ASSESSING THE FORCE-VELOCITY CHARACTERISTICS OF THE LEG EXTENSORS IN WELL-TRAINED ATHLETES: THE INCREMENTAL LOAD POWER PROFILE

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ABSTRACT

Sheppard, JM, Cormack, S, Taylor, K-L, McGuigan, MR, and Newton, RU. Assessing the force-velocity characteristics of the leg extensors in well-trained jumping athletes: the incremental load power profile. *J Strength Cond Res* 22: 1320–1326, 2008—The purpose of this research project was to evaluate the methodology of an iso-inertial force-velocity assessment utilizing a range of loads and a group of high-performance athletes. A total of 26 subjects (19.8 ± 2.6 years, 196.3 ± 9.6 cm, 88.6 ± 8.9 kg) participated in this study. Interday reliability of various force-time measures obtained during the performance of countermovement jumps with a range of loads was examined, followed by a validity assessment of the various measures' ability to discriminate among performance levels, while the ability of the test protocol to detect training-induced changes was assessed by comparing results before and after an intensive 12-week training period. Force and velocity variables were observed to be reliable (intraclass correlation coefficient 0.74–0.99). Large effect size statistic (ES $>$ 0.50) differences among player groups were observed for peak power (1.36–2.25), relative peak power (1.57–2.42), and peak force (0.74–0.95). Significant ($p < 0.05$) and large (ES $>$ 0.50) improvements were observed in the kinetic values after the intensive training period. The results of this study indicate that the incremental load power profile is an acceptably reliable, valid, and sensitive method of assessing force and power capabilities of the leg extensors in high-performance and elite volleyball players.

KEY WORDS assessment, jump squat, volleyball, football

INTRODUCTION

Although leg extensor strength and power assessment are fundamental components in the testing of high-performance athletes, a great deal of debate exists about the most reliable, valid, and insightful means by which to accomplish this task (1,8,15,19). Some authors have investigated the use of unloaded and loaded jump squats and squat jumps in their assessment of lower body power while collecting force plate data (4,17,18). This testing concept seems to be very insightful, as comparisons of velocity characteristics against varying isoinertial loads can be made. Based on the time in the training cycle, the athlete's developmental level, and the sport in which they are involved, this analysis could be useful in making decisions regarding the training needs of each athlete. The athlete's ability to accelerate a given load and achieve high power outputs would seem to indicate what emphasis along the force-velocity spectrum they need to emphasize to see further gains in power (5).

Several researchers have used a spectrum of loaded jumps to evaluate strength and power characteristics (4,16,17,18), yet a comprehensive evaluation of the reliability, validity, and sensitivity of this measure could not be found. Although both Sands et al. (17) and Stone et al. (18) reported high intertrial reliability of several measures obtained from loaded jumps, interday reliability and validity of these measures to discriminate between higher and lower performers have not been reported in the literature. A comprehensive understanding of the reliability of a measure is important to confidently interpret observed changes as those that are outside (real change) or within the typical error (TE) limits (14). In addition, if it is unknown whether a measure is able to discriminate among performance levels within a sport or to detect changes induced by sport-specific training, the importance of improving results observed in the variable is questionable.

A complete force-velocity assessment spanning a range of loads would seem helpful in assessing the underlying force-velocity capabilities of the leg extensors. However, this methodology has not received comprehensive research evaluation.

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Therefore, the purpose of this research project was threefold: to evaluate the reliability of an isoinertial force, velocity, and power assessment utilizing a range of loads and a group of high-performance athletes. Additionally, a discriminate validity assessment was undertaken to determine whether the test and measures were able to identify between a closely matched group of higher and lower performers in men's volleyball and to evaluate whether the testing protocol was able to detect changes induced by training over a 12-week period.

METHODS

Experimental Approach to the Problem

To assess the interday reliability of various measures obtained during the performance of countermovement jumps with a range of loads (body mass, body mass + 25%, body mass + 50%), a group of high-performance volleyball (n = 8) and Australian Rules Football (n = 8) players were familiarized with the experimental procedures and tested on two separate occasions separated by 7 days.

The validity of the various measures' ability to discriminate between levels of performance was assessed by comparing the performance of 14 volleyball players who were classified as the Developmental National Team (DNT) (n = 7) and Senior National Team (SNT) (n = 7). The SNT group comprised players who had played open-age international matches, whereas the DNT comprised players who had not played any open-age international matches. The researchers hypothesized that force, velocity, and power measures would be reliable when assessed with body mass (unloaded) and loaded jumping movements; that these assessments would result in superior scores for higher performing volleyball players; and that these measures would be sensitive to training-induced changes after a 12-week training period.

