Validity and Reliability Assessment of 3-D Camera-Based Capture Barbell Velocity Tracking Device

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Word count: 3868

Abstract word count: 214

Number of Tables: 3

Number of Figures: 4

Abstract

Velocity-based training (VBT) requires the monitoring of lift velocity plus the prescribed resistance weight. A validated and reliable device is needed to capture the velocity and power of several exercises. *Objectives:* The study objectives were to examine the validity and reliability of the Elite Form Training System® (EFTS) for measures of peak velocity (PV), average velocity (AV), peak power (PP), and average power (AP). *Design:* Validity of the EFTS was assessed by comparing measurements simultaneously obtained via the Qualisys Track Manager software (C-motion, version 3.90.21, Gothenburg, Sweden) utilizing 6 motion capture cameras (Oqus 400, 240Hz, Gothenburg, Sweden). *Method:* Six participants performed 6 resistance exercises in 2 sessions: power clean, dead lift, bench press, back squat, front squat, and jump squat. *Results:* Simple Pearson correlations indicated the validity of the device (0.982, 0.971, 0.973, and 0.982 for PV, AV, PP, and AP respectively) and ranged from 0.868 to 0.998 for the 6 exercises. The test-retest reliability of the EFTS was shown by lack of significant change in the Pearson correlation (<0.3% for each variable) between the 2 sessions. The multiple count error rate was 2.0% and the missed count error rate was 2.1%. *Conclusions:* The validity and reliability of the EFTS were classified as excellent across all variables and exercises with only one exercise showing a slight influence by the velocity of the movement.

Keywords: Velocity-based training; strength and conditioning; resistance training; squat; bench press; power clean

Introduction

Typical periodization resistance training for sport performance has involved the manipulation of sets, repetitions, loads, rest periods, and exercises used in order to elicit peak training adaptation at the desired time.[1,2] This general scheme allows for adaptive and recovery responses to cyclic variations of the training plan.[2] However, some have pointed to these traditional methods as lacking adaptability or flexibility to variations in the training capacity of a given athlete on a given day.[1,3] Recently, manipulation of the weighted resistance to affect the velocity of the movement in order to elicit a desired training response has grown in popularity, particularly relating to sport performance.[3] Adoption of this variable as the primary means of training prescription, as opposed to absolute load, is termed Velocity Based Training (VBT).[3] As long as the athlete exerts a maximal effort, VBT has been shown to be a viable programming method for sport performance, in particular for tasks involving higher speeds.[4,5] Due to the increasing popularity of VBT in the performance field, the market for devices which measure barbell velocity has grown substantially in recent years.

Many studies on VBT, particularly those involving measuring barbell velocity, have utilised linear position transducers (LPT) to determine bar displacement and velocities.[6–9] These devices utilise a retractable cable linked to a microprocessor which can record velocity or displacement information in real time, and are often considered the gold standard for equipment used for VBT.[7,10] Additionally, accelerometers attached to the bar have shown to be a practical and portable method of monitoring barbell kinematics during training.[3,9,11] However, due to many practitioners' and researchers' desire to assess a variety of movements with greater convenience, new devices have entered the market. The strength and conditioning field has seen an influx of camera-based systems and apps purported to measure velocity of a given barbell movement.[10,12] While some research does exist on the validity and reliability of some of these systems, the applicability to all camera-based systems is not possible due to differences in recording system, frame rates, and algorithms for data calculation.[10,12,13] Thus, it is important for an individual system to be independently shown to have acceptable validity and reliability before widespread adoption within a given organization or field.

The Elite Form Tracking System (EFTS) is a 3-D based camera system used to track the position and motion of a barbell during a weighted resistance exercise. Through real-time feedback, the EFTS can provide athletes and coaches with objective data in the form of peak and average velocity as well as peak and average power exerted during an exercise for evaluation in VBT. The aim of this study was to assess the validity and reliability of the EFTS to measure average and peak velocity (AV and PV) as well as average and peak power (AP and PP) while performing 6 commonplace resistance exercises in sport performance programs: power clean (PC), deadlift (DL), bench press (BP), back squat (BS), front squat (FS), and jump squat (JS). It was hypothesised that the results of the validity study would show strong correlation across all tests and that values obtained using the EFTS would not differ from those of the criterion instrument, the Qualisys Motion Capture system (MC). Strong correlations were expected across a range of velocities and power outputs for all exercises observed. Furthermore, consistently strong correlations were expected in both testing sessions indicating a high reliability of the EFTS in all exercises.

Methods

Six healthy, resistance-trained males (age = 23.78 ± 4.53 yrs; height = 178.44 ± 6.94 cm; weight = 86.60 ± 10.22 kg; body fat = 19.87 ± 3.31%; years of resistance training = 7.57 ± 1.59) participated in this investigation. Participants were required to meet the following criteria to be included: (a) minimum of 4 years of resistance training experience, (b) no current or recent musculoskeletal problems that could be exacerbated by a resistance exercise bout, and (c) be proficient with the lifts performed in the investigation. Prior to giving their oral and written informed consent, participants received information regarding the requirements of the investigation and potential injury risks. All procedures were approved by the University Institutional Review Board and all participants signed an informed consent form before testing.

