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Comparison of Different Methods of Determining Power Output in Weightlifting Exercises

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summary

Measurement of power output during weightlifting movements provides useful information about an athlete's performance. However, there are various methods used, each with specific considerations, advantages, and disadvantages. This article discusses the methods of measuring power output in weightlifting exercises in these terms.

Figure 1. In our laboratory, the position transducer is placed above the ceiling.

Introduction

Position transducers (Figures 1and 2) and force platforms (Figures 3 and 4) are widely utilized by scientists and strength and conditioning specialists, who use this equipment to measure power output during exercise and thus obtain useful information to evaluate athletes' speed strength (17).

Because weightlifting exercises (e.g., power clean and power snatch) are effective training methods to improve speed strength and cause less landing impact than the jump squat does, many athletes utilize these exercises in their training (4, 10). Thus, it would be helpful to coaches if they could measure the power output in weightlifting exercises and in particular understand the limitations of the different measurement systems. Further, although many studies have measured power output in the jump squat using a position transducer and-or a force platform (1–3, 5, 14, 15, 19, 20), few studies have been performed on weightlifting exercise to date (7, 8, 13, 16, 21). Although there are 4 methods to obtain power output in the jump squat based on previous research (5), it is important to

Figure 2. The cable end of the position transducer can be attached to the barbell.

know whether we can utilize all of these methods for measuring power output in weightlifting exercises.

The purpose of this article is to provide readers with a basic knowledge of the various methods commonly used to measure power output in weightlifting exercises. This knowledge is important to strength and conditioning specialists, who can apply it toward understanding the underlying processes of measurement and calculation used by the various power measurement systems. However, to explain the complete biomechanics of power is beyond the scope of this article, and the interested reader is therefore referred elsewhere (5). Through the following sections, we first introduce the four common methods to measure power output in the jump squat. Then we discuss whether these methods can be applied to measure power output in weightlifting exercises. Finally, we discuss how coaches can utilize the power output data for testing and training their athletes.

Measuring Power Output in the Jump Squat

Ground reaction force (GRF) can be determined by performing jump squats on a force platform, and barbell displacement data can be obtained by using a position transducer attached to the bar. Usually, these data are collected as analogue data from a position transducer or force platform and then converted to digital data and interfaced with desktop or laptop computer hardware. Once data are stored, calculations are performed by special software. Analysis of GRF data, barbell displacement data, or both reveals four possible methods of obtaining power output in the jump squat (5) (Table 1):

- Method 1: Calculation from barbell displacement and known mass (barbell mass and lifter's body mass).
- Method 2: Calculation from barbell displacement and known mass (barbell mass only).
- Method 3: Calculation from GRF and known mass (barbell mass and lifter's body mass).
- Method 4: Calculation from barbell displacement and GRF.

In method 1, the displacement data are obtained at each time point based on the sampling rate (number of measurements of position recorded per second). Velocity is calculated from displacement data and sampling rate using the process of differentiation, which basically involves determining the rate of change of displacement between successive samples. To calculate acceleration data, the process is repeated, termed *double differentiation,* but in this case the rate of change of velocity between two consecutive time points is calculated. Force is then calculated by multiplying the known mass (barbell mass and lifter's body mass) by the acceleration data. Power is calculated by multiplying the force data by the velocity data (5). This method assumes that the displacement of center of gravity (COG) of the system mass (total of barbell mass and lifter's body mass) is the same as the displacement of the barbell (5). This is clearly a limitation of the method because even a cursory observation of the jump squat movement reveals that the lifter's body and in particular the lower legs and feet do not move synchronously with the barbell. Also, there are well-established inaccuracies in using this *inverse dynamics approach,* which estimates force output based on the displacement-time data. Suffice to say that this method does not provide as accurate force data as does direct measurement.

In method 2, the process of calculation is basically the same as method 1. The only difference is that the lifter's body mass is not included in the calculation of force and subsequently power output. This does overcome the problem of assuming

Figure 3. Hang power snatch (start) is performed on a force platform.

