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Maximum Strength-Power-Performance Relationships in Collegiate Throwers

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ABSTRACT

Presently the degree to which peak force influences power production or explosive performance such as strength training movements or throwing (shot-put and weight-throw) is unclear. This study describes the relationships between a measure of maximum strength, isometric peak force (IPF), dynamic peak force (PF), peak power (PP), the 1-repetition movement power snatch (SN), and throwing ability over an 8-week training period. Five male and 6 female ($n = 11$) well-trained collegiate throwers participated. PF was measured using an AMTI force plate; PP was measured using an infrared-ultrasonic tracking device (V-Scope, Lipman Electronics). Clean pulls from the midthigh position were assessed isometrically and dynamically at a constant load, 30% and 60% of IPF. Specific explosive strength was evaluated using an SN and using the shot-put (SP) and weight-throw (WGT) measured under meet conditions. Variables (PF, PP, SN) were assessed 3 times at 0 weeks, 4 weeks, and 8 weeks. Each measurement period preceded a field meet by 3 days. Peak force, peak rate of force development, and PP increased over the 8 weeks. Correlation coefficients (r) indicate that IPF is strongly related to dynamic PF and PP 30%, 60% of the IPF. Furthermore, strong correlations were found for the SN and the distance for the SP and WGT, and these relationships tended to increase over time. Results suggest that maximum strength (i.e., IPF) is strongly associated with dynamic PF. In addition, maximum strength is strongly associated with PP even at relatively light loads such as those associated with sport-specific dynamic explosiveness (i.e., SN, SP, WGT).

Key Words: strength, power, throwing

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Introduction

Strength can be defined as the ability to produce force (22, 24). As force is a vector quantity, the display of strength will have a magnitude and direction. Strength can also be associated with a rate of production. Strength can be displayed isometrically or dynamically and depends on a number of factors such as the type of contraction, rate of motor unit activation, and degree of activation. Because power is the product of force and velocity, then alterations in force should affect changes in power production.

Schmidtbleicher (21) indicates that maximum strength is the basic quality affecting power output. Potentially maximum strength could effect peak power because: (a) a given load would represent a smaller percentage of maximum, thus making this load easier to accelerate; (b) it is possible that a person with a higher maximum strength level would have a greater percentage or greater cross-sectional area of type II fibers, which strongly contribute to high power outputs; and (c) as a result of strength training (i.e., attaining greater maximum strength) several power-improving alterations occur simultaneously, these alterations could include hypertrophy of type II fibers, increases in the type II/I cross-sectional ratio, and alterations in motor unit activation (10).

Although it is generally believed that maximum strength should have its greatest effect on power produced at heavy loads, some evidence indicates that maximum strength influences power over a much wider range than might be expected (18, 25). Review of the literature indicates that the association of maximum strength with power accounts for 50% or more of the variance (24). However, the exact relation of maximum strength with peak power and the context of explosive strength performance, particularly with light loads, remain unclear.

Schmidtbleicher (21) has characterized explosive exercise as having maximum or near maximum rates of force development (RFD). Thus, either isometric or dynamic exercises can be classified as explosive, provided maximum RFD is attained. Explosive strength is defined as the peak RFD and has been associated with acceleration capabilities (21). It can be argued that for many sports the ability to produce force rapidly may be more important than maximum force production. Rate of force production is a change in force divided by change in time. The rate of force development is primarily a function of the rate of increase in muscle activation by the nervous system (13, 32). Although force is directly responsible for the acceleration of an object, it may be argued that the faster a given force is attained, the more rapid the corresponding acceleration occurs. Thus rate of force development can be associated with the ability to accelerate objects (21). So, attaining a high peak rate of force development or explosive strength would be associated with high acceleration capabilities.