Before each testing and data collection session, participants performed a standard warm-up with upper and lower body joint mobility exercises. All testing and data collection sessions were supervised by a National Strength and Conditioning Association (NSCA) Certified Strength and Conditioning Specialist (CSCS), and one repetition maximum (1RM) testing was performed in accordance with NSCA guidelines.[2] In the BS exercise, participants were allowed to use either high-bar technique with the bar placed just below the C7 vertebra or low-bar technique with the bar positioned on the lower trapezius.[14] For all sessions, participants were asked to perform all exercises to a full range of motion (ROM) for a successful repetition.

The 1RM testing consisted of a PC, BP, and BS. These 1RM values were used as the most accurate method to provide suitable numbers for future percentage-based lifting.[15] The 1RM data were collected over 2 sessions, with PC on the first day, followed 24 hours later by BS and BP testing. Rather than taxing the participants with another max effort lifting session, the remaining 1RM values were estimated based upon a percentage of BS (JS 1RM at 60% and FS 1RM at 80%).[2] The DL 1RM was estimated at 83% plus 15kg of the back squat 1RM.[16] Although this DL formula's intent is for a 6RM value estimation, the corresponding estimated 1RM calculation and percentage based loads served the study's purpose by inducing a range of velocities.

After the 1 RM testing, each exercise was performed for a total of 100 repetitions; 10 repetitions in 5 sets of increasing percentages of the respective 1RM in 2 separate training sessions. Each training session was separated by at least 24-48 hours and no consecutive sessions consisted of the same exercises to allow for recovery and to minimize fatigue. Training sessions were replicated the following week in both order and time of day to maintain consistency across sessions and to best replicate the same training environment.

The 5 increasing resistances in each exercise were determined with intent to induce a range of velocity and power outputs. Using a percentage of a 1RM, the weights of each of the 5 sets were established so that the basic velocity zones would coincide with those proposed by Mann, et al.[3] The resistances were set at 15-, 35-, 55-, 75-, and 85% of the 1RM for 5 of the 6 exercises. The JS weights were set at 10-, 20-, 30-, 40-, and 50% of the 1RM BS weight. Within each exercise in a single training session, participants lifted the three lightest weights in sets of 10 repetitions. The fourth weight was done as 2 sets of 5 repetitions. The fifth and heaviest weight was lifted as 5 sets of 2 repetitions. Between sets, participants were allowed 2 to 3 minutes of rest.

Retro-reflective markers (12.7mm; B&L Engineering, Santa Ana, CA) were placed on the center axis of the barbell on each end to create 2 physical landmarks from which the center of the bar could be calculated and a virtual landmark created (Figure 1). Three-dimensional motion trajectories of the respective markers were collected whilst performing each exercise using 6 Qualisys 'Pro Reflex' infrared cameras (120 Hz; Model number: MCU 240, Gothenburg, Sweden) via the Qualisys Track Manager software (C-motion, version 3.90.21, Gothenburg, Sweden) (Figure 1). Prior to data collection, MC cameras were calibrated to a residual of ≤ 2 mm for each camera.

Figure 1 near here

Raw marker trajectory data were exported for analysis using data analysis software (Visual3D, C-Motion, Germantown, MD, USA). Marker trajectories were filtered using a 12 Hz low-pass Butterworth filter. A virtual landmark was created at the midpoint between each marker. The derivative of the displacement of the virtual landmark was calculated using a forward difference method to represent the velocity of the barbell. The resulting time series of barbell velocity was then multiplied by the mass of the total load (mass of barbell + additional load) and the acceleration due to gravity (9.81 m/s^2) to create a new time series of power. Body weight contributions were not factored into the power calculations.

The time series of velocity and power were analyzed to calculate the instantaneous peak occurrence and the average value of each variable during the lift. Average value was calculated over the duration of the upward movement of the lift. This time duration was from the instant of vertical lift initiation, defined as the instant initial ascent of the barbell began from the lowest point, until termination, defined as the instant of the first peak height of the barbell. For five of the exercises, this instant of termination represented the full range of the lift. However, it should be noted that the first local maximum height in the PC was considered the end point of the lift. This end point may not have been the overall peak height of the lift if the participant dropped under the bar during the catch and stood erect creating two ascents of the barbell (potentially leading to a multiple-movement error). Outcome measures were average velocity (AV), peak velocity (PV), average power (AP), and peak power (PP) for each lift for each measurement method (EFTS and MC).

Similar to Cronin, et al. and other studies, the MC system was used as the criterion instrument for comparison and the overall validity of the system was assessed using a Pearson correlation between the EFTS and MC data gathered on the same movement through four variables: PV, AV, PP, and AP.[7,17,18] The validity was tested first across all lifts (n=3600) and then for each of the six different exercises (n=600) using Pearson correlation between the MC and the EFTS. Thirdly, regardless of the prescribed weights in each set for each participant in each lift, the velocity and power variables were broken into five quintiles (n=120) based on the AV of the movements (measured by MC) to observe the validity of the EFTS device through a range of velocity. These quintiles were set by AV to ensure no overlap in quintiles would exist for fair comparison. Had the quintiles been divided by prescribed resistance, despite maximum effort from the human subjects, overlap in quintile velocity could have occurred. Since the quintiles were defined by the AV of the MC data, it did not make sense to analyze the correlation of the AV and PV. It would just have been a narrowed window of the overall AV and PV correlation with n=120 instead of n=600. Thus, the correlation was found for each of the quintiles in PP and AP. The first quintile was defined as the fastest 20% of all the movements in a lift regardless of the weight lifted. Each subsequent quintile was the next fastest 120 repetitions with the fifth quintile being the slowest 20% of the repetitions.

