context and scenario is important for a coach when using a device. Ensuring the data collected from technological devices can be beneficial as a tool to help quantify the athlete's performance, but contextual caution should be used when using the data for making decisions. Individuals monitoring BV should understand the validity and reliability behind the devices they use to monitor velocity-based performance to ensure they are collecting consistent and accurate data to make decisions from.

5. Conclusions

BV is a key performance metric for many sports, especially baseball. As the validity and reliability of devices that measure BV is important for both researchers and practitioners alike, the present study found good reliability between three commonly used commercially available radar devices. When having pitches fed from a pitching machine, often utilized by batters and catchers in baseball practices, having a device that coaches or members of a team recording BV can trust to give accurate readings is important for appropriate feedback for players. As the findings in the present study display excellent concurrent validity and reliability of these radar devices, this provides evidence for the practical use of either device for BV measurements when using a pitching machine with baseball players.

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Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest.

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