From a practical or applied standpoint, it is also important to understand the relation between maximum strength, rate of force development, and power-oriented explosive sport performance, such as throwing. These relations could influence the degree of emphasis placed on maximum strength training as part of the overall training program. Resistance training, simply providing a strength overload may not be sufficient to optimize the training effect. It may be argued that to most effectively enhance strength or power attributes for a specific sport, the training program should contain exercises that address the concept of mechanical specificity (4, 29). It can be further argued that to effectively measure force-power, alterations resulting from training or measure performance transfer as a result of training that mechanically specific exercises or tests must be included. Mechanical specificity is not limited to movement patterns or velocity considerations but also is concerned with peak force, rate of force development, and positional characteristics. Positional characteristics (as opposed to movement pattern) concern using appropriate relative trunk and limb positions for isometric testing (19, 29, 33). Some evidence indicates that the most appropriate position for isometric maximum strength testing is likely to be the joint angle(s) at which peak forces are developed (33). This angle(s) or position may allow the best inference to dynamic activity. Thus, it may be argued that isometric tests, provided positional characteristics can be satisfied (19, 29), could potentially be used to characterize the results of a strength-power training program.

The primary purpose of this study was to examine the relations between maximum strength (peak isometric force) and dynamic peak force, rate of force development, and peak power measured during mid-thigh pulls and to relate this variable to the 1 repetition maximum (1RM) snatch, and throwing ability (shot-put and weight-throw). Potential variations in these relationships were assessed over an 8-week training period.

Methods

Experimental Approach to the Problem

The relationship of maximum strength to various types of performance is unclear, especially potential changes in relationship over a training period. To better understand this relationship, a group of well-trained collegiate throwers were followed up (measured) over an 8-week portion of their general preparation phase training. In this experimental observation, a single group, repeated measures design was incorporated to ascertain statistically significant alterations in the dependent variables associated with maximum strength and power. The relationships between a measure of maximum strength (IPF) and dynamic measures of performance were determined using a Pearson's product moment correlation.

Subjects

Five male and 6 female (n = 11, age = 18–21 years, initial body mass = 101.3 ± 25.3 kg; % fat = 21.9 ± 8.9) collegiate throwers participated in the study. All subjects signed informed consents prior to the study. Previous strength training experience ranged from 0.5–4 years, and previous throwing experience ranged from 1 to 6 years. The group included 2 NCAA national provisional qualifiers.

Training

This study deals with the observation of collegiate throwers during a planned preparation phase prior to the indoor season. All throwers had just finished a 6-week high-volume training period prior to the initiation of the study. The high-volume phase emphasized strength-endurance. The following 8-week training program emphasized increased maximum strength (weeks 1–4) and strength-power (weeks 5–8; Tables 1 and 2). During a training session, maximum efforts were emphasized on all exercises regardless of the load.

Body Mass and Composition

Body mass was measured to the nearest 0.1 kg using an electronic scale. A 7-site skin-fold (SF) was used to determine approximate body fat percentages (12). Experience laboratory personnel measured all SFs on the right side (Table 3).

Performance Tests

All subjects had been familiarized with the tests before the testing began. Isometric and dynamic peak force (PF) was measured using an AMTI force plate (500 Hz). Peak power (PP) was measured using the V-

Table 1. Experimental training protocol.

High-volume phase 6 weeks* (3 × 10)
Tests (T1)
Training
Week 1: 3 × 5 (1 × 5)
Week 2: 3 × 5 (1 × 5)
Week 3: 3 × 3 (1 × 5)
Week 4: 3 × 3 (1 × 5)
Test (T2)
Week 5: 5 × 5
Week 6: 3 × 5 (1 × 5)
Week 7: 3 × 3 (1 × 5)
Week 8: 3 × 2 (1 × 5)
Test (T3)

* Sets in parentheses are down sets performed at 40–50% of estimated 1RM.

