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# Theoretical and Practical Considerations for Enhancing Power to Improve Athletic Performance

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THEORETICAL AND PRACTICAL CONSIDERATIONS  
FOR ENHANCING POWER  
TO IMPROVE ATHLETIC PERFORMANCE

by

Douglas A. Herron  
Bachelor of Science in Physical Therapy  
University of North Dakota, 1997

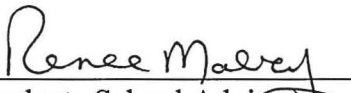
An Independent study  
submitted to the graduate faculty of the  
Department of Physical Therapy  
School of Medicine  
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in partial fulfillment of the requirements  
for the degree of  
Master of Physical Therapy

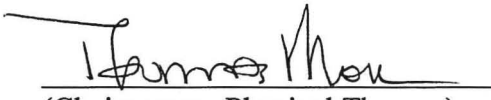
Grand Forks, North Dakota  
May  
1998



This Independent Study, submitted by Douglas A. Herron in partial fulfillment of the requirements for the Degree of Master of Physical Therapy from the University of North Dakota, has been read by the Faculty Preceptor, Advisor, and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

  
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(Faculty Preceptor)

  
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(Graduate School Advisor)

  
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(Chairperson, Physical Therapy)

## PERMISSION

Title           Theoretical and Practical Considerations for Power Enhancement to Increase Athletic Performance.

Department   Physical Therapy

Degree        Master of Physical Therapy

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## ABSTRACT

Power is of extreme interest to coaches and athletes alike because of the crucial role it plays in athletic performance. This independent study examines the essence of power and attempts to describe its components in detail as they relate to various sporting events and explores theoretical and practical considerations for anaerobic power augmentation using mathematical arguments as a basis for the suggested changes to traditional training protocol.

Specifically, this study suggests changes to traditional resistance training protocol during the power phase of a mesocycle by decreasing the percentage of the maximal lift from 90% through 95% to 60% through 85%. In addition, two formulas have been presented. One offers a minimum strength and condition standard as a prerequisite for athletes desirous of incorporating upper extremity plyometric drills into their training program. The other offers a normalized platform height off which an athlete can step to perform in-depth jumps, a shock intensity level drill utilized with plyometric training.



## ANAEROBIC POWER AND ITS RELEVANCY TO ATHLETIC PERFORMANCE

Anaerobic power, simply stated, is the combination of speed and strength. Power is of extreme interest to many coaches and athletes because of its function in athletic performance. Fleck and Kraemer describe power as the most functional component of most sports.<sup>1</sup> This is intuitively obvious when one recognizes that most sports not only require brute strength but also components of power such as agility and acceleration. The success of a running back for example depends not only on the force at which he can break through the line but also the speed and maneuverability with which he can do it. Power can be thought of as explosive strength. Power contains not only strength but the vital component of velocity which is frequently not emphasized in athletic training. John Grogan, the Conditioning Coordinator of North Dakota State College of Science explains, “Strength training is very popular. Almost every athlete we get has participated in some sort of program. However, what a lot of strength programs lack is the transformation of strength gains into sport-specific power!”<sup>2</sup> In other words an athlete’s preoccupation with a particular one repetition maximum (1RM), i.e. bench press or squat, may not translate into sport specific improvement on the field to the extent that training for power would. Wathen and Roll<sup>3,4</sup> explain that power is most important and may contribute most to an athlete’s speed. It is practical then to say an “ideal” training program is one that not

only improves strength but also incorporates explosive strength (power) and its component of velocity into the training regimen to enhance performance in a specific sport. This discussion develops naturally into the question whether in fact greater power gains can be realized by improving or modifying traditional training methods.

In order to fully understand power, analyzing and defining its components will be helpful. It is not feasible to attempt separating power and strength because strength is actually a component of power. In an attempt to define strength one must understand the nature of force. Sir Isaac Newton described and defined force as an object's mass multiplied by an acceleration ( $F=ma$ ).<sup>5</sup> It is commonly measured in kilogram-meters/second<sup>2</sup> ( $\text{kg} \cdot \text{m}/\text{s}^2$ ) or simply Newton (N) after its discoverer. An example of a force is gravity holding a mass on the ground. Gravity is measured at  $9.8 \text{ m}/\text{s}^2$ . The force pinning an object to the ground is then gravity multiplied by the object's mass. To pick an example towards which many athletes and weight lifters seem to gravitate is the bench press. Suppose a lifter has a maximal lift of 100 kg. The force being exerted by gravity on this mass is measured at 980 N ( $9.8\text{m}/\text{s}^2 \cdot 100\text{kg}$ ). For simplicity sake, let us assume that the bar starts at the lowest point and is resting on the lifter's chest. If the bar is pushed upwards, the force being generated against the bar by the lifter is greater than 980 N. If the force is considerably higher the bar travels up relatively fast, but if the force is just slightly higher than 980 N the bar will travel upward more slowly. This phenomenon is a manifestation of the force-velocity curve. The force-velocity curve is simply the inverse relationship between the strength of a muscle (force production) and

the velocity at which the athlete can press a particular weight. Suppose half way up, the length, tension, and joint angle relationship of the involved muscles and joints became disadvantaged to the point where the force equals 980 N. Many lifters describe this as the “sticking point”. This would now be referred to as an isometric contraction because, although the bar is not moving, tension or force production within the muscle is still present. As the athlete tires, the force exerted on the bar diminishes and the load starts to descend. The muscle is producing a force on the bar which is less than 980 N at this point and is lengthening. This is called an eccentric contraction.

Strength therefore should be defined in terms of force produced by a certain cross-sectional area of muscle without consideration to the movement of the mass. In other words, an athlete could be considered strong if he can hold an intense isometric contraction for a certain time period even though nothing is visibly happening. Clearly strength is required to exert 980N in an isometric contraction even though the bar is stationary. However, since pure force exerted by muscle is impractical to measure due to the joint angle differences through the range, a more crude measurement of repetition maximum (RM) is used. Unfortunately RM's do not account for lever arm advantages or disadvantages between different athletes. Therefore, two different athletes may produce different forces at the muscular level and lift the same weight. RM's do however provide a practical and convenient measurement of strength because it is functional and measuring output is relatively easy.

Along with force (strength), work is also an important constituent of power.

Work is closely related to force; the main difference being work requires displacement of a mass against an opposing force. In other words, unlike force, work requires that an actual movement takes place as opposed to simple tension in the muscle. Work then is the product of a force and a distance ( $W=F \cdot d$ ).<sup>5</sup> Work is normally calculated in units of newton-meters or simply joules (J). In the preceding bench press scenario, positive work is being performed when the bar is elevating and negative work is being performed when the bar is lowering. Negative work can also be thought of as work being performed on the muscle itself. Suppose that the lifter in the previous example successfully lifted 980 N a distance of 0.5 meters (m) from his chest back onto the holding rack. The work performed then would be  $(980 \text{ N}) \cdot (0.5 \text{ m}) = 490 \text{ J}$ . It is also an interesting side note that joules is the unit for energy. In other words, the lifter transformed chemical and mechanical energy (needed to raise the bar) into 490 J of potential energy. Clearly then, work and energy are very closely related. It should be noted that the definition for work expresses nothing of a time concern; if it takes an hour or a split second to move a particular mass a certain distance, it is irrelevant to work. It is only the distance covered that is of consequence. This is important because for the competitive athlete it is not enough to simply move from point A to B but it is how quickly this is done that is of real concern.

During the isometric contraction phase of the lifter's failed attempt to press the weight, no work was performed because no motion occurred. This is precisely the reason

why strength is defined as force and not work. Anyone who has ever held a large weight just off their chest will attest to the role of strength in performing such a task. Although one should technically define strength as force and not as work, work is a useful measurement due to its importance as a component of power. It is this power that will allow an athlete to truly excel in most sporting events.

In the bench press example work truly was performed. This is because work describes a mass being moved by a force against an opposing force which causes a displacement to occur. The opposing force in this case happens to be gravity. On the field or court this opposing force could be a shove from an opposing player, friction, wind resistance, or inertia (the tendency of a body to resist changes in velocity or direction). In other words, by the strict laws and definitions of physics, “no work is done if the only motion is perpendicular to the direction of the opposing force.”<sup>5</sup> To illustrate this point, assume that this same 100 kg bar and weights of which we have been speaking is placed in deep space without the influence of gravity or any other force. Furthermore, this mass is in motion at the brisk velocity of 100 m/s. Although the bar is covering distance at a staggering rate, no work is being performed on the bar because nothing is opposing its forward progression. This embodies Newton’s third law (i.e. law of inertia) which states, “every body continues in its state of rest or uniform speed in a straight line unless it is compelled to change that state by a net force acting upon it.”<sup>5</sup> If a force or summation of forces were in fact opposing this forward progression, another force or summation of forces of equal value would be needed to keep the bar’s velocity constant.

If this were the case then work would have been performed on the bar. In other words where there is no opposing force, there is no work. This is important to comprehend because where there is no work, there is no power. Both physical laws demand that motion of a mass take place against an opposing force.

