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Comparison of Four Different Methods to Measure Power Output During the Hang Power Clean and the Weighted Jump Squat

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Abstract. Hori, N., R.U. Newton, W.A. Andrews, N. Kawamori, M.R. McGuigan, and K. Nosaka. Comparison of four different methods to measure power output during the hang power clean and the weighted jump squat. *J. Strength Cond. Res. 21(2):314–320. 2007.*—Measurement of power output during resistance training is becoming ubiquitous in strength and conditioning programs, but there is great variation in the methods used. The main purposes of this study were to compare the power output values obtained from 4 different methods and to examine the relationships between these values. Male semiprofessional Australian rules football players ($n = 30$) performed hang power clean and weighted jump squat while ground reaction force (GRF)-time data and barbell displacement-time data were sampled simultaneously using a force platform and a linear position transducer attached to the barbell. Peak and mean power applied to the barbell was obtained from barbell displacement-time data (method 1). Peak and mean power applied to the system (barbell + lifter) was obtained from 3 other methods: (a) using GRF-time data (method 2), (b) using barbell displacement-time data (method 3), and (c) using both barbell displacement-time data and GRF-time data (method 4). The peak power values (W) obtained from methods 1, 2, 3, and 4 were (mean ± *SD*) 1,644 ± 295, 3,079 ± 638, 3,821 ± 917, and 4,017 ± 833 in hang power clean and 1,184 ± 115, 3,866 ± 451, 3,567 ± 494, and 4,427 ± 557 in weighted jump squat. There were significant differences between power output values obtained from method 1 vs. methods 2, 3, and 4, as well as method 2 vs. methods 3 and 4. The power output applied to the barbell and that applied to the system was significantly correlated ($r = 0.65–0.81$). As a practical application, it is important to understand the characteristics of each method and consider how power output should be measured during the hang power clean and the weighted jump squat.

Key Words. barbell displacement, position transducer, ground reaction force, force platform, weightlifting

Introduction

Power is the mechanical quantity defined as the rate of doing work and is obtained as work ÷ time or force × velocity (14). For a given task, the success of performance is largely affected by how much power is applied toward objects (e.g., ground, ball, sporting equipment). Thus, improving power output during sports performance is one of the most important goals for strength and conditioning programs (1). To maximize the power output during specific movements in sport, a strength and conditioning program should incorporate a long-term strategy (16). For example, the emphasis of a program may shift from one phase to the next phase targeting capabilities of maximum force output (i.e., maximum strength), maximum power output, or power output against relatively light loads. To monitor the changes in the athlete's capability of power output during a given task at a given load, it is meaningful to measure power output frequently, at least before and after each training phase (1, 10, 13). Although the training modality should satisfy the needs of the sports for which one is training (e.g., muscle groups involved, characteristics of force-time curve, form of muscle action: concentric, eccentric or isometric, energy system utilized, etc.), it seems important that the form of testing be close to the form of training to monitor the athlete's progress. For this reason, considerable research attention has been directed at measuring power output during common resistance training exercises, such as hang power clean and weighted jump squat (2, 8, 11, 15, 17, 21). There are several methods to measure power output, and the following 4 methods were commonly utilized in recently reported research (7, 10).

- Method 1: From displacement-time data of barbell movement, power applied to the barbell is obtained using an inverse dynamics approach (3, 12).
- Method 2: From ground reaction force (GRF)-time data, power applied to the system (barbell + body) is obtained using a forward dynamics approach (8, 11).
- Method 3: From displacement-time data of the barbell, power applied to the system (barbell + body) is obtained using an inverse dynamics approach (2, 4, 17).
- Method 4: From both displacement-time data of the barbell and GRF-time data, power applied to the system (barbell + body) is obtained as the barbell velocity × GRF (5, 19, 21).

