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Original Research

Internal Consistency of Two Testing Modalities for Barbell Velocity and Power During the Back Squat

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ABSTRACT

Internal consistency can be defined as the reliability across similar items in a test. Considering the importance of power and velocity during resistance training, it is crucial to have accurate testing methods for quantifying these variables. With recent technological advancements, various devices are increasingly used to quantify barbell velocity and power in the weight room to better understand the exercises prescribed. The purpose of the study was to determine the internal consistency of a novel 3-D camera system and a commonly used tether-based dynamometer by comparing them to a laboratory-based linear position transducer. To assure a consistent stimulus, one weight-trained male (age = 28 yrs, height = 1.78 m, mass = 97.1 kg, 1RM squat = 226.8 kg) completed 10 sets of 1 repetition with maximal concentric acceleration at each prescribed load of 30, 40, 50, 60, 70, and 80% of his individual 1RM, for a total of 60 repetition trials. All devices used in this study collected the data simultaneously. All three methods of measurement exhibited strong correlations ($r \geq 0.80$) while Cronbach α values for mean velocity, peak velocity, mean power, and peak power were 0.998, 0.995, 0.981, 0.951, respectively. Bland-Altman plots showed that all four variables were well within 95% limits of agreement. Based on our results, we can conclude that the use of a 3-D camera system or a tether-based external dynamometer provides measures of barbell velocities and powers consistent with laboratory-derived measures. These findings indicate strength and conditioning professionals can monitor resistance training with any of the systems used and achieve similarly consistent values.

Keywords: Kinematics, Kinetics, Biomechanics, Technology, Lifting

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Introduction

Internal consistency can be defined as the reliability across similar items in a test. For example, on a written exam or survey, multiple questions are often included on the same topic. Responses to these items should be similar for a well written and conducted assessment. This concept can also be applied to the weight room or sport performance laboratory where lifting performances can be evaluated using multiple methods (e.g. force plates, position transducers, external dynamometers, motion capture systems). If multiple devices are used simultaneously, each should provide consistent results. In the case of the weight room, high internal consistency would indicate strong agreement between the different testing devices. With the rapid development of new testing technologies for the weight room, establishing strong internal consistencies between these various devices helps coaches, athletes, and sport scientists establish confidence in the kinetic and kinematic data being generated.

It is well accepted that high levels of muscular strength and power are critical for many sport performances. Additionally, agility (i.e. the ability to change directions of body positions) requires considerable strength and power. Indeed, successful performances in rugby (1-2), American football (3-4), basketball (5), and sprinting (6), to name a few, have been associated with muscle force and power. All of these suggest that improvements in strength and power can contribute to progression in sports performance and would provide athletes a better opportunity for success.

It is readily apparent that both strength and velocity are important contributors to the power that is needed for high performance in many sports (7). Although, there are numerous training theories and methods for developing muscular power, it has been suggested that due to the importance of muscular force to the generation of power, heavy resistance training loads can be an important stimulus for the development of muscular power (7). Furthermore, a mixed-methods approach to training, incorporating both strength and speed, has been suggested to have greater overall influence on the entire spectrum of power (8-11). This would make it more applicable and transferable to the athletic environment due to the development of both aspects of the force-velocity relationship (8-11). It is believed by some that the training with the load that maximizes mechanical power during different training exercises may be the optimal approach. This is thought to be more beneficial for power because, in one study (12), training with the load that maximized power had the best overall training effect relative to dynamic athletic performance. However, identifying the optimal load to maximize power output can be challenging. Several studies have reported differing external loads associated with maximal power (13-15), but it is becoming clear that these results are highly-dependent on the exercise, the testing devices used, the use of system mass versus barbell mass, and the range of motion, among other factors (16).

If power and velocity during resistance training are important, then it is crucial to have accurate testing methods for quantifying these variables. Furthermore, although mean and peak power for an exercise are typically reported, they are not necessarily interchangeable. Previous studies on the jump squat have reported both peak power (13) or mean power (17), and Hori et al. reported a strong relationship between peak and mean power for the hang power clean and weighted jump squats (18). On the other hand, Harman et al. found peak power was highly correlated with vertical jump performance, but average power was not (19).

