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VALIDATION OF A ROTARY ENCODER AND POWER PREDICTION
EQUATIONS DURING A JUMP SQUAT

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Exercise and Sport Science

Andrew A. Pustina

College of Science and Health
Human Performance-Applied Sport Science

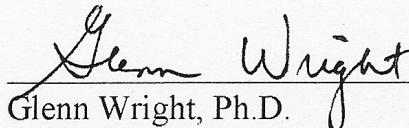
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By Andrew Pustina

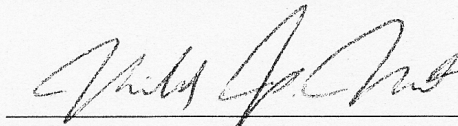
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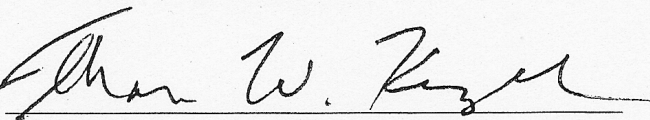
Glenn Wright, Ph.D.
Thesis Committee Chairperson

7-19-10
Date



Richard Mikat, Ph.D.
Thesis Committee Member

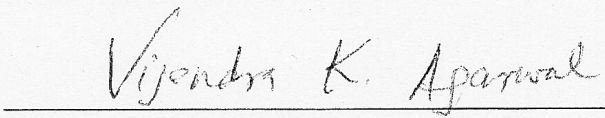
8-27-10
Date



Thomas Kernozek, Ph. D.
Thesis Committee Member

8-27-10
Date

Thesis accepted



Vijendra K. Agarwal, Ph.D.
Associate Vice Chancellor for Academic Affairs

9/2/10
Date

ABSTRACT

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The purpose of this study was twofold: first, it was to determine the validity of a rotary encoder at measuring power and velocity; second, it was to expand the validity of the use of various power prediction equations using counter movement jump height. **METHODS:** Sixty college students (men n=30; women n=30) performed a jump squat with applied loads of 20%, 40%, and 60% of their body mass. Each jump squat (JS) was simultaneously monitored using a force plate, a rotary encoder, and a contact mat. Peak power (PP) was calculated using the time and position data derived from the rotary encoder, while the force plate determined PP from vertical ground reaction force. The contact mat measured jump height, which was entered into the prediction equations (8,19) to estimate peak power. All calculations were compared to the force plate. A significant difference was found between force plate measurements and TWA measurements of peak power, average power, peak velocity and average velocity ($p < 0.01$). Pearson correlations showed that rotary encoder power measurements had a strong relationship to force plate power measurements at all loads ($r = >0.80$). In addition, no significant difference between force plate PP and predicted PP by the Harman equations was found ($p = 0.06$). The Harman equation had a greater correlation with the force plate in men ($r = 0.93 - 0.94$) than in women ($r = 0.65 - 0.72$). The results of this study suggest that the Harman equation should be used to estimate PP of a loaded JS because it was found to be both reliable and valid.

ACKNOWLEDGEMENTS

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INTRODUCTION

The rate at which work is performed is called “mechanical power” and is the product of the force and velocity of a movement (16). An athlete’s ability to produce high levels of lower body mechanical power is an essential component of success in many sports (8,9,16,19). Thus, it can be useful for strength and conditioning (S & C) professionals to assess lower body power over the course of a training program. By measuring this variable at regular intervals, S & C professionals may be able to better optimize the effectiveness of their training programs.

Many S & C professionals have used various types of vertical jump-based movements to develop and measure lower body power (23,8,19,7,4). Recently, lower body power has been assessed using maximal countermovement jumps (CMJ) performed with a loaded barbell across the shoulders (13,15), which will be referred to in this paper as jump squats (JS). The JS is a versatile exercise that can be used to both measure and as a training tool to develop lower body power.

Assessment of lower body power using the JS has been performed using various methodologies, including the use of a force plate and different types of portable measurement systems, such as rotary encoders. Historically, the force plate has been widely used to measure ground reaction force to determine power (9,14,19). The use of force platforms has been regarded by some as the “gold standard” for force measurements in the assessment of human performance (4). However, force plates are expensive and produce large amounts of data that may be difficult and time consuming to

analyze. Further, force plates appear to be sensitive to external vibrations that are produced from dropping weights in strength training facilities (4).

In recent years, many S & C professionals have utilized rotary encoder devices to monitor bar velocity and assess power production (4,5). The TENDO Weightlifting Analyzer (TWA; Trencin, Slovak Republic) is one such rotary encoder that has gained some popularity in training centers. Although the device has been recently studied for its reliability, it has not been validated against criterion measures in any published, peer-reviewed studies. Although the cost of a rotary encoder is significantly less than a force plate, the rotary encoder may be still too expensive (around \$1,600.00) for many small colleges and high schools to afford.

Lower body power production has also been estimated by the use of prediction equations utilizing the body mass of the individual and height of a vertical jump (8,19). It may be possible to measure changes in lower body power during a JS training bout if the same prediction equations accurately estimate power production under loaded conditions utilized in training. The prediction equations have been derived using the jump and reach test to determine jump height. Another method used to determine jump height during a JS is based on flight time and uses a contact mat. Instead of body mass being entered into the equation, mass of the body + bar (system) could be used. It is unknown how these different methodologies and measurement devices compare in the assessment of peak power during a loaded JS. It was therefore the purpose of this study to (1) determine the validity of a rotary encoder in measuring power and velocity and (2) to validate the use of various power prediction equations in estimating peak power of a loaded JS.

METHODS

Experimental Approach to the Problem

The study was designed to assess the reliability and validity of different methods and measuring systems for determining lower body power during a loaded JS. The reliability and validity of a rotary encoder commonly used in S & C facilities (TENDO Weightlifting Analyzer, TENDO Sport Machines, Trencin, Slovak Republic) to measure lower body performance was analyzed by comparing the peak power (PP), peak velocity (PV), average power (AP), and average velocity (AV) measurements during the JS with criterion data obtained simultaneously from a force plate. In addition, the reliability and validity of the prediction equations to estimate peak power (8,19) was assessed during JS performance by comparing the estimated peak power from the equations to force plate measures. To assess the usefulness of the different methods using varying applied loads, the JS was performed using three load conditions (20%, 40%, and 60% of body mass). To determine if gender influenced the validity of the prediction equations for estimating peak power production during the JS, men and women were analyzed independently.

Subjects

A heterogeneous group of 30 female (body mass = 64.8 ± 7.5 kg; height = 164.1 ± 6.5 cm) and 30 male (body mass = 88.4 ± 16.1 kg; height = 179.9 ± 8.3 cm) college students were recruited from a weight training facility to be participants in this study. All subjects had performed the squat exercise in their training programs for at least one year prior to being enrolled. The Institutional Review Board for the Protection of Human

Subjects at the University of Wisconsin-La Crosse approved all procedures prior to data collection, and all subjects signed an informed consent before participation.

Procedures

Subjects completed a familiarization session prior to completing the experimental session. An identical experimental session was completed 48-72 hours after the familiarization session. Height and body mass were determined during the familiarization session. During each session, subjects warmed up for three to five minutes on a stationary bike at a low to moderate self-selected intensity followed by a set of three unloaded sub-maximal countermovement jumps. Following five minutes of passive rest, three repetitions of maximal JS were performed at each load condition (20%, 40%, and 60% of body weight) as recommended by Dugan et al. (6) . To control for fatigue, order effect, and practice-related changes in technique, each load condition was presented in a randomized order. Subjects were given 60 seconds of rest between repetitions and three minutes of rest between load changes (10). The best JS from each load condition determined from the peak power measurement on the force plate was used in the analysis. Test-retest interclass reliability between the familiarization and the experimental session was high (ICC = 0.97) for PP measured by the force plate using the three different load conditions, suggesting that a single familiarization trial was sufficient for this study.