scope; an infrared-ultrasonic tracing device (Lipman Electronic Engineering Ltd., Ramat Hahayal, Israel). A more detailed characterization of the V-scope has been presented by Stone et al. (25). Isometric midthigh pulls were measured from a position identical to that used in training (knee angle 135°–145°, hip angle 155–165°). Dynamic midthigh pulls began at a position identical to the isometric position: dynamic pulls were finished with a simultaneous maximum effort shoulder shrug and plantar flexion. This method (midthigh pulls) of assessing PF and PP was chosen because it was a movement-position used in training, previous research (9) had established its potential usefulness as a test, and the positions (hip and knee angle) achieved in the test and the explosive nature of the tests are similar to that of critical aspects and positions of weightlifting and throwing movements (4, 5, 14, 15, 28). Measurements were made isometrically and dynamically at 30% and 60% of the IPF using a specially designed adjustable power rack (Sorinex, Orange, SC). Peak rate of force development was measured using a 5-millisecond window. Test-retest reliability was PF (ICC) = 0.98, peak rate of force development (PRFD) (ICC = 0.81) and PP (ICC) = 0.86. Sport-specific explosive strength was measured using a power snatch (SN), the shot-put (SP) and the weight throw (WGT) under meet conditions. Throwing implements were those used for men and women (shot, men = 7.26 kg; women = 4 kg; weight, men = 15.9 kg; women = 9.1 kg). Peak force, PRFD, PP variables, and SN were measured 3 and 2 days, respectively, prior to each meet.

Statistical Analyses

Longitudinal data were analyzed using linear polynomial contrasts. Effect size and statistical power were calculated (see Table 4). Correlations were calculated using Pearson's *r*.

Table 2. Exercise protocol.

Weeks 1–4	
Monday and Friday	Tuesday, Thursday, Saturday
1. Squats	Various sprints, agility work, fast foot work, throw (overweight from front × sets and reps), midsection work, flexibility work
2. Push press (front squat 1st rep)	
3. Bench press (10° incline)	
Wednesday	Friday
1. Shoulder shrugs (1st from floor)	15–20% lighter than Monday
2. Clean pulls (from floor)	
3. Clean pulls (from mid-thigh)	
4. Stiff legged deadlift	
Saturday	
1. Snatch grip shoulder shrug	
2. Power snatch	
Weeks 5–8	
Monday and Friday	Tuesday, Thursday, Saturday
1. Heavy ¼ squats*	Various sprints, agility work, fast foot work, throw (overweight from front × sets and reps), midsection work, flexibility work
2. Weighted jumps	
3. Dumbbell bench press (10° incline)	
Wednesday	Friday
1. Shoulder shrugs (1st from floor)	15–20% lighter than Monday
2. Clean pulls (from mid-thigh)	
3. Stiff legged deadlift	
Saturday	
1. Power snatch	

* Exercises 1 and 2 complexed.

Table 3. Body mass and composition alterations (n = 11).

	T1	T2	T3	p Value	Eta²	Power
Body mass (kg)	101 ± 25.3	101.5 ± 27.1	103 ± 27.4	0.004	0.589	0.926
Lean body mass (kg)	78.3 ± 18.6	78.8 ± 18.6	80.2 ± 14.7	0.015	0.463	0.754
Percent fat	21.9 ± 8.7	21.5 ± 7.9	21.5 ± 7.7	0.481	0.051	0.102

* T1 = 0 weeks; T2 = 4 weeks; T3 = 8 weeks; Eta² = effect size.

Table 4. Mean force and power values for the midthigh pull (n = 11).*

				% Change		
	T1	T2	T3	T1–T2	T2–T3	T1–T3
IPF	2,881 ± 921	2,894 ± 836	3,002 ± 933	0.5	3.7	4.1
30 PF	2,370 ± 627	2,393 ± 581	2,566 ± 517	1.0	7.2	8.3
60 PF	2,809 ± 745	2,851 ± 765	3,006 ± 677	1.5	5.4	7.0
PP	1,909 ± 858	2,243 ± 959	2,326 ± 651	17.5	3.7	21.8
30 PP	2,065 ± 921	2,427 ± 871	2,434 ± 683	17.5	0.4	17.9
60 PP	1,621 ± 589	2,025 ± 792	2,178 ± 686	24.9	7.5	34.4
IPRFD	15,047 ± 5,243	18,873 ± 7,659	18,000 ± 8,357	25.4	−4.6	19.6
PRFD30	25,161 ± 6,221	29,010 ± 7,632	31,446 ± 7,734	15.3	8.4	24.9
PRFD60	21,315 ± 5,851	25,932 ± 7,613	27,262 ± 7,041	17.8	5.1	27.9