Mean and peak barbell velocity are also of interest to researchers and practitioners. Although mean and peak velocity may not always be compared directly to each other, their importance for the calculation of mean and peak power is paramount (7). Also, while power is certainly of interest to many practitioners, it may be more important to observe the velocity spectrum of each exercise to more clearly delineate between strength-speed and speed-strength. The former occurs in the low velocity, high force conditions, and the latter occurs in the moderate to high velocity, low force conditions (20). It may also be important to identify the velocity at which maximum power occurs as opposed to a percentage of 1RM (13).

As athletes develop strength and power over time, coaches must be able to adjust training loads to accommodate improvements and facilitate training readiness. Previous research shows that load prescriptions can be individualized based on maximum power output, and regularly gathering accurate data is essential to making appropriate adjustments within that training paradigm (15). Because very few weight room facilities are equipped with force plate technology or advanced motion capture systems, other devices have been developed to make these measurements more assessable to strength and conditioning practitioners. However, before these alternative measurement systems may be used with confidence for monitoring performance, their accuracy must be determined. A recent report indicated that a 3-D camera system appeared to be reliable for kinetic and kinematic measures but did not report actual values and grouped data for six different exercises (21). A tether-based linear position transducer has been previously shown to be a reliable method of measurement, but the focus was on the reliability of the testing protocol rather than the testing device itself (13,22). Hence, the purpose of this study was to determine the internal consistency of a new 3-D camera system and a tether-based external dynamometer for measuring barbell velocity and mechanical power when compared to a laboratory-based linear position transducer.

Material and Methods

Participants

One weight trained male (age = 28 years, height = 1.78 m, mass = 97.1 kg, barbell high bar back squat 1RM = 226.8 kg) volunteered to participate in this study. The subject provided written informed consent to participate in the study as approved by the University's committee for research with human subjects.

Experiment procedure

An observational analytic design was used to compare two experimental devices designed to assess barbell velocity and power with the criterion measure of a calibrated laboratory linear position transducer (LPT). The subject was asked to perform multiple squats while power and velocity measurements were simultaneously recorded by each device for each repetition in order to observe internal consistency for both experimental devices examined in this study. The subject completed two sessions in the laboratory on separate days. The first session included a test to determine 1RM in the barbell high bar back squat. The second session was for data collection to be used in the study. During session two, the subject was positioned with a barbell across his shoulders in a high bar position. The squat was performed to a position of thigh parallel to the floor where the inguinal fold reached the point of being level with the top of the knee, and then a return to the full standing position. In order to eliminate a single-subject design issue, the subject was asked to complete a large number of repetitions (24). The subject completed 10 sets of 1 repetition at each prescribed load of 30, 40, 50, 60, 70, and 80% of his individual 1RM in the squat, for a total of 60 repetition trials. These percentages were used because it would provide the opportunity for a large range of bar velocities. In addition, several previous studies examining the load that elicits peak power output have used this range of loads (14, 25-28). Each repetition was done as a separate set of 1 repetition, as opposed to a single set of 10 repetitions. A minimum of two minutes rest was allowed following each repetition. The subject was instructed to perform the squad with maximal acceleration through the concentric phase of the lift.

In order to validate the 3-D camera system and the tether-based external dynamometer, each repetition trial was simultaneously measured using the LPT as the standard. Criterion measures of barbell displacement were collected by a ceiling-mounted Uni-Measure (Corvallis, OR) tether-based position transducer, and barbell velocity was derived from position data using LabView software (National Instruments, Austin, TX). LPT signals were collected at 1000 Hz with a BioPac data acquisition system (Goleta, CA). In addition to the criterion position transducer, the tether from a separate external dynamometer (Weightlifting Analyzer Tendo, FiTROdyne, Bratislava, Slovakia) was also attached to the barbell immediately next to the point of attachment of the LPT, which recorded data with a linear encoder at a variable sampling rate. A 3-D camera system (EliteForm PowerTracker, Lincoln, NE) was mounted on a Power Lift (Jefferson, IA) half-rack weight training station. Using proprietary video capture methods sampling at 30 Hz, barbell power and velocity data were derived from the 3-D camera system. This technology uses the combination of RGB cameras in depth sensors (infrared projectors with monochrome complementary metal-oxide semiconductors) to monitor the barbell movement. Variables collected from all measurement systems included peak and mean velocity and peak and mean power.