Although past studies (2, 8, 11, 15, 17, 21) utilized one of these methods to calculate power output during resistance training exercises, no studies have ever examined if there are any differences in the power output values obtained from the different methods during a given task. Methods 1 and 2 are logically valid, even when the center of gravity (COG) of the barbell and that of the system do not move in parallel, but the validity of methods 3 and 4 would depend on whether the COG of the barbell and that of the system move in parallel or not. In the weighted jump squat, previous studies (2, 4, 5, 17, 21) assumed that the COG of the barbell and that of the system move in parallel. However, it is obvious that the COG of the barbell and that of the system do not move in parallel during weightlifting exercises, such as snatch, clean, jerk, and variations of these exercises (10). For this reason, methods 3 and 4 have been used in previous research measuring power output during weighted jump squat (2, 4, 5, 17, 21), but not during the weightlifting exercises, except for one study that used method 4 to measure power output during power clean from the floor (19). Given the increasing use of power measurement to assess performance changes and provide feedback to the athlete and coach, it is important to assess the common methods utilized during 2 of the most commonly measured movements so as to elucidate reliability, validity, and methodological issues of these techniques. Further, some studies report mean power (2, 3, 4) and others peak power (8, 11, 15, 18, 19, 21), so it would be instructive to compare these measures across movement and measurement techniques.

The purposes of this study were to (a) examine if there is any difference between the power output values obtained from methods 3 and 4 and the value obtained from method 2, (b) examine the relationships between the power applied to the barbell and the power applied to the system during hang power clean and weighted jump squat, and (c) examine the relationships between peak and mean power values obtained from each method. First, it was hypothesized that methods 2, 3, and 4 would exhibit similar power output values during the weighted jump squat but that the values obtained from methods 3 and 4 during the hang power clean would be quite different from the value obtained from method 2. Second, if the ability to apply power to the system largely influences the ability to apply power to the barbell, the power output values obtained from methods 1 and 2 would be significantly correlated. Because a position transducer is generally less expensive and easier to transport than a force platform, the position transducer may be considered a reasonable alternative to the force platform if the values obtained from methods 1 and 2 are well correlated (10). Third, it was hypothesized that the peak and mean power values would be closely correlated and thus scientists and practitioners could use either measure as a performance indicator. In general, mean power values obtained from the concentric phase are believed more reliable (10). However, this requires determination of exact start and end points of the concentric phase, which can be somewhat arbitrary, with small errors resulting in significant changes in resulting mean power. It is much more exact and faster to obtain peak power measurements, and if peak and mean power essentially reflect the same performance capability, it would be recommended to measure peak power.

METHODS

Experimental Approach to the Problem

Thirty subjects performed hang power clean and weighted jump squat on a force platform with a linear position transducer attached to the barbell. The vertical component of GRF and the displacement of the barbell were sampled simultaneously. The power applied to the barbell was calculated using method 1, and the power applied to the system (barbell + body) was calculated using methods 2, 3, and 4. Peak and mean power (method 1: power applied to the barbell; methods 2, 3, and 4: power applied to the system) and peak velocity (methods 1, 3, and 4: velocity of the barbell; method 2: velocity of the COG of the system) and peak force (method 1: force applied to the barbell; methods 2, 3, and 4: force applied to the system) obtained from these 4 methods were compared. In addition, to examine the relationships between peak and mean power applied to the barbell and that applied to the system (barbell + body), the correlations between values obtained from methods 1 and 2 were calculated.

TABLE 1. Intraclass correlation coefficient of the measurements.

	Method 1	Method 2	Method 3	Method 4
Hang power clean				
Peak velocity	0.89	0.86	0.89	0.89
Peak force	0.62	0.89	0.89	0.89
Peak power	0.67	0.90	0.71	0.89
Mean power	0.74	0.90	0.66	0.91
Weighted jump squat				
Peak velocity	0.84	0.96	0.84	0.84
Peak force	0.71	0.94	0.58	0.94
Peak power	0.79	0.97	0.65	0.91
Mean power	0.70	0.89	0.70	0.89

Subjects

Thirty men were recruited from a semiprofessional Australian Rules Football team. Their age, height, body mass, and one repetition maximum (1RM) hang power clean were (mean ± *SD*) 21.3 ± 2.7 years, 181.6 ± 6.3 cm, 84.0 ± 8.3 kg, and 75.3 ± 8.6 kg, respectively. The subjects had at least 3 months of experience in performing resistance training exercises, such as hang power clean and squat, at the time of data collection. None of the subjects had any illness or injuries that would affect the test results. This study was conducted during January and February 2006. These months were the off season between their 2005 and 2006 seasons. This study was approved by the University's Human Research Ethics Committee. All subjects read the information letter explaining the procedure of the study and signed the informed consent document.