Additionally, the absolute difference between the EFTS and MC results was plotted against the increasing average in the Bland-Altman plots to show validity through the range of velocities and power levels. Linear regression gave the slope of the trend (r) as the difference in measured value over the entire range. An r-value of zero was considered exact meaning that there was no increase in measured difference with an increase in velocity or power. First, the Bland-Altman plot was created for all exercises combined in PP, AP, PV, and AV and then for each specific exercise in AV.

For the reliability analysis, the correlations of the EFTS data between session 1 and session 2 across all sets and exercises for each of the four variables were found. However, the paired EFTS data from session 1 to session 2 by set and exercise assumes consistent velocity and power output for the same weight resistance on two separate days. Therefore, the simple correlation between EFTS and MC was found for all exercises in the first session and the second session separately (n=600). The difference in session correlations was calculated both in value and percentage to be used as a measure of reliability.[19]

The number of error evaluations by the EFTS device was a simple count of errors by the type of exercise. An error was categorised as either a multiple-movement error or a missed-movement error. A multiple-movement error was defined as when the EFTS device recorded more than one repetition for a single movement (e.g. two ascents measured during PC as previously discussed). A missed-movement error was counted when no recording was made despite a successful repetition by the participant.

Results

The correlations between the EFTS device and MC system across all lifts, sets, sessions, and participants for PV and AV were found to be 0.982 and 0.971 respectively. The PP and AP correlations were 0.973 and 0.982 respectively (Table 1, Figure 2). The correlations between the EFTS device and MC systems within each exercise and each session are shown on Table 1.

Table 1 near here

Figure 2 near here

In the Bland-Altman plots, where an ideal correlation between the mean and difference of two systems is zero, all four variables had a correlation less than 0.50, indicating the ranges of velocity and power across all exercises had little to no influence on the validity (Figure 3).

Figure 3 near here

When broken into the individual exercises, the BP resulted in the highest correlation between EFTS and MC for PV, AV, and AP while the DL had the highest correlation in PP (Table 1). The JS resulted in the lowest correlation in the PV at 0.876. The BS had the lowest PP correlation (0.901) while the PC gave the lowest correlations for the AV and AP (0.868 and 0.963).

The correlations for each quintile of AV for each exercise is shown in Table 2. The only correlations lower than 0.90 occurred in the two slowest (heaviest) BS quintiles.

Table 2 near here.

On the Bland-Altman plots for each exercise, the relationship of AV difference with increasing speed was quantified using linear regression of the difference in speed to the average speed (Figure 4). Low correlation indicated little influence of mean velocity on the validity through the entire range of velocity. The only *r*-value of significance was defined as *moderate* correlation. This was in the JS (r = 0.687). All other movements had correlations less than 0.50 and were therefore categorised as *poor* or *little-to-no* correlation proving the velocity of the movement had little influence on the validity. Furthermore, the limits of agreement for each Bland-Altman plot show no biases with small 95% ranges (Table 3).

Figure 4 near here

Table 3 near here

For reliability analysis, the correlation between EFTS Session 1 and EFTS Session 2 was found by pairing repetitions within sets and exercises for each participant. All four correlation values were classified as *excellent* (> 0.900) (Table 1). For further reliability analysis, the absolute difference in correlations between the EFTS and MC within each session for each variable was measured and found to be 0.003 or less (< 0.3%) (Table 1).

The greatest number of missed-movement errors occurred in the DL exercise (Table 4). A total of 9.5% of the 600 DL repetitions in the two sets were missed. The second greatest number of misses came in the BS with 1.8%. None of the rest of the lifts had a miss rate of greater than 0.3%. Overall, of the 3600 repetitions across the six lifts, the total number of misses was 72 giving a miss rate of 2.0%. It could be noted that with the DL data excluded, the total miss rate dropped to 0.5% for a 99.5% capture rate.

Table 4 near here

Of the 3600 attempted repetitions, 74 or 2.1% were incorrectly counted as more than one single movement. Of those 74 errors, 72 were collected in the heaviest two sets of the PC exercise (Table 4).

Discussion

The AV and AP variables are highly dependent on the defined beginning and end of a movement. For the BP, BS, FS, and JS, the beginning of the movement was the instant the center of the bar transitioned from the lowest height (the bottom of the movement) into the upward direction. The end of the movement was the next local peak following the beginning of the movement. The MC frequency was set to 120 Hz while the EFTS device used a 30 Hz capture rate. Therefore, the precise instant of beginning and end may have differed slightly between the EFTS and the MC system. Furthermore, the data filtering process may have also caused a difference in the exact time interval of the movement.

With the MC system considered the criterion instrument for recording movement, the very strong correlations between the EFTS and MC systems demonstrated high validity for the EFTS device. As observed in Table 1, each of the four variables (PV, AV, PP, and AP) resulted in correlations greater than 0.97, classifying the correlation as *excellent*.