Statistical analysis

Relationships between power and velocity for each of the devices were determined with Pearson correlation coefficients. Bland-Altman plots (Tukey mean difference analyses) illustrate agreement for the relative difference of values from each system. For comparisons with the laboratory LPT, which was used as the standard, the Bland-Altman analyses used percent differences from the LPT. For Bland-Altman plots comparing the two experimental devices, results were compared with the mean of both devices. All data are reported as means and standard deviations. Cronbach's α was used to measure internal consistency for each of the dependent variables examined in this study. Linear regressions were also calculated for all comparisons, resulting in correlations coefficients (r) and standard errors of estimate (SEE).

Results

Correlation coefficients for mean velocity, peak velocity, mean power, and peak power comparing all three methods of measurement can be seen in Figures 1-4. There were strong correlations ($r \geq 0.80$) between all three methods but were highest for mean velocity and peak velocity. Bland-Altman plots, showing the mean difference of values, are also seen in Figures 1-4. Mean velocity and mean power were shown to be within the limits of agreements when comparing either the 3-D camera system and the LPT or the external dynamometer and the LPT, while peak velocity and peak power were outside of the limits of agreement. However, a comparison of the 3-D camera system and the external dynamometer shows that all four variables were within 95% limits of agreement, indicating that the two experimental devices were in agreement with each other. Cronbach's α values for mean velocity, peak velocity, mean power, and peak power were 0.998, 0.995, 0.981, and 0.951, respectively. The SEE compared to the LPT were very modest (≤ 0.025 $m \cdot s^{-1}$). All comparisons of mean power with the LPT exhibited low SEE (≤ 29.1 W), whereas peak power SEEs were considerably greater (≥ 74.5 W).