Tests and Measurement Order

The testing was administered on 3 different days, and each test day was separated by at least 48 hours to minimize the effects of fatigue. The order of test measurements was as follows: (a) day 1: weighted jump squat with 40 kg; day 2: 1RM hang power clean; day 3: hang power clean with 70% of 1RM load.

Test Procedures

On day 1, subjects performed jump squat with countermovement with a 40-kg barbell carried across the shoulders. The subject's feet position and grip width were self-selected. The barbell was placed on their upper trapezius, immediately below C7. They squatted down to a self-selected depth (typically 90° knee flexion) and then immediately jumped as high as possible. The subjects performed the weighted jump squat twice, and the average of peak velocity, peak force, and peak and mean power values of the 2 repetitions were used for statistical analysis. Intraclass correlation coefficient (ICC) and coefficient of variation (CV) were calculated from the 2 repetitions and are presented in Tables 1 and 2. The rationale for selecting this load was (a) this load has been used previously when testing professional Australian Rules Football players (21), and (b) 40 kg had been the load most frequently utilized during weighted jump squat training by the subjects, and so they were accustomed to jumping with this load.

On day 2, 1RM hang power clean was tested. The hang power clean was started from a position in which

Table 2. Coefficient of variation of the measurements.

	Method 1	Method 2	Method 3	Method 4
Hang power clean				
Peak velocity	3.1	4.5	3.1	3.1
Peak force	15.1	4.7	15.4	4.7
Peak power	13.9	6.0	14.9	6.2
Mean power	12.4	7.9	15.3	6.7
Weighted jump squat				
Peak velocity	2.5	1.2	2.5	2.5
Peak force	2.7	1.8	9.0	4.7
Peak power	4.0	1.8	10.4	3.3
Mean power	6.8	3.6	11.1	3.9

the subject was standing holding the barbell in front of his body. The subjects began the movement by lowering the barbell to above their knees. From this position, the subjects lifted the barbell upward explosively and brought the barbell to their shoulders in one movement (11). Subjects' 1RM was estimated from recent training histories. Based on this estimated 1RM, the weights to be lifted during a series of warm-up sets was determined. In each set, subjects performed 1 to 3 repetitions, and the weight was increased after each set. Subjects started the warm-up set with the bar only (20 kg), 20 to 40 kg was added to each set until the load was about 60% of estimated 1RM, and then 5 to 10 kg was added until the load was 90% of estimated 1RM. After these sets were completed, the weight was increased by 2.5 or 5 kg after each set until their 1RM was determined.

On day 3, subjects performed the hang power clean using 70% of 1RM load. The barbell was placed on the 40-cm pulling blocks. The subject picked the barbell up from the blocks and performed the hang power clean as previously described. Data sampling was started after the barbell was lifted off the pulling blocks. The subjects performed the hang power clean twice, and the average of peak velocity, peak force, and peak and mean power values of the 2 repetitions were used for statistical analysis. The ICC and CV were calculated from the 2 repetitions and are presented in Tables 1 and 2. The selection of this load was based on the report that the power output during the hang power clean was maximized at around 70% of 1RM load (11). Additionally, 70% of 1RM has been the load most frequently utilized during hang power clean training by the subjects.