* T1 = 0 weeks; T2 = 4 weeks; T3 = 8 weeks; IPF = peak isometric force; 30 PF = peak force at 30% of IPF; 60 PF = peak force at 60% of IPF; 30 PP = peak power at 30% of IPF; 60 PP = peak power at 60% of IPF; IPRFD = isometric peak rate of force development; PRFD30 = peak rate of force development at 30% of IPF; PRFD60 = peak rate of force development at 60% of IPF; force = newtons; power = watts.

Results

Analyses of men vs. women showed no differences in the rates of adaptation to the program. Thus, data are presented as one group. Alterations in body mass and body composition are shown in Table 3. Body mass and lean body mass (LBM) increased over time. Changes in peak force, peak rate of force development and power outputs are shown in Tables 4 and 4a. Although measures of PF, PRFD, and PP increased over time, both PRFD and PP had greater increases during the first 4 weeks, and PF generally had the greatest increases during the second 4 weeks of training. The results of the sport performance variables, SN, SP, and WGT are shown in Table 5, all variables showed significant increases over time. Correlations between IPF, the mid-thigh force and power variables and performance variables are shown in Table 6. Measures of PRFD did not correlate well with any variable (r values ranged from 0 to 0.27). The results of this correlational study indicated that maximum strength (IPF) is strongly related to PP and dynamic sports performance but not PRFD.

Table 4a. Statistical analyses for PF and PP variables.

Variable	p Value	Eta²	Power
Peak force	0.0001	0.557	0.998
IPF	0.115	0.114	0.349
PF30	0.017	0.243	0.698
PF60	0.010	0.277	0.771
Power	0.0001	0.533	0.997
PP30	0.015	0.249	0.710
PP60	0.0001	0.563	0.999
PRFD	0.0001	0.441	0.998
IPRFD	0.115	0.114	0.349
PRFD30	0.001	0.422	0.961
PRFD60	0.001	0.443	0.973

* PF = peak force; PP = peak power; Eta² = effect size; Peak force = total peak force (IPF + PF30 + PF60); power = total power (PP30 + PP60); PRFD = total PRFD (IPRFD + PRFD30 + PRFD60); IPF = peak isometric force; PF30 = peak force at 30% of IPF; PF60 = peak force at 60% of IPF; PP30 = peak power at 30% of IPF; PP60 = peak power at 60% of IPF; IPRFD = isometric peak rate of force development; PRFD30 = peak rate of force development at 30% of IPF; PRFD60 = peak rate of force development at 60% of IPF.

Discussion

The findings of this study indicated that a measure of IPF can be strongly associated with power and explo-

Table 5. Mean values for the snatch (SN), shot-put (SH), and weight throw (WGT) (n = 11).

	SN	SP	WGT
T1	61.8 ± 19.8	11.99 ± 1.9	11.55 ± 2.9
T2	65.5 ± 20.3	12.25 ± 1.8	12.43 ± 2.6
T3	67.7 ± 21.4	12.63 ± 1.7	12.97 ± 2.5
	p Value	Effect size	Power
SN	0.003	0.602	0.938
SH	0.006	0.541	0.871
WGT	0.008	0.517	0.838

Table 6. Correlation of IPF with midthigh pull and performance variables.*

	30PF	60PF	30PP	60PP	SN	SP	WGT
T1	0.77	0.85	0.77	0.60	0.95	0.67	0.70
T2	0.88	0.87	0.81	0.69	0.98	0.74	0.76
T3	0.85	0.92	0.80	0.87	0.94	0.75	0.79