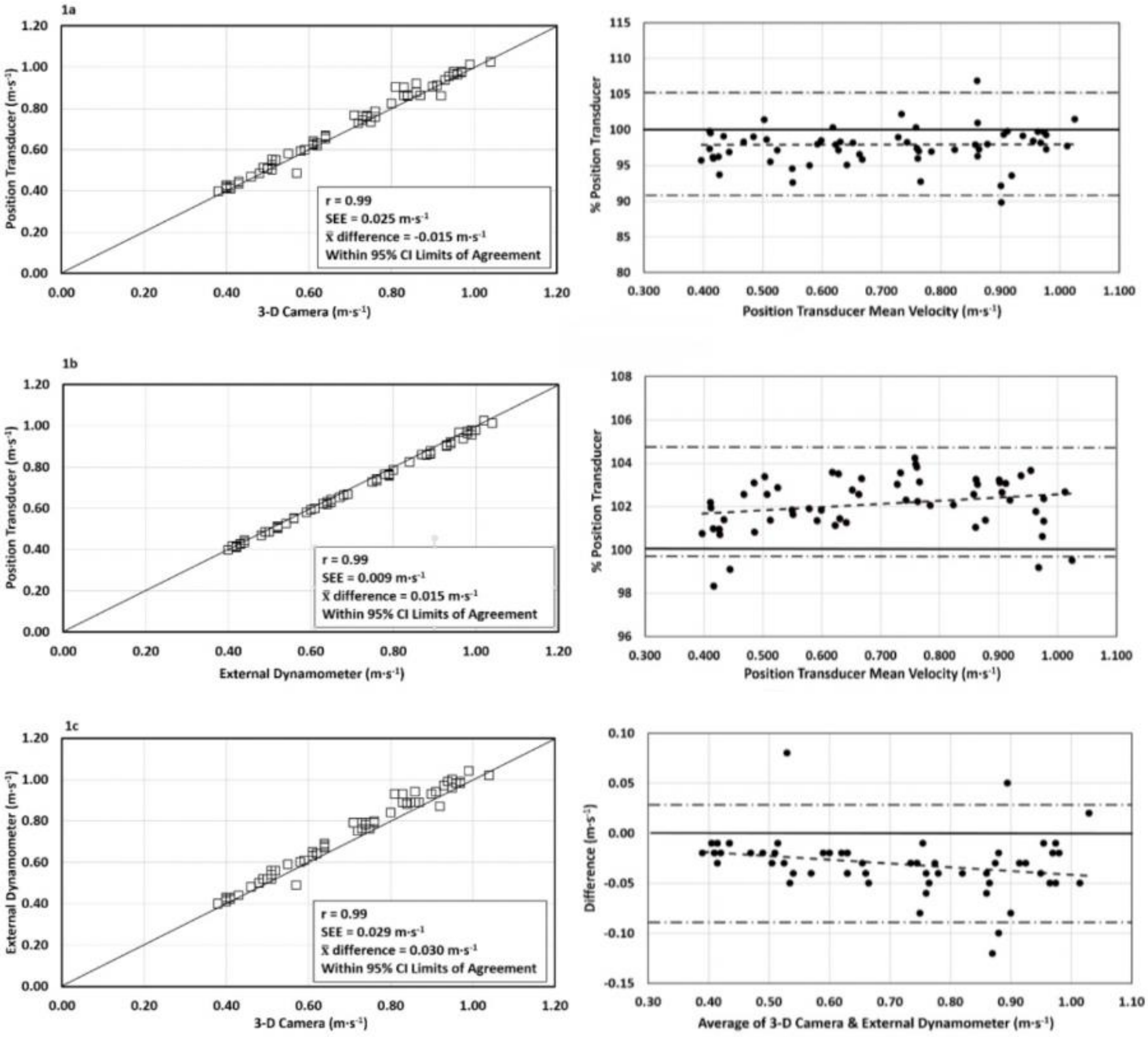

Figure 1. Scatter plots of the linear regression analyses (left panels 1a, 1b, 1c), and Bland-Altman limits of agreement (right panels 1a, 1b, 1c) between 3-D camera and linear position transducer (1a), external dynamometer and linear position transducer (1b), and 3-D camera and external dynamometer (1c) for mean barbell velocity in the barbell back squat. The solid line (left panels 1a, 1b, 1c) represents the line of the agreement for each plot. In the right panels, the dot-dash line represents 95% confidence limits. The solid line (right panels 1a, 1b) depicts 100% of

LPT values, and the mean of the 3-D camera and the external dynamometer (right panel 1c). The dashed line shows the regression line for the comparisons.