Another example, perhaps more down to earth, points out the need for an opposition of forces. Suppose the lifter is finished with the bench press and decides to return the bar to the far end of the gym. Relatively, no motion is occurring vertically but a considerable amount of motion is happening horizontally as the bar is being carried across the room. Is work being done on the bar as it is being put away? In actuality work is needed initially to overcome the effects of inertia. Since work is required to overcome inertia, inertia is then a force. As the acceleration of the bar approaches zero, however, no work is being done on the bar except perhaps to overcome the negligible resistance of air. This opposing force of inertia in athletics is why a sprinter does not come out of the blocks at full velocity. It takes a considerable amount of force, work, and energy to accelerate the athlete's body. The success of smaller, lighter sprinters in the 60m dash (an extremely short sprint in indoor track and field) may be attributed in part to less inertial force opposing the forward progression of the lighter athlete's body. Wind resistance and friction between the shoes and track also constitute a small opposition which must be overcome. By and large, however, the main opposing forces in athletics which effect the athlete are gravity, an opposing player, and the effects of inertia. To

overcome these forces the athlete must generate opposing forces greater than those which are encountered. By so doing the athlete produces work.

With an understanding of strength (force production) and work, it is simpler to understand power. Earlier in the chapter power was defined in layman's terms as explosive strength. Technically power is work per unit time ( $P = w / t$ ).<sup>5</sup> Power is measured in joules / second or simply watts. Unlike work, it is power that is concerned with how fast an object is displaced. One can well imagine that power is much more functional in sports than the ability to do work alone. Another way to think of power comes when manipulating the power equation:  $P = w/t = F \cdot d/t = F \cdot v$ . As you can see power can also be thought of as the product of a force and a velocity of an object. Looking at the equation from this point of view, one can see that it is not feasible to develop power without developing strength (defined as force). Strength is a vital component of power. In other words, by strengthening an athlete, power is also enhanced. What strength does not account for however is the component of velocity or distance covered per unit time. In order to develop power, an athlete must work on both factors of the equation to achieve maximal functional gains on the field or court. As was previously stated, where there is no work, there is no power. This is obvious when viewing the power equation. Power then is nothing more than the measure of how quickly work can be performed. During the isometric contraction phase of the failed bench press (RM) mentioned in the beginning of the chapter, force was shown to be present but yet no movement of the bar occurred. In this case since displacement of the

object did not occur parallel with the opposing force, no work and likewise no power was achieved. Isometrics are important for some sports (i.e. arm wrestling, wrestling) but for most sports, power enhancement would cause the greatest functional gains. One can well imagine the importance power plays in athletic performance. To be competitive, it is not enough that a sprinter can reach maximum velocity. This velocity must be reached in the shortest possible time. To say a sprinter is powerful describes the explosive start from the blocks and the measure of the body's acceleration until maximum velocity is achieved. It is not enough that a competitive basketball player has the strength in the lower extremity extensors to overcome gravity, it is how quickly that strength can be applied which creates height in a vertical jump. In fact the vertical jump is one of the most practical methods for determining the measure of an athlete's power. Any experienced bob sledder knows that a split second difference at take off can make or break chances for an Olympic gold medal. The sledder must not only generate the work that propels the sled initially, but do this in the shortest possible time. Any skilled football running back knows the value of maneuverability (overcoming the force of inertia quickly). Great maneuverability requires an athlete to possess great power. Power is vital in order to accelerate and decelerate quickly. Power, therefore, is the measurement which should be of utmost importance to coaches, sports trainers, and athletes.

Given this knowledge, a program specially designed for power increases should lead to a greater functional improvement in comparison with a traditional program



emphasizing strength alone. In other words, training solely for strength in the weight room, which is commonly accentuated, may not develop an athlete's full potential as it relates to the respective sport. Strength training programs have traditionally stressed achieving great 1 RM strength gains but have shown less regard for speed specificity. This is perhaps not in the athlete's best interest. Research shows in fact that greater values of force are developed at an athlete's training velocity.<sup>1,10,13</sup> Although there is strength carry over at other velocities besides that of the training speed, it appears that training at a rate similar to an athlete's sport, displays the greatest practical force increases.<sup>1,10,13</sup> This speed specificity is why the power clean and other cleans and jerks for example are so effective in increasing anaerobic power. These power maneuvers force an athlete to raise the weight quickly against gravity, thereby increasing the ability to produce force at that velocity. If the weight travels upwards too slowly the lift will be aborted and fail. Due to this relatively high speed, a 1 RM at the clean truly does train for power, whereas a 1 RM for another exercise (i.e. bench press), trains principally for strength.

This author contends that in order to train for power with an exercise such as the bench press, a sub-maximal lift could be utilized in order to increase velocity. As stated earlier, the phenomenon whereby the acceleration of a mass is determined by opposing force ratios is termed the force-velocity curve. In other words, a mechanical system can increase the velocity at which a mass is propelled when the resistive weight (force) decreases. Although research backs the efficacy of sport-specific velocity training, it is

incongruous that much resistance training is in fact performed methodically and more slowly than many sports demand.

Indeed a slow lift is safer and encourages a lifter to utilize proper form. Also high intensity (i.e. 1 RM) exercises are indicated for power improvements as well as strength gains.<sup>1,10-14</sup> For the high level athlete that can perform proper lifting technique at relatively high speeds however, the principle of speed specificity reasons that training closer to the particular sport velocity should incur greater functional gains in force production.<sup>1,10-14</sup> It appears then that the mind set should be altered from methodically 'feeling the burn' to 'exploding with power' during some resistance training sets. This is not to say that this explosive lifting method, power training (power cleans, push-presses, jerks etc.) and plyometric training should completely replace traditional lifting for strength but should be an important adjunct to the athlete's regimen. Certainly the value of program variability (e.g. periodization, acute / chronic variable manipulation) and the practicality of 1 RM measurements are indispensable. The realization that power training is crucial to performance on the field, court, or track ushers in this question; what are the theoretical and practical considerations for enhancing anaerobic power to improve athletic performance ?

This is the question that will be attempted to be answered within the chapters of this independent study. The significance for addressing the question of best power enhancement methods is simply to assist athletes in reaching their genetic potential and to excel in their chosen sport. Not only would this information be highly valuable for the

amateur athlete but from an economic standpoint regarding professional athletics in today's market, implementing superior methods for power training could be highly profitable.

## PERIODIZATION AS A TOOL FOR POWER ENHANCEMENT

The purpose of this chapter is to provide a brief outline behind the concept of periodization and specifically how this form of training affects power augmentation. The chapter will also present an alternative approach of training during the power portion of periodization. This new approach appears to be promising with regards to training purely for power as justified mathematically.

Periodization is a method of training whereby exercise volume, intensity, and type are manipulated over a variable time frame.<sup>15</sup> The concept to periodize or to manipulate training variables began in the 1960's by Leo Matveyev, a Russian physiologist. American exercise scientists Stone and O'Bryant further expanded upon his philosophy adding distinct phases to the existing periods already set forth by Matveyev. The training philosophy was developed in response to Seyle's General Adaptation Syndrome (GAS) theory which simply describes an individual's adaptation to physical stress. The GAS theory proposes three phases whereby an athlete's body adapts to the training to which it is subjected. The shock / alarm phase occurs when the tissues are compelled to perform in a way to which they are not accustomed. Usually lasting 1-2 weeks, this phase can create soreness and performance decrements. The resistance / super-compensation phase occurs when the body makes adjustments to accommodate this new stimulus. Stone and

O'Bryant describe this physical change: "The athlete adapts by making various biochemical, structural, mechanical, and likely physiological adjustments that lead to increased performance."<sup>15</sup> The maladaptation phase occurs next. During this phase, over-training, exhaustion or lack of new stimulation occurs. It is this 'plateau' which so many lifters experience with frustration. During this phase, performance can actually decrease even though a person is training harder than ever. It is this third phase which one would like to avoid. In short, periodization manipulates the training variables at the right times to avoid the stagnation that comes with the third phase of the GAS theory.

The periodization structure divides training into time frames of macrocycles (lasting usually one year) and mesocycles (lasting several months). These mesocycles have been further divided into preparatory, competitive, and transition periods. Each of these periods contains one or more weekly microcycles.<sup>16</sup> The training system attempts to help the athlete develop a foundation of conditioning, strength, power, and endurance without the complications of stagnation. Because of the seeming complexity of these concepts, many coaches and athletes find them confusing and difficult to utilize in a practical setting. The guidelines to periodization however are quite loose and one should not feel constrained by them. As long as the basic concepts are followed, there are countless program variations which can be formed to enhance performance.

Due to the great individuality between sports and the differences in season length and competition frequency, advocates for periodization training acknowledge that it is impossible to create rigid rules by which all athletes should adhere. Instead, general

guidelines have been suggested in an attempt to help athletes arrive at peak performance levels at the most crucial times and to avoid slumps throughout the training year. The backbone of periodization is the concept of regular variation in training. In other words, one should not feel bound by this method of training but feel free to manipulate the training variables to suit the unique circumstances of the athlete. Fig. 2.1 shows a visual breakdown of periodization.

### Training Considerations within the Power Phase and Competition Period of Periodization

In chapter 1, the role of power in athletics was emphasized as the most important factor for many athletic events. This is incorporated into the concept of periodization. One can see that just before the competitive period, the power phase of the preparatory period appears. See fig. 2.1. This is due to the need for power to be at peak levels to ensure optimal performance during the competition. It is during this power phase, when training intensity is high and volume is low, that the musculoskeletal system is conditioned for greatest anaerobic power production during the competitive events. Although power is crucial, one can also see the importance of possessing a good foundation of strength. For this reason the hypertrophy and strength phase come before the power phase during the preparatory period. Once a good strength base has been established, power can be addressed.