Hang power clean and weighted jump squat were performed on a force platform (Performance Plate, Fitness Technology, Adelaide, Australia), and a linear position transducer (PT5A-150-V62-UP-IK-C25, Celesco, Canoga Park, CA) was attached to the barbell. The vertical component of GRF and displacement of the barbell were sampled simultaneously at 200 Hz for 5 seconds using computer software (Ballistic Measurement System, Innervations, Perth, Australia), and the vertical component of power output was obtained using the 4 different methods. Method 1: To obtain the velocity-time data of the barbell, the displacement-time data of the barbell were smoothed using a Butterworth 4th order digital low-pass filter with a cut-off frequency of 16 Hz prior to differentiation using finite difference technique. To obtain barbell acceleration-time data, displacement-time data of the barbell were smoothed using a Butterworth 4th order digital low-pass filter with a cut-off frequency of 10 Hz prior to double differentiation using a finite difference technique. Force applied to the barbell was obtained as the barbell mass × barbell acceleration + barbell weight (barbell mass × g, where $g = -9.81\ m{\cdot}s^{-2}$) at each time point. To obtain power applied to the barbell, the force applied to the barbell was multiplied by the velocity of the barbell at each time point. Method 2: Velocity of the COG of the system (barbell + body) was calculated from GRF time data based on the relationship between impulse and momentum in which impulse is equal to the changes in momentum (forward dynamics approach) (7, 10). Power applied to the system was calculated as the product of velocity of the COG of the system and GRF at each time point. Method 3: The velocity and acceleration of the barbell were obtained as described in method 1. Force applied to the system was obtained as the system mass (i.e., barbell mass + body mass) × barbell acceleration + system weight ([barbell mass + body mass] × g, where $g = -9.81\ m{\cdot}s^{-2}$) at each time point. To obtain power applied to the system, the force applied to the system was multiplied by the velocity of the barbell at each time point. Method 4: Displacement-time and velocity-time data for the barbell were obtained as described in method 1. Power applied to the system was obtained as GRF × barbell velocity at each time point.

In all 4 methods, peak power and mean power (method 1: power applied to the barbell; methods 2, 3, and 4: power applied to the system [barbell + body]), as well as peak velocity (methods 1, 3, and 4: velocity of the barbell; method 2: velocity of the COG of the system) and peak force (method 1: force applied to the barbell; methods 2, 3, and 4: force applied to the system), were obtained. The mean power was determined as the average of the concentric phase. The beginning of concentric phase was defined as the time point where the direction of displacement (methods 1, 3, and 4: displacement of the barbell; method 2: displacement of the COG of the system) changed from downward (eccentric phase) to upward (concentric phase), at which point the velocity (methods 1, 3, and 4: velocity of the barbell; method 2: velocity of the COG of the system) became 0 m/s (i.e., power became 0 W). The end of concentric phase was defined as the time point where the acceleration of the barbell became $-9.81\ m{\cdot}s^{-2}$ in methods 1 and 3 and the GRF became 0 N in methods 2 and 4. However, during the hang power clean, some of the subjects' feet were not projected into the air, even if they finished their concentric muscle action of hip, knee, and ankle extension. If this was the case, the acceleration of the barbell did not reach $-9.81\ m{\cdot}s^{-2}$ in methods 1 and 3 and GRF did not become 0 N in methods 2 and 4. Therefore, the completion of concentric phase was determined as the time point where acceleration of the barbell (in methods 1 and 3) or GRF (in methods 2 and 4) was at a minimum.

Statistical Analyses

Mean ± *SD* was calculated using standard methods. In each exercise, the peak velocity, peak force, and peak power and mean power values obtained from the 4 methods were compared using 1-way analysis of valiance (ANOVA) with Tukey's posthoc test. Pearson's product moment correlation coefficients were obtained to examine the relationships between the peak and mean power values obtained from the 4 methods. In addition, Pearson's product moment correlation coefficients between peak and mean power values obtained from each method were calculated. Criterion alpha level for significance was set at $p \leq 0.05$ for all analyses.

TABLE 3. Peak velocity, peak force, peak power, and mean power during hang power clean and weighted jump squat (mean ± *SD*).

	Method 1	Method 2	Method 3	Method 4
Hang power clean				
Peak velocity (m/s)	2.16 ± 0.25‡	1.48 ± 0.20*	2.16 ± 0.25‡	2.16 ± 0.25‡
Peak force (N)	1,022 ± 171‡	2,512 ± 310*	2,358 ± 453*	2,512 ± 310*
Peak power (W)	1,644 ± 295‡	3,076 ± 638*	3,821 ± 917*‡	4,017 ± 833*‡
Mean power (W)	795 ± 164‡	1,325 ± 333*	1,832 ± 414*‡	1,804 ± 401*‡
Weighted jump squat				
Peak velocity (m/s)	2.23 ± 0.16‡	1.99 ± 0.12*	2.23 ± 0.16‡	2.23 ± 0.16‡
Peak force (N)	718 ± 43‡	2,151 ± 172*	2,159 ± 231*	2,151 ± 172*
Peak power (W)	1,184 ± 115‡	3,866 ± 451*	3,567 ± 494*†	4,427 ± 557*‡
Mean power (W)	675 ± 80‡	1,936 ± 221*	2,032 ± 341*	2,324 ± 291*‡

* Significant difference from method 1 ($p < 0.01$).
† Significant difference from method 2 ($p < 0.05$).
‡ Significant difference from method 2 ($p < 0.01$).