Compared to the Tendo Weightlifting Analyzer System (TWAS) in the BP and BS, the EFTS has a higher validity in all variables for BP as well as higher validity in the PP and AP in the BS, while the TWAS has a slightly higher correlation in the PV and AV in the BS.[18] The EFTS also has a higher BP AV correlation comparted to the optical encoder device mentioned in the study by Drinkwater, et al.[7]

The validity of the EFTS device in the 6 different lifting exercises showed different correlations based on the velocity of the exercise (Table 1). The highest correlations between EFTS and MC in PV and AV were in the BP (0.993 and 0.997). This could be because the BP proved to be the exercise with the lowest velocity as well as a small ROM compared to the other exercises meaning that the EFTS device was most accurate at tracking the barbell velocity in a slow movement over a short distance. The best PP correlation was in the DL (0.989), and the highest AP correlation occurred in the FS (0.998). Values higher than 0.900 were defined as *excellent* while values between 0.710 and 0.900 were defined as *good* [20]. Therefore, all exercises but two were classified as *excellent*. Only the PC and JS resulted in any correlation lower than 0.90 (0.868 and 0.876) and were classified as *good*. These were the two fastest of the 6 exercises with mean AV of the lightest sets over 1.7 and 1.4 m/s respectively. This gave reason to breakdown the investigation further into velocity quintiles for each lift to see how the EFTS device performed at different average velocities (Table 2).

Only the two slowest quintiles of the BS lift gave PP correlations in the *good* range (0.880 and 0.712) and just the single slowest quintile of BS resulted in the *good* range (0.879). All other values were classified as *excellent* with the majority being over 0.97 across all lifts. Despite the lowest correlations in the slowest movements of the BS, there was no significant trend of change in correlation with the increase in velocity as supported by the Bland-Altman analysis. Furthermore, there did not seem to be a general trend of increasing or decreasing correlation with velocity for any lift. For example, the lowest AP correlation in the DL occurred in the slowest repetitions (0.913) while occurring in the fastest quintile of the JS (0.941). Other lifts had the lowest correlations in the mid-velocity repetitions with no observable pattern.

To further investigate any potential tendencies with increasing velocity, a linear regression analysis of the Bland-Altman plots was done. Here, an ideal *r*-value of zero would indicate no influence of velocity on the validity of the EFTS. The results showed a *moderate* trend of discrepancy when using the EFTS device only in the JS (0.687). All other exercises displayed a *poor* *r*-value (< 0.50) or *little-to-no* significant correlation (<0.30) with increasing velocity.[20] This conclusion was further evidenced by the Bland-Altman 95% confidence interval range and the limits of agreement of the JS (Table 3). Where the range for all other exercises was less than 0.19 m/s, the range for the JS exercise was over 0.36 m/s showing that the validity of the JS exercise was moderately influenced by the velocity. Therefore, according to the Bland-Altman analysis, it can be concluded that, while all exercises showed *excellent* overall validity with low velocity bias, the only exercise in which the velocity of the movement had an effect on the validity was in the JS.

The test-retest reliability of the EFTS device was first assessed by the correlation between sessions by pairing the EFTS variables for the same repetitions within sets and exercises for each participant. All the correlations were classified as *excellent* showing high reliability from session 1 to session 2. However, with human subjects, controlling the weight in two different sessions in a resistance exercise does not ensure that the participants will exert consistent velocity and power. Therefore, the correlation between the EFTS and MC system within session 1 was compared to the correlation within session 2. The difference in those values for each of the four variables was 0.003 or less which is less than

0.3%. Such a low difference indicated that the EFTS device was highly consistent between the two sessions. Therefore, it can be concluded that the EFTS device was quite reliable across multiple sessions with very little to no variance in comparable lifts throughout a range of velocities and power outputs.

The EFTS device did not capture all of the repetitions during the study. Overall, 98.0% of all the repetitions were obtained, while 72 of the 3600 repetitions were missed (Table 4). The vast majority of the missed-movement errors occurred in the DL exercise. Forty-four were missed in the first session and another 13 were missed in the second session. The typical small ROM of the exercise from the floor may be the reason for the number of missed-movement errors, but future research needs to be done to confirm the reasoning as well as the cause for difference in number of misses between sessions.[21,22] If the DL exercise was eliminated from the study and only the other five lifts were analyzed, the capture rate would increase to 99.5% where only 15 of 3000 repetitions would have been missed. The second highest number of misses came in the BS exercise. Eleven total misses occurred in the BS and it was observed after the data collection that the majority of these misses came when a participant used a low-bar technique. While neither the validity nor reliability of the captured data appeared to be affected by the technique, future investigations could better determine the correlation of BS technique with missed-movement errors captured by the EFTS. Only 4 total misses occurred in the other lifts.

