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# Validity and Reliability of a Computer Vision System to Determine Bar Displacement and Velocity

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## ABSTRACT

This study examined the validity and reliability of a video-based smartphone application (VBA) to measure displacement and velocity in the barbell bench press, back squat, and deadlift. Nine resistance trained subjects (three females; six males; age: 24.2±4.2 years; height 175.8±8.1 cm; body mass 87.2±18.2kg) completed two test-retest sessions for the barbell bench press, back squat, and deadlift one week apart. Eight repetitions were completed for the bench press, back squat, and deadlift with a load of 40kg and completed at fast and slow velocities. Bar displacement and average velocity were measured simultaneously using 3-D motion capture (MC) and a VBA. The VBA's validity and reliability were analyzed by Pearson's product-moment correlation coefficient ( $r$ ), intraclass correlation coefficient (ICC), and Bland-Altman Plots. Displacement data showed moderate to nearly perfect correlations ( $r = 0.43-0.94$ ) and moderate to excellent reliability (ICC= 0.67-0.98) and Bland-Altman plots revealing little bias (< 2cm). Average velocity data showed large to nearly perfect correlations ( $r = 0.67-0.95$ ) and good to excellent reliability (ICC= 0.79-0.94) with Bland-Altman revealing little bias (< 0.06 m/s). Taken together the VBA examined in this study was both valid and reliable compared with a gold standard criterion measurement of MC. These results provide evidence that the VBA may be used in the tracking of displacement and average velocity in the bench press, back squat, and deadlift at both fast and slower movement velocities.

**Keywords:** Strength Training; Monitoring; Testing

## INTRODUCTION

The tracking of barbell velocity during resistance training (velocity-based training, VBT) has become common practice in training of athletes. The theory behind this method is that certain fitness qualities (e.g., max strength, strength-speed) can be developed by lifting various loads at particular velocities which will drive specific adaptations (7). There are many ways of incorporating VBT into the development of athletes. Most commonly, VBT is used to provide immediate feedback during training to motivate athletes and adjust the load on the barbell to account for fatigue (14). Immediate barbell velocity feedback may enhance performance when combined with training resulting in better training results in as little as six weeks (12). Additionally, using velocity thresholds to drive performance has influenced strength, power, and hypertrophy with different amounts of velocity loss (10, 15). For these reasons, VBT may be used during training to improve performance outcomes.

Previous investigations have examined the reliability and validity of various VBT devices such as linear position transducers (LPT), accelerometers, and inertial measurements sensors (3, 11, 13, 16). Of these, LPT devices demonstrate the highest agreement and reliability when compared against the gold standard measurement of 3-D motion capture (MC) (8, 9, 16). Previously, wireless accelerometers exhibited lower levels of agreement and reliability,

however, limited data from newer wireless inertial measurement sensors have revealed that they may be more valid and reliable than previous technology (3, 4, 8). With advances in computer vision, it may be possible to track barbell kinematics from video, however, fewer studies have been completed on computer vision applications related to VBT (1, 13, 16).

In addition, new applications leveraging computer vision are being developed and may be cost efficient and valid tools for coaches and athletes. One such application is Metric VBT (Core Advantage, Melbourne, Australia), a smartphone application that records video with the phone's onboard camera and utilizes computer vision to identify and track barbell position. These new applications, while promising, need to be analyzed for validity and reliability before widespread adoption. Therefore, the purpose of this study is to examine the criterion validity and reliability between a novel video-based smartphone application (VBA), Metric VBT, and the gold standard measurement criterion of MC. Specifically, this study will determine if the VBA can provide similar measurements of mean concentric velocity (MCV) and concentric phase range of motion (ROM) of common strength training exercises compared to MC.

## METHODS

Nine resistance trained subjects (three females; six males; age:  $24.2 \pm 4.2$  years; height  $175.8 \pm 8.1$  cm; body mass  $87.2 \pm 18.2$  kg) participated in this study. All subjects needed to be familiar with the bench, squat, and deadlift exercises. Subjects needed to be regularly engaged in resistance training for the past three months to be included. Subjects needed to be capable of lifting 40 kg for multiple sets of eight repetitions in the three exercises. Prior to the start of the study, subjects were informed of the procedures, allowed to ask any clarifying questions, and gave their written informed consent. This study was approved by the University's institutional review board (IRB#220519B) and all procedures complied with the Declaration of Helsinki.