TABLE 4. Correlation between peak power values obtained from different methods.

	Method 1	Method 2	Method 3	Method 4
Hang power clean				
Method 1				
Method 2	0.70*			
Method 3	0.70*	0.74*		
Method 4	0.72*	0.97*	0.81*	
Weighted jump squat				
Method 1				
Method 2	0.74*			
Method 3	0.69*	0.86*		
Method 4	0.80*	0.98*	0.89*	

* Correlation was significant at the 0.01 level.

TABLE 5. Correlation between mean power values obtained from different methods.

	Method 1	Method 2	Method 3	Method 4
Hang power clean				
Method 1				
Method 2	0.65*			
Method 3	0.68*	0.63*		
Method 4	0.63*	0.94*	0.67*	
Weighted jump squat				
Method 1				
Method 2	0.81*			
Method 3	0.79*	0.80*		
Method 4	0.85*	0.98*	0.79*	

* Correlation was significant at the 0.01 level.

RESULTS

The comparison of values obtained from the 4 methods is presented in Table 3, and relationships between peak and mean power values obtained from the different methods appear in Tables 4 and 5. The relationships between peak and mean power values obtained from each method are presented in Table 6. In addition, the displacement-time curve, velocity-time curve, force-time curve, and power-time curve of representative subjects in the hang power clean (Figures 1, 2, 3, and 4) and the weighted jump squat (Figures 5, 6, 7, and 8) are presented. Although data were sampled for 5 seconds, the values obtained before 1.5 and after 4.0 seconds are not presented for clarity. Peak and mean power values applied to the COG of the system obtained from methods 3 and 4 in the hang power clean were significantly different from the values obtained from method 2 ($p < 0.01$). Peak power values obtained from methods 3 and 4 in weighted jump squat were significantly different from the value obtained from method 2 ($p < 0.05$). The mean power value obtained from method 4 in the weighted jump squat was significantly different

TABLE 6. Correlation between peak and mean power values obtained from different methods.

	Method 1	Method 2	Method 3	Method 4
Hang power clean	0.87*	0.82*	0.90*	0.80*
Weighted jump squat	0.90*	0.86*	0.93*	0.91*

* Correlation was significant at the 0.01 level.

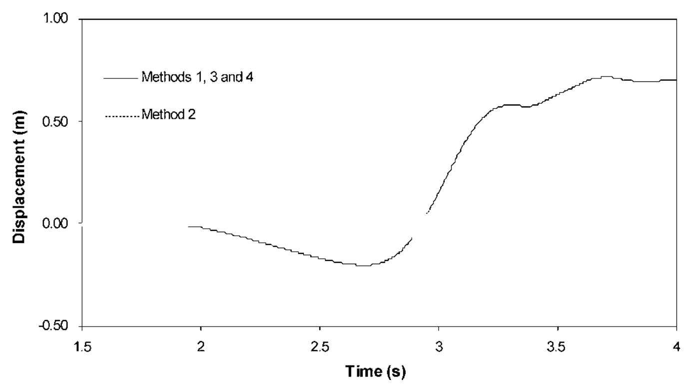

FIGURE 1. Displacement-time curve during hang power clean.

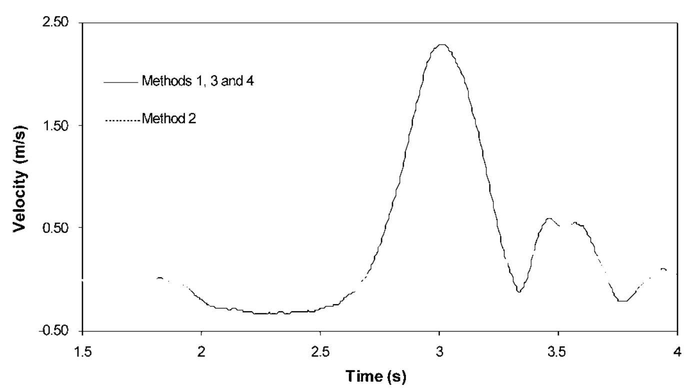

FIGURE 2. Velocity-time curve during hang power clean.