Overall, 2.1% of the repetitions were counted as multiple repetitions for a single movement (Table 4). This was defined as a multiple-movement error. It should be noted that, despite the extra repetition count, the data from the true repetition was obtained and counted in each instance. Therefore, the desired data of interest was in fact collected and proven to be valid and reliable. The extra counted repetition(s) in a multiple-movement error was just additional unnecessary data that could be ignored. That is, the data of interest was not missed. Nearly all of the multiple-movement errors occurred in the PC. In fact, only two errors of the total 74 came from other lifts. Anecdotally, all of the errors that occurred in a PC lift were from a heavy attempt in which an athlete would pull the bar from the floor as high as possible, drop under the bar, and then stand fully erect. While this is certainly considered proper technique for a heavy clean, the second upward motion of the barbell (similar to a front squat lift) was often recorded as a second repetition. Therefore, the EFTS user should be aware that the AV and AP for a PC may only reflect the first pull and may not include the entire ROM from the floor to the final barbell height. There were 72 total multiple-movement errors (12%) counted over the total 600 power clean repetitions. All of these came when the participant was lifting their heaviest two weights in which they were not able to complete the lift in one single upward motion. Only two other multiple-movement errors were counted in the study: one in the BP and one in the BS. If the PC data were omitted, the total multiple repetition error rate would have been only 0.067% (99.93% capture rate).

Conclusion

Overall validity of the EFTS was proven through high correlations between the EFTS and MC systems across all exercises and classified as *excellent* in AV, PV, AP, and PP. While the AP and PP correlations were lowest at slow velocities in the BS, the other exercises proved to have high validity at all velocities. Through a linear regression analysis of a Bland-Altman plot, only the JS exercise, which was the fastest movement exercise, had a moderate variance in validity as velocity increased from slow movements to faster movements. The validity in all other exercises was not affected by the velocity of the movement.

The test-retest reliability of the device was proven by a small and insignificant difference in correlation between each session (< 0.003) showing consistency between sessions for all exercises.

Furthermore, with the exception of the missed error rate in the DL exercise (> 9.0%) and the multiple-movement error rate of the PC exercise (>12.0%), the overall error rates for both missed movements (2.1%) and multiple movements (2.0%) help assure the user of adequate data collection using the EFTS device for VBT.

Practical Implications

- With proper set-up and calibration, the EFTS device can be used to collect vital data for a VBT program prescribed by strength and conditioning professionals in several different exercises through a range of velocities and power output levels. This noninvasive camera-based device allows the assessment of velocity and power without cables and accelerometers as opposed to other VBT devices.[7,18,19]
- The EFTS device can be used as a reliable tool over multiple training sessions with insignificant variance during regular training while monitoring the velocity and power output of an exercise.

- It can be expected that the results collected using the EFTS device will contain very few missed-movement errors with the exception of a DL exercise and multiple-movement errors with the exception of the PC exercise.