It is recommended that during the power phase, sport-specific ability drills, high intensity plyometrics, and high intensity weight training be performed.<sup>16</sup> The weight

# Periodization Outline

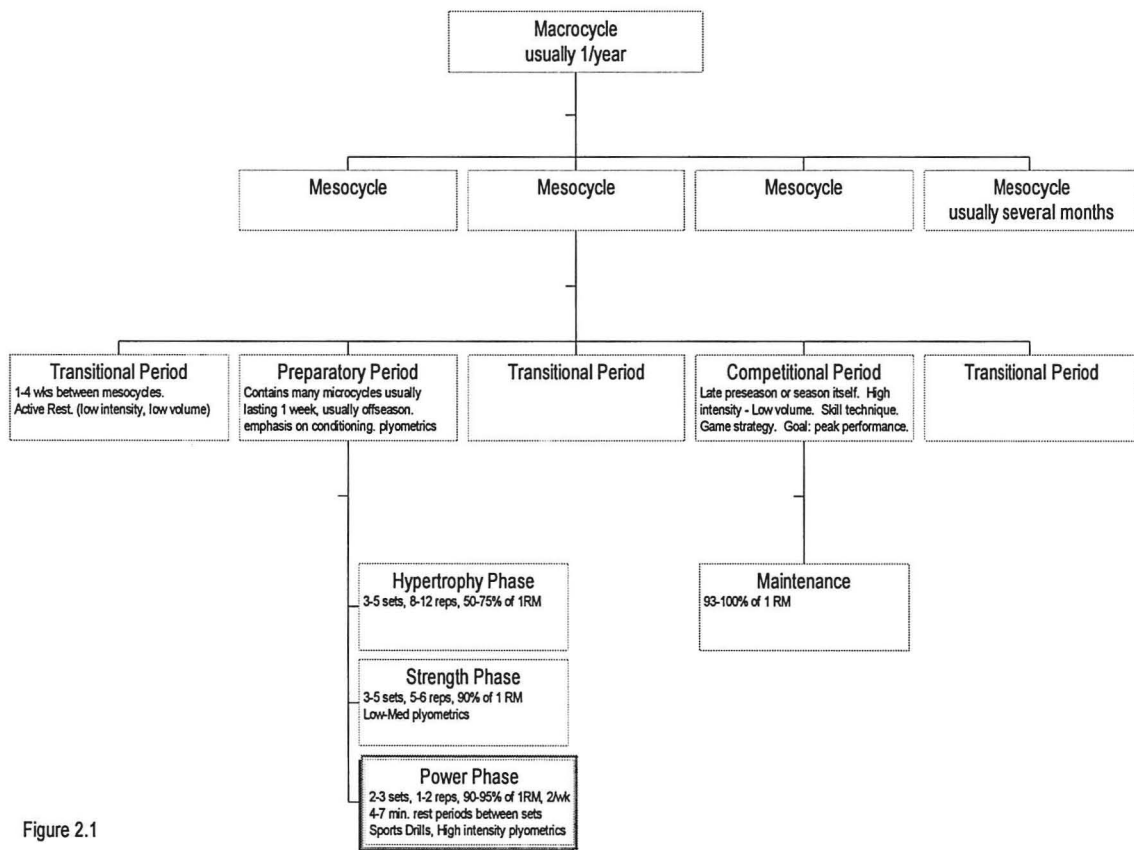


Figure 2.1

training reported to be helpful for power enhancement includes power exercises (i.e. cleans, snatches, push presses etc.), hip sled, and bench press. The specifications for these exercises as outlined by Wathen include 2 to 3 sets of 1 to 2 repetitions twice weekly. The load is suggested to be 90% to 95% of the athlete's 1 RM and the rest period should span a time from 4 to 7 minutes between sets to allow for full recovery.

Near maximal lifts for "power" exercises such as the clean and snatch truly do train for power because of the speed with which one must perform them. This is because velocity stays relatively high even when loads approach the athlete's 1 RM. Such high velocities ensure that power is being produced. Maximal resistance on a hip sled pulled a relatively short distance would also train for both speed and strength, the two components of power. Exercises such as the bench press, however, and other similar "nonpower" lifts which do not require the higher velocities to complete, are training theoretically and computationally for strength during near maximal lifts since the lift velocity is relatively slow. As was previously mentioned, the force-velocity curve limits the speed at which these exercises are performed when nearing the 1 RM.

Although the guidelines before mentioned for exercises such as the bench press seem to be generally accepted, this author contends that the percentage of a 1 RM at which an athlete trains during the power phase of a mesocycle is dependent upon the sport with which he is involved. An individual training for a weight lifting competition for example would benefit from training at 95+ % of the 1 RM during the power phase because specificity claims that the closer the training resembles the actual sport, the more



appropriate it is to enhance the actual performance. As was previously stated however, most sports rely on power for top performance as opposed to strength alone. The NSCA's guideline is 90% to 95% of the athlete's 1RM for training with all exercises during the power phase. This percentage may in fact be too large to obtain a relatively quick velocity for exercises such as the bench press. It appears that if one were to truly train for power, that person must train at velocities more representative of the sport.<sup>1,10-16</sup> These higher velocities are not only more sport-specific but yield a greater total power mathematically. The relationship between the product of force · velocity and power is much like a bell curve. With relatively high force production, velocity is relatively small. This can be readily seen for example with the completion of a 1 RM bench press which may take several seconds. With relatively low force production on the other hand, velocity is relatively high. Neither of these extremes lends itself to optimal power production. Somewhere in the middle, however, where velocity and force are of average value, one realizes maximal power production. This is not to say that training for absolute power production is always the best scenario; but for most sports it is likely that the optimal position on the force · velocity vs. power curve from which to train would be located centrally where power is relatively high. Therefore, if one truly wishes to train for power during the power phase of a mesocycle, it is conceptually correct to train at velocities which produce great power output.

Valuable research has been performed in this area by Perrine and Edgerton.<sup>21</sup>

These researchers found that power percentages are a function of training velocity. See

fig. 2.2. This is valuable information because one can plainly see that the greatest power output occurs at angular velocities between 192 and 288 degrees per second and quickly tapers off when velocities become slower than around 180 degrees per second. In other words, if a lifter takes longer than around a half second to press weight from off his chest in a bench press, power is not being increased as effectively as possible. According to this research, it appears that the load lifted, when training for power, should be of such intensity as to allow the athlete to train between 192 and 288 degrees per second. These velocities of training would be desirable to achieve during portions of periodization where power is of greatest interest.

It is during the Power phase and Competition period that power should be developed and maintained. Depending on the sport, one may wish to train at the high or low end of this range in an attempt to reach similar velocities required by the sport. The problem arises in that it is impractical to accurately assess the angular velocity at which one is exercising in the weight room. It would be much more helpful to have an outlined percentage of the athlete's 1RM as the load necessary to arrive at the appropriate workout velocity. Because of the inverse relationship between velocity and force, the athlete would simply need to be concerned with lifting the weight as fast and explosively as possible. With the proper weight, the velocity would then be self limiting and power would be at its greatest values. Since research has been conducted by Perrine and Edgerton showing the relationship between velocity and power percentage and since