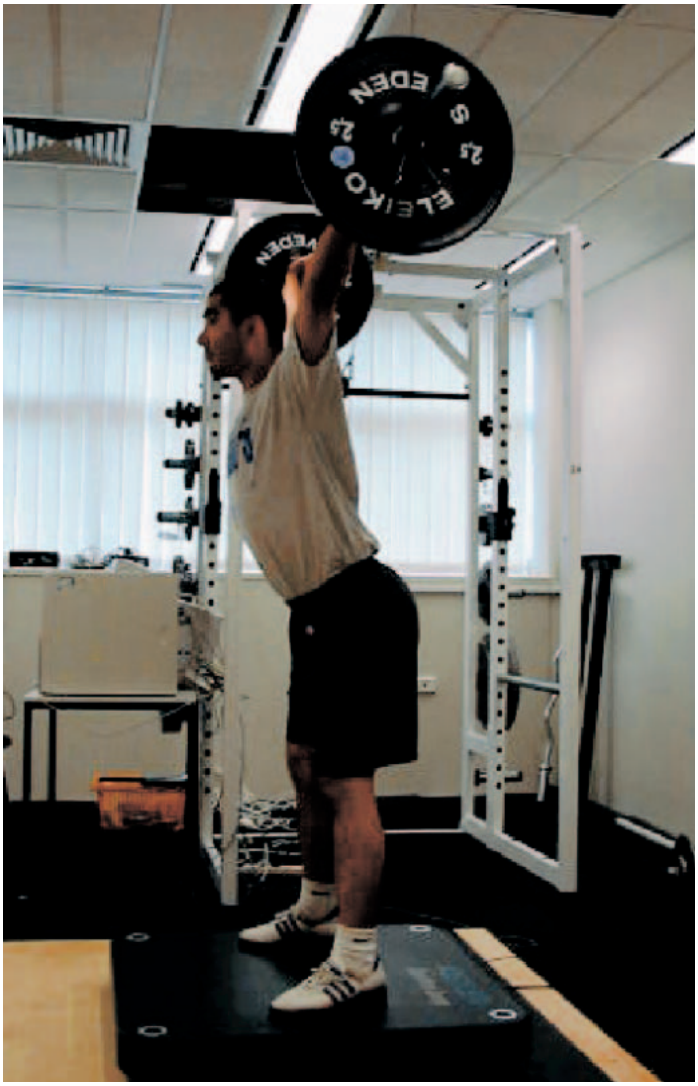

Figure 4. Hang power snatch (finish).

the barbell movement is representative of the whole system of barbell and lifter. However, one should note that the power output value obtained from method 2 will be significantly lower than that obtained from methods 1, 3, and 4 because only the power being applied to the barbell is being calculated, and, as such, this method underestimates the actual power output of the leg and trunk extensors being applied to the ground (5). This method has the added advantage that it can be reliably utilized for measuring power output in a wide range of resistance exercises, including upper body movements, such as the bench press.

In method 3, the force exerted by feet on the ground is directly obtained from a force platform at each time point. From force data, acceleration is calculated by dividing the force by the known mass (barbell mass and lifter's body mass) since force is the product of mass and acceleration (5). Velocity is calculated from the force data using the impulse-momentum relationship (equation 1).

$$\text{Equation 1: } F \cdot t = m(v_f - v_i)$$

Where F = force, t = time, m = mass, v_f = final velocity, v_i = initial velocity.

This process, termed the *forward dynamics approach,* involves integrating (calculation of area under the curve) the force-time data and dividing by the known mass to determine change in velocity between consecutive samples. A crucial requirement for this analysis is that the initial velocity at the start of data collection be 0. In other words, when data collection starts, the lifter and barbell must be stationary. Power output is calculated by multiplying the measured force by the calculated velocity (5). Because force is obtained from the force platform as GRF, it does not matter if the

Table 1
Methods of Measuring Power Output in Weightlifting Exercises

	Method 1	Method 2	Method 3	Method 4
Equipment	Position transducer	Position transducer	Force platform	Position transducer Force platform
Mass	Barbell + lifter's body	Barbell	Barbell + lifter's body	Barbell + lifter's body
Acceleration	Obtained from velocity data and known sampling rate	Obtained from velocity data and known sampling rate	Force / mass	Not necesary for calculation of power
Force	Mass x acceleration	Mass x acceleration	Obtained from the force platform	Obtained from the force platform
Velocity	Obtained from barbell displacement data and known sampling rate	Obtained from barbell displacement data and known sampling rate	Acceleration obtained from force. Velocity obtained from acceleration if initial velocity is zero.	Obtained from barbell displacement data and known sampling rate
Power	Force × velocity	Force × velocity	Force × velocity	Force × velocity
Application	Valid for jump squat. Validity for weightlifting exercises is questionable.	Vailid for both jump squat and weightlifitng exercises	Vailid for both jump squat and weightlifitng exercises	Reasonable for jump squat. May be acceptable for peak power during weightlifitng exercises.