All JS testing was performed in the confinement of a Plyometric Power System (PPS; Norsearch, Lismore, Australia; Figure 1). This device restricts barbell movement to the vertical plane, like a Smith Machine. On this machine, linear bearings are attached to each end of the barbell. These bearings allowed the barbell to slide along two hardened steel shafts with minimum friction. To perform the JS, subjects were instructed to stand

motionless in an upright position with an Olympic barbell held tightly across their shoulders and then to perform a countermovement to a self-selected depth, immediately followed by a jump for maximal height. If the barbell moved off the subject's shoulders during the jump, the trial was repeated.

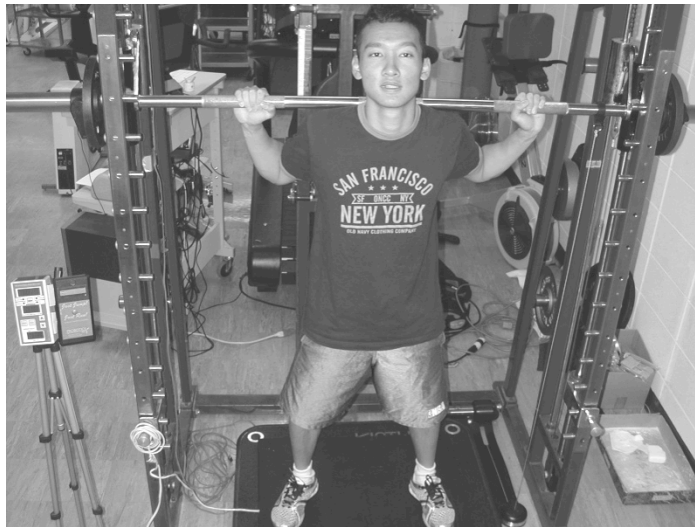


Figure 1. PPS, TWA, Just Jump, and force plate arrangement for data collection.

Equipment

Bar displacement, flight time, and vertical ground reaction force data were recorded simultaneously via the TWA, a contact mat, and a force plate for all subjects with all applied loads. The entire mass of the system defined as the subject's body mass + bar, measured from a standing position on the force plate, was used to determine power output using each method (6,13).

TENDO Weightlifting Analyzer

The TWA was placed directly in line with the two vertical steel shafts of the PPS. The TWA consists of both a velocity sensor unit and a microcomputer. The velocity sensor unit is made up of an optical sensor and a light source with the slotted disk for displacement and time measurement, and a DC motor for movement orientation. A cord

wound around the slotted disk is designed for attachment to a barbell or weight stack with a Velcro strap; barbell movement causes the cord to unwind, which in turn, causes the slotted disk to spin. As the disk rotates, light shines through the slots of the disk, and is converted to electrical impulses by the optical sensor. Each pulsation corresponds to a given displacement (22). The sensor relays the information to the microcomputer, which determines the rate at which the cord is being displaced. By design, the sampling rate of the TWA is determined by the velocity of disk rotation. Thus, the TWA's sampling rate is dependent on this technique of measurement.

The TWA has been designed to measure the velocity of concentric movements. From the discrete velocity data, both the average and instantaneous velocities are produced. Mass of the system is manually entered into the TWA microcomputer to obtain the magnitude of force using gravitational acceleration (9.81m/s^2). Peak and average power were determined by multiplying the peak and average velocity measurements by this estimated force.

Force Plate

The JS was performed simultaneously on a force plate (Quattro Jump, Type 9290AD, Kistler, Switzerland) with a sampling rate of 500 Hz. Velocity and power were calculated from vertical ground reaction force data using the impulse-momentum theorem (6,14). A change in the momentum of the body or the system during the JS is relative to the impulse (area under the vertical force-time curve) produced. This method involves collecting vertical ground reaction force data, beginning when the subject is standing stationary with the load across their shoulders and ending when the subject leaves contact with the force plate. The impulse is determined by calculating the area under the vertical

force – time curve for that portion of the JS. Force – time data was used to calculate power and velocity for the entire JS. Instantaneous velocity was calculated using the formula: previous sample's velocity + (force – (system mass × 9.81 m/s²)) × Δt / system mass, where velocity is measured in meters per second, force is measured in Newtons, system mass is measured in kilograms, and Δt is equivalent to the change in time (1/500 of a second) between each sample. Force and velocity from the same sample were then multiplied to determine instantaneous power. The peak power was the highest value measured during the JS.

Prediction Equations

The prediction equations used in this study are listed in Table 1. Normally, jump height and body mass are entered into these equations provided by Harman et al. (8) and Sayers et al. (19). However, in order to validate these equations under loaded conditions, the mass (kg) of the entire system was substituted for body mass. A contact mat (Just Jump, Probotics, Huntsville, AL) was used to determine jump height simultaneously during our testing protocol. When an athlete jumps and their feet leave the mat, a timer is activated. As they return to the ground their feet contact the mat, stopping the timer. Flight time was measured with precision to 0.01 seconds. The system's computer calculates displacement of the body's center of mass (COM) using the formula: jump height = (t² × g)/8. Where g is gravitational acceleration and t is flight time (11). Jump height was displayed in inches (to the nearest 0.1 inch) on the Just Jump's screen and converted to centimeters (1 inch = 2.54 cm) for direct comparison. Once jump height (cm) and total mass of the system (kg) were determined, they were entered into the prediction equations to estimate PP. During data collection, the contact mat was placed

directly on top of the force plate and the force plate was calibrated with the contact mat in this position.

Table 1. Prediction equations used to determine peak power.

Harman, (8)	$61.9 \times \text{Jump Height (cm)} + 36 \times \text{Body Mass (kg)} - 1822$
Sayers, SJ (19)	$60.7 \times \text{Jump Height (cm)} + 45.3 \times \text{Body Mass (kg)} - 2055$
Sayers, CMJ (19)	$51.98 \times \text{Jump Height (cm)} + 48.9 \times \text{Body Mass (kg)} - 2007$

Statistical Analysis

Dependent variables consisted of PP (W), PV (m/s), AP (W), and AV (m/s) from the force plate and TWA and PP estimated from the prediction equations. Load condition (20, 40, and 60% body weight) was used as the independent variable. All statistics were performed using the Statistical Package for the Social Sciences (SPSS Version 17.0, SPSS Inc., Chicago, IL).

Paired Samples T-tests were used to determine if differences existed between the data from the force plate and the TWA. Pearson correlations were used to determine the relationships between TWA and force plate variables of interest (PP, PV, AP, and AV). Intraclass Correlation Coefficients (ICC) and Coefficients of Variation percentage (CV) were used to determine the relative and absolute reliability of the force plate and TWA at measuring PP, PV, AP, and AV. Force plate measurements from all 3 jumps were used to determine the ICC and CV values. The CV was calculated ($CV = SD / \text{mean} \times 100$) for each individual and then the mean CV was determined for the entire sample.

To determine the reliability and validity of the prediction equations in predicting peak power, men and women were examined as separate groups. A 3 (applied load –

20%, 40% and 60% body mass) \times 4 (method – force plate, and three prediction equations) factorial analysis of variance (ANOVA) was used to examine differences between PP estimated by the prediction equations and PP measured by the force plate. When appropriate, Tukey post-hoc comparisons were used to identify differences within the methods and applied load conditions. Pearson correlations were then used to determine the relationship between estimated PP and PP measured by the force plate. Absolute and relative reliability of the prediction equations were assessed using ICC and CV, respectively. Overall, statistical significance was set at $\alpha = 0.05$, while statistical power for all tests was between .90 and 1.00.