% Maximum Power

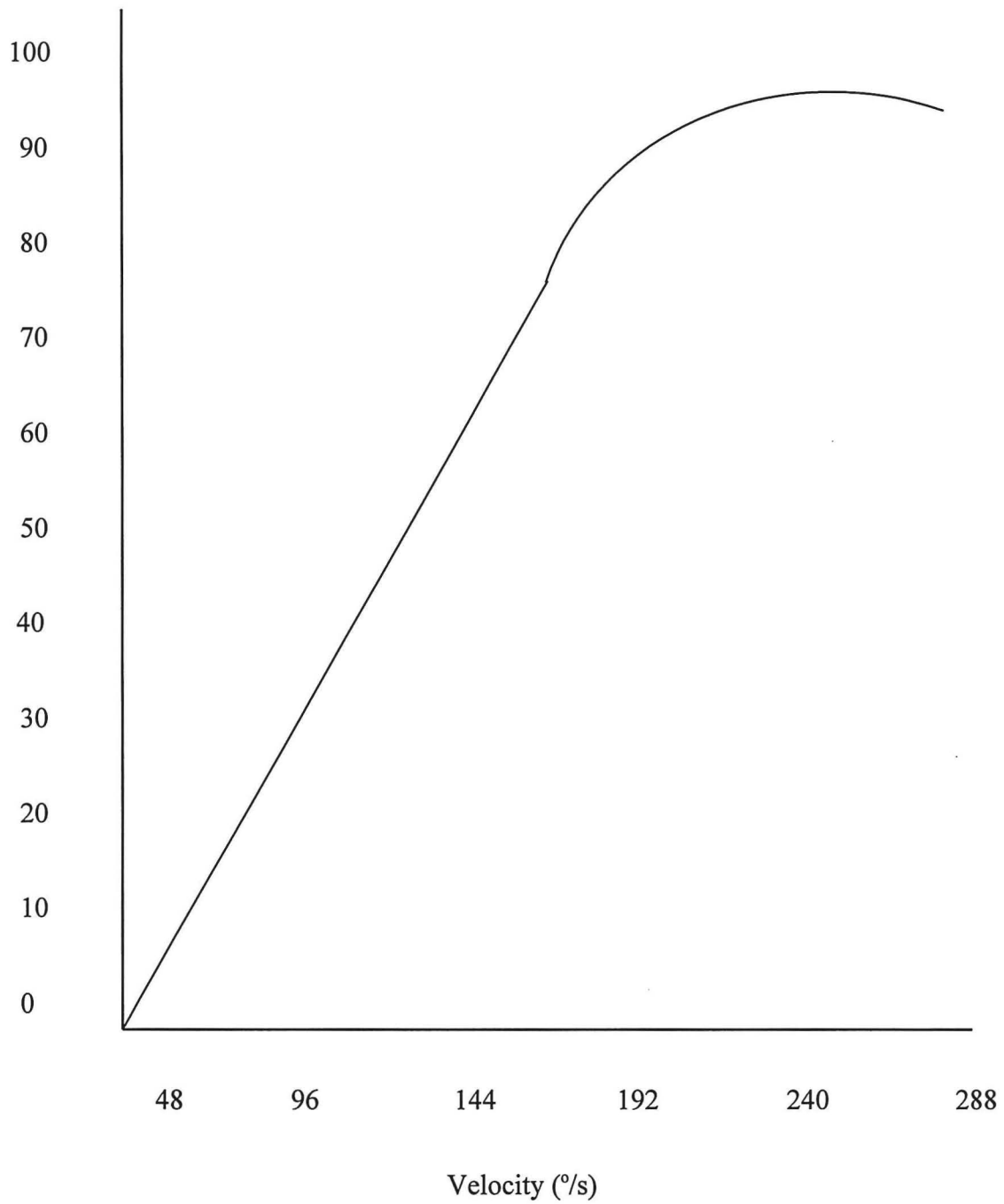


Figure 2.2 Muscle power as a function of muscle contraction speed.  
Reformatted from Perrine and Edgerton (1978)

athletes commonly know their 1 RM for most lifts, we can arrive at a range of 1 RM percentages that will drive the angular velocity between 192 and 288 degrees per second.

With respect to the power equations offered previously, power also equals the product of mass, acceleration, lever arm distance, and angular velocity or simply the product of torque and angular velocity. By this formula we can discover the power production during a 1 RM lift and from this amount we can calculate the athlete's maximal power using information from fig. 2.2. From this value we can determine 1 RM percentages that correspond to the two chosen velocities previously mentioned. It is known from this graph that one arrives at maximal power output at roughly 240 %/s. Also, gravity is usually the accelerating force in question unless there is some other type of resistance which the machine utilizes. (e.g. advanced cams, hydraulics, springs, etc.) The numerical value for the acceleration is of no consequence however since it cancels itself out. The acceleration is of no consequence because whatever the acceleration may be for the 1RM (usually  $9.8\text{m/s}^2$ ), it remains the same during the workout session. The same principle applies for the lever arm measurement. Therefore, we need not be concerned with it either. As long as the lever arm and acceleration stay constant between a sub-maximal and maximal lift, these values cancel. This negation is calculated below.

Assuming that an athlete's 1 RM is 50 kg on an arbitrary piece of equipment and the lift is performed at 24 %/s. Furthermore, the lever arm length of his arms is roughly 0.3m. The rest of the information can be taken from the velocity-power percentage relationship graph. The calculation is as follows:

$$(.3\text{m}) \cdot (24\%/s) \cdot (9.8\text{m/s}^2) \cdot (50\text{kg}) = 3,528 \text{ watts}$$

Therefore 3,528 watts is the individual's power output during a 1 RM. To obtain the greatest power achievable, one can make a ratio between this value and the percent power this velocity represents by referring to Fig 2.2. One can see that the percent power which coincides with the angular velocity of 24°/s is roughly 14%.

$$3528 \text{ W} = (.14) \cdot X_{\text{max power}}$$

$$X_{\text{max power}} = 25,200 \text{ watts}$$

25,200 watts therefore, is the maximum power that this athlete can generate with this particular machine or free weight. One can see from this calculation just how little power is actually being trained when a lift is relatively slow, i.e. 25,200 W vs. 3528 W. It is for this reason that training at near-maximal intensity levels during the power phase and competition period, as is the traditional protocol, may not be in the athlete's best interest.

Because muscle power has a direct relationship with muscle contraction speed, it is also irrelevant how fast the 1 RM occurs. In other words, let us suppose that another individual's 1 RM lift velocity is twice that of the previous example; namely 48°/s. Furthermore, this athlete also lifts 50kg. Upon examination of fig. 2.2, one discovers that a velocity of this magnitude represents roughly 28% of an individual's maximal power output. After substituting these new numbers into the equation, the maximal power output is shown to be identical. i.e. :

$$(.3\text{m}) \cdot (48^\circ/\text{s}) \cdot (9.8\text{m}/\text{s}^2) \cdot (50\text{kg}) = 7,056 \text{ Watts}$$

$$7,056 \text{ W} = (.28) \cdot X_{\text{max power}}$$

$$X_{\text{max power}} = 25,200 \text{ Watts}$$

Notice that the total power output is the same regardless of the 1 RM lift velocity. This is due to the near linear relationship between velocity and power when 1 RM lift velocity is slower than 180 °/s. It is safe to say that nearly every athlete's 1 RM lift velocity is slower than 180 °/s with regards to “non-power” exercises. With this information, the amount of weight the athlete should lift to drive the angular velocity between 192 and 288 °/s can then be discovered; the high and low ranges for high power output. This is done by setting a ratio between the high and low extremes of velocity at which the actual weight is lifted and the percent of maximal power achieved at that velocity. We can then compare this calculated weight to the maximal lift to arrive at a percentage of the 1 RM.

$$\begin{array}{ll}
 (.95) \cdot 25200 \text{ W} = (X \text{ kg}) \cdot (9.8) \cdot (192) \cdot (.3\text{m}) & (.97) \cdot 25200 \text{ W} = (X \text{ kg}) \cdot (9.8) \cdot (288) \cdot (.3\text{m}) \\
 X = 42.4 \text{ kg} & X = 28.9 \text{ kg} \\
 42.4 / 50 = 85 \% & 28.9 / 50 = 58 \%
 \end{array}$$

One arrives at the same percentages (i.e. 58 to 85%) regardless of acceleration, 1 RM load, 1 RM velocity, or lever arm length used. According to these calculations, a load roughly between 60% to 85 % of a 1 RM will naturally force the competitor to train between 192 and 288 °/s if the competitor's mind set is to perform the contractions explosively. This author wishes to name the explosive training within these two percentages, during non-power lifts, the “Power Zone”. This combination of load and velocity will be appropriate if wishing to train in the competitor's most powerful zone. There may be a window of experimentation between the two percentages to arrive at a training velocity which most closely represents the sport. Supportive research is requisite

before making claims of superiority that this type of power training would actually increase performance more than traditional training during the Power phase and Competitive period. (i.e. 60% to 85 % of the 1RM while lifting explosively vs. 90% to 100% of the 1 RM). Theoretically however, if one truly wishes to train for power during the power phase and competition period of a mesocycle, that person may do well to stay between these two percentages.

It stands to reason that the athlete would develop greater power gains when training at the greatest power levels. In order for this type of training to be safe an athlete would need to possess a solid strength foundation. Otherwise the high velocities and loads may be a catalyst for injury. Again, because of the nature of “power” exercises such as cleans, snatches, and push presses, training at >90% of a 1 RM, as suggested by the National Strengthening and Conditioning Association (NSCA), during the power phase or competition period would be appropriate for power production. It is the “nonpower” exercises to which this discussion of the appropriate 1 RM lift percentages apply. This author suggests that for most sports, weight training close to maximal resistance with regards to “nonpower” exercises should be performed during the strength phase of a mesocycle.

In summary, periodization is a useful tool to effectively hypertrophy muscle, increase strength, and enhance power.<sup>15-20</sup> Periodization also seems to be effective in reducing stagnation and overtraining which occur during the maladaptation phase of the GAS theory.<sup>15,17,18</sup> Further research is needed to assess whether the recommended 90 to

95% of a 1 RM load should be decreased to 60 to 85% (while lifting with explosive power), with regards to “non-power” exercises, in order to produce significant power improvements during the power phase and competition period of a mesocycle.



## THE HERRON FORMULA

One form of plyometric power-enhancing exercise used routinely in training is the in-depth jump. The in-depth jump consists of the well-trained athlete stepping off of a box or raised platform.<sup>1,7,16,22</sup> As the jumper hits the ground, the lower extremities are flexed to reduce the impact and then immediately extends the lower extremities to jump as high or as far out as possible. In-depth jumps make use of the stretch reflex principle which is the phenomenon whereby a muscle reacts with a reflex contraction when stretched quickly. The time interval between the time of impact with the ground until the start of an athlete's explosion from the ground is termed the amortization period.<sup>1,7,16,22</sup> This period must take place during a finite period of time and the stretch is less effective in employing the muscle if the amortization time frame is too long.<sup>16,22</sup> If amortization is too slow, the muscle spindles will not be stretched appropriately to facilitate the stretch reflex principle in the lower extremities. This reflex, when combined with a forceful voluntary contraction, is theoretically beneficial in training for power. As the extensor muscles of the lower extremities eccentrically fire to slow the body's downward progression, the muscle spindles become stretched sending a signal to the central nervous system (CNS) to contract the muscle. This reflex increases the eventual elevation reached after the body's explosive push off after the amortization period. This type of

training exploits the physiological stretch reflex response to obtain a more powerful contraction mainly from the quadriceps (49%), gastrocs (23%) and hip extensors (28%).<sup>24</sup> This training is thought to enhance power because of it's explosive nature.