The sensitivity of the testing protocol was assessed by evaluating a group of DNT and SNT volleyball players (n = 18) before and after an intensive 12-week training period. Each week of the training and competition block included approximately two to four strength training sessions (Table 1A) per week (32 total for the 12-week period), seven to 10 technical and tactical training sessions (Table 1B) lasting 120 minutes, recovery sessions (contrast spas), and one or two remedial training sessions (dependant on an individual's requirements).

Subjects

A total of 26 subjects (19.8 ± 2.6 years, 196.3 ± 9.6 cm, 88.6 ± 8.9 kg) who were part of full-time training programs that included regular jump training and weighted jump squat training were recruited for this study. All participants received a clear explanation of the study, including the risks and benefits of participation. Testing was in accordance with and approved by institutional ethics committees, and written consent for testing was obtained in the athlete's scholarship holder's agreement and/or professional contract.

Procedures

Incremental Load Countermovement Jump Assessment. Subjects attended a familiarization session and two assessment sessions for the reliability analysis, and a single session of testing for the validity analysis. The reliability assessment sessions were conducted at the same time of day 1 week apart. Physical activity 48 hours before the assessment was

TABLE 1A. General composition of strength and power training sessions during 12-week training block.

Preparation	Cycling Remedial ankle and shoulder training	5 min 2–3 exercises each
Low-load power training	Medicine ball throws	4–6 sets × 3–5 repetitions
1–2 exercises per session	Jump squats (20–30kg)	3–4 sets × 3 repetitions
High-load power training	Cleans	3–6 sets × 1–5 repetitions
1–2 exercises per session	Power cleans	
	Snatch	
	Jerks	
	Clean pulls	
Strength 1–2 exercises per session	Back squat	5–6 sets × 2–4 repetitions
	Front squat	
	Deadlift	
	Romanian deadlift	
General conditioning 3 exercises per session	Pressing and pull movements for upper body, remedial training for lower body as needed	3–4 sets × 5–7 repetitions

Total sets per workout were not less than 18 and not more than 24. Subjects completed 32 strength training sessions over the 12-week period.

Table 1B. Weekly outline of training types during 12-week training period.

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Strength training	Individual technical session	Strength training	Individual technical session	Strength training	Supplementary conditioning	Rest
Volleyball training	Volleyball training	Volleyball training	Volleyball training	Volleyball training	Volleyball training	Rest
Recovery session	Physical therapies	Recovery session	Physical therapies		Recovery session	

standardized to reduce the potential impact of previous training activities on performance of the tests.

Subjects performed a maximal effort countermovement jump at body mass (BM), BM + 25%, and BM + 50%, with the intent to jump as explosively as possible. Jumps were conducted with the subjects standing on a commercially available force plate (400 Series Performance Force Plate; Fitness Technology, Australia). A position transducer (PT5A; Fitness Technology) was connected to a fiberglass pole (bodyweight jumps) or Olympic weight-lifting bar (BW + 25% and 50%) held across the shoulders. Both the force plate and position transducer were interfaced with computer software (Ballistic Measurement System; Fitness Technology) that allowed direct measurement of force-time characteristics (force plate) and displacement-time and velocity-time (position transducer) variables as outlined by Dugan et al. (11).

Statistical Analyses

Reliability of measures was assessed by calculating the relative change in the mean between observations, intraclass correlation coefficients (ICC), technical errors (TE) as an absolute, and percentage of covariance (%CV). To assess the

Table 2. Reliability data for the incremental load power profile.

Realiability values	TE	Change in mean (%)	% CV	ICC
Unloaded (BM) jump				
Peak distance (m)	0.03	1.7	7.2	0.77
Peak velocity ($m \cdot sec^{-1}$)	0.24	4.1	7.3	0.25
Peak force (N)	78.58	1.8	3.5	0.96
Peak power (W)	554.43	5.0	9.5	0.80
Mean power (W)	243.50	0.2	7.1	0.89
Relative power ($W \cdot kg^{-1}$)	6.56	5.0	9.5	0.74
Max RFD ($N \cdot sec^{-1}$)	1067.74	11.1	36.3	0.43
Loaded jump 1 (BM + 25%)				
Peak distance (m)	0.03	3.8	8.3	0.71
Peak velocity ($m \cdot sec^{-1}$)	0.10	0.5	3.3	0.83
Peak force (N)	89.03	4.0	4.0	0.95
Peak power (W)	231.72	4.5	4.0	0.95
Mean power (W)	117.49	0.7	3.0	0.98
Relative power ($W \cdot kg^{-1}$)	2.72	4.5	4.0	0.94
Max RFD ($N \cdot sec^{-1}$)	2033.10	−9.0	47.4	−0.04
Loaded jump 2 (BM + 50%)				
Peak distance (m)	0.01	−1.0	3.0	0.95
Peak velocity ($m \cdot sec^{-1}$)	0.17	−0.7	6.4	0.71
Peak force (N)	67.10	3.6	3.1	0.97
Peak power (W)	278.51	2.4	5.9	0.90
Mean power (W)	208.57	1.3	7.9	0.86
Relative power ($W \cdot kg^{-1}$)	3.33	2.4	5.9	0.87
Max RFD ($N \cdot sec^{-1}$)	1097.68	13.6	19.4	0.79