RESULTS

The intrasession trial-to-trial reliability of PP, PV, AP, and AV of the two devices across the applied load conditions can be observed in Table 2. The trial-to-trial measurement of PP, PV, AP, and AV using the three loads on the force plate produced ICC values of 0.916 – 0.997 while the TWA also produced high ICC values of 0.986 – 0.998. The CV% produced from TWA measurements ranged from 2.2-2.5% for PP, 2.0 - 2.2% for PV, 2.4- 2.5% for AP and 2.5-2.7% for AV. The CV% produced from force plate measurements ranged from 2.9 – 3.6% for PP, 2.1 – 2.8% for PV, 5.7 – 6.7% for AP, and 4.0 – 5.2% for AV.

Table 2. Intraclass correlation coefficient (ICC) and coefficients of variation (CV%) for the force plate and TENDO Weightlifting Analyzer (TWA) at each loading condition (20%, 40%, and 60% body mass).

	Peak Power		Peak Velocity		Average Power		Average Velocity	
	ICC	CV%	ICC	CV%	ICC	CV%	ICC	CV%
Force Plate								
20%	0.997	2.93	0.989	2.06	0.979	5.66	0.918	3.99
40%	0.994	3.28	0.984	2.08	0.961	6.12	0.916	4.90
60%	0.993	3.58	0.970	2.90	0.983	6.57	0.942	5.16
TWA								
20%	0.994	2.51	0.993	2.08	0.998	2.51	0.986	2.72
40%	0.998	2.15	0.991	2.17	0.998	2.53	0.990	2.56
60%	0.997	2.23	0.992	1.99	0.998	2.38	0.991	2.46

The means and standard deviations, Pearson product moment correlations, and p-values for PP, PV, AP, and AV for each JS assessed by the TWA and the force plate is

depicted in Table 3. Differences were found between the force plate and TWA measurements ($p < 0.01$) for all variables. Associations between the TWA and force plate were strong for peak power ($r = 0.90 - 0.94$), peak velocity ($r = 0.78 - 0.85$), and average power ($r = 0.81 - 0.86$), but weak for average velocity ($r = 0.66 - 0.69$) across the three applied load conditions.

Table 3. Mean (\pm SD), correlations and t-test results for variables measured by the force plate and TWA across the three loading conditions (20%, 40% and 60% body mass).

	Force Plate mean (SD)	TWA Mean (SD)	Pearson Correlation r-value	T-test p-value
Peak Power (W)				
20%	5021 (1562)	1904 (646)	0.90	$p < 0.01$
40%	4887 (1465)	2040 (686)	0.92	$p < 0.01$
60%	4647 (1487)	2095 (699)	0.94	$p < 0.01$
Peak Velocity (m/s)				
20%	3.03 (0.36)	2.08 (0.32)	0.83	$p < 0.01$
40%	2.73 (0.33)	1.91 (0.30)	0.78	$p < 0.01$
60%	2.40 (0.32)	1.71 (0.27)	0.85	$p < 0.01$
Average Power (W)				
20%	2407 (873)	1167 (407)	0.81	$p < 0.01$
40%	2195 (752)	1237 (422)	0.82	$p < 0.01$
60%	2043 (774)	1263 (422)	0.86	$p < 0.01$
Average Velocity m/s)				
20%	1.58 (0.28)	1.27 (0.20)	0.66	$p < 0.01$
40%	1.35 (0.23)	1.16 (0.19)	0.68	$p < 0.01$
60%	1.17 (0.26)	1.03 (0.18)	0.69	$p < 0.01$

ICC and CV values for the prediction equations and force plate can be seen in Table 4. ICC values for men using the prediction equations across the three applied loads ranged from 0.949 – 0.998 and CV values ranged from 1.0 – 3.3%. For women, ICC values ranged from 0.956 – 0.995 and CV values ranged from 1.2 – 7.0%. The ICCs and CVs for men and women were similar to those calculated for the force plate.

Table 4. ICC and CV values for the force plate and prediction equations.

	Men		Women	
	ICC	CV%	ICC	CV%
Force Plate				
20%	0.994	2.5	0.978	3.4
40%	0.991	2.6	0.934	4.0
60%	0.989	2.6	0.949	4.5
Harman				
20%	0.989	3.3	0.956	7.0
40%	0.992	2.4	0.983	5.3
60%	0.949	3.3	0.984	5.0
Sayers SJ				
20%	0.989	3.2	0.957	6.8
40%	0.993	2.2	0.984	4.8
60%	0.993	2.3	0.986	4.1
Sayers CMJ				
20%	0.996	1.6	0.974	2.9
40%	0.998	1.0	0.993	1.8
60%	0.985	1.4	0.995	1.2

Peak power from the force plate and the estimated peak power from the prediction equations for men and women can be seen in Figure 2. No method by load interaction was identified ($p = 0.39$) in men or in women ($p = 0.08$).

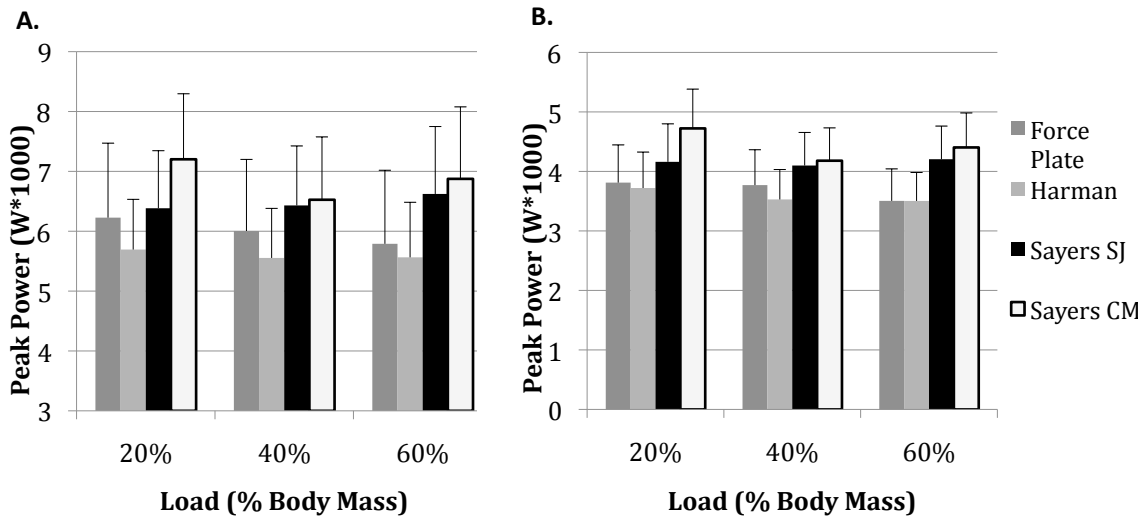


Figure 2. Mean (\pm SD) for PP (W) from the prediction equations (8, 19) and the force plate across the three loading conditions for (A) men and (B) women.

For men, a significant ($p < 0.01$) main effect by method was found, where post hoc analysis determined that there was no difference between data from the force plate and the Harman ($p = 0.06$) equation (Figure 3a). However, differences occurred between the force plate and the Sayers CMJ equation ($p < 0.01$) and the Sayers SJ equation ($p < 0.02$). Similar results were found in women, with a significant main effect by method ($p < 0.01$) identified. Post hoc analysis determined that there was a difference between the force plate and the Sayers CMJ equation ($p < 0.01$) and the force plate and the Sayers SJ equation ($p < 0.01$; Figure 3b). No difference was observed between the force plate and the Harman equation for both men ($p = 0.06$) and women ($p = 1.00$).