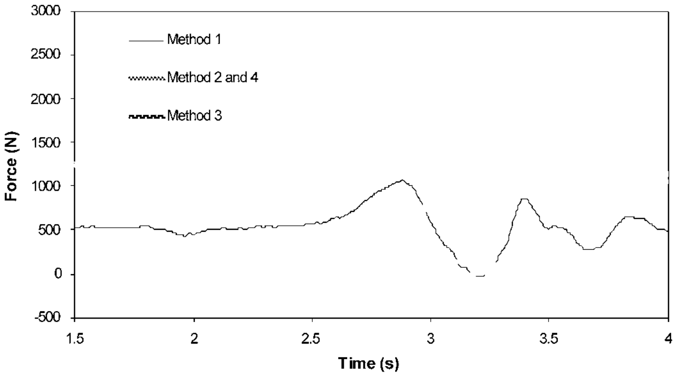

Figure 3. Force-time curve during hang power clean.

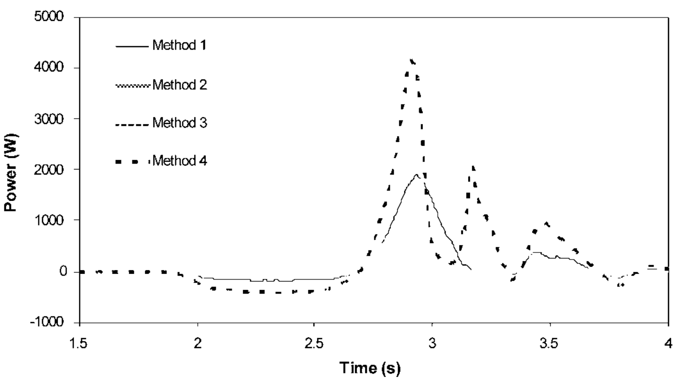

Figure 4. Power-time curve during hang power clean.

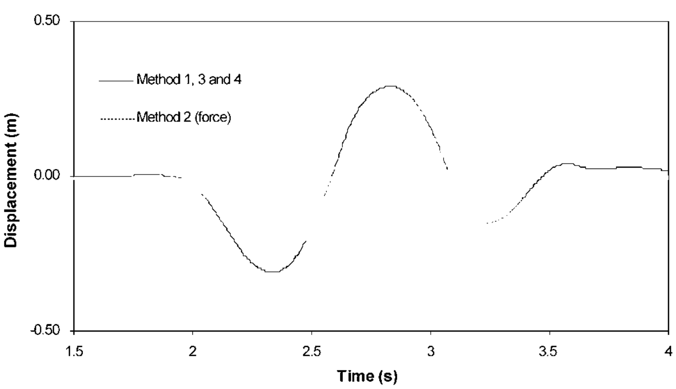

Figure 5. Displacement-time curve during weighted jump squat.

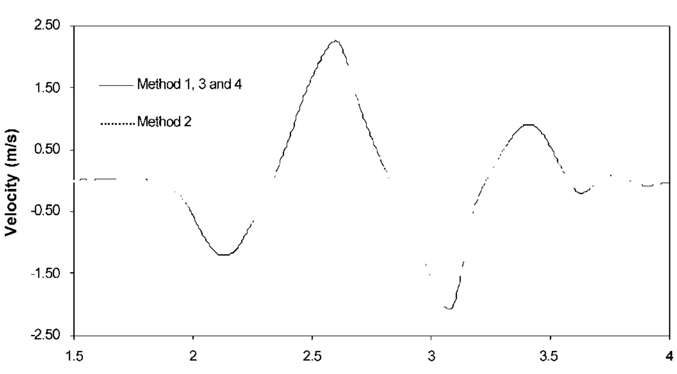

Figure 6. Velocity-time curve during weighted jump squat.