TE = typical error; CV = covariance; ICC = intraclass correlation coefficient; BM = body mass.

TABLE 3. Validity data for differences between player groups.

	Difference between player groups			
	DNT score (mean ± *SD*)	SNT score (mean ± *SD*)	*p* value	Effect size
Body mass				
Jump height (m)	0.43 ± 0.54	0.47 ± 0.48	0.186	0.75
Peak velocity ($m\cdot sec^{-1}$)	3.09 ± .40	3.47 ± .23	0.053	1.14
Peak force (N)	2075.86 ± 269.94	2299.70 ± 196.32	0.101	0.95
Peak power (W)	5905.71 ± 802.89	7386.00 ± 324.21	0.001	2.25
Relative power ($W\cdot kg^{-1}$)	63.34 ± 7.07	79.30 ± 7.13	0.000	2.42
Body mass + 25%				
Jump height (m)	0.37 ± 0.57	0.41 ± 0.53	0.225	0.68
Peak velocity ($m\cdot sec^{-1}$)	2.74 ± 0.25	3.00 ± .15	0.036	1.26
Peak force (N)	2297.29 ± 325.40	2493.30 ± 184.42	0.191	0.74
Peak power (W)	5616.86 ± 756.06	6652.00 ± 549.31	0.026	1.36
Relative power ($W\cdot kg^{-1}$)	60.39 ± 8.25	71.40 ± 8.02	0.013	1.57
Body mass + 50%				
Jump height (m)	0.32 ± 0.74	0.33 ± 0.51	0.759	0.17
Peak velocity ($m\cdot sec^{-1}$)	2.39 ± .26	2.57 ± .16	0.137	0.85
Peak force (N)	2433.71 ± 359.03	2719.86 ± 238.93	0.105	0.94
Peak power (W)	5142.29 ± 765.14	6170.86 ± 512.53	0.025	1.37
Relative power ($W\cdot kg^{-1}$)	55.37 ± 8.88	66.20 ± 6.84	0.012	1.58

DNT = Developmental National Team; SNT = Senior National Team.

validity of the test methodology to discriminate between player groups and to detect training-induced changes after a 12-week training period, Cohen's effect size statistic (ES) was calculated, and the magnitude of differences was interpreted according to the criteria of Cohen (7), where 0.0–0.1 = trivial, 0.1–0.3 = moderate, and 0.3–0.5 = large effect (6,7). In addition, p values were calculated for differences between groups, using Student's t-test with an α level of significance of $p < 0.05$.

RESULTS

Peak force (PF; ICC 0.95–0.97), peak power (PP; ICC 0.80–0.95), mean power (MP; ICC 0.86–0.96), and relative peak power (RPP; ICC 0.74–0.94) were observed to be reliable. Large ES statistic (> 0.50) differences between player groups were observed for PP (1.36–2.25), RPP (1.57–2.42), and PF (0.74–0.95).

The TE, percent change in mean, %CV, and ICC values for the force-velocity variables for the BM, loaded jump 1 (BM + 25%), and loaded jump 2 (BM + 50%) are presented in Table 2. Discriminate validity data are presented in Table 3. Significant ($p < 0.05$) and large (ES > 0.50) changes were detected by the testing protocol pre and post the 12-week intensive training and competition period for several kinetic and kinematic variables used for analysis (Table 4).

DISCUSSION

The purpose of this research project was to evaluate the reliability, validity, and sensitivity of an isoinertial force, velocity, and power assessment utilizing a range of loads and a group of high-performance athletes. The primary and unique finding of this study is that high reliability was observed for the majority of the variables outlined in the incremental load power profile and that these variables were also valid in discriminating between higher and lower performers in two closely matched groups of volleyball players. After a 12-week intensive training period, notable changes were detected by the testing protocol. These results suggest that the incremental load power profile can be a useful method in testing and monitoring, as it was observed to be reliable, valid, and sensitive for use with high-performance athletes.