* T1 = 0 weeks; T2 = 4 weeks; T3 = 8 weeks; IPF = peak isometric force; 30PF = peak force at 30% of IPF; 60 PF = peak force at 60% of IPF; 30 PP = peak power at 30% of IPF; 60 PP = peak power at 60% of IPF; SN = snatch; SP = shot-put; WGT = weight throw.

siveness. It should be noted that the number of subjects was relatively small (n = 11); however, this group was made up of well-trained collegiate throwers and contained 2 NCAA national provisional qualifiers. The group all had a strength training and throwing background and was strength trained in the same manner for 6 weeks prior to the initiation of the study and thus represented a relatively homogenous group from a training protocol standpoint. Furthermore, conceptually, the results agree with the observations of recent studies and review indicating a strong relationship between dynamic measures of maximum strength and peak power (18, 24, 25).

Specificity of training was exhibited in that IPF showed the smallest percent gain, which was not statistically significant. The percent gains associated with peak force at 30% of IPF and peak force at 60% of IPF were larger and reflect the dynamic nature of the training program.

Increasing power output (or work rate) is likely the most important aspect in improving the performance of a specific movement. Peak power represents the maximum power produced at a particular movement during a brief moment under given set of conditions.

The results of this study suggest that improving maximum strength can result in the improvement of peak power output during lifting at percentages of maximum ability. The results of this study also indicate that maximum strength markedly contributes to power production during the movement of light resistances as well as heavy resistances. Thus, improving maximum strength could improve movements with light (or zero) external loads. Indeed the improvement in maximum strength and power likely contributed to the gains noted in the sports performance variables (SN, SP, WGT).

Of particular interest is the differential effect of training on PF, PRFD, and PP. Generally, PP showed its greatest improvements during the first 4 weeks and PF generally showed the most improvements during the last 4 weeks. This observation is particularly interesting in that the first 4 weeks of training emphasized maximum strength rather than power. Explanations for this differential effect include:

- Stimulus-fatigue-recovery-adaptation. Conceptually an appropriate stimulus can result in fatigue-recovery and an adaptation such that performance is eventually improved (i.e., supercompensation). This concept is not limited to a single exercise response but may be viewed on a longer basis producing training adaptations. Verkhoshansky (30, 31) noted that a concentrated load of strength or strength-endurance training for several weeks could result in a diminished speed-strength (power) capability among track and field athletes. On returning to normal training, increased power performance can often be observed, sometimes beyond baseline values. Similar results have been observed among young weightlifters after a planned high volume overreaching phase (8, 23) and may be linked to alterations in anabolic-catabolic hormones. Thus, a high-volume strength-endurance phase may have potentiated gains in power when moving to lower volume phases. This phenomenon may have played a role in the relatively large PP (and PRFD) increase noted during the first 4 weeks of strength training after the high-volume phase.
- Potentiation and different rates of adaptation. Associated with the concentrated loading theory is the concept of sequenced training and one training phase potentiating the subsequent phase. Wilson et al. (34) demonstrated that among heavy weight-trained subjects with reasonable maximum strength levels, switching to high power training (squats) improved a variety of performance variables beyond that of continued heavy weight training. Similar observations have been made among elite weightlifters (17) and American collegiate football players (11). It may be argued that because the subjects in the present study were already reasonably strong, a switch from high-volume strength- and endurance-oriented training to a lower volume of strength training containing a reasonable amount of power-oriented exercises potentiated improved power but did not produce marked increase in PF (because they were al-

ready reasonably strong). This concept is supported by the observation that the greatest PF measurements occurred as lean body mass (LBM) increased over the last 4 weeks. Thus, an increase in LBM was necessary for the additional enhancement of maximum strength (PF) to occur.

