# Techniques for Analyzing Power in our Training
## Part 2 of Physics and Training with Weights

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## Introduction

In Part 1 of the series, entitled "Physics and Training with Weights," techniques for analyzing the work you perform in your training were demonstrated [1]. In the following sections, we're going to discuss some techniques for analyzing the power you perform during your training.

As pointed out in Part 1, work and power are two parameters that are often discussed with respect to weight training. Some training programs focus on work as a parameter that must be increased over time whereas other programs insist that power is the parameter that must increase. Indeed, work and power are both intimately related to the intensity and volume that we use in our training. But the two are different: work is energy you expend during your training, and power is the rate with which you expend that energy. Simply performing more reps and sets of an exercise will increase the work you perform, but it won't do the same for the power you perform. To find out why this is so, let's take a closer look at the concept of power.

Before discussing power, it should be mentioned that in Part 1, we made point of avoiding the work performed when lowering weights. An argument was given as to why work performed during the lowering, or eccentric, portion of a repetition is also positive work performed by our muscles [1]. On the basis of that argument, herein we shall include the eccentric portion of repetitions as contributory to the total work performed. This is important if we are to accurately quantify the total power performed in our training.

## Overview of Power

Power is a measure of the amount of work performed during a particular interval of time. In its simplest form, the equation for power is

$$P = \frac{W}{T}, \qquad (1)$$

where $P$ is the power, $W$ is the work performed, and $T$ is the time interval during which the work is performed. Recall that the expression for work in our training can be expressed as $W = FD$, where $F$ is the weight we are lifting, and $D$ is the distance the weight moves [1]. Upon substituting $FD$ for the work $W$ in Eq. (1), the power becomes

$$P = \frac{FD}{T}. \qquad (2)$$

This familiar equation will be very useful in analyzing the levels of power performed in our training. Let's briefly see how Eq. (2) is used.

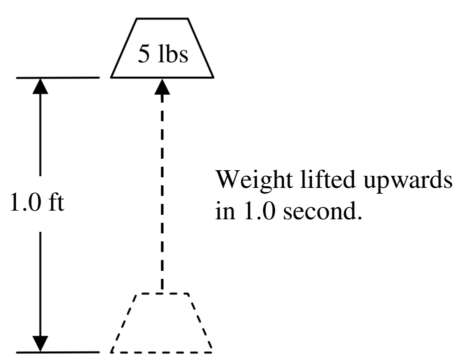
Suppose we lift a 5-lb weight upward a distance of 1 ft, as shown in Figure 1, and we do it 1 second's time. Using Eq. (2), we find that

$$P = \frac{(5.0\,\mathrm{lbs})(1.0\,\mathrm{ft})}{(1.0\,\mathrm{s})} = 5.0\,\frac{\mathrm{ft}\cdot\mathrm{lbs}}{\mathrm{s}}.$$

Thus, our power output during this lift is 5 ft-lbs/s. Now, suppose we do the lift again, but this time we do it in half a second. Equation (2) then gives

$$P = \frac{(5.0\,\mathrm{lbs})(1.0\,\mathrm{ft})}{(0.5\,\mathrm{s})} = 10.0\,\frac{\mathrm{ft}\cdot\mathrm{lbs}}{\mathrm{s}}.$$

Notice that now the power output is doubled even though the load, 5 lbs, is no different than before. Although the work performed is the same for each lift, the power performed is doubled by lifting the load in half the time.




**<u>Figure 1: Weight Lifted 1 ft Upwards in 1 Second</u>**

An important distinction between power and work is that performing more sets of an exercise does not increase your power output like it does with your work performed. For example, consider a lifter that performs 3 reps of Squats with 200 lbs. As the lifter tires, the reps will take longer to complete. Suppose the 3 reps take 2.0, 2.2, and 2.5 seconds, respectively. Assuming the lifter moves the weight 2 ft upward and then 2 ft downward during each rep, the power performed during each rep is

$$P_1 = \frac{(200\,\text{lbs})(4.0\,\text{ft})}{(2.0\,\text{s})} = 400\,\frac{\text{ft}\cdot\text{lbs}}{\text{s}}\,,$$

$$P_2 = \frac{(200\,\text{lbs})(4.0\,\text{ft})}{(2.2\,\text{s})} = 364\,\frac{\text{ft}\cdot\text{lbs}}{\text{s}}\,,$$

$$P_3 = \frac{(200\,\text{lbs})(4.0\,\text{ft})}{(2.5\,\text{s})} = 320\,\frac{\text{ft}\cdot\text{lbs}}{\text{s}}\,.$$

Clearly, the power performed by the lifter drops as fatigue slows the lifter's rep-speed. The important thing to notice, however, is that you cannot just add the power values above and then assume that the lifter performed a total power of 1084 ft-lbs/s! Rather, we must consider the total distance covered by the weight during the 3 reps and the total time it takes for the weight to move through this distance. In the present case, the weight is lifted upward 2 ft and then downward 2 ft during each rep, so the total distance for 3 reps is 12 ft. Assuming the lifter didn't pause between reps, the total time taken is 6.7 seconds. Therefore, the power performed during the 3 reps is

$$P_{1-3} = \frac{(200\,\text{lbs})(12.0\,\text{ft})}{(6.7\,\text{s})} = 358\,\frac{\text{ft}\cdot\text{lbs}}{\text{s}}\,.$$