Although the work by Viitisalo (20) suggested that poorer reliability is observed in loaded jumps as the load increases, we did not come to the same conclusion. In fact, for PP, PF, and RPP, higher reliability was observed with the loaded jumps than with the unloaded jumps. Based on the ICC, TE, and %CV scores across the entire load spectrum, PP, PF, MP, and RPP measures are of the highest reliability, whereas RFD had the highest variability. From a practical perspective, utilizing tests with low TE and %CV scores are important in the evaluation of physical performance, as this allows greater sensitivity to training-induced changes. In other words, if the variable measured in a test has high reliability (as demonstrated by low TE values), the test is more sensitive to training-induced changes because a smaller change would be required to exceed the TE limits, which is required for the practitioner to confidently interpret these changes as real changes induced by training.

TABLE 4. Changes in kinetic and kinematic variables obtained from the incremental load power profile after 12 weeks of intensive training.

	Pretraining period (mean ± *SD*)	Posttraining period (mean ± *SD*)	Change (%)	*p* value	Effect size
Body mass					
Jump height (m)	0.46 ± 0.10	0.48 ± 0.07	3.02	0.058	0.23
Peak velocity ($m \cdot sec^{-1}$)	3.21 ± .30	3.47 ± .46	7.97	0.058	0.67
Peak force (N)	2095.30 ± 230.50	2162.89 ± 179.84	3.24	0.045	0.33
Peak power (W)	6313.44 ± 998.30	7171.78 ± 1244.03	13.60	0.000	0.76
Relative power ($W \cdot kg^{-1}$)	69.86 ± 10.00	78.64 ± 12.00	12.60	0.000	0.79
Body mass + 25%					
Jump height (m)	0.40 ± 0.10	0.39 ± 0.06	−1.23	0.347	0.12
Peak velocity ($m \cdot sec^{-1}$)	2.82 ± 0.30	2.89 ± .29	2.58	0.099	0.24
Peak force (N)	2237.00 ± 258.50	2354.17 ± 230.61	5.24	0.001	0.48
Peak power (W)	5732.50 ± 816.30	6221.83 ± 766.16	8.54	0.000	0.62
Relative power ($W \cdot kg^{-1}$)	63.49 ± 8.40	68.41 ± 7.29	7.75	0.001	0.63
Body mass + 50%					
Jump height (m)	0.32 ± 0.10	0.32 ± 0.05	−0.06	0.403	0.00
Peak velocity ($m \cdot sec^{-1}$)	2.42 ± 0.20	2.42 ± 0.23	−0.30	0.427	0.00
Peak force (N)	2448.24 ± 264.90	2616.67 ± 245.17	6.98	0.000	0.66
Peak power (W)	5372.65 ± 637.60	5368.22 ± 1518.81	−0.08	0.474	0.00
Relative power ($W \cdot kg^{-1}$)	59.12 ± 7.10	59.33 ± 16.80	0.35	0.490	0.00

In interpreting the findings by Viitisalo (20) that higher variability is observed as the external load increased, one must consider that although a force platform was used, maximal displacement (increase of height of center of gravity) was inferred using time in air (TIA) calculations. This is considered a questionable method for obtaining this measure, particularly because an accurate prediction using the TIA method requires the subject to land in the same position in which they took off (3,12,13). Considering that as external loads increase a subject would be more likely to use a less erect landing position, it stands to reason that variability of loaded jumps using this instrumentation method would increase as external load increased. In support of this, previous research has reported high intertrial reliability during loaded jumps for displacement, PF, and PP using the impulse-momentum approach with data collected from a force platform (17). Similarly high intertrial reliability and agreement (precision) with force plate methodology has been observed for PP when using infrared and ultrasound technology (triangulation) (18). Therefore, it would seem that, when measuring force-time characteristics and displacement directly, high reliability is observed in loaded jump testing.

The incremental load power profile seems to be a reliable test, and a valid test in discriminating between higher and lower performers in volleyball. In particular, it seems as though PP, PF, and RPP have the largest utility in discriminating between higher and lower performers in volleyball. Considering that this phenomenon is also prominent as the load increases, this suggests that a key performance indicator in volleyball is power output. As competitive level increases, volleyball players have considerably greater force- and velocity-producing capabilities and, consequently, greater power outputs with lighter and heavier isoinertial loads.