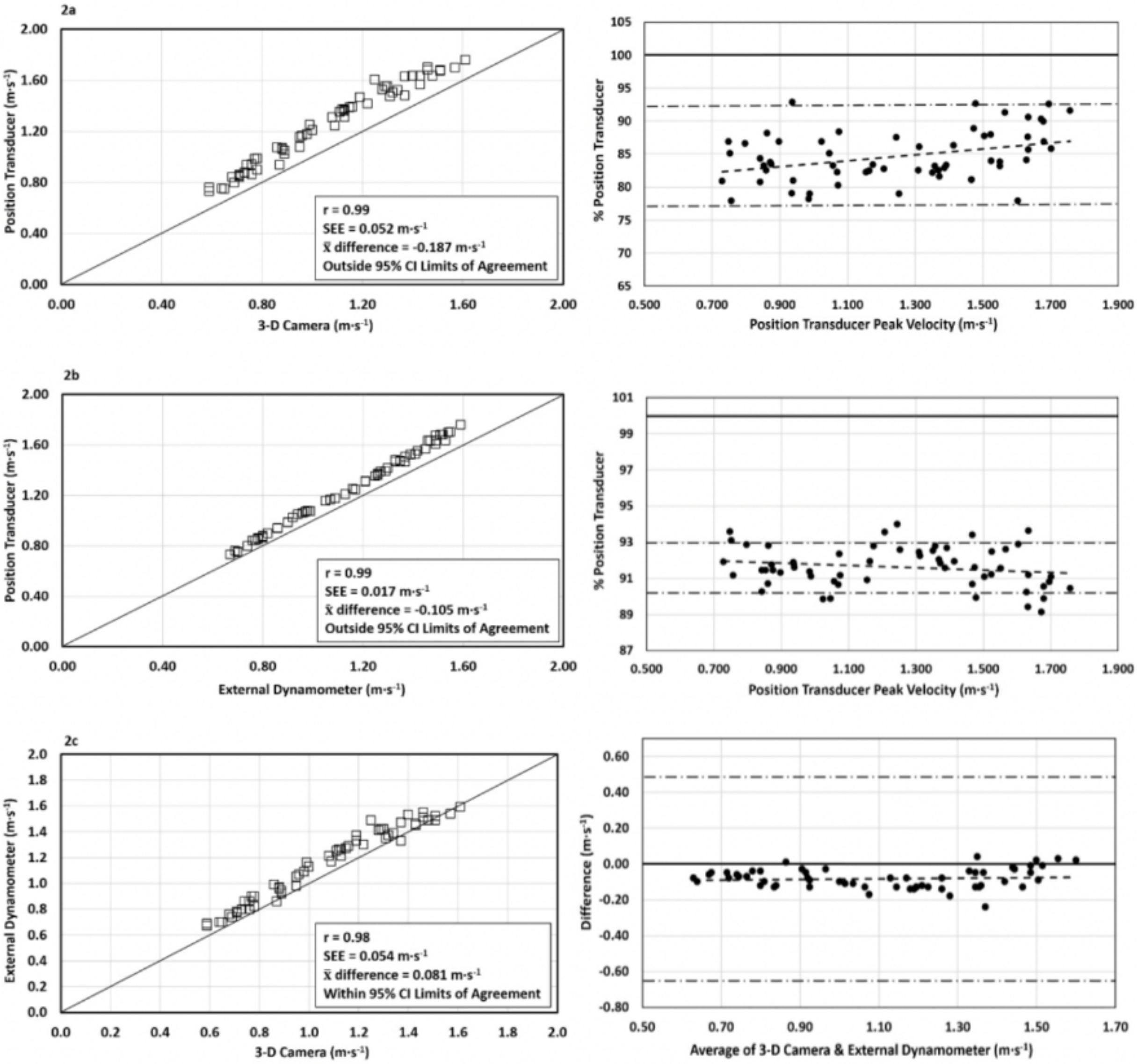

Figure 2. Scatter plots of the linear regression analyses (left panels 2a, 2b, 2c), and Bland-Altman limits of agreement (right panels 2a, 2b, 2c) between 3-D camera and linear position transducer (2a), external dynamometer and linear position transducer (2b), and 3-D camera and external dynamometer (2c) for peak barbell velocity in the barbell back squat. The solid line (left panels 2a, 2b, 2c) represents the line of the agreement for each plot. In the right panels, the dot-dash line represents 95% confidence limits. The solid line (right panels 2a, 2b) depicts 100% of LPT values, and the mean of the 3-D camera and the external dynamometer (right panel 2c). The dashed line shows the regression line for the comparisons.