This reliability and validation study was performed in two sessions one week apart at approximately the same time of the day and under the same ambient conditions. Data from VBA was collected simultaneously alongside MC in both sessions. To examine VBA's criterion validity, data from VBA was compared to MC for each trial. To examine reliability,

VBA data from the first session was compared to the second session. During the first session, basic demographic information was collected alongside informed consent before the experimental procedures. Next, subjects completed a brief body weight general warm-up (20 jumping jacks, 10 body weight squats, 5 lunges each leg, and 10 arm circles forward and backward) followed by two sets of eight repetitions for the squat, bench press, and deadlift exercises. A 20 kg barbell (Pendlay, Nexgen) was used with an additional 20 kg of load, totaling 40 kg for each exercise. The first set of each exercise was completed with a slow movement tempo. Subjects were instructed to perform each movement with a two second eccentric and two second concentric tempo. The second set of each exercise was completed with a fast movement tempo. Subjects were instructed to control the eccentric portion and stand up explosively as possible on the concentric portion. In total, 48 repetitions (16 repetitions per exercise) were collected for each subject with 24 fast and 24 slow trials. Approximately seven days later, the subjects reported back to the lab to complete the second collection day (an additional 48 repetitions per subject) with the exact same order of procedures as week one.

## Data collection

Videos for the VBA were captured using the onboard camera of a tablet (iPad Pro, Apple, CA, USA). The tablet was oriented vertically for all data collection and mounted on a tripod for stability. The device was placed 2.5m from the end sleeve of the barbell and fixed at a height of 99.0 cm. All data were collected with a resolution of 1080p and a sampling rate of 60 Hz. Videos were collected and analyzed by the MetricVBT application (version 0.5.4) which calculated the range of motion (ROM) and mean concentric velocity (MCV) for each repetition.

For the motion capture data, a reflective marker was placed on the center of the end of the barbell sleeve. Marker positions were collected using 14 Vicon Vero cameras (Vicon Motion Systems Ltd, Oxford, UK) at a frequency of 240Hz. The MC data were filtered with a second-order recursive lowpass Butterworth filter with a cutoff frequency of 10 Hz. The concentric phase of each repetition was then identified as the period of positive vertical bar velocity, as defined by negative-to-positive zero-crossings of the bar's vertical velocity. ROM was calculated as the vertical displacement of the barbell between the start and end of the concentric phase. MCV was calculated as the barbell's mean

vertical velocity during the concentric phase. All MC data analysis was performed in MATLAB R2020b (Version 9.9.0.1495850, The MathWorks, Natick, MA, USA) for analysis

Data was assessed for normality using the Shapiro-Wilks test. Mean and standard deviations were calculated for descriptive statistics. To determine the relationship between the VBA and the MC, a Pearson’s zero-order product-moment correlation was used with 95% confidence intervals and linear regression. Correlation values were interpreted with a scale by Hopkins as 0.0-0.1, 0.1-0.3, 0.3-0.5, 0.5-0.7, 0.7-0.9, and 0.9-1.0 and interpreted by descriptors of trivial, small, moderate, large, very large, and nearly perfect (5). Reliability was assessed by using a 2-way mixed effect, single-rater, intraclass correlation coefficient (ICC), and coefficient of variation (CV). Intraclass correlation coefficient values were interpreted as poor, moderate, good, or excellent based on scale by Koo and Li as 0.50, 0.50–0.74, 0.75–0.90, or 0.90, respectively (6). Accepted within-session variability was classified as <10% (2). Bland-Altman plots and CV were calculated in a custom Excel sheet (Version 2019, Microsoft, WA). All statistical analyses were performed with JASP (version 0.11.1, Amsterdam, NL), using  $p \leq 0.05$  as standard statistical significance.

**RESULTS**

All data was normally distributed. A total of 864 repetitions were analyzed. Reliability data for MCV can be found in Table 1 and for ROM in Table 2. ICC

and CV data for MCV showed moderate to excellent reliability on slow repetitions of squat, bench press, deadlift, and good reliability on fast repetitions of squat, bench press, deadlift. ICC and CV data for ROM showed good reliability on slow repetitions of squat, bench press, deadlift and excellent reliability on fast repetitions of squat, bench press, and deadlift.

Descriptive data and Pearson correlation coefficients for MCV can be found in Table 1 and ROM can be found in Table 2. Significant correlations were found between VBA and MC for both ROM and MVC on slow and fast repetitions. Bland-Altman plots for ROM can be found in Figure 1 and MCV in Figure 2. For MCV, biases for squat, bench press, and deadlift were all less than 0.06 m/s. Bias in ROM was largest for the bench press and deadlift exercises at fast and slow repetitions, with the highest bias being just over 2 cm.