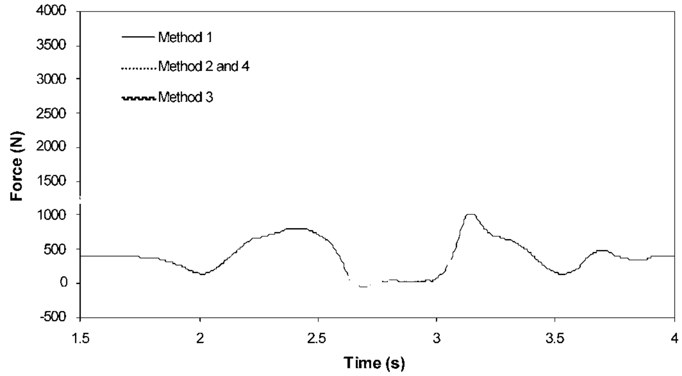

Figure 7. Force-time curve during weighted jump squat.

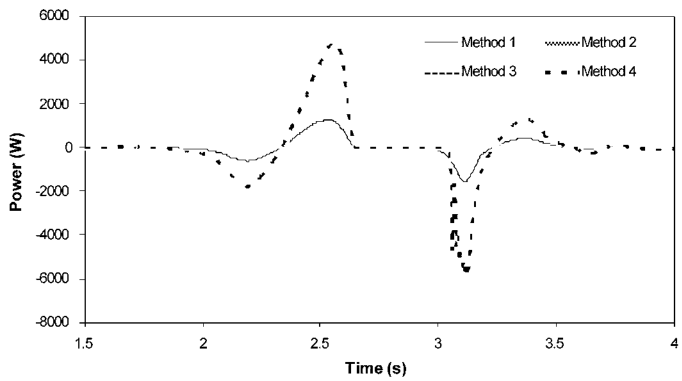

Figure 8. Power-time curve during weighted jump squat.

from the value obtained from method 2. In addition, the peak velocity of the COG of the system obtained from method 2 was significantly lower than that of the barbell obtained from methods 1, 3, and 4 in both exercises. Peak force, peak power, and mean power applied to the barbell obtained from method 1 were significantly lower than the values applied to the system obtained from methods 2, 3, and 4 in both exercises. There were significant correlations between the peak and mean power values obtained from methods 1 and 2 in hang power clean and weighted jump squat ($r = 0.65–0.81$, $p < 0.01$). The peak and mean power values were significantly correlated in all 4 methods ($r = 0.80–0.93$, $p < 0.01$).

Discussion

The major finding of this study was significant and meaningful differences in results for force, power, and velocity, depending on how these measures were derived. Further, method 2, which involved measurement of all variables based only on GRF, proved to be the most reliable technique (Tables 1 and 2). Theoretically, method 2 is valid unless the exercise is started from the floor or pulling blocks because the force platform cannot measure forces applied remote to the plate surface (10). On the other hand, methods 3 and 4 are valid only if the COG of the barbell moves in parallel with the COG of the system. The displacement and velocity of COG of the barbell and system during the weighted jump squat (Figures 5 and 6) were not as different as those curves of the hang power clean (Figures 1 and 2). However, the velocity of COG of the barbell and that of the system during the weighted jump squat were still significantly different, and the power outputs obtained from methods 3 and 4 were different from that obtained from method 2 (Table 3). Thus, we should not assume that the COG of the barbell and that of the system move exactly in parallel, even during weighted jump squat. Because power is the product of force × velocity, the difference between the displacement-time curve (Figure 5), velocity-time curve (Figure 6), and force-time curve (Figure 7) obtained from different methods may be enlarged when force is multiplied by velocity. Although several studies (2, 17, 21) assumed that COG of the barbell and that of the system move in parallel during weighted jump squat, this appears to be an erroneous assumption, because marked differences have been shown in the present study. On the other hand, the displacement of the COG of the barbell during the hang power clean was clearly larger than that of the system, and this was even more evident for velocity (Figures 1 and 2). Because Hori et al. (10) suggested that the COG of the barbell and that of the system did not move in parallel during weightlifting exercises, these results were expected in hang power clean.