Basic guidelines from the National Strengthening and Conditioning Association (NSCA) include a range of heights from which to jump spanning 0.4m to 1.1m with 0.8m being the norm.<sup>9,16,26-32</sup> The NSCA also suggests that an athlete possess a good strength foundation before attempting this type of training in order to prevent injury.<sup>16</sup> It is also recommended that those athletes over approximately 230 lb not participate in in-depth jumps due to the risk of injury.<sup>25,16</sup> One source found, however, that those over 230 lb should not perform in-depth jumps from a platform higher than .5 meters.<sup>16</sup>

Although these guidelines provide a practical range in which the athlete can experiment to find an estimate of jumping height, they do not provide specific information about jump height differences between athletes of differing body styles and abilities. Since conditioned muscle displays roughly the same qualities among individuals, it is also theoretically logical that all healthy athletes could reap the benefits from in-depth jumps regardless of weight. It would seem that every conditioned athlete could enjoy power gains based on the physiological stretch reflex principle if the appropriate jump height for that person could be discovered. This author defines the "appropriate" jump height as the height at which one athlete's muscle tissue experiences the same force/cm<sup>2</sup>/ unit time upon impact as the muscle tissue of an average sized athlete when jumping from average height.

For these reasons the Herron formula was developed to offer a practical method of arriving at the appropriate jump height for a variety of different athletes with regards to power differences, weight, height, and level of conditioning. In order to fully understand how the formula derives jump height one must grasp several physical principles to which mechanical systems on our world are subject.

#### Strength / Body Size Ratio

It is widely known that on the norm smaller athletes are stronger than larger athletes pound for pound.<sup>33,34</sup> One can intuitively recognize the difference in the strength per pound ratio when looking at systems at the extreme ends of size, i.e. an ant vs. an elephant. An ant can carry phenomenal amounts of weight in comparison to its body size (up to 20 times), and yet an ant the size of an elephant would literally be crushed under its own weight. Only the elephant's thick dimensions allow the larger creature to exist. Although an elephant is extremely strong by our standards, it pales in comparison to an ant with regards to strength per body size. It would be extremely unreasonable to expect an elephant to carry many times its own body weight and yet an ant experiences no problems when faced with the same ratio. This strength / body size ratio is also apparent when comparing athletes of different sizes. These ratios are always larger on average for the smaller athlete. This is also the reason that smaller athletes can seem to effortlessly start, stop, and cut whereas the larger athlete seems clumsier and relatively helpless in attempting to overcome the greater inertia created by a larger mass (i.e. basketball guard vs. the center).

This discrepancy is due to the fact that the strength of a biological system is determined by the cross-sectional area of a muscle and not its volume. In other words, as a biomechanical system gets proportionally larger, so does the cross-sectional area and volume of the muscle. This occurs however at nonproportional rates. For example, if a box has the dimensions 1in by 1in by 1in and was to increase proportionally in size to 3in by 3in by 3in, the cross-sectional area would have increased from  $1\text{in}^2$  to  $9\text{in}^2$ . Although this is a relatively large increase, the volume of the box exhibits a staggering increase; from  $1\text{in}^3$  to  $27\text{in}^3$ . Since strength is determined by cross-sectional area and not volume, one can visualize that the larger athlete has less cross-sectional area of muscle per unit of body weight than does the smaller athlete. For this reason, inertia, one of the most challenging obstacles in athletics, is in fact a greater problem to larger athletes. Like many sports, the in-depth jump also requires an athlete to overcome inertia produced by the competitor's own mass and velocity.

Mathematically, the rate of change from volume to cross-sectional area is described by taking a person's volume to the  $2/3$  power. Taking our  $27\text{in}^3$  box to the  $2/3$  power for example yields  $9\text{in}^2$  which is, of course, the cross-sectional area of the box. Therefore, estimations of strength can be determined if the volume of lean muscle mass is known.

The fact that larger athletes are weaker pound for pound is precisely the reason why most cannot be expected to jump from the same heights as smaller athletes. For the reason some larger athletes were sustaining injury, the NSCA recommended that those

athletes over approximately 230 lb not participate in in-depth jumping.<sup>16</sup> Theoretically, however, these larger athletes could also benefit from the fundamental principle of the stretch reflex if the appropriate jump height could be discovered.

Since it is not practical to accurately assess how much cross-sectional area of muscle an athlete has available by weight alone, another method for assessing strength would be appropriate. A lower extremity lift such as the squat would provide a nice comparison between the various athletes' strength but technically is not the ratio which would produce the best comparisons for appropriate jump height calculations. The problem with using the squat as a basis for athlete comparison is that it is in fact a measurement of strength and not power. Although these two units are reasonably correlated due to the fact that they are actually components of one another, it is entirely possible that a person may have a wonderful strength base to squat weight but is unable to exploit this muscle reserve quickly. This contraction speed is essential when considering power. In other words, although an athlete may be relatively strong, this strength may not necessarily be used explosively. The in-depth jump relies on the athlete's ability to explosively rebound the body's momentum. Therefore, using a strength comparison among athletes would be a crude method of determining power disparities between athletes and would have to rely on the correlation between a person's strength and power. A more accurate comparison between athletes would be to create a power ratio. The Herron formula utilizes a power comparison due to the power requirements needed to rebound from an in-depth jump. The most convenient and

accurate measurement for power is the vertical jump.<sup>35</sup> It is this test for power which the formula puts to use. The vertical jump provides an accurate comparison of power for at least five reasons:

- 1) Similar muscular involvement as compared with in-depth jumps.
- 2) Lever arm disparity is accounted for among individuals.
- 3) Will detect if much of the athlete's weight comes from tissue other than muscle by presenting lower vertical jump scores as compared with a more muscular athlete of the same weight.
- 4) Is relatively convenient to measure without expensive equipment.
- 5) Relatively little motor learning differences exist between individuals; in contrast to complicated power lifts such as the power clean.

As was shown in the first chapter, power is equivalent to the subject's mass multiplied by the acceleration to which the body is exposed multiplied by the velocity.

$$P = m \cdot a \cdot v \text{ or } f \cdot v$$

One of the conveniences of using the vertical jump is that a person's mass and acceleration are equal whether an athlete jumps up or down from a platform. Therefore, the only measurement to consider is the velocity at which the athlete leaves the ground. With regards to a vertical jump, one can calculate the precise velocity at which an athlete leaves the ground by measuring the height jumped. This is because the body becomes helpless against gravity once it is airborne. In other words, an athlete wishing to increase vertical jumping ability, can only do so by increasing the velocity at which the ground is

left. The power comparison for the formula can be thought of as power / weight compared with an average value of power / weight. The denominator of this ratio was found to be (0.015248 m/s/lb) using data from 15 male subjects and 15 female subjects ages 15-20 yr. selected randomly from the data banks of the Sports Acceleration Program in Grand Forks, ND. This ratio compares athletes of different sizes with regards to power (velocity when leaving the ground) per unit weight (i.e.  $A \text{ m/s} / B \text{ lb} / .015248$ ). As with strength, power per pound in smaller athletes is greater on average because of the increased cross-sectional area per unit volume and the decreased mass which must be moved against the force of inertia. This is precisely why an athletic guard in basketball can sometimes jump at comparable absolute heights as a larger center.

#### Height Perception

Another factor to consider when determining platform heights is how an athlete perceives height. Although this concept may seem a bit dubious at first glance, upon further investigation it becomes intuitively obvious. Although not normally significant, height perception does play a role with in-depth jumps. Imagine an average 69in athlete standing on a 0.8m high platform. Standing next to this athlete on the same platform stands a 5in smurf who is also desirous to incorporate in-depth jumps into his training regimen. For the athlete of average height, the distance appears to be relatively low, but to the smurf, the height appears to be significantly greater. This author contends that height perception is a very real factor in determining jump distances for any mechanical system. It is important to realize that this is not just a psychological perception but a real

phenomenon whereby different body sizes actually experience the same height in different ways. Even though the absolute height remains the same, it is the interaction between body size and platform height which is relevant. This “size relativity” is a concept which is seen everyday and is intuitively obvious yet infrequently discussed. A large flight of stairs to a small child for example, proves to be a colossal obstacle whereas to an adult the stairs appear to be a relatively insignificant nuisance. A #8 sized fishhook may cause relatively little tissue damage to large fish but to a very small fish it could be life threatening. Although the stairs and the fishhook stay the same size in absolute terms it is the relative size difference between the interaction that is relevant. One can see, therefore, that height perception between a 69in and a 5in athlete is a very real discrepancy that must be taken into account.

Since height disparities of this magnitude among humans is fictitious and since smurfs rarely engage in competitive athletic events however, one might counter with the argument that height perception is not significant. Although this may be true for most individuals, there is a difference in height perception among athletes of differing sizes, however small that may be. This difference increases in significance when comparing jump heights for athletes of large height differences (i.e. a 7ft basketball player vs. a 5ft gymnast).

The average height of the 30 subjects was 69in. If this height is the norm, the average athlete of 69in tall perceives the average jump distance to be 0.8m, which in reality it is. Athletes of differing heights however perceive that 0.8m to be more or less



than the 69in athlete perceives it to be, i.e.  $(.8m) \cdot (69in) / (X in) = (55.2 m \cdot in) / (X in)$ .

This calculation is the perceived meters in height. Therefore, a 5in smurf perceives 0.8m to be 11.04m in comparison to the a 69in athlete's perception of the platform height.