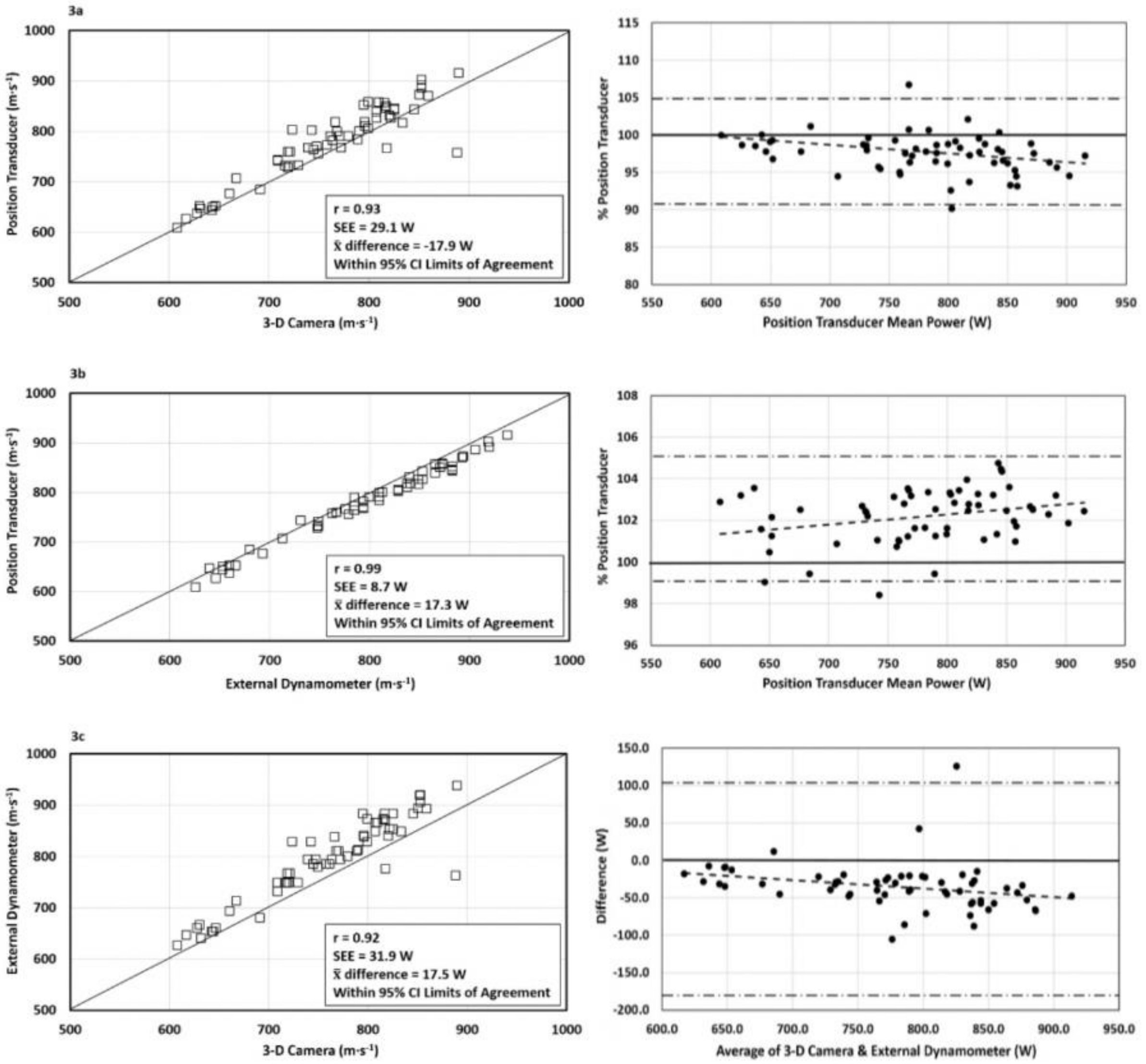

Figure 3. Scatter plots of the linear regression analyses (left panels 3a, 3b, 3c), and Bland-Altman limits of agreement (right panels 3a, 3b, 3c) between 3-D camera and linear position transducer (3a), external dynamometer and linear position transducer (3b), and 3-D camera and external dynamometer (3c) for mean barbell power in the barbell back squat. The solid line (left panels 3a, 3b, 3c) represents the line of the agreement for each plot. In the right panels, the dot-dash line represents 95% confidence limits. The solid line (right panels 3a, 3b) depicts 100% of LPT values, and the mean of the 3-D camera and external dynamometer (right panel 3c). The dashed line shows the regression line for the comparisons.