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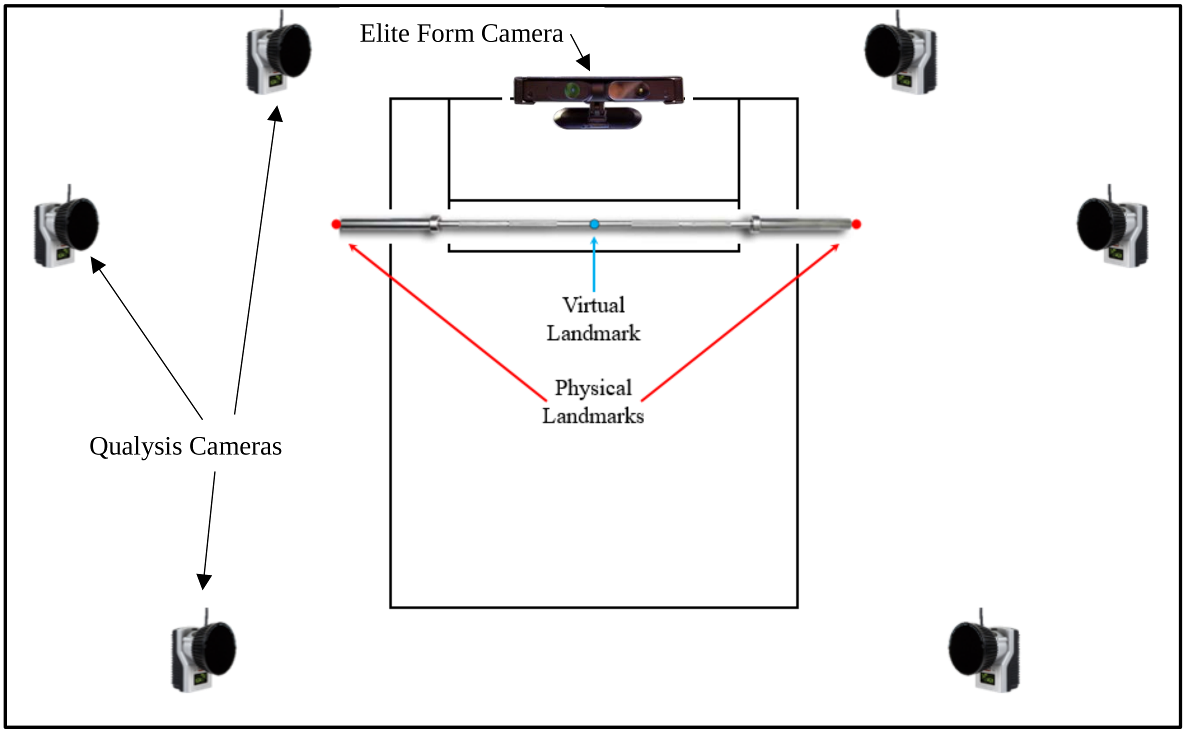
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Virtual
Landmark
Physical
Landmarks
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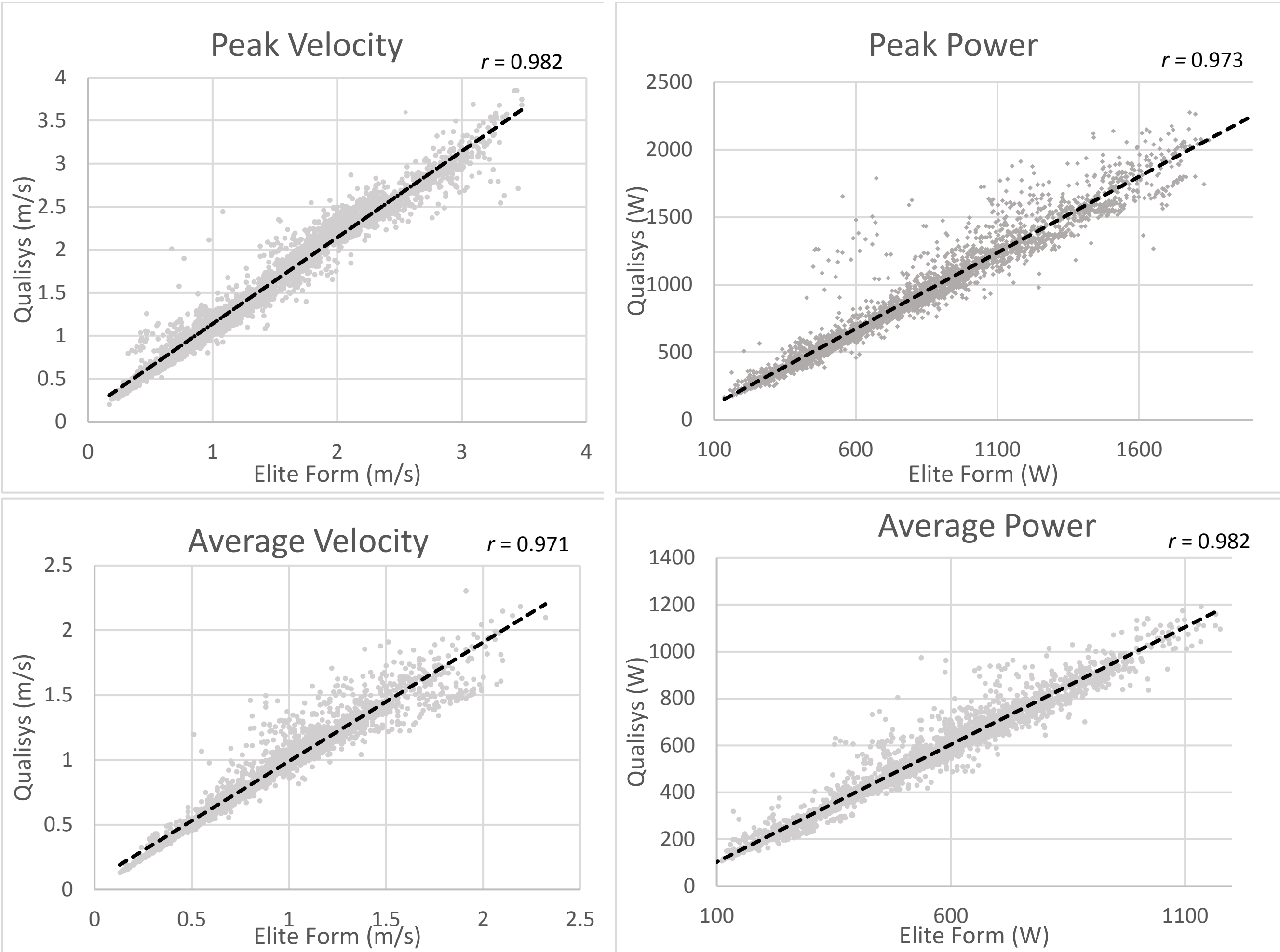
Peak Velocity
r = 0.982
Qualisys (m/s)
Elite Form (m/s)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