An interesting concept follows height perception. Gravitational acceleration is  $9.8 m/s^2$  and is constant with very minimal fluctuations at various locations on earth. All matter is subject to this constant force accelerating us towards the earth's surface. When air resistance is not a factor all matter falls at the same rate of acceleration. Although this is true, if height perception differences exist, acceleration perception differences exist also. When both our 5in and 69in athlete leap from the .8m platform they will arrive on the ground at the same instant. The smurf however perceives he is accelerating towards the ground at a much faster rate since he is covering much more perceived distance per time. This is apparent if one places everything to scale (i.e. the smurf enlarges to 69in and the platform raises to 11.04m). The real 69in athlete, however, is still perched on the .8m platform. If these two athletes jump off the respective platforms simultaneously, in order for the smurf to hit the ground at the same instant as the average sized athlete, they would have to be experiencing 2 different gravities. Namely, the average-sized athlete traveling towards the earth at  $9.8m/s^2$  and the smurf traveling at  $(55.2m \cdot in) / (5 in) / (0.2857s^2) = 135.25 m/s^2$ ; with (.2857s) being the time necessary to complete the journey for both. i.e. square root of  $(0.8m / 9.8m \cdot s^2) = 0.2857s$ . We know however in reality that they both experience the same gravitational attraction towards the earth and will both hit the ground traveling at 2.8m/s, i.e.  $(.8m) / (.2857s) = 2.8m/s$ .  $135.25 m/s^2$  is therefore the

perceived acceleration which the smurf is experiencing. An interesting side note is that gravitational acceleration perception is dependent only on height disparities between individuals and not on the set platform height norm.

With this information in mind, the question remains; from what platform height should the smurf jump if experiencing a  $135.25\text{m/s}^2$  gravitational pull to land precisely when his velocity reaches  $2.8\text{ m/s}$  ? Therefore:  $(135.25\text{m/s}^2) \cdot (1\text{s}/2.8\text{m}) = 48.3\text{s}^{-1}$  or  $.0207\text{s}$ . In other words, in order for the smurf to experience the same perceived jump as the average sized athlete, he should be in the air a total of  $.0207\text{s}$  or  $4.287 \times 10^{-4}\text{s}^2$ . In order to arrive at the actual platform height, one must then multiply the seconds squared by the perceived gravitational attraction:  $(4.287 \times 10^{-4}\text{s}^2) \cdot (135.25\text{m/s}^2) = .058\text{m}$ . This is the actual height from which the smurf should jump to experience the same perceived velocity upon impact as the larger athlete. To find the real velocity upon impact we multiply the real gravitational acceleration by the actual height and take the square root: square root of  $(.058\text{m}) \cdot (1\text{s}^2 / 9.8\text{m}) = .07693\text{ m/s}$ . The previous steps are compiled into a compact form in order to produce the height perception portion of the formula.

$$\frac{1 / ((55.2 / \text{in} / .2857^{\wedge}2) (1 / 2.8)^2) (55.2 / \text{in} / .2857^{\wedge}2)}{\sqrt{(1 / ((55.2 / \text{in} / .2857^{\wedge}2) (1 / 2.8)^2) (55.2 / \text{in} / .2857^{\wedge}2) / 9.8)}}$$

This calculated real velocity at impact is found without regard to the increased power per body weight as compared with the average athlete. In order to set up a meaningful power ratio in which to contrast athletes to the norm, we must manipulate the

previously mentioned power per pound ratio in terms of a person's actual jump height instead of take-off velocity.

$$(A \text{ m/s} / B \text{ lb}) / (0.015248) = \frac{\sqrt{V_{Jm} \cdot 9.8}}{(lb) \cdot (0.015248)}$$

This conversion is done for the convenience of the formula user. The user needs only to enter the athlete's vertical jump height as opposed to calculating the take-off velocity that this height represents. This manipulation is a series of 4 steps using gravitational acceleration to discover take-off velocity with respect to vertical height jumped. This is done by dividing take-off velocity by gravity, taking the square root, then multiplying by gravity.

$$1) (Xm) (s^2 / 9.8m) = (Xs^2 / 9.8)$$

$$2) (Xs^2 / 9.8)^{1/2} = (X^{1/2}s / 9.8^{1/2})$$

$$3) (X^{1/2}s / 9.8^{1/2}) (9.8 \text{ m/s}^2) = ((X^{1/2}s / 9.8) / (9.8^{1/2})) \text{ m/s}$$

$$4) ((X^{1/2}s / 9.8) / (9.8^{1/2})) \text{ m/s} / (lb) / (0.015248) = \frac{\sqrt{V_{Jm} \cdot 9.8}}{(lb) \cdot (0.015248)}$$

Once the power difference ratio and actual velocity from height perception differences are calculated, these two values can be multiplied to arrive at the true velocity at which the athlete should hit the ground to experience the same jump intensity as the average athlete. From this value the true height from which the athlete should jump can be calculated using the real gravitational acceleration. This is done by dividing the true

velocity by the acceleration of gravity, squaring this value, and multiplying the result by the acceleration of gravity once again. This number is the actual platform height from which a person can step off and experience the same intensity drop as the average athlete jumping from the average height. When all the above steps are integrated, the formula appears like this:

$$\left[ \frac{\sqrt{\frac{VJm \cdot 9.8}{(LB) \cdot (.015248)}} \cdot \frac{1 / ((55.2 / \text{in} / .2857^2) (1 / 2.8)^2) \cdot (55.2 / \text{in} / .2857^2)}{(1 / ((55.2 / \text{in} / .2857^2) (1 / 2.8)^2) \cdot (55.2 / \text{in} / .2857^2) / 9.8)}}{9.8} \right]^2 \cdot 9.8 = \text{platform height}$$

The formula is then simplified:

$$\sqrt{\frac{(VJ) \cdot (Ht)}{(Wt)}} \cdot C = \text{Platform height}$$

Height and vertical jump should be entered in inches. Weight should be entered in lb's and the constant ( C ) chosen will yield the platform height in meters or inches. Constants ( C ): .3794 for platform heights in meters. 14.94 for platform heights in inches.

The above bolded formula is the Herron formula in its simplest form. The formula calculates from what height an athlete should perform in-depth jumps with regards to the individual's height, weight, and vertical jump (power). It is from this calculated height that the athlete's body will sustain the same intensity as the average-

sized athlete when stepping off a platform of average height (165 lb and 0.8 m respectively). The following examples were the two most extreme calculated platform heights from the 30 males and females from which the data was taken:

<u>Gender/Age:</u>	<u>Weight:</u>	<u>Height:</u>	<u>Vertical Jump:</u>	<u>Calculated platform height:</u>	<u>NSCA's guidelines</u>
M/17	160lb	78in	33in	1.06m	1.1m - High
F/17	225lb	69n	15in	0.45m	0.4m - low

All other calculated jump heights for the 30 subjects fell within the platform height values of 0.45m to 1.06m. These calculations are in rough agreement with the NSCA's guidelines for in-depth jumps, i.e. 0.4m to 1.1m appearing to be the optimal jump heights discovered experimentally. Another interesting side note which the formula makes apparent is that jump heights which are calculated for individuals nearing 230 lb (the weight at which the NSCA recommended in-depth jumps not be used due to injury risks) start becoming increasingly close to their own vertical jump height. In the case of the lowest jump height calculation for example, the individual could vertically jump 15 in and the platform height was calculated at 0.45m or 17.7 inches. If one speculates on measurements of an individual over 230 lb, it can be seen that the vertical jump height and in-depth jump calculated height are surprisingly close. i.e. 245 lb, 15 in vertical jump, 70 in tall = 16 in in-depth jump platform. This makes sense intuitively that a heavier individual can sustain the impact momentum which is imposed by the self-same athlete. When moving towards a discussion of more powerful athletes, however, one can see that

calculated in-depth jump platforms are considerably higher than that person can vertically leap, e.g. the athlete which ranked highest concerning calculated platform heights among the 30 individuals tested could step off the platform from a height over a full meter.

In summary, the assumption that the Herron formula makes is that athletes of different heights, weights, and strengths can sustain the same momentum at impact sustained by the average-sized athlete jumping at .8m after accounting for the differences in body composition. The formula utilizes fundamental physical principles to arrive at the appropriate calculated platform height using measurements of height in inches, weight in pounds, and power in inches of vertical leap. The calculated platform height which the formula produces may be suitable for a variety of athletes of both genders and diverse physical abilities. The author hopes it will prove to be a convenient and practical method whereby a coach or athlete can easily incorporate plyometric in-depth jumps into a training program.

## POWER ENHANCEMENT THROUGH SPEED TRAINING AND PLYOMETRICS

Speed training is of interest in most sports because of the inherent need for an athlete to quickly move from place to place on the court, field, or track. Speed also enhances a competitor's power because of power's speed component. When one recognizes the import of evading a tackle, reaching the near out-of-bounds ball, or beating an opponent to the play, it is obvious how fundamentally essential speed is to athletic performance.

Some may think speed is purely genetically determined. Although it is very true that genetics play a vital role in speed and athletics in general, almost everyone can increase their sprint times with the proper training.<sup>36</sup> The main components of running speed are stride frequency, stride length, endurance, and form.<sup>37</sup> In order to increase running times, one must develop running form to allow for increased stride frequency, stride length, or both. Local muscular and aerobic endurance is also an important consideration for running speed but is not included within the scope of this paper since we are looking primarily at anaerobic power. For short term sprint improvements therefore, an athlete would do well to work on running form to improve stride length and frequency.