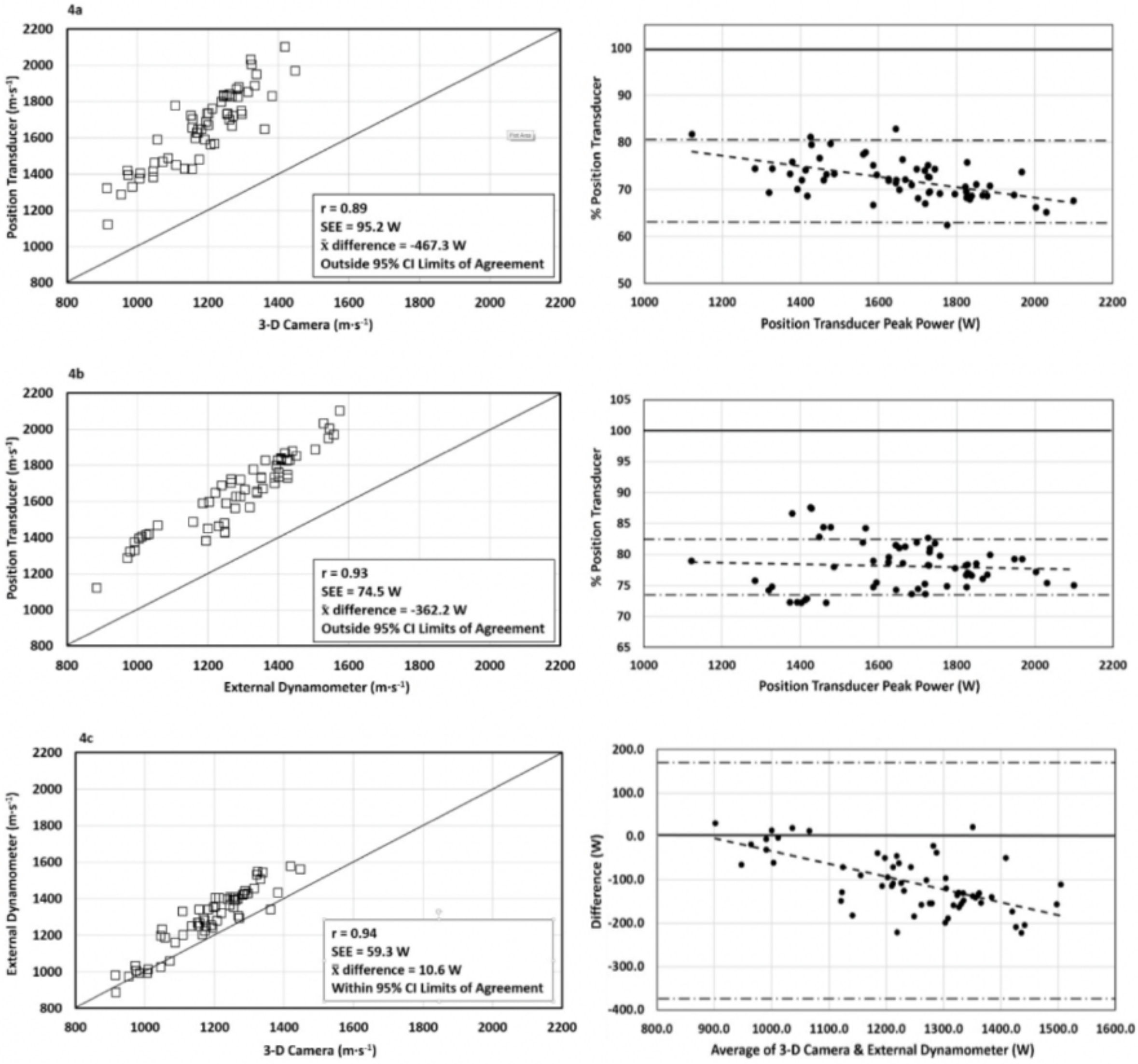

Figure 4. Scatter plots of the linear regression analyses (left panels 4a, 4b, 4c), and Bland-Altman limits of agreement (right panels 4a, 4b, 4c) between 3-D camera and linear position transducer (4a), external dynamometer and linear position transducer (4b), and 3-D camera and external dynamometer (4c) for mean barbell power in the barbell back squat. The solid line (left panels 4a, 4b, 4c) represents the line of the agreement for each plot. In the right panels, the dot-dash line represents 95% confidence limits. The solid line (right panels 4a, 4b) depicts 100% of LPT values, and the mean of the 3-D camera and external dynamometer (right panel 4c). The dashed line shows the regression line for the comparisons.

Discussion

In general, many of the values recorded for both mean and peak barbell velocity and mean and peak barbell power were accurate and reliable, and suggest that both the 3-D camera system and the external dynamometer are acceptable for many uses in the training facility of the laboratory for the back squat exercise. However, several notable exceptions are apparent and are discussed below.