COG of the barbell and that of the lifter move simultaneously or separately and the lifter's body mass is included into the calculations of velocity and power. This method is also prone to errors in velocity and power calculation because the integration process magnifies any slight measurement errors in force. For this reason it is critical that the force plate system is accurately calibrated and in particular is correctly set to 0 prior to data collection (5). A further limitation is that the system must be isolated on the force platform and no part of the lifter or barbell can be in contact with any other surface. For example, it is not recommended to measure power output by using method 3 during the exercises started from the floor (e.g., power snatch from floor), but the lifts can be started from anywhere in mid-thigh, knee, or below-knee level. This is because the system mass must not be changed during the movement. If the exercises are started from the floor, the system mass used in calculation is altered after the barbell is lifted off the floor. While the barbell is in contact with the floor, the weight (mass times gravity) of the barbell is not applied to the force platform. Then, as soon as the barbell is lifted off, the weight of the barbell is applied to the force platform through the lifter's feet in addition to the weight of the lifter's body. In this manner, the system mass is not constant during the movement, and acceleration, velocity, and power data cannot be obtained from force data.

In method 4, force is obtained directly from a force platform and velocity is obtained from barbell displacement data. Thus, power is obtained as the product of the force and velocity data. As in method 3, the lifter's body mass and barbell mass are included in the calculations because the force data are directly obtained from force platform as GRF. In this method, data are sampled from the force platform and position transducer simultaneously. Because force data include the lifter's body mass and velocity data are based on the barbell displacement, there is the limitation already discussed of assuming the COG of barbell and that of lifter are moving as one (5). The advantage of this method is that displacement is measured directly and a much better approximation of barbell velocity is obtained. Also, measurement of force developed through the feet is direct and more accurate than the value obtained from a position transducer as explained in methods 1 and 2. As long as the COGs of barbell and body move simultaneously, there is less risk of errors occurring compared with the other methods (5). However, the applicability of this method is limited to lifts in which the bar moves with the lifter, as when the bar is held on the shoulders in the jump squat. It is not applicable for lifts like the jerk, in which the body and bar move at different velocities and even in different directions.

No matter which method is utilized, power can be obtained at any time point, so that researchers can report these data as the peak power, or average between 2 time points (e.g., mean power during the propulsive phase). Among previously reported research, McBride et al. (14, 15) and Newton et al. (19) reported peak power; Baker and Nance (2) and Wilson et al. (20) reported mean power; and Chiu et al. (3) reported both peak and mean power in the jump squat. Theoretically, both mean and peak values will provide a good representation of athlete performance. However, in terms of absolute explosiveness of the movement, the peak value may be more relevant (5). For example, Harman et al. (9) reported that peak power had a higher correlation to vertical jump performance than mean power (r = 0.88 versus r = 0.54). This is because the high power is exhibited within a very short time (e.g., the last 150 ms of the jump) and mean power was affected by total time taken (i.e., total time can be lengthened or shortened by slowing down or speeding up parts of the movement) (9). However, due to problems of data smoothing, differentiation, and integration, mean power output may be less error prone, particularly if calculated simply as concentric work done over time.

Measuring Power Output in Weightlifting Exercises

In weightlifting exercises such as the snatch and clean, the COG of the barbell and that of the lifter's body move independently. For example, in the hang power snatch (Figures 3 and 4), the COG of the lifter's body moves only 0.12 to 0.15 m while COG of the barbell moves from mid thigh to overhead (6).

Because methods 2 and 3 are valid even if the COG of a barbell and that of a lifter move separately, these methods are preferred to measure power output in weightlifting exercises.

Theoretically, if the interest of coaches is to evaluate the lifting performance, it seems that method 2 gives more important information because the success of weightlifting depends on the power applied to the barbell and thus how high the lifter can pull (in the snatch and clean) or drive (in the jerk) the barbell rather than the lifter's body mass.

On the other hand, if the athlete's leg and trunk extensor power output capability is of primary interest, method 3 would best express this. If the athlete's power output capability is the issue, it is better to include the lifter's body mass into the calculation because weightlifting exercises involve a considerable amount of movement of the lifter's body mass.