- Sufficient power-oriented training. Evidence indicates that PP power occurs at approximately 30–60% of 1RM; training at these loads may enhance power better than training at heavier loads. Although maximum strength was being emphasized during the first 4 weeks, there was a considerable amount of power-oriented exercises included. Major exercises such as pulls and squats all had down sets performed at 40–50% of the 1RM. Furthermore, there were light and heavy days included. For example, the loading for squats on Thursday was reduced by 15–20%, compared with the loading on Monday. Because maximum efforts were encouraged, movement speed and power would be increased. Thus, many of the movements were in fact high power in nature during the first 4 weeks. McBride et al. (16) have shown that training at weights (squats) producing higher peak power outputs, compared with heavier loads have greater effects on power over a short-term training period. Baker et al. (2, 3) have noted similar improvements in average power among rugby players over a season. Thus, although the emphasis was on maximum strength development, the inclusion of power-oriented movements during the first 4 weeks may have contributed to the relatively large initial adaptations in PP.

As observed in the present study and previous study (9), higher power movements are also accompanied by higher PRFD. Thus, power training may also optimize adaptations in PRFD. Increases in PRFD across time may also be related to the same training factors associated with the increased power production. It is also possible that combinations of the above factors are responsible for the observed alterations in performance.

It is also of interest to note that the correlations among IPF, PF, PP, and the performance variables tended to increase over time, agreeing with the observations of Robinson et al. (20). It has been previously postulated that there is a lag time in being able to incorporate alterations in maximum strength (or power) into a specific performance (1, 7). The general increases in relationship between IPF and dynamic variables may indicate that as training preceded, the ability to use maximum strength (or a higher percentage of maximum) was enhanced (i.e., a lag time). For example, the improvements in the weight throw may have occurred, at least partially, as a result of being able to incorporate the increased levels of maximum strength (or power) into the technique of the throw.

Exactly how PRFD affects the types of performance measured in this study is not clear. PRFD measures did not correlate well with IPF, nor did PRFD measures correlate well with any variable (data not shown). However, if one assumes that there are critical time periods (and therefore positions) within a movement, in which performance depends on achieving the highest possible force development (6), then RFD during this critical period would contribute markedly to the overall performance of the movement. In this study, PRFD increased with training time but was not statistically associated with improved performance. However, the measurement procedures used did not include characterization of critical time periods for the performance variables measured. Measurement of force during these critical time periods may be more important then simply measuring PRFD, which may not occur during the critical time period.

Specifically these results indicate that: (a) a measure of isometric maximum strength (i.e., IPF) is strongly related to the ability to generate PF dynamically; (b) maximum strength is strongly related with PP, even at relatively light loads that are associated with sport-specific dynamic explosiveness (i.e., SN, SP, WGT); and (c) these relationships tend to increase with training time.

Practical Applications

These results indicate that maximum strength markedly contributes to power and explosiveness at light and heavy loads. Therefore, improvement of maximum strength as a result of strength training could improve power and explosiveness and therefore performance in a variety of movements associated with both light and heavy resistances. The results of this study suggest several possibilities associated with strength training.

1. Increased maximum strength as a result of training can enhance force generation and power production.
2. Training for maximum strength can result in changes in other factors such as power and peak rate of force production that can also contribute to improved sports performance.
3. However, no longitudinal study has shown that maximum strength, power, or specific performance variables change at exactly the same rate. Furthermore, the increases in strength may continue after the changes in power or sport performance become asymptotic. It is possible that the lack of direct correspondence between maximum strength gains and other performance variables is associated with a lag time (7). Lag time deals with a period of time in which the athlete learns how to use the increased strength; the lag time may extend many months in some cases. It is possible that lag time may be reduced by careful coaching strategies in which the

potential link between strength and technique is pointed out to the athlete. This may partly be accomplished by pointing out similarities between training exercises (i.e., mechanical specificity) and performance exercises.

4. Caution should be exercised in completely depending on maximum strength gains to enhance power output or sport performance, especially among advanced or elite athletes. To maximize power and explosiveness, specialized programs that also specifically train power and speed are necessary (26, 27). This would include the use of sequenced periodized programs in which the initial phase emphasizes strength gains, with later phases emphasizing power and speed (11, 24, 25).

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