The tether-based external dynamometer has been previously shown to be reliable for the barbell bench press, barbell squat jump, and arm curl exercises, but the accuracy of the measurement has not been well established (22-23). The major finding of the present study is that the technologies examined provide a very reliable means of assessing mean and peak velocity measurements in the practical setting, and the mean velocity values were consistently in agreement with the criterion measures from the LPT (our criterion measure) for the back squat exercise. Our mean velocity data demonstrated good agreement with observations reported by Mann for velocity-based training (29). It should be noted that the peak velocity measures were less accurate for both devices. For the power measures from both the 3-D camera system and the tether-based external dynamometer, both mean and peak power were very reliable. However, only the mean power measures for both devices were in agreement with LPT. Consistently, the measurements from both the 3-D camera system and tether-based external dynamometer were in close agreement with each other, but not with LPT. The reliability of these devices was in agreement with the previous reliability reports for the external dynamometer used in the present study (22-23).

It should be noted that stronger relationships in agreements were evident for mean values than for peak values when comparing the 3-D camera system in the external dynamometer to the LPT. This may be due in part to the sampling rates of the technologies examined, and is in agreement with the previous research, suggesting that mean values are more reliable and valid than peak values in general when using devices such as these (30). The correlation coefficients for all velocity comparisons were extremely high ($r \geq 0.98$), and the mean difference when comparing the 3-D camera system to the LPT, and the 3-D camera system to the tether-based external dynamometer was $-0.015\ m \cdot s^{-1}$ and $0.030\ m \cdot s^{-1}$, respectively for mean velocity. These differences are very modest, especially in a practical setting. When looking at mean power measurements, correlation coefficients were still high ($r = 0.93$ for 3-D camera system and LPT, and $r = 0.99$ for external dynamometer and LPT), and mean differences were -17.9 W and 17.3 W. Again, these differences are very modest.

An important additional finding of the current study is that validity is considerably reduced when calculating peak velocity or peak power using either of these devices. Despite high correlations, the numbers were less accurate for peak values. This is particularly true for the 3-D camera system where the mean difference for peak power was over 400 W and over 300 W for the tether-based external dynamometer. Coincidentally, when comparing the 3-D camera system to the tether-based external dynamometer, the main difference was very small (10.6 W). As suggested by previous authors, this study agrees that despite the strong relationship between the three methods, they must sometimes be viewed as different, and practitioners should be careful with a direct comparison of data from each system (18,31). Each measurement device has different sampling rates and calculation methods for determining values for selected variables. For example, some manufacturers and researchers have included only acceleration due to gravity, and ignored barbell accelerations due to the lift, when deriving force from positions transducers. This would produce erroneously low peak forces, and, as a result, erroneously low peak powers. We surmise that this would not be a problem for mean values. The lower peak velocities for the external dynamometer and the 3-D camera system are likely due to the lower sampling rates. Both the 3-D camera system and the external dynamometer produced peak power values that were significantly lower than the LPT, and the relatively larger differences for peak powers may be due to both the sampling rates and how lifting acceleration is included in the calculations. It is also important to note that both the 3-D camera system and the external dynamometer were consistently in close agreement with each other, thus permitting comparison between the two. Additionally, analyses such as reported here need to be performed for other resistance exercises and their variations, as well as for different ranges of motion for these exercises. Both of these factors can contribute to differing velocity and power profiles. Also, ballistic and high-velocity resistance exercises must be closely examined as well, since the acceleration and deceleration characteristics of the exercise may influence the velocity and power measures of interest (16).

Conclusion

In conclusion, the present study shows very strong relationships between the three methods of measuring barbell mean velocity and mean power output for the back squat. Both mean velocity and mean peak power were within limits of agreement in all comparisons. While peak velocity and peak power were outside the limits of agreement when comparing the 3-D camera system and external dynamometer to the LPT, both variables were within limits of agreement when compared to each other. The use of 3-D camera system or a tether-based external dynamometer provides very reliable measures of barbell velocities and powers and will provide consistent measures over time. However, only mean velocity and mean power measures were in close agreement with actual values as determined by the criterion measure of a laboratory-based LPT. Thus, peak values of velocity in power may introduce undesirable error to the measurements for the barbell back squat. Both the 3-D camera system and tether-based external dynamometer were in consistent agreement with each other for all measures and can provide compatible measures if used interchangeably.

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