Peak Power
r = 0.973
Qualisys (W)
Elite Form (W)
0
500
1000
1500
2000
2500
100
600
1100
1600
Average Velocity
r = 0.971
Qualisys (m/s)
Elite Form (m/s)
0
0.5
1
1.5
2
2.5
Average Power
r = 0.982
Qualisys (W)
Elite Form (W)
0
200
400
600
800
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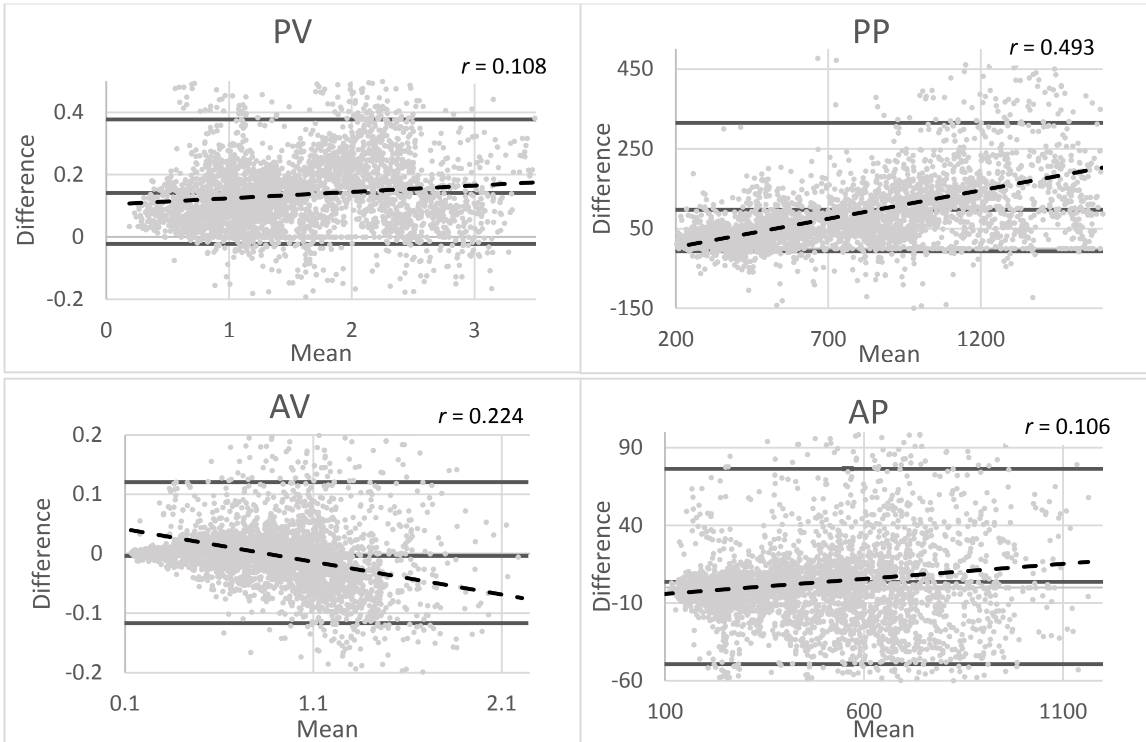
1200
1400
100
600
1100