The peak force, peak power, and mean power values applied to the barbell obtained from method 1 were significantly lower than the values applied to the system obtained from method 2 in both the hang power clean and the weighted jump squat. This was expected because method 1 only accounts for the forces applied to the barbell and does not consider the acceleration or mass of the lifter's body. Thus, the differences between methods 1 and 2 are expected when power is measured during the exercises that include large movement of the lifter's body, such as hang power clean and weighted jump squat (10). Further, the less the relative weight of the barbell to body weight, the greater disparity between measures of force and power. Although method 1 exhibited lower power output values than method 2, it does not mean method 1 is incorrect. Rather, method 1 is specifically measuring the power applied to the barbell, which may be a primary outcome measure when assessing weightlifting performance. However, the correlations between power measured by methods 1 and 2 suggest such barbell measures do not completely reflect the actual power output developed by the athlete and transmitted through the feet. Because most sports involving jumping, sprinting, and change of direction are dictated by power transfer through the lower extremities to the ground, this is an important consideration with regard to the validity of method 1 for measuring sport relevant power performance.

It is noteworthy that the power value obtained from method 2 (ICC = 0.89–0.97, CV = 1.8–7.9) exhibited higher ICC and smaller CV than that obtained from other methods (ICC = 0.58–0.94, CV = 2.5–15.4, Tables 1 and 2). To explain this fact, 2 reasons are speculated. First, it seems that the subjects' power application toward the barbell was not as consistent as the power application toward the force platform. Although there was a significant correlation between the power applied to the barbell (method 1) and that applied to the system (method 2), it seems likely the ability to exert power toward the barbell is influenced by factors other than the ability to exert power toward the ground. Second, to calculate force applied to the barbell in method 1, the displacement-time data of the barbell was differentiated twice to obtain acceleration and thus force applied to the barbell or to the COG of the system, and thus small errors are amplified, resulting in reduced accuracy of force measurement. On the other hand, the GRF-time data were measured directly from the force plate and then integrated once to obtain velocity of the COG of the system in method 2. Because method 1 requires additional calculations, it may be possible that small measurement errors occurring in displacement-time data of the barbell are magnified during the double differentiation process. This combined with the influence of data filtering and cut-off frequency can influence derived measures, such as peak and mean power, a phenomenon well described in the biomechanics literature (20).

As was expected, there were very strong relationships between peak and mean power values (Table 6). Further, although mean power is believed more reliable than peak power (10), it was not the case in this study (Tables 1 and 2). In addition, it is suggested that peak power value is more related to the actual athletic performance (7, 9, 10). Thus, scientists and practitioners should consider using peak power values rather than mean. As mentioned previously, it is generally easier to find the peak power than to calculate the mean power, so this finding would be useful.

In conclusion, the present study revealed the power output values applied to the COG of the system obtained from the barbell displacement-time data only (method 3), and both the barbell displacement-time and the GRF-time data (method 4) were significantly different from the value obtained from the GRF-time data only (method 2). In addition, this study found significant correlation between the power applied to the barbell (method 1) and that applied to the COG of the system (method 2), as well as the strong correlation between peak and mean power values obtained from each method. It is speculated that the findings of this study might be applicable for female athletes, but the present study involved men only. Thus, future research investigating the validity and reliability of these methods in female athletes is warranted.

PRACTICAL APPLICATIONS

Because of the difference between values obtained from the 4 methods, it is important to consider the results presented in previous studies using methods 3 and 4 with caution (2, 4, 5, 17, 19, 21). Practitioners are recommended to use displacement measurement and bar mass to estimate power output applied to a barbell and to use measurement of GRF to measure power output applied to the COG of a system during hang power clean and weighted jump squat. Practitioners should also be aware of the fact that power output values calculated using these 2 methods are basically different quantities. Usually, it is the latter (i.e., power output applied to the COG of a system) that is of importance because the displacement of the COG of a subject's body accounts for a meaningful portion of mechanical work during such exercises as hang power clean and weighted jump squat (6). Thus, the use of GRF data may be the most direct and valid way to measure power output during hang power clean and weighted jump squat. If practitioners use barbell displacement measurement as an alternative to GRF measurement, they should be aware of the limitations of this method. Although the values obtained from methods 1 and 2 were significantly correlated (r = 0.65–0.81), measurement of barbell kinetics and kinematics may not adequately explain the effects of a training intervention on changes in whole body power capacity. In other words, the improvement of power output applied to the barbell may not necessarily be associated with the improvement of the power output of the total body applied the ground. For example, it may be that power applied to the barbell is improved due to the improvement of lifting technique, even if the ability to exert force and power toward the ground is not improved.

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