**DISCUSSION**

The purpose of this study was to examine the criterion validity and reliability between VBA and MC. The data indicate that the VBA is moderately to nearly perfectly correlated to MC for ROM and demonstrated large to nearly perfect for MCV across fast and slow movements in the squat, bench press, and deadlift. Additionally, the device expressed good to excellent reliability for both slow and fast repetitions. Bias was present in ROM measurements of the bench and deadlift, where the VBA tended to underestimate the ROM compared to MC during

**Table 1.** Descriptive data, correlation coefficients, and intraclass correlations between motion capture and video-based phone application for barbell displacement.

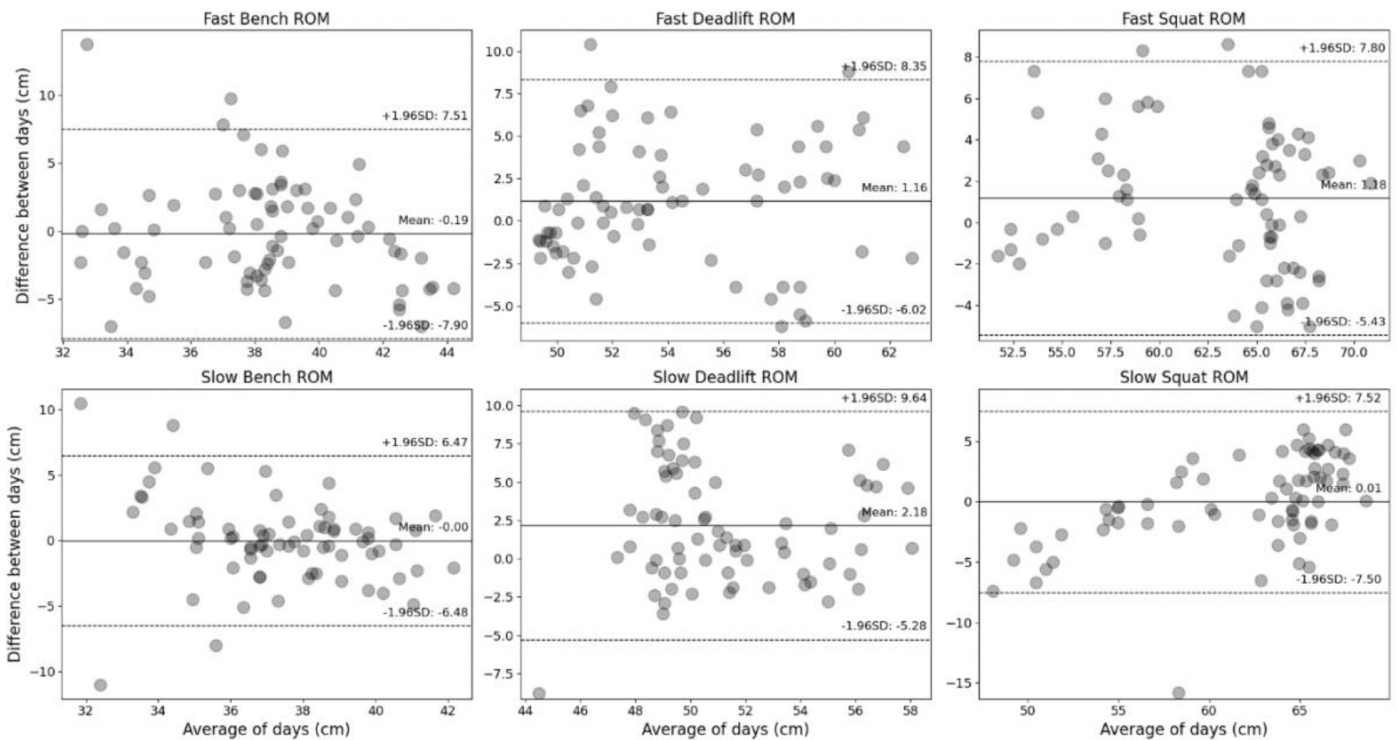
Exercise	Speed	ROM (cm)	r	95% CI for r	ICC	CV (%)	ICC Descriptor
Squat	Slow	VBA: 61.8 ± 5.8 MC: 63.1 ± 6.1	0.94*	0.91 - 0.96	0.98	11.1	Excellent
Bench Press	Slow	VBA: 37.4 ± 2.8 MC: 40.0 ± 3.0	0.43*	0.29 - 0.55	0.67	7.6	Moderate
Deadlift	Slow	VBA: 51.3 ± 3.7 MC: 54.6 ± 3.0	0.70*	0.61 - 0.78	0.76	6.4	Good
Squat	Fast	VBA: 62.9 ± 5.3 MC: 63.7 ± 6.0	0.75*	0.66 - 0.81	0.89	8.9	Good
Bench Press	Fast	VBA: 38.4 ± 3.5 MC: 41.7 ± 3.9	0.73*	0.65 - 0.80	0.80	9.2	Good
Deadlift	Fast	VBA: 54.3 ± 5.0 MC: 57.6 ± 3.9	0.77*	0.70 - 0.83	0.84	8.0	Good

ICC = Interclass Correlation Coefficient; CV = coefficient of variation

**Table 2.** Descriptive data, correlation coefficients, and intraclass correlations between motion capture and video-based phone application for barbell mean concentric velocity.