PV
r = 0.108
Difference
Mean
PP
r = 0.493
AV
r = 0.224
AP
r = 0.106

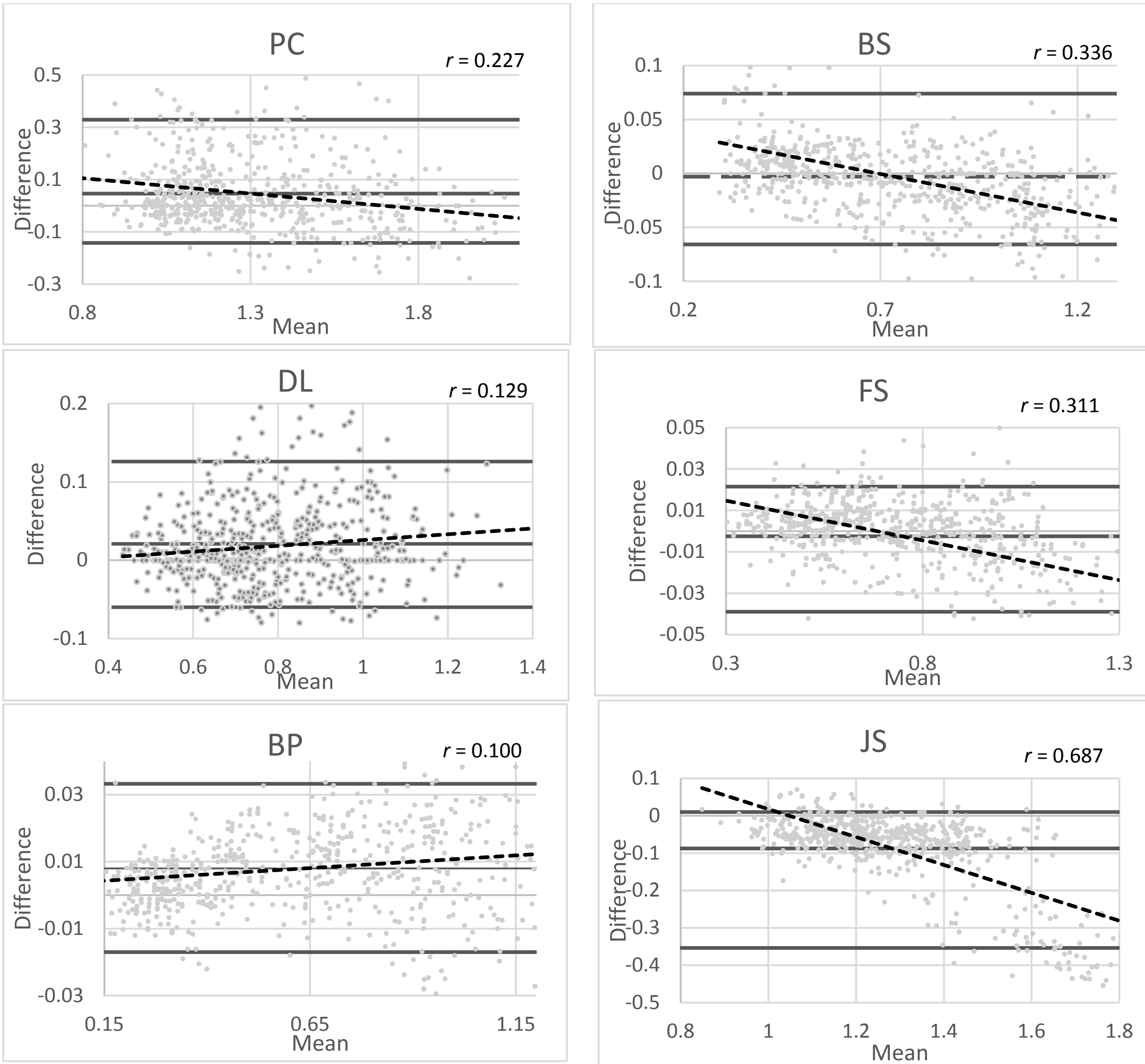

PC
r = 0.227
Difference
Mean
0.5
0.3
0.1
-0.1
-0.3
0.8
1.3
1.8
BS
r = 0.336
0.1
0.05
0
-0.05
-0.1
0.2
0.7
1.2
DL
r = 0.129
0.2
0.1
0
-0.1
0.4
0.6
0.8
1
1.2
1.4
FS
r = 0.311
0.05
0.03
0.01
-0.01
-0.03
-0.05
0.3
0.8
1.3
BP
r = 0.100
0.03
0.01
-0.01
-0.03
0.15
0.65
1.15
JS
r = 0.687
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
0.8
1
1.2
1.4
1.6
1.8

Table 1. Correlation of PV, AV, PP, and AP.

	PV	AV	PP	AP
Between EFTS and MC across both sessions (n=3600)				
All Exercises	0.982	0.971	0.973	0.982
Between EFTS and MC across both sessions (n=600)				
PC	0.964	0.868	0.986	0.963
DL	0.976	0.939	0.989	0.979
BP	0.993	0.997	0.957	0.997
BS	0.902	0.979	0.901	0.979
FS	0.961	0.993	0.979	0.998
JS	0.876	0.920	0.978	0.992
Between EFTS Session 1 and EFTS Session 2 (n=1800)				
All Exercises	0.961	0.935	0.959	0.949
Between EFTS and MC across all exercises (n=1800)				
Session 1	0.983	0.970	0.974	0.982
Session 2	0.982	0.972	0.971	0.983
Difference	0.001	-0.002	0.003	-0.001
% Difference	0.15%	-0.28%	0.27%	-0.09%

Table 2. PP and AP Correlations within AV Quintiles.

Lift	Quintile	Average Velocity (m/s)	Correlation	
			PP	AP
PC	1	1.74	0.994	0.976
	2	1.46	0.996	0.950
	3	1.28	0.993	0.932
	4	1.16	0.985	0.952
	5	1.04	0.957	0.963
DL	1	1.08	0.989	0.985
	2	0.90	0.993	0.984
	3	0.77	0.992	0.984
	4	0.68	0.985	0.965
	5	0.57	0.980	0.913
BP	1	1.09	0.994	0.996
	2	0.85	0.985	0.997
	3	0.62	0.970	0.995
	4	0.40	0.949	0.990
	5	0.25	0.939	0.991
BS	1	1.10	0.950	0.978
	2	0.90	0.977	0.991
	3	0.71	0.921	0.984
	4	0.53	0.880	0.961
	5	0.40	0.712	0.879
FS	1	1.07	0.991	0.997
	2	0.89	0.990	0.998
	3	0.73	0.970	0.996
	4	0.59	0.966	0.998
	5	0.46	0.972	0.995
JS	1	1.48	0.975	0.941
	2	1.32	0.952	0.979
	3	1.22	0.940	0.980
	4	1.13	0.962	0.990
	5	1.03	0.949	0.986

AV Bland-Altman Limits of Agreement

	PC	DL	BP	BS	FS	JS
Mean Difference (MC – EFTS) (m/s)	0.046	0.021	0.008	-0.003	-0.002	-0.087
Upper 95% (m/s)	0.329	0.126	0.033	0.074	0.022	0.010
Lower 95% (m/s)	-0.142	-0.060	-0.017	-0.066	-0.039	-0.354

Table 4. EFTS Capture Errors

Lift	Session	Missed Errors (Error %)		Multiple Errors (Error %)	
PC	1	0 (0.0%)	0.0%	31 (10.3%)	12.0%
	2	0 (0.0%)		41 (13.7%)	
DL	1	44 (14.7%)	9.5%	0 (0.0%)	0.0%
	2	13 (4.3%)		0 (0.0%)	
BP	1	0 (0.0%)	0.0%	0 (0.0%)	0.2%
	2	0 (0.0%)		1 (0.3%)	
BS	1	5 (1.7%)	1.8%	0 (0.0%)	0.2%
	2	6 (2.0%)		1 (0.3%)	
FS	1	0 (0.0%)	0.3%	0 (0.0%)	0.0%
	2	2 (0.7%)		0 (0.0%)	
JS	1	1 (0.3%)	0.3%	0 (0.0%)	0.0%
	2	1 (0.3%)		0 (0.0%)	
Total		**72**	**2.0%**	**74**	**2.1%**