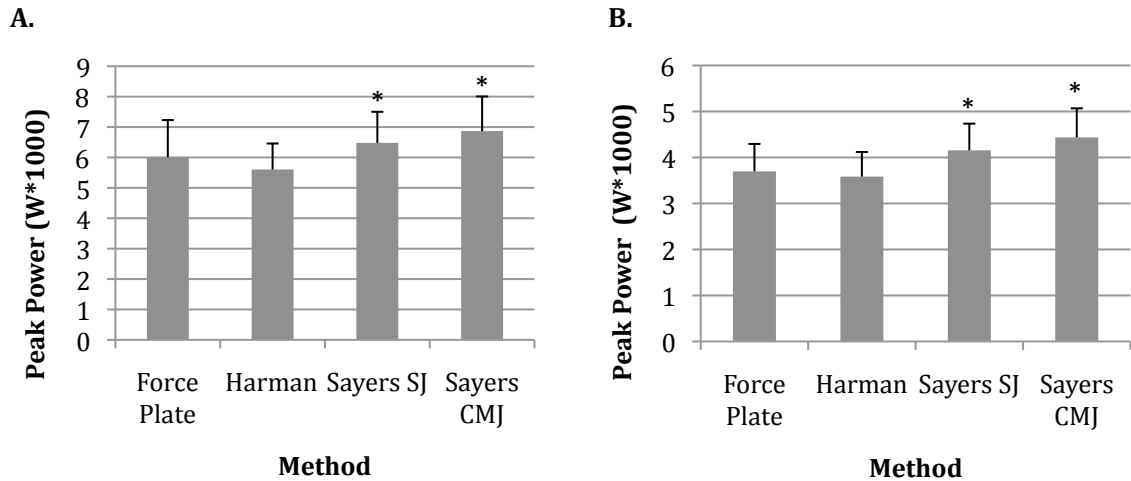


Figure 3. Mean (\pm SD) with combined loads for (A) men and (B) women. * indicates a significant difference between the prediction equation and the force plate.

No significant main effects by load were found ($p = 0.19$) within men (Figure 4a). In contrast, a significant main effect by load was found ($p < 0.01$) for women. Post hoc analysis (Figure 4b) determined that there was a difference between 20% and 40% ($p = 0.01$) and 20% and 60% ($p = 0.02$) body mass, but no difference between 40% and 60% load condition ($p = 0.99$). In addition, Pearson correlations in Table 5 indicate that the association between the estimated PP from the equations and PP from the force plate was stronger for men ($r = 0.84 - 0.94$) than for women ($r = 0.50 - 0.72$).

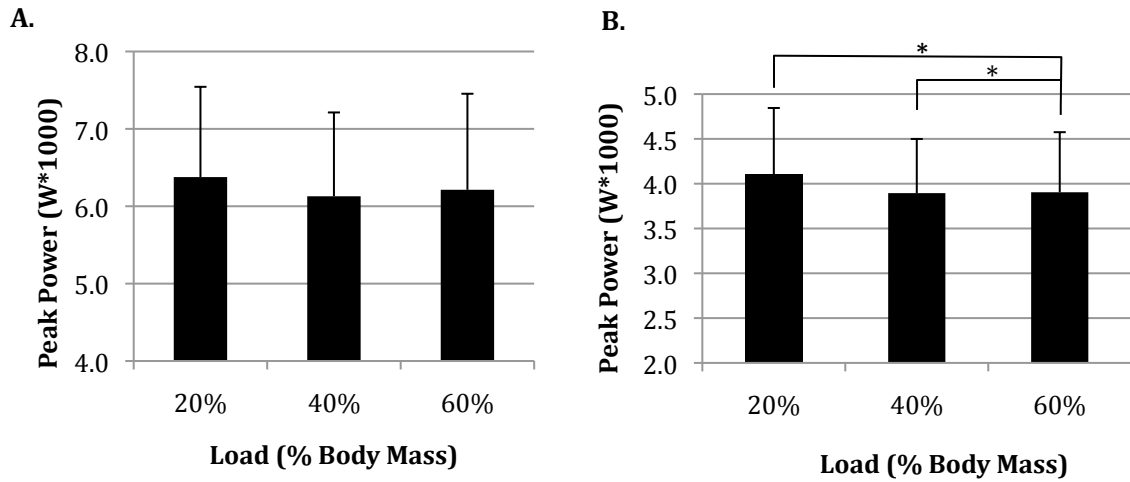


Figure 4. Combined mean (\pm SD) of the force plate and prediction equations at each load for (A) men and (B) women. * indicates significant difference between PP and load.

Table 5. Pearson correlation coefficients between the force plate and prediction equations (8,19) for men and women.

	Men			Women		
	Harman	Sayers CMJ	Sayers SJ	Harman	Sayers CMJ	Sayers SJ
20%	0.94	0.86	0.94	0.72	0.65	0.70
40%	0.93	0.84	0.89	0.65	0.60	0.63
60%	0.94	0.87	0.90	0.65	0.50	0.57

DISCUSSION

One purpose of this study was to validate the TWA by comparing measurements of PP, PV, AP, and AV to force plate measurements. The findings from this study indicate that the measurements of PP, PV, AP, and AV obtained from the TWA appear to be reliable but not valid. Other findings indicate a strong linear relationship between force plate and TWA measures for PP, PV, and AP.

When investigating the reliability and validity of an experimental method it is usually recommended to assess the reliability of the method prior to the validity since the validity of a method depends on the method's reliability. To determine the magnitude of the measurement error associated with calculating power and velocity variables during a loaded JS, relative (ICC) and absolute (CV) reliability measures were calculated. It is recommended that ICC values be greater than 0.90 to be considered to have high reliability (1). The ICC values were > 0.90 for all measures among all loading conditions in this investigation. In addition, it is recommended that the CV be below 10% for data to be considered reliable (1). Findings from the present study produced CV values less than three percent for the TWA for all measurements across the three applied load conditions. These data suggests that the TWA measurements are very reliable from trial-to-trial for the loaded JS.

Reliability findings from this study are comparable to those found by Jennings et al. (10), who assessed the reliability of a similar product by the same manufacturer, the Fitrodyne (TENDO Fitrodyne Powerlyzer, Trencin, Slovak Republic), using bicep curls

and squat jumps. The Fitrodyne operates using the same rotary encoder system as the TWA. The primary difference between the two devices is that the TWA calculates and displays peak and average power and peak and average velocity, while the Fitrodyne displays only average power and velocity. Jennings et al. (10) reported that the Fitrodyne had high reliability ($ICC = 0.97$) for determining average power for both exercises. Jennings concluded that the Fitrodyne was reliable but did not examine the validity of the device and encouraged further research to make that determination.

Paired samples t-tests were used to determine the validity of the TWA's measurements by comparing them with force plate data. Significant differences were found between the force plate and TWA for PP, PV, AP, and AV measurements, indicating that the measurements obtained from the TWA were not valid for any of these variables. Pearson correlation coefficients were used to determine the relationship between force plate and TWA measurements. Strong correlations indicate a good linear relationship between the two instruments. Pearson correlations are thought to be sufficient if $r > 0.70$ but the closer these values get to 1.00 the stronger the relationship becomes (21). In our study, strong relationships were found between the force plate and the TWA across loads of 20%, 40%, and 60% body mass for PP, PV, and AP. However, when assessing the relationship between the force plate and TWA measurement of AV, the strength of this association was weak. These results may raise questions regarding the validity of the data measured by the Fitrodyne that has been used in a number of recent studies (17, 18) since the Fitrodyne only provides AP and AV data.

Peak velocity measurements from the TWA were approximately 30% lower than the PV force plate measurement among the three applied loads. It is likely at least part of

the explanation for differences between the TWA and force plate is due to differences in the determination of velocity by these methods. The TWA measures velocity directly, based on the displacement of the bar, while the force plate measures VGRF to determine the velocity of the system's COM. Li Li et al. (13) reported that velocity of the bar and the velocity of COM of the system increase at different rates, with the bar velocity being faster at the initiation of the upward movement requiring the COM to increase to catch up to the already high velocity of the bar before takeoff. They concluded that the velocity that should be used to accurately determine power during a JS is the velocity of the COM of the system and not bar velocity.