As previously stated, methods 1 and 4 are valid only if the COG of a barbell and that of a lifter's body move simultaneously, but the COG of a barbell and that of a lifter's body move independently during weightlifting exercises. Thus, methods 1 and 4 are not logical for measuring power output during weightlifting exercises. However, if only peak power is the issue, method 4 may be appropriate for the following reasons. First, the peak power would occur most likely during the second pull phase of the snatch and clean (6). Because the bar is moving very close to the COG of lifter's body during the second pull, maybe it can be approximated that the COG of the barbell and that of the lifter's body move simultaneously. Second, as explained previously, method 4 has less risk of error compared with the other methods. However, the validity of method 4 in weightlifting exercises has not been examined to date, and additional investigation is needed.

In general, a position transducer is less expensive than a force platform. Roughly, the cost of a position transducer can be $1,000 or less, whereas the cost of a force platform can be $40,000 or more. Thus, if data using methods 2 and 3 are well correlated, coaches may consider a position transducer to be useful equipment even if a coach's interest is the athletes' power output capabilities rather than their lifting performance. However, currently there is no study comparing the values obtained from different methods of determining the power outputs in weightlifting exercises. In previous studies, Moore et al. (16) and Haff et al. (8) measured power output by using method 2 only; Kawamori et al. (12) and Haff et al. (7) used method 3 only; and Winchester et al. (21) used method 4 only.

Practical Application

If coaches measure the power output in weightlifting exercises using several different external loads, the power output can be different at each external load. The effects of different external loads on power output are explained by the fact that the power is the product of force and velocity and that the higher the external load, the lower the velocity output and the higher the force output (1).

The highest power output value among the measurements at several different loads is called the *maximum power output* (1, 17). Potentially, maximum power output is one of the most important mechanical quantities to determine athletes' performance in strength/power-oriented sports (18). Therefore, monitoring the maximum power output may give coaches useful information. Baker (1) has closely monitored the maximum power output of athletes and found it to clearly reflect the conditioning of the athletes. The maximum power output correspondingly increases if athletes positively adapt to the strength training program and decreases if athletes have stopped training due to intense competition (1). For example, the maximum power output increased from 1,426W to 1,811W as a result of 12 weeks of strength/power training and then decreased to 1,661W after the competition and active recovery (1).

The load at which the maximum power output is achieved is called the *optimal load* (1, 17). Previously, Kaneko et al. (11) reported that 30% of isometric maximum force is the optimal load and suggested that athletes train with loads of 30% of isometric maximum force. However, the optimal load appears to be different from exercise to exercise, as well as from individual to individual (12, 13). In addition, the optimal load will increase after the maximum strength phase and decrease after the maximum speed phase, so that the optimal load can be different in each test occasion even within the same individual (1, 17). Because of this individual difference, Kawamori et al. (12) reported no statistical difference between the peak power outputs of 15 male subjects performing hang power clean with 50, 60, 70, 80, and 90% of 1RM loads. Thus, if coaches need to know the optimal load for each athlete, it is necessary to periodically administer the power output measurements using several different weights with a narrow range (i.e., every 5–10 kg or every 5–10% of 1RM). By monitoring the optimal load, coaches can see how the athletes have adapted to the previous training periods as previously described (19).

However, measuring power output for every 5 kg (e.g., 40, 45, 50, 55, 60, 65, 70, and 75 kg) takes a considerable amount of time. Spending too much time could be a problem for those who coach many athletes and have limited time available for testing (e.g., football, ice hockey, and baseball coaches). If that is the case, it may not be practical to measure power output using a number of different loads. Rather, to measure power output at one or two loads only (e.g., 40 and 60 kg) may be more efficient. As a result of the period of training, the power output at the same external load should increase (21). Therefore, as long as the same loads are used in every test, coaches can monitor the improvement of athletes' power output even if they can see neither the athletes' maximum power output nor the optimal load. Also, if power output decreases at the same loads, it may be because of fatigue, and this information could be used to prevent overtraining.

Summary

In summary, coaches can use either a force platform or a position transducer to measure power output in weightlifting exercises. However, they should be cognizant of the limitations and assumptions of each method. In calculation of power in weightlifting exercises, only barbell mass should be used when a position transducer is used. On the other hand, when a force platform is used, both barbell mass and the lifter's body mass should be used. Both methods are logical and valid, and by using one or both of these methods, coaches can monitor the athletes' power output capability at any external load. However, additional investigation of the validity of these methods is needed. If power outputs are measured at several different external loads, maximum power output and optimal load can be obtained. By observing these values, coaches can monitor how athletes respond to training programs over a long period. ♦

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