For the sake of comparison, let's consider the work that the lifter performs during the 3 reps. Using the expression for the work [1], it's straightforward to see that the work performed by the lifter during each of the three lifts is

$$W = (200\,\text{lbs})(4.0\,\text{ft}) = 800\ \text{ft}\cdot\text{lbs}\,.$$

This is the amount of energy expended by the lifter during each of the lifts, regardless of how long it takes to lift the weight. Since the work performed is additive, the total work performed by the lifter during the 3 reps is 2400 ft-lbs!

It is useful to think of work as the energy you expend during your training, and power as the rate with which you expend that energy. Using this approach, we can say that the lifter performed 2400 ft-lbs of work at a rate of 358 ft-lbs per second during the set.

Another thing that we must keep in mind is that work is different than the popular parameter, "total pounds lifted." Total pounds lifted is a sum of the weights concentrically lifted during a set of reps. In the example above, the lifter hoisted 200 lbs for 3 reps, thus the total pounds lifted is 600 lbs for the set.

## Power Performed During a Set

Equation (2) is a general expression for power that isn't terribly convenient for application to our training. To simplify Eq. (2), note that for any exercise that you perform, the rep-max (RM) weight that you lift can be viewed as a fractional value of the maximum weight that you can lift one time. This fractional value can be used to express the load you're lifting in terms of your 1RM weight. Thus, we shall put $F = fL_M$, where $L_M$ is your 1RM weight and $f$ is the fractional value [2-3].

Another simplification presents itself upon noting that $D$ is not limited to the distance the load moves during 1 repetition. Rather, $D$ is the sum of the upward and downward distances the load moves throughout the entire set. For example, suppose that when you perform 1 rep of Squats, the load moves upward 2 ft and then downward 2ft. Thus, the distance covered by the weight during 1 rep is 4 ft. Then, if you perform 10 reps, the total distance $D$ is 10 x 4 ft = 40 ft! Therefore, we can put $D = Rd$, where $R$ is the total number of reps performed during a set, and $d$ is the distance the load moves during 1 rep. Using these simplifications in Eq. (2) leads to

$$P = \frac{fL_M Rd}{T}\,. \tag{3}$$

At this point, it is worthwhile to mention that some readers may have noticed that Eq. (3) is very similar to an equation they know as a Power Factor [4-5]. This is easier to see when Eq. (3) is written in a slightly different form:

$$P = \left[\frac{fL_M R}{T}\right]d\,. \tag{4}$$

The ratio within the square brackets is the Power Factor. That is, $fL_MR$ is the total weight lifted during a set of $R$-many reps, $T$ is the time taken to complete the entire set, and $d$ is the distance the weight moves during 1 rep, which [4] chooses to drop from calculations. There do seem to be some problems that arise when using the Power Factor approach, however [5]. Let's take a look at some these problems and see how they can be fixed.

One problem with the Power Factor approach is that one cannot just drop the distance $d$. This distance varies from exercise to exercise and from lifter to lifter. Moreover, if you're using a partial range of motion (ROM) [4-5], the distance $d$ is vastly different than when you use a full ROM. If you want to compare results with other lifters or for different exercises, you'll ultimately have to consider the distance $d$. A better way to avoid dealing with individual distances is to set $d$ = 1.0 ft and then remember that now we're dealing with power per "linear foot" that the weights move. This is the approach that we'll use herein.

Another problem arises when we use true weight values. For instance, it's difficult for one lifter having a 1RM weight of 500 lbs to use the same analysis as a lifter having a 1RM weight of, say, 200 lbs. Directly comparing the two lifters' Power Factors is like comparing apples and oranges. This is easier to see by considering the following example.

Consider two lifters, A and B. Lifter A has a 1RM weight of 316 lbs for Squats, and lifter B has a 1RM weight of 433 lbs. Suppose these lifters want to compare their power outputs with 235 lbs. Both lifters perform as many reps as possible with the 235 lbs during a 2-minute period. Lifter A performed 22 reps and lifter B performed 30 reps. Using Eq. (4) suggests that lifter A performed 43 ft-lbs/s of power while lifter B performed a power of 59 ft-lbs/s. Clearly, lifter B vastly outperformed lifter A. Problem is: their 1RM weights are not the same, and so this analysis is not calibrated for comparing the power performed by the two lifters. For instance, 235 lbs is about 74% of lifter A's 1RM weight, whereas 235 lbs is about 54% of lifter B's 1RM. Therefore, the power performed with 235 lbs doesn't mean the same thing for the two lifters simply because 235 lbs is less weight for lifter B than for lifter A.

This problem is alleviated, however, by using percentages or fractions of 1RM weights. We can convert to fractions of 1RM by setting each lifter's 1RM weight equal