The error observed for the TWA was much higher for power [PP (62.1 – 54.9%) and AP (51.5 – 38.2%)] than velocity [PV (31.4 – 28.8%) and AV (19.6 – 13.7%)]. This is probably the result of several factors. First, in order for the TWA to calculate force, mass and acceleration ($F = M \times A$) data are needed. Body mass can easily be determined by weighing the individual with the loaded barbell in place. Acceleration could be determined in the TWA's microcomputer by dividing the change in velocity by the change in time. However, the acceleration variable is determined using the acceleration of gravity as a constant (9.81 m/s^2 ; 23) which may not be accurate for an object in motion (14).

Another error in the method of using a tethered cord attached to the bar during a JS may be in determining which acceleration needs to be measured; the bar or the COM of the system. Li Li et al. (13) reported that bar acceleration (measured from a high-speed camera system) and COM acceleration (measured from a force plate) were different while performing a JS. During the initial take-off phase of a JS, the bar accelerated at a

greater rate than the system's COM, but towards the end of the take-off phase of a JS, when PP was achieved, the system's COM acceleration was greater than bar acceleration. It is therefore possible that the TWA, as designed, would produce differences in acceleration during the JS as a result of: 1) using a fixed gravitational constant rather than directly measuring acceleration through changes in system velocity during the movement and 2) the attachment point of the TWA. The combination of these errors related to acceleration may lead to an erroneous calculation of total force, and therefore peak power by the TWA.

Another interesting finding in the present study was that the relationship between applied load and peak power for the TWA and the force plate did not match. As the load increased from 20% to 60% body mass, PP and AP measured on the force plate decreased 7.4% and 15.1%, respectively. A similar relationship was observed by Cormie et al. (3), who reported that optimal power was produced when an athlete jumped with no external load. Therefore, it was expected that PP would decrease as the applied load was increased. In contrast, as the load was increased, the TWA measured a 10% increase in PP and an 8% increase in AP. Simultaneously, PV and AV values decreased for both the force plate and the TWA as the load increased, which would be expected by the force-velocity relationship (16). This suggests that the use of a gravitational acceleration constant by the TWA rather than a system acceleration variable may have affected the relationship between applied load and PP. During the JS with increasing loads, the velocity and the related acceleration of the bar and COM should decrease as load increases. With the TWA, the acceleration stays constant rather than decreasing as the load increases. However, the increase in force remained high enough to counteract any

decrease in velocity calculated with the power formula ($P = F \times V$). Therefore, as load increases, PP from the TWA may be influenced only by a decrease in bar velocity, while PP from the force plate is influenced by both decreased acceleration and decreased velocity of the system COM.

Cronin et al. (4) and Drinkwater et al. (5) performed similar validation studies on devices like the TWA. Cronin et al. (4) attached a linear position transducer cord to a belt, which was positioned around the subject's waist. High ICC (0.86 – 0.98) values and low CV (2.1 – 8.4%) values indicated that the linear position transducer device was reliable for various unloaded jumping performances. Kinetic variables were compared between a force plate and a linear position transducer during various types of jumps and no differences between the two using a paired t-test were found ($p = 0.06 - 0.96$). Additionally, high correlations ($r > 0.80$) were found with the linear position transducer's measurements of peak and mean force. Thus, the linear position transducer was said to have both reliable and valid measures of both mean and peak force for jumping.

Drinkwater et al. (5) compared kinetic measures during squats and bench press throws during simultaneous recordings from a video camera and an optical encoder and found high correlations ($r = 0.97 - 1.00$) between the two methods. Based on the low CV (1 - 3%) and standard error of estimate ($<14.5w$), Drinkwater concluded that the optical encoder provided valid measurements of power for these exercises. Drinkwater et al. (5) validated the optical encoder by comparing bar measurements. These findings suggest that comparing measurements from the same location (bar to bar or COM to COM) may be the best method for validating a device. Based on studies by Cronin and Drinkwater, it appears that the concept for the TWA is a good one, and simple changes in the

determination of bar acceleration and cord attachment may help make it a more useful device during loaded jumping conditions.

A second purpose of this study was to determine the efficacy of using prediction equations to determine peak power under externally loaded conditions for men and women. Results of reliability assessment indicate that the Harman (8), Sayers CMJ (19) and Sayers SJ (19) prediction equations were highly repeatable for determining PP during the JS from trial-to-trial.

Peak power estimated by the Harman equation was not significantly different from PP measured by the force plate for both men and women. In contrast, the Sayers SJ equation and the Sayers CMJ equation were found to be significantly different from the force plate for men and women. Therefore, the Harman equation was the only equation tested in the present study that was found to be both reliable and valid for predicting PP for both men and women.

Although no significant difference was found between the Harman equation and the force plate, PP was underestimated by the Harman equation 9%, 8%, and 4% as load increased from 20, 40, and 60% of body mass, respectively. Results from the present study indicate the usefulness of using the Harman equation for estimating PP production during the JS for loads between 20% and 60% of body mass. Since this study is the first to analyze the utility of established prediction equations for determining PP from loaded jump squats, results can only be compared to studies that have produced or validated the current equations using unloaded countermovement jumps. Present study results are supported by other studies that found the Harman equation to underestimate PP by similar differences when a counter movement jump (CMJ) was performed Duncan et al.

(7; Sayers et al. 1999). Sayers et al. (19) found that the Harman equation underestimated PP by 7% and Duncan et al. (7) found that it underestimated PP by 6% in male basketball players.

No significant difference for men or women was found between force plate PP and PP from the Harman equation. This study found that as the applied load increased from 20, 40, and 60% of body mass, the Harman equation underestimated PP in women by 2%, 14%, and <1%, respectively. The results from the present study did not lead to any explanation as to why there was such a large difference between the force plate and the Harman equation during the JS using 40% body mass compared to the 20% and 60% trials. Canavan and Vescovi (2) similarly found no significant difference when they compared PP from the Harman equation to force plate PP. However, for their group of women, PP during a CMJ was overestimated by 6% in college women.

In the present study, a significant difference was found between PP from both of the Sayers prediction equations and the force plate. Both Sayers equations produced an overestimation of PP during the JS. However, the Sayers SJ equation was a better predictor of PP during the JS than the CMJ equation. This was primarily due to smaller differences observed between the SJ equation (men; 3%, 7%, 14% and women; 9%, 9%, 20%) and the force plate than the CMJ equation (men; 16%, 9 %, 19% and women; 24%, 11%, 27%) and force plate across the three loads. Sayers et al. (1999) also found that the SJ equation yielded a more accurate prediction of PP than the CMJ equation, however, present study results demonstrated greater error under loaded conditions than have been reported in previous studies with unloaded JS. Results from the present study also differ from those of Duncan et al. (7) who found the Sayers SJ and Sayers CMJ equations

underestimated PP by 12% and 3%, respectively during a CMJ (7). The underestimations of PP from the Sayers SJ and CMJ equations found by Duncan et al. (7) could be due to the fact that subjects were elite basketball players with more jumping experience than the subjects in the present study.

Another interesting finding from this study's results was that for both men and women, the Sayers SJ equation was a better predictor of actual PP than the Sayers CMJ equation. Sayers et al. (19) also found that the SJ equation yielded a more accurate estimation of PP than the CMJ equation, however, results from the present study demonstrated the use of the Sayers equations to predict PP produced greater error under loaded conditions than they did when unloaded.