Poor reliability was observed in the rate of force development variable (Table 2). This large variation would make it difficult for a sport scientist to effectively use this variable in interpretation, as very large changes would be required to satisfy confidence of a training-induced change (rather than a change associated with the parameter's inherent variability). Therefore, maximal rate of force development, determined by selecting the largest change in force between two data samples, is likely not a useful parameter for monitoring training-induced changes. It is suggested that future investigations examine the reliability and utility of average rate of force development (average rate of change across all samples in the propulsive portion of the force-time curve) as a possible alternative.

Although the use of jump squats and squat jumps, with and without loads, as a strength and power assessment is not novel (2,4,16), the assessment of power has been a somewhat contentious issue in the literature (1). There has been much debate, ranging from measurement methodology, inclusion or exclusion of body mass in calculations, reporting average versus peak power, and a myriad of other methodological issues (1,11,13). The present study used data collection methods outlined by Dugan et al. (11), in which force, velocity, and position data were collected directly (not inferred through calculation), with body mass included in the load considered for peak and average power output calculations. It is our finding that the test methodology as outlined is reliable, valid, and sensitive for use with high-performance athletes. Importantly, it is our belief that this testing methodology is useful for interpreting individual strength and power characteristics of athletes. Further study using higher loads (75% and 100% of body mass as external load) is underway to assess the utility of incorporating these higher loads into the testing protocol.

After the 12-week training period, notable improvements (2.6–13.6%) were observed in most kinetic and kinematic variables for the BM and BM + 25% condition, with improvements in PF (6.9%) for the BM + 50% condition (Table 4). The changes observed over the 12-week training period, across the variables assessed under different load conditions, highlight the utility of the testing protocol in assessing specific areas of improvement induced by training, and determining the individual needs of each athlete. As external load increases, velocity capabilities (acceleration, peak velocity) are diminished. The extent to which the velocity capabilities diminish as external load increases is a potential method for insightful interpretation of test results. It would seem as though athletes with well-developed force capabilities have less relative drop off in velocity qualities as load increases. Considering that force is composed of mass and acceleration, this observation is predictable in that stronger athletes can accelerate larger masses, whereas weaker athletes cannot accelerate (or achieve relatively high peak velocities) as loads increase. This observation seems to provide a valuable tool in evaluating the training needs and monitoring the progress of athletes (5).

The results of the incremental load power profile also allows for a determination of optimal load for average and peak power output, and this is believed to be an important consideration in designing power training programs (4,10,11). Although it is not clearly known whether this is a critical consideration in designing training programs (9), it is likely a useful outcome of performing this test. The strength and conditioning coach, in an aim to increase PP capabilities, may train using a range of loads that are above, at, and below the load that optimized peak power with that athlete. In other words, if during a testing bout, PP in the loaded jump squat was observed to be achieved at 25 kg of additional mass, the strength and conditioning coach may design a program that involves an emphasis on loads of 15–35 kg. Follow-up testing would not only determine whether increases in peak power occurred, but also determine whether the load at which PP occurred changed as a result of the training intervention.

Using a three-step approach–the incremental load power profile, 1RM, and field testing (e.g. spike jump testing, sprint speed), and measures of performance within a sport (e.g., number of kills, blocks, etc.) –can be a useful model for athlete assessment. The role of the incremental load power profile is to evaluate the underlying force and velocity capabilities. 1RM testing and field testing can be used to assess the application of these capabilities into various movements and to determine appropriate strength training loads, whereas sport-specific testing can be used to assess the application of all these qualities into the sport-specific task.

In conclusion, the purpose of this research project was to evaluate the reliability, validity, and sensitivity of an isoinertial force, velocity, and power assessment using a range of loads and a group of high-performance athletes from varying sporting backgrounds. The results of this study indicate that the incremental load power profile is a reliable test methodology, is valid in discriminating between higher and lower performers, and is sensitive enough to detect training-induced changes in men's volleyball.

PRACTICAL APPLICATIONS

In conjunction with sport-specific testing, field testing, and 1RM testing, assessing the force-velocity qualities of the leg extensors against a range of external loads can provide the sport scientist and strength and conditioning coach with insight into the training needs of an individual athlete. As an example, if an athlete's results demonstrate that their acceleration and velocity is poor as external load is added, then the strength and conditioning coach can interpret this and design training accordingly (i.e., emphasis on heavy load strength and high load power training). If an athlete's test results demonstrate that they decrease very little in their acceleration and velocity qualities as external load is added, yet body mass and low load power is considered an important attribute for this athlete, the strength and conditioning coach can interpret this finding and design training accordingly (i.e., emphasis on unloaded/low load jumps, plyometrics, etc.).

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