Exercise	Speed	MCV (m/s)	r	95% CI for r	ICC	CV (%)	ICC Descriptor
Squat	Slow	VBA: 0.52 ± 0.10 MC: 0.45 ± 0.11	0.81*	0.74 - 0.86	0.87	22.2	Good
Bench Press	Slow	VBA: 0.43 ± 0.11 MC: 0.35 ± 0.08	0.67*	0.57 - 0.75	0.79	24.4	Good
Deadlift	Slow	VBA: 0.49 ± 0.09 MC: 0.44 ± 0.08	0.77*	0.69 - 0.83	0.87	18.8	Good
Squat	Fast	VBA: 0.86 ± 0.23 MC: 0.83 ± 0.21	0.95*	0.94 - 0.97	0.98	25.8	Excellent
Bench Press	Fast	VBA: 0.77 ± 0.23 MC: 0.74 ± 0.21	0.87*	0.82 - 0.90	0.94	30.0	Excellent
Deadlift	Fast	VBA: 0.85 ± 0.23 MC: 0.82 ± 0.20	0.86*	0.81 - 0.90	0.94	26.0	Excellent

ICC = Interclass Correlation Coefficient; CV = coefficient of variation



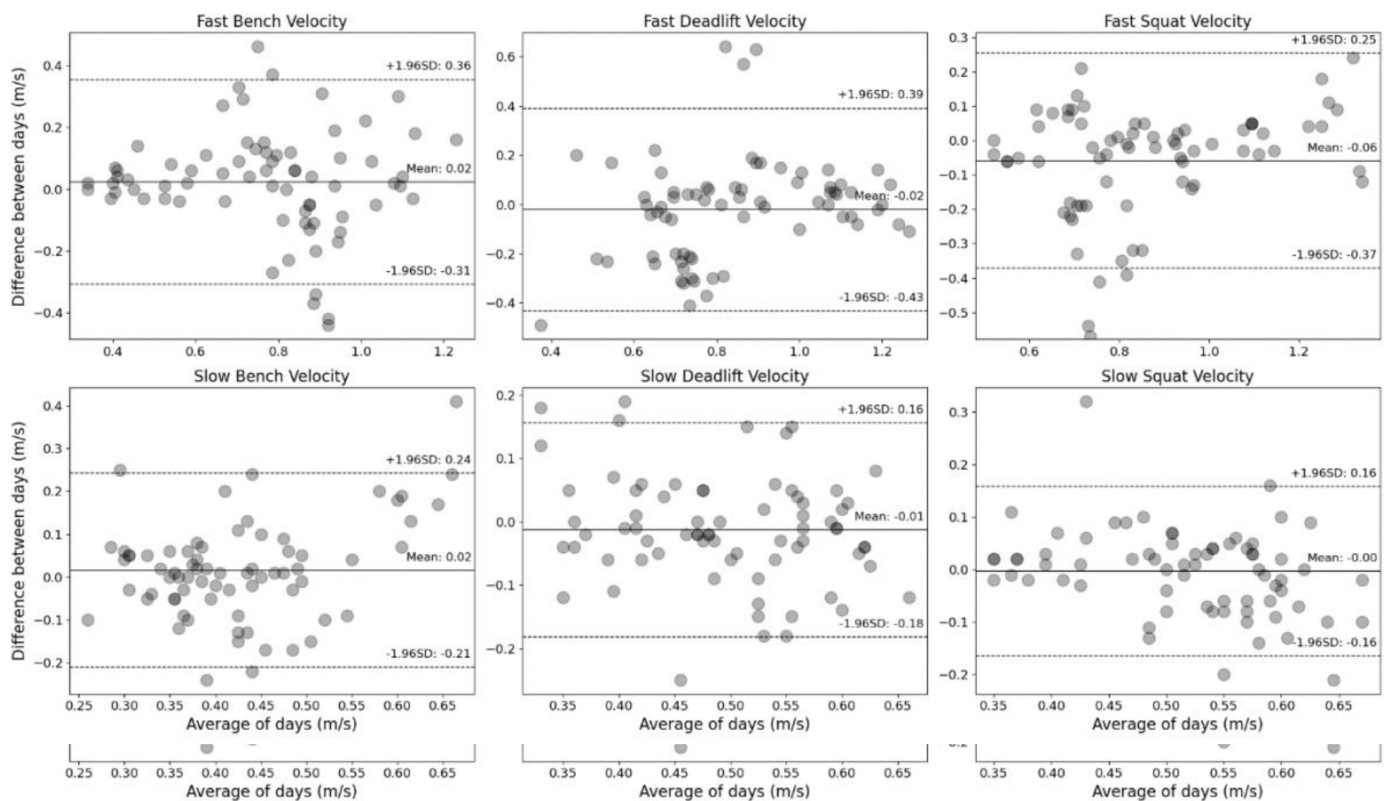
**Figure 1.** Bland-Altman analysis for displacement with limits of agreement ( $\pm 1.96$  SD)