This study had limitations that may have impacted the results. The three prediction equations used in this study were derived using vertical jumps with full arm swing during a jump and reach test. Prior to this study, it was not known if performing a vertical jump without an arm swing on a contact mat with a load across the shoulders would affect the accuracy of the prediction equations. The Harman and Sayers equations rely on jump height obtained from a jump and reach test, while the present study used a contact mat to estimate jump height from flight time. Linthorne (14) found that using a contact mat results in an overestimation of true jump height (0.5 – 2.0 cm); because the height of the jumper's COM at landing is lower than that at takeoff. Further, Leard et al. (12) found that the Just Jump system was more accurate than the Vertec when compared to a three-camera system. As a result, jump height measured using the jump and reach test was ~10% (9.8%) underestimated. Harman et al. (8) also studied the effect of arm swing on VJ power and found that arm swing contributes about 10% to PP. It appears,

therefore, that the added jump height calculated by the contact mat is cancelled out by the loss of the power produced by swinging the arms. Therefore, the use of a contact mat should not cause significant problems in the predicting PP produced during a JS.

Another possible limitation to this study was that the JS was performed in a PPS, where the bar's movement was limited to a vertical plane, while the prediction equations were derived from free jumps without such limitations. Sheppard et al. (20) compared measures of PP, AP, PV, peak force, mean force, and displacement recorded during a Smith machine JS and a free weight JS. All these measures were found to be similar except for the AP variable. Therefore, the use of a Smith machine may not create significant differences between JS methods.

The usefulness of the prediction equations for tracking PP production was assessed using a Pearson Product-Moment correlation between the equations and the force plate. The present study shows that the relationships between estimated PP and actual PP were much stronger for men ($r = 0.84 - 0.94$) than for women ($r = 0.50 - 0.72$). Additionally, for women, the relationship between estimated PP and actual PP for all equations was observed to be lower as the load increased. As a result, women should use these equations with caution. Conversely, it appears that PP can be monitored at regular intervals for men using any of these equations with applied loads between 20-60% of body mass.

It is recommended that future research use flight times to estimate jump height to develop revised regression equations. This would be an affordable and practical method for determining PP output so that S & C professionals may be able to more effectively monitor training.

PRACTICAL APPLICATIONS

The TWA appeared to be a reliable but not valid method for measuring power in the loaded JS. The TWA may, however, be used as an effective system for monitoring changes in PP, PV, and AP during different times in the training year.

The Harman equation was found to be a reliable and valid estimate of PP output of a loaded JS in men and women. However, the equation was less accurate for women than it was with men.

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APPENDIX A
INFORMED CONSENT

APPENDIX B

REVIEW OF RELATED LITERATURE

REVIEW OF RELATED LITERATURE

It is beneficial for strength and conditioning (S & C) professionals to monitor their athletes as they train for competition. Power output has been frequently documented to be the main determinant of athletic performance (14,29,34). Additionally, monitoring power production in specific exercises has been utilized to motivate maximal effort attempts in training movements necessary for sport training (40). Therefore, in order to optimize training, S & C professionals seek various economical and practical methods for monitoring power production in their athletes.

When monitoring lower body power output, it is important for S & C professionals to use a simple movement that produces high amounts of power. The jump squat (JS) exercise is commonly used because it utilizes the stretch-shortening cycle of a muscle, which is regularly performed in most sports (30). To perform a JS one begins standing in an upright position while holding a barbell tightly across their shoulders. Next they perform a downward countermovement to a self-selected depth and immediately explode upwards, jumping for maximal height. The JS requires lower amounts of skill than most Olympic lifts, and subjects can generally use a greater range of loads, making it an effective exercise for training. Additionally, the JS has been used in a number of studies to compare the relationships between load and power and have been used to determine the load at which maximum power is achieved, which has been found to range

from 0 to 63% 1RM (2,8,11,26,29,33,43,46,48). For these reasons the JS is an ideal exercise for assessing and training for power development.

Force platforms have been used in most exercise science laboratories and identified as the “gold standard” in measuring power output (35). Although their measurement is accurate, their use may be limited in training facilities because external vibrations may cause interference with vertical ground reaction force (VGRF) measurements. External vibrations are common in training facilities, especially ones with platforms for Olympic lifts. Moreover, data obtained using these devices is vast and may require further processing. Most S & C professionals do not have the time to process data for all of the athletes they train. Furthermore, these devices cost several thousands of dollars, which is out of range for the budgets of most college and high school training facilities. Therefore, a more economical device that processes data automatically and provides accurate, instantaneous feedback is desired.

For this purpose, many S & C professionals have utilized a rotary encoder called a TENDO Weightlifting Analyzer (TWA; Tendo Sport Machines, Trencin, Slovak Republic). Although the cost of the TWA is significantly less than the force platform, the TWA is still relatively expensive for many small college and high school S & C center budgets. In addition, while studies of the reliability of the TWA have been performed (24) with promising results, we are not aware of any studies that have tested the validity of the TWA to see if the kinematic variables determined by this device are comparable to the force plate.

Lower body power has been estimated from vertical jump tests using PP prediction equations (14, 41). To estimate PP these equations require input of the

subject's body mass and the height of the vertical jump. While these equations have been found to accurately predict lower body peak power from a vertical jump, they have not been assessed of their accuracy to predict PP from a loaded jump. Logically, it would seem plausible to substitute the subject's body mass with the body mass + bar (mass of the system) to predict lower body power during a JS. If the equations were assessed under loaded conditions, they may become more useful to S & C professionals. A primary reason for assessing PP using JS is that PP is not always generated under conditions where external body weight is lifted. Stone et al. (43) determined that as an athlete becomes stronger, the load at which maximum power is achieved becomes higher. This is because the maximum force that a muscle produces becomes greater. If an athlete produces PP at 10% of their 1RM and they increase their 1RM by 20lbs, then the load that maximum power is achieved (10% of their 1RM) will increase. Thus, the load-power inverted U-shaped curve shifts towards the load side. With continued strength training, the load that produces the maximum amount of power may become too high for a simple vertical jump test to measure. For that reason, it would be more useful to have a JS prediction equation that can estimate PP using external loads. Therefore, the purpose of this review is to shed light on various methods of measuring JS power, so that S & C professionals can more effectively monitor training programs.

Monitoring Training

When assessing athletic ability, apart from skill, coaches want to know two important athletic traits: how fast is the athlete, and how strong is the athlete? Power is a combination of strength and speed, which is mathematically known as the product of force and velocity of movement. Therefore, in order to determine athletic ability, it is

important to know how much power an athlete can produce. Harman et al. (14) reported that lower body PP was highly correlated to jump performance ($r = 0.88$). Additionally, Young et al. (43) found that the initial acceleration phase of sprinting (2.5 m) had a strong correlation ($r = -0.86$) with a concentric-only JS. Furthermore, Baker and Nance (2) found that the JS was significantly related to a 10-m sprint performance ($r = -0.52$ - 0.61), but no significant correlations were found between the JS and 40-m sprint times.

Assessing power production over the course of a training period allows the S & C professional to determine weaknesses an athlete must overcome to improve performance as well as understanding changes that may be needed in the program design if the athletes are not progressing on the planned training program. Additionally, S & C professionals can track progress, making sure that an athlete's fitness status is increasing from week to week and season to season. Tracking changes in power production utilizing jump squats is simple using laboratory methods; however, at this point these methods are not feasible to be done by all athletes on a regular basis because of time involvement and cost of equipment.

Determining Power Output to Monitor Training

There are many devices that have been used to determine power output from vertical jump performance. Some of these devices include the Vertec that is used for jump and reach tests, contact mats, accelerometers, linear position transducers, video analysis, optical encoders, rotary encoders, and the force plate. Common variables that are measured are VGRF, acceleration, displacement, and flight time.