Stride frequency is the number of steps or strides taken per unit time.<sup>38</sup> Increasing stride frequency involves decreasing the time frame between foot contacts. The branch of training designed to increase stride frequency is called sprint-assisted training. Such training uses downhill running (slope of 3 to 7 degrees)<sup>37-38</sup> and towing (being pulled slightly faster than the athlete can run, usually by a stretch cord).

Stride length is the distance covered during a stride or step while running. This length can be increased by increasing the ability to exert maximal force during high-velocity movements. In other words, by increasing power, stride length can be increased. It has been shown that the greatest improvements to exert force come at the velocity at which someone trains.<sup>24</sup> Suggestions for stride length improvements include strength training, resisted running (towing a sled or pulling against a stretch cord), running uphill or up steps, and plyometrics.

Running form is a motor learning process that is most effectively learned at 60-75% of maximum speed.<sup>39</sup> Form running is the term used for running drills which emphasize certain aspects of sprinting biomechanics. There exist several of these drills from high knees to rear heel kicks and multiple varieties in between. When analyzing the strengths and weaknesses of an athlete's running style, one should search for running form errors and try to improve them. The six main errors in sprinting form are outlined by Allerheiligen.<sup>38</sup>

1. Head Sway- The head should maintain a relaxed upright position without swaying in any direction.



2. Arm Swing- Arm swing should come from the shoulder while the elbow stays roughly at 90 degrees. There should be minimal lateral movement of the arms which should stay in the sagittal plane as much as possible. The hands should stay relaxed and should not cross the midsection of the body nor travel higher than the axillae.
3. Rear heel kick- The faster the sprint speed the higher the kick.
4. Upper body lean- A slight forward lean promotes speed.
5. Foot placement- Feet should point relatively straight ahead and the sequence of contact should be heel-ball, taking advantage of the foot's natural ability to utilize and create momentum.
6. Relaxation- Great sprinters have the ability to relax all muscles that are not crucial for sprinting. Hands and muscles of the jaw / face should be relaxed.

### Plyometrics

In addition to sprint training and form running, another way to enhance power is through plyometric training. Plyometrics are exercises which exploit the physiological stretch reflex principle in order to obtain more forceful concentric contractions. Conceptually this enables a muscle to reach maximal strength in as short a time frame as possible. The name plyometrics has Latin roots and literally means “measurable increase”. The stretch reflex principle is simply the phenomenon whereby the stretching of a muscle induces a reflex response to contract the muscle which is experiencing the

stretch. This is one method whereby the body protects itself from injury related to muscle tears. The mechanism behind this reflex is called the muscle spindle. These spindles are located within intrafusal muscle fibers and are highly sensitive to the rate and to a lesser degree the magnitude of a stretch. Sensory neurons exit from the muscle spindles and synapse with a motor neuron in the spinal cord. This motor neuron returns to and enervates the extrafusal muscle fibers. This is a built in self-defense mechanism whereby the muscle protects itself from rapid stretching and from injury.

Plyometrics is a training form dedicated to harnessing this reflex contraction in order to increase force output per unit time (power). The rate of stretch is perhaps the most crucial component of plyometric training. Higher stretch rates result in greater muscle tension and concentric contraction.<sup>28,33</sup>

Plyometrics have been broken down into 3 components: the eccentric phase, in which muscle spindles and fibers are stretched and loaded, the amortization phase, the time from the beginning of eccentric loading to the beginning of concentric contraction, and the concentric phase, the period during which the muscle is contracted forcefully. To optimize the benefit from the stretch reflex, the amortization period should be as short as possible. This is again due to the importance of stretch rate - “greater power is produced when the depth of the counter movement is short and rapid rather than large and slow”.<sup>16</sup>

Like progressive resistance training, plyometrics also utilize the overload principle. Training should progress from basic to difficult drills and from low to high intensity. Plyometrics should not be thought of as conditioning exercises but as speed,

motor learning, and power maneuvers. For this reason, rest and training periods must be of adequate length. Due to the nature of these exercises, fatigue should be avoided to prevent injury. The emphasis should be placed on intensity and quality, not quantity.

### Program Specifications

Before an athlete engages in a plyometric program, there is a certain strength and conditioning base which must first be established as recommended by the NSCA. The recommended strength level for the lower extremity is the ability to back squat 150% of the athlete's own body weight.<sup>16</sup> Regarding the upper extremities, strength requirements include the ability to perform five clap push-ups in a row. It is also recommended that one should also be able to bench press 100% body weight if weighing > 250 lb and 150% body weight if weighing < 165 lb.<sup>40</sup>

One might contend that it is unfair to require that the larger athlete squat one and a half times their own body weight while requiring the same from a smaller athlete. One may argue this point due to the relative strength differences among athletes of different sizes (i.e. larger athletes are on average weaker pound for pound due to decreased muscle cross-sectional area per volume). In other words, to normalize athletes of different sizes and in effect place them in a world free of relative strength differences where size and strength are always proportional, one would need to create a comparison of cross-sectional area (force capability) at a competitor's disposal per weight lifted and compare it to the average cross-sectional area per average weight lifted. This would in effect put every athlete on the same playing field with regards to resistance training. In actuality

however, nonproportionality does exist between size and strength here on earth and because of the nature of lower extremity plyometrics, it is required of an athlete to deal with personal weight and momentum as the feet strike the ground. For this reason, it may indeed be reasonable to require that every athlete possess the strength to back squat 1.5 times body weight. For the larger athlete then, in order to implement plyometric training into the program, the same strength pound for pound must be possessed in comparison to the smaller athlete. This is of course much more difficult but requisite if desiring to sustain the intensity this type of training affords. At any rate one can see the caution which must be observed when large athletes perform plyometric exercise.

When considering upper extremity plyometrics, there may actually be room for leeway since one can experiment with different-sized medicine balls and other plyometric tools. Although presumed, requiring a 165 lb or lighter athlete to bench press 1.5 times body weight may be too stringent. One would need to be quite strong at 165 lb to bench press 248 lb. This is especially true with regards to females, as they display only  $\frac{2}{3}$  the strength on average as their male counterparts. Upper extremity plyometrics also seem to be different in that often the competitor does not need to sustain body momentum but must instead manipulate a medicine ball or other object. For this reason, setting a ratio of body cross-sectional area available per force capability should be appropriate.

Recognizing that muscle cross-sectional area can be estimated by taking volume (or in this case weight) to the  $\frac{2}{3}$  power, as was shown in chapter 3, one can determine the

relative strength differences between athletes of different sizes. For upper extremity plyometrics, there is a disparity with the strength suggestions. i.e.

$$(250^{2/3} \text{ lb}) / 250 = .159 \quad \text{vs.} \quad (165^{2/3} \text{ lb}) / (165) \cdot (1.5) = .122$$

In other words for a 165 lb athlete, bench pressing  $(165) \cdot (1.5) = 248$  lb is more difficult than a 250 lb athlete benching 250 lb. This is shown by the greater calculated body cross-sectional area per strength ratio of the larger athlete (i.e. .159). One might contend that an individual's weight to the  $2/3$  power is not an accurate representation of cross-sectional area available to the athlete since only a percentage of the body's weight is muscle. Since we are in fact creating a ratio of body cross-sectional area per weight lifted to the normal body cross-sectional area per weight lifted, however, the output is the same. In addition, the reason that body tissue differences among athletes is not considered to be a confounding factor with this formula is because the formula will allude to the fact of a difference in body composition (i.e. fatter athlete), by producing a higher value for the cross-sectional area per weight pressed ratio. This is because the athlete will not have as much force production per pound as a more muscular individual of the same weight. If the average of the above two ratios are taken as the norm, i.e.

$$(.159) + (.122) = .14$$

then we arrive at the number whose value or less is the ratio of body cross-sectional area per strength a person should be able to achieve to incorporate upper extremity plyometric training into the program. The formula for upper extremity plyometric strength requirements takes shape below:

### Upper Extremity

$$(\text{weight in lb}^{(.67)}) / (.14) = \text{minimum bench press weight needed to perform upper extremity plyometrics}$$

From these calculations one can see that for the 165 lb athlete, it is the same level of difficulty to press roughly 218 lb as it is for the 250 lb athlete to press 288 lb. i.e.,

$$(165\text{lb}^{(.67)}) / (.14) = 218 \text{ lb}$$

as compared with

$$(250\text{lb}^{(.67)}) / (.14) = 288 \text{ lb}$$

One can further observe that in absolute terms, the larger athlete is (288 lb / 218 lb) = 132% strong as the smaller athlete. However, with regards to weight lifted relative to body weight, the larger athlete is only 76% as strong as the smaller athlete. i.e.,

$$(218 \text{ lb} / 165 \text{ lb}) = 1.32$$

as compared with

$$(288 \text{ lb} / 250 \text{ lb}) = 1.15$$

$$(1.15 / 1.32) = .76 \text{ or } 76\%$$

Although the strength differs in absolute terms and with regards to weight pressed per body size between the two athletes, there exists no relative strength difference when comparing the 165 lb athlete who can press 218 lb and the 250 lb athlete who can press 288 lb. This means as long as the medicine ball or other plyometric tool is scaled to fit the athlete's body size, upper extremity plyometric exercise is expedient. This author contends that this formula provides a more specific criterion against which a male can be compared than the traditional suggestion by the NSCA for upper extremity strength requirements. This formula may need to be modified with a higher cross-sectional area per weight pressed ratio for female athletes since it may be unreasonable to expect these competitors to press the same weight per body size as their male counterparts due to gender differences in strength. As stated earlier, with many upper extremity plyometric drills intensity can be altered (i.e. smaller medicine ball) to suit an athlete's needs. Although mathematically sound, research is needed to assess if the risk of injury is changed when adhering to the guidelines of this formula. If the athlete does not possess sufficient strength, plyometrics must be delayed until minimum standards are achieved. Once it is established that there is an adequate strength base by virtue of this formula or by an estimate using the recommended criteria, (i.e. squatting 1.5 times a person's body weight), specific sport demands, equipment, and program design must then be determined.