bench press and deadlift for both slow and fast repetitions. Very little bias was present for MCV for measurements compared to MC. Overall, the data indicate that the VBA is both reliable and valid across a range of common exercises and velocities compared with the gold standard criterion of MC.

The main outcome from this study suggests that compared to the criterion (MC), the VBA provided a valid measure of ROM and MCV during three resistance training exercises at two velocities. These values are similar to values obtained in other studies examining mobile phone and tablet

application (16). In contrast, the CVs in this study were acceptable for ROM with only the fast squat falling outside the acceptable range ( $>10\%$ ) (16). Compared to other studies using MCV tracking the CVs in this study fell outside the acceptable range (16). Overall, fast repetitions tended to have higher correlation values compared to the slower variables in both the ROM and MCV. When examining each exercise individually, squats presented the highest correlation values in both ROM and MCV. Deadlifts and bench press tended to have lower correlation values on both ROM and MCV. With the exception of the bench press, which had a moderate correlation





**Figure 2.** Bland-Altman analysis for mean concentric velocity with limits of agreement ( $\pm 1.96$  SD)

for ROM (0.43), all other variables demonstrated large to nearly perfect correlation values.

The between-day reliability values obtained in this study were good to excellent for all exercises for both ROM and MCV with the exception of the bench press ROM. Squats presented the highest reliability for ROM (ICC = 0.98) and MCV (ICC = 0.98) followed by deadlift and finally bench press. The MCV measurements tended to have higher ICC values across all metrics (0.79-0.98) compared to ROM measurement (0.67-0.98). Squats which had the largest ROM also had the highest reliability values in the study. Finally, in both ROM and MCV the faster repetitions tended to produce higher reliability values compared to slow repetitions.

While validity compared to MC was strong for VBA, the results could have been affected by differences in analysis choices between our custom software and Metric VBT, such as filter design and cutoff frequency and the method for identifying the concentric phase. ROM should be particularly sensitive to the filter's cutoff frequency as it is calculated from the minima and maxima of bar displacement. Slower movements tended to have less distinct peaks in the displacement data than faster movements and occasionally had multiple zero crossings in the velocity data. To detect the end of the concentric phase, the first zero crossing

in the velocity data for each repetition was used. As the VBA may have employed a different strategy to solve this issue, VBA and MC may not have been detecting the exact same point as the end of the concentric phase of each rep. This could have led to the lower correlations generally found for slow movements compared to fast movements.

This study is not without limitations. First, the weight used in this study was fixed. It is unknown if lifting heavier weights, closer to a subject's maximum would affect the outcomes. Both fast and slow repetitions were completed so it should not alter the outcomes but it was not tested. Next, the exercises in this study were all linear in nature. Changes may occur if the bar is lifted in a curvilinear motion based on how the VBA calculates variables and detects the start and ends of the motion. Finally, only three exercises were tested in this study and it is unclear if other movements with different executions will have the same reliability and validity.

In conclusion, this investigation provides another tool which coaches can use to track and monitor barbell kinematics for their athletes. Analysis revealed moderate to nearly perfect correlations for MCV and ROM. Previously, wireless sensors have been less valid and reliable compared to LPT for tracking common strength movements (8). However, newer technology such as computer vision and inertial

movement sensors have established some initial promise in being both reliable and valid against MC in common exercises (3).

## PRACTICAL APPLICATIONS

This investigation revealed that VBA is a valid and reliable measurement tool in the measurement of MCV and ROM. This new VBA provides coaches with a low-cost, simple, phone-based application which can be used for VBT. Future studies should investigate the validity and reliability of this VBA and its use for monitoring and tracking peak power and range of motion in explosive movements such as the snatch and clean and jerk which are widely used in field of strength and conditioning.

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