Force Plate

As previously mentioned, force plates are considered the “gold standard” for measuring vertical jump performance (35, 29). This is because they can be used to accurately assess many variables of various vertical jumps. Velocity and power are calculated from VGRF data using the impulse-momentum theorem (11,30). The impulse (force/time) produces a change in the momentum of the body or system center of mass (COM). During a JS, this method involves collecting VGRF data, beginning when the subject is standing stationary with the load across their shoulders and ending when the subject leaves the ground during the jump. Ground reaction force impulse is determined by calculating the area under the force – time curve for that portion of the JS. Force – time data is used to calculate power and velocity for the entire JS movement.

Instantaneous velocity is calculated from force plate data using the formula: previous sample’s velocity (m/s) + (force (N) – (mass (kg) × 9.81 m/s²)) × Δt / mass (kg), where Δt is equivalent to the change in time between each sample (1/500 of a second). Force and velocity from the same sample are then multiplied to determine instantaneous power.

Rotary Encoder

The TENDO Weightlifting analyzer (TWA) is a type of rotary encoder that consists of two functional components to measure displacement and time; a velocity sensor unit and a microcomputer. The velocity sensor unit is made up of a slotted disk with an optical sensor and a light source. A cord is wrapped around a slotted disk. The loose end of the cord can be attached to a weight stack or barbell. For an accurate measurement to be taken, the cord must be aligned parallel to the load’s path of movement. When the load is moved, the cord unravels, causing the slotted disk to spin.

Light shines through the slots of the spinning disk and is read by the optical sensor. The rate of pulsation corresponds to a given displacement (TENDO 2005). The sensor relays the information to an onboard microcomputer, which determines the rate at which the cord is being displaced.

From this data, average and peak velocity is calculated. Mass of the load is entered into the TWA's microcomputer, which allows it to calculate force using gravitational acceleration (9.81m/s^2). To calculate force, the TWA uses the product of gravitational acceleration and the load lifted in kg, which becomes problematic. This results in the force being a constant value during the JS. Consequently, for the TWA to have an accurate calculation of force, it needs to calculate the acceleration of the load. To obtain an accurate force measurement, load acceleration should be multiplied by the mass of the load. The product of the velocity measurement and the force calculation determines the power output ($P = F \times V$). As a result of this error in the calculation of force using the acceleration of gravity constant by the TWA, we hypothesize there may be some error in the power output data.

Jennings et al. (24) assessed the reliability of the TENDO FitroDyne (FitroDyne; Fitronic, Bratislava, Slovakia) using the biceps curl and squat jump exercises. The only difference between the FitroDyne and the TWA is the microcomputer software. The output on the Fitrodyne displays only average power and average velocity, while the TWA displays peak power, peak velocity, average power, and average velocity. Therefore, the differences between the devices are simply due to the computing ability of their microcomputers. They found high ICC values ($r=0.95 - 0.98$) for these exercises. Jennings et al. (24) concluded that the FitroDyne is a reliable tool for measuring average

power and average velocity. He also suggested that future research should determine its validity. Cronin et al. (5) and Drinkwater et al. (10) performed validation studies on devices similar to the TWA with promising results. Cronin et al. (5) compared kinetic variables between a force plate and a linear position transducer (LPT) during various types of jumps. In his study, the LPT wire was attached to the subject's center of mass (COM) which is the same location that the force plate method measures. High ICC ($r = 0.864 - 0.982$) and low CV (2.1- 8.4%) values indicate that the device was reliable from test-to-test. Paired students t-test ($p = 0.056 - 0.957$) showed no significant differences between the force plate and LPT, which indicated that the method they used was valid. Lastly, Pearson correlations showed strong relationships ($r > 0.80$) between the linear position transducer and the force plate measurements of peak and mean force. Thus, Cronin et al. (5) concluded the linear position transducer to have both reliable and valid measures of both mean and peak force.

Drinkwater et al. (10) compared peak and mean power measures during squats and bench press throws during simultaneous recording by a video camera and an optical encoder. All measurements were taken from the position of the bar. Results produced high Pearson correlations ($r = 0.97 - 1.00$). Based on the low CV (1 - 3%) and standard error of estimate ($<14.5W$), Drinkwater et al. (10) concluded that the Gymaware optical encoder was a valid method for determining peak and mean power.

One concern with use of the TWA is the sampling frequency. Because of its design, its sampling frequency depends on the rate at which the slotted disk spins (velocity of movement). This creates potential concern when movement velocities are slow. If the sample frequency is too low, the amount of data collected may not be enough

to produce a valid measurement. A TWA salesperson communicated that, “As velocity of the bar increases, the sampling rate increases proportionally” (personal communication with a TWA salesperson, 1/28/2010). The salesperson explained that, a velocity of one meter per second is sampled at a frequency 100Hz.

Recently, it has been determined that when the sampling frequency is <200 Hz, differences in the measurement of force, power, velocity from the VGRF on a force plate during a CMJ are markedly enlarged (23). Therefore, if peak velocities measured by the TWA are < 2.0 m/s, the sample may not be adequate for peak power. As a result sampling error may affect the accuracy of the results. This error will be magnified if calculations are made from data that is not sampled at a sufficiently high enough rate.

Aleman et. al. (1) found peak velocity to range from 2.0 to 2.3 m/s when his subjects performed a JS with 30% of their 1RM. Cormie et. al. (8) found peak velocity to be highest at 3.6 m/s when the load was at 0% 1RM. Although this peak velocity is sufficient, it is likely that the average velocity will be well below 2.0 m/s, meaning that for the calculation of average power most of the data points are determined at sample rates less than 200 Hz. Velocity steadily decreased with increasing loads. The heaviest load was 85% of 1RM, where subjects moved the bar at about 1.2 m/s (8). With respect to these previously mentioned velocities, the TWA sampling rate should be more acceptable for lighter loads, where loads are moved at higher velocities. If the concept of low sampling rate leading to variable data on the force plate carries over to errors due to the rotary encoder low sampling rate, then the velocity during the concentric portion of the JS may not be adequate to produce valid data. Concern will be given to the heavier loads that are moved at slower velocities (<2.0 m/s).

Prediction Equations

The equations listed in Table 1 have made it easier for S & C professionals to assess jumping power. Each equation requires the input of jump height and total body mass to estimate peak power. The jump height coefficients of these equations were all derived using a jump and reach test.

Table 1. Prediction equations used to determine peak power. Traditionally, measurements of jump height (Jump HT) in centimeters and body mass (BM) in kilograms are required to estimate peak power. For our purposes BM was equivalent to the sum of the subject's body mass and the loaded barbell.

Harman, (14)	$61.9 \times \text{Jump HT} + 36 \times \text{BM} - 1822$
Sayers, Squat Jump (Sayers 2001)	$60.7 \times \text{Jump HT} + 45.3 \times \text{BM} - 2055$
Sayers, CMJ (Sayers 2001)	$51.98 \times \text{Jump HT} + 48.9 \times \text{BM} - 2007$

Harman et al. (14) was one of the first to develop an accurate prediction equation to estimate peak leg power from a vertical jump test. To create the prediction equations, two separate vertical jumps were used to collect data: one using a measurement of jump height during a jump and reach test, and one where subjects performed a separate maximal jump and reach test on a force plate. When Harman et al. (1991) had subjects jump and reach on a force plate there was no target to reach for, which may change the task to some degree. Furthermore, the different jumping conditions required the subjects to divide their attention between reaching and jumping for one jump and then simply attempt to mimic the movement with another jump (27, 28). This method may also be problematic because the two measurements should be from the same jump for an ideal comparison (4). Despite these technical and methodological problems, the Harman equation has been shown to accurately predict vertical jump peak power. Canavan and Vescovi (4) found no significant difference between PP estimated by the Harman

equation and the PP measured by the force plate, while both Sayers equations significantly overestimated PP. In their study jump height was measured using a force plate while subjects performed jumps with hands on their hips. In Addition, Sayers et al. (41) found the Harman equation to underestimate PP by only 6.9% while performing a CMJ.