The sport-specific demands one must consider when implementing plyometrics are mainly what movements are most important for the sport. Therefore, depending on

the sport, lateral, linear, vertical, or a combination of these movements define which plyometric exercises would be the most appropriate. Frequency, volume, and intensity must also be managed to fit the sport and season (i.e. in-season , off-season, pre-season).

The equipment needed for plyometrics is relatively simple and inexpensive. Perhaps the most important piece of equipment is footwear. Shoes should possess good ankle and arch support as well as a wide, nonslip sole. A cross-training shoe may be ideal for plyometrics because of its good lateral stability to prevent ankle turnover while flats or racing shoes may be contraindicated especially for lateral movement plyometrics due to the narrow sole.

The surface on which this training type should be performed must have resilient shock absorbent properties. It is suggested that a grass field, artificial turf, or a wrestling mat may be optimal. Very hard surfaces like tile, concrete, or hardwood floors may be too traumatic for body structures upon impact. At the other end of the spectrum, excessively thick mats (i.e. > 15 cm) may not give the muscle spindles an adequate stretch rate. This would increase the amortization period and be counterproductive. Equipment must be of proper sturdiness or collapsibility depending on its purpose. (i.e. a sturdy box to be jumped off vs. a flimsy laundry basket to be jumped over.) Each piece of equipment must serve its purpose so as to prevent injury. When designing an exercise program, proper frequency, volume, and intensity must be used with consideration to an athlete's needs at a particular time in training.



Frequency is defined as plyometric workouts per week. A typical program may consist of 2 sessions / wk on Monday and Friday.<sup>16</sup> These workouts are to be done as an adjunct to other training types. Frequency is dependent on sport and season. For example, the NSCA recommends 1 to 3 workouts/wk for most sports during the off-season and 1 workout/week for football and 2 to 3/wk for track and field during the in-season. The recommendations for in-season plyometrics are to perform only those which are specific to the athlete's sport and to cease these drills during the championship season<sup>27</sup>. Frequency is also influenced by other training type volumes and intensities (i.e. resistance training). Reason must be utilized when arriving at plyometric frequencies for individuals to allow for appropriate overload and recovery so as to avoid overtraining.

Volume is a training variable in plyometrics which is expressed in units of foot contacts/workout and less frequently as distance/workout with some drills. The usual number of foot contacts/session ranges between 80 to 140 . These include single foot or double foot contacts. The purpose again for the relative small volume is that plyometrics are for speed and power training as opposed to conditioning. These drills should be performed as error free and as quickly as possible to develop the highest degree of neuromuscular control that is genetically possible. Volume of foot contacts/session should progress as with any other overload training and should be inversely proportional to intensity. In other words if a drill is considered very difficult, volume should be low. It is also suggested that volume be lowered by 10 foot contacts/drill for individuals weighing 200 to 250 lb and by 20 foot contacts/drill for individuals weighing > 250 lb

due to the increased joint stress for the larger athlete.<sup>27</sup> The progression of volume should be from low to high.

Intensity is somewhat difficult to objectively define but is an attempt to measure the amount of stress placed on the competitor's muscle tissue, joints, ligaments, and other structures. As previously stated the higher the training intensity, the lower the volume should be. Intensity should progress from low to high. Some of the factors which increase intensity are the following:

1. High horizontal speed.
2. The more external weight (weight vests, ankle and wrist weights), that is used, the more demanding on body structures.
3. One-foot lands are more stressful than two foot lands.
4. Intensity increases the higher the center of gravity is raised above the ground.
5. Vertical jumps are usually more demanding than horizontal jumps.

Although recovery may be somewhat different among individuals, some general guidelines have been offered by the NSCA. Because plyometric activities should be performed with maximal effort, maximal recovery time should be allowed to prevent injury and to enhance the drill's effectiveness. Recovery time between workouts must be adequate (e.g. 2 to 4 days between workouts). Recovery between repetitions may be as much as 5 to 10 seconds of rest between repetitions and up to 3 minutes between sets depending on the level of intensity.

## Drill Movement Types

Drill types are categorized into jumps, hops, bounds, shocks, and upper body plyometrics. They can also be classified into levels of intensity (i.e. low, medium, high, and shock).<sup>16</sup> Although intensity level classification is somewhat ambiguous, it provides an estimate of how the body may react to the training stimulus. While there are drills that have been proven with time, only one's imagination limits the endless possibilities for exploiting the stretch reflex response. The main points to remember when developing a plyometric program are to keep training volume, intensity, and frequency appropriate with regard to the season, sport, athlete's condition, and other training factors (i.e. resistance training). One must also consider safety, body size, and direction of motion specificity.

Hops are movements that begin and end with the athlete leaving and striking the ground on the same foot or with both feet. Short-response hops and long-response hops are considered to be medium to high intensity. Short-response hops are usually performed with 10 repetitions or less and include exercises such as double and single leg hop, speed hop, and lateral hop. Long-response hops are performed for at least 30 meters and include double and single leg hops and the speed hop. Both of these hop types can be further intensified with the addition of external weights.

Jumps are movements which end with an athlete striking the ground with both feet. A single jump is considered to be a repetition and a set usually consists of 10 repetitions. The intensity of in-place jumps normally range from low to high. Examples

of these include the tuck, pike, split squat, squat, and power jumps. The intensity of standing jumps are normally considered medium intensity and include standing long, triple, and lateral jumps. The standing jumps are considered to be a 1 RM.

Bounds are movements in which the athlete jumps from one foot and lands on the other. Sometimes these are performed in rapid sequence. Bounds are usually measured in linear distance and are considered medium intensity drills. As with hops there are short-response and long-response bounds. Short-response bounds are those movements lasting 25-60 meters and include alternate, single, and combination leg drills. Long-response bounds are those movements lasting over 60 meters and include the previously mentioned bound drills. A shock factor can also be initiated with bounds by adding external weight.

Shocks include the in-depth jump and box jumps and are considered shock level intensity. These are nervous system exercises which greatly tax body structures. It is crucial to determine if the athlete is conditioned for plyometric activity before attempting these high intensity activities. Athletes who engage in sports which require competitive amounts of vertical leaping ability (i.e. track and field, volleyball, basketball) can benefit most from shocks since it trains the vertical component of jumping. These shock drills are considered the highest intensity (shock intensity). A set may consist of 1 to 10 repetitions.

Upper body plyometrics are exercises classified as low to medium intensity and include sit-ups, push-ups, and medicine ball activities. As was previously stated, these

exercise drills are only limited by the imagination and can not only be beneficial but fun as well.

Other sources have more complete explanations and instructions for specific plyometric drills.<sup>16,28-37</sup> This training type not only adds spice to a workout but has proven to be safe and effective in increasing power.<sup>40</sup>

## Summary

Power is the most important performance factor with many sports because it combines crucial speed with the force production athletes must exhibit. Since power is a must in athletics, it is reasonable that this is the measurement for which competitors and coaches should be most concerned. It is also reasonable to submit new ideas for the purpose of creating larger and faster power gains in order to aid athletes in reaching their potentials, which are limited only by their own genetics, physiology, and desire. These are the grounds which this independent study uses to suggest possibilities which may create greater power gains.

Besides exploring what has worked well in past attempts to enhance power, this author recommends several possible variations and changes to some traditional protocols concerning aspects of resistance training, periodization, and plyometrics. These suggestions appear conceptually promising to help competitors reach genetic power potentials more quickly. Specifically, this study suggests changes to traditional resistance training protocol during the power phase and competition period of a mesocycle whereby an individual should “explode with power” as opposed to “methodically feeling the burn”. The study also suggests that the percentage of the maximal lift should be lowered from 90% through 95% to 60% through 85% during these portions of periodization to

allow for higher velocity and power outputs. In addition, two formulas have been presented. One offers a minimum strength and condition standard as a prerequisite for athletes desirous of incorporating upper extremity plyometric drills into their training program. This formula appears below:

### Upper Extremity

$$(\text{Weight in lb}^{(.67)}) / (.159) = \begin{array}{l} \text{minimum bench press weight} \\ \text{needed to perform plyometrics} \end{array}$$

The other formula offers a normalized platform height off which an athlete can step to perform in-depth jumps, a shock intensity level drill utilized with plyometric training. This formula uses power, height, and weight measurements to determine the appropriate platform height for a variety of different individuals. This formula is as follows:

$$\frac{\sqrt{(VJ) \cdot (Ht)}}{(Wt)} \cdot C = \begin{array}{l} \text{Platform} \\ \text{height} \end{array}$$

Height and vertical jump should be entered in inches. Weight should be entered in lb's and the constant ( C ) chosen will yield the platform height in meters or inches. Constants ( C ):  
 .3794 for platform heights in meters  
 14.94 for platform heights in inches

The foundation for these recommendations are mathematical and research regarding the efficacy of these claims is requisite before conclusions of training type superiority are made.

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