In contrast to methods used by Harman et al. (14), Sayers et al. (41) simultaneously measured ground reaction forces and jump height. To achieve this, subjects performed a jump and reach test on a force plate. With these more sound methods and a heterogeneous sample of 108 college men and women, Sayers et al. (41) published two new cross-validated prediction equations, one using a CMJ and one using a squat jump (SJ). Standard error of estimate (SEE) was 382.4 W for the Sayers SJ 579.4 W for the Sayers CMJ equations. Sayers et al. (41) also assessed the Harman equation and found a similar SEE of 372.9 W for the SJ protocol (10.7% difference from the mean) and 579.9 W for the CMJ protocol (15.7% difference from the mean). For the entire sample, PP was overestimated with the Sayers CMJ equation by 2.7%, while the Sayers SJ equation underestimated PP by 1.9%. PP estimated from the Sayers CMJ and SJ equations produced high correlation coefficients when compared to force plate PP $r = 0.91$ and $r = 0.93$, respectively. An interesting finding from the Sayers et al. (41) study was that the equations could be used interchangeably to predict peak power of a squat jump or countermovement jump for both men and women.

Hertogh and Hue (18) assessed the Harman (14) and Sayers CMJ (41) equations using competitive male volleyball players and non-athletic males. The two groups performed maximal CMJ's for power assessment. Hertogh and Hue (18) found a significant

underestimation between estimated PP and force plate PP for both equations in elite volleyball players. Analysis of the data for all subjects showed that PP was significantly different between the Harman equation and the force plate, while no significant difference was found between the Sayers CMJ equation and the force plate. When analyzing the data by separate groups, non-athletic subjects produced PP that was not different from the force plate when using both the Harman and Sayers equations. In contrast, in volleyball players, peak power was underestimated using both equations compared to the force plate. Hertogh and Hue (18) also found that both equations were accurate enough to distinguish significant differences in peak power output between the two groups.

Methods for Calculating Power

All prediction equations have previously used the jumper's body mass as a variable to estimate peak power. When using these equations under loaded conditions, the sum of the mass of the jumper and the external load must be used when predicting peak power under external loads. Therefore, to validate these equations, similar methods of mass calculation must be used.

When determining peak power of jumping activities from a force plate, there are three commonly used methods: 1) the mass of the bar alone may be used, 2) the subjects body mass and the external load may be incorporated together as a system (11), or 3) the system mass may be used while neglecting shank and foot mass (7). Each method varies when determining the masses that are integrated into the power formula.

The exclusion of body mass (bar mass alone) method should not be used for determining kinetic data from a JS because the ground reaction forces are produced to

overcome the weight of the body as well as the load on the bar, so the body weight must be included. This method is more commonly used with exercises like the bench press, which do not require movement of the participant's own body mass.

Cormie et al. (7) determined that the shank and foot remain fairly static during the phase of the jump when peak power is measured. Therefore, the masses of the shank and foot may not need to be incorporated into the power equation (11, 7). Cormie et al. (9) compared power outputs using inclusion of body mass, exclusion of body mass, and exclusion of shank mass for the JS exercise. To account for shank mass, 12% of the participant's body mass was deducted (7). It has been theorized that neglecting shank and foot mass is the most valid way to incorporate body mass while performing the JS exercise (7). However, this method must not be used in the present research, because the prediction equations were originally derived from using the total mass of the jumper. This is equivalent to using the mass of the system, when jumping with an external load. Therefore, in order to compare the equations under externally loaded conditions, mass of the system must be used to estimate peak power.

Measuring Vertical Jump Height

The jump and reach test is commonly performed using a wall or a Vertec (Vertec, Sprots Imports, Hilliard OH) or a wall to measure displacement. The Vertec consists of an upright adjustable metal pole with plastic swivel vanes attached to it. The vanes are arranged 0.0127 meters apart, and are displaced when the athlete obtains a standing reach height, and again when they perform the actual jump and reach. To determine jump height, the difference between the standing reach height and the jump reach height is calculated.

The jump and reach test is great for determining jump height of basketball and volleyball players (18,12), but when the goal is to determine lower-body power, a jump and reach test may not be the most favorable method (4). This is because obtaining reach heights can cause variability. Canavan and Vescovi (4) discussed that flexibility in the shoulder and the side bending of the trunk may not precisely measure the displacement of the COM. Furthermore, for many sports, it is more useful to S& C professionals to know how much power an athlete can produce under varying load conditions. For the purpose of measuring power output of a loaded JS, jump height cannot be validly determined using a jump and reach test. Thus, a contact mat or force plate must be used.

Contact mat systems determine jump height from flight time rather than displacement. Flight time is measured using a switch that is located inside the mat. When an athlete jumps and their feet leave the mat, a timer is activated. As they return to the ground their feet contact the mat, stopping the timer. The mat's computer calculates displacement of the body's center of gravity using the formula $(t^2 \times g)/8$. Where g is gravitational acceleration and t is flight time (27). Linthorne et al. (30) explained that the contact mat tends to overestimate jump height (<2cm). This is because the body's center of mass is often lower when landing than at takeoff (30). Leard et al. (28) found that the Just Jump (contact mat $r=0.967$) had a higher correlation than a Vertec (jump and reach $r=0.906$) when both were compared to video analysis. Furthermore, no significant difference in jump height measurement was found between the contact mat and the criterion reference (3-camera system; $p = 0.972$), while the jump and reach test was determined to be significantly different from the criterion reference ($p=0.005$). As a result, jump height measured using the jump and reach test was ~10% (9.8%)

underestimated. Harman et al. (14) also studied the effect of arm swing on VJ power and found that arm swing contributes about 10% to PP. It seems the added jump height by the contact mat may be cancelled out by the loss of the power produced using the arms. Therefore, the using a contact mat should not cause any problems in the accuracy of predicting PP produced during a JS.

Instructing Participants

When assessing power during explosive exercises, it is important to assure the subject is contributing maximal effort. Young et al. (47) investigated various forms of instruction and how they affected jump height. He found that performance was best when instructing subjects to jump for height, rather than minimize contact time, or try a combination of both. Young et al. (47) observed that when subjects were instructed to jump for height only, subjects crouched lower, and demonstrated a longer takeoff time, which contributed to better jump heights. This mental goal may help athletes better utilize mechanical and physiological characteristics of their own bodies.

Force Plate vs. TWA Measurement

To the author's knowledge, there is no data comparing force plate VGRF measurements to TWA displacement measurements. However, Li Li et al. (29) compared barbell linear displacement measurements from a high-speed camera system to force plate measurements of the system's COM. He found that the bar velocity was greater than the velocity of the COM of the body during the initial push-off phase of the JS. During the final push-off stage, the velocities were similar. Therefore, the velocity of the COM has to increase in order to match the already high velocity of the bar at take-off. As a result, during the final push-off phase, when PP is achieved, the COM was accelerating

at a greater rate than the bar. It appears that measurement taken from two different areas on the system (COM and bar) could cause variances in power measurement between the devices and the COM is the more accurate acceleration to use in the determination of power in a JS (29).

Summary

This discussion was intended to shed light on some of the major issues that must be accounted for when using a force plate, TWA, and prediction equations to determine jump kinetics. When possible, a force plate should be used, because it is the most accurate method (35, 29). However, it is understood that S & C professionals may not desire these devices, because of their impracticalities in most training facilities. Although each of these three devices measure different variables of a jump, all power measurements are expected to be fairly similar. The TWA has been used to monitor power output in various studies (36,39), but to the author's knowledge, has not been validated. Similarly, prediction equations have been found reliable for estimating peak power of a squat jump and countermovement jump, but have not been validated under externally loaded conditions using the JS exercise. With this understanding, the present study will examine the reliability and validity of kinetic measurements from the TWA and prediction equations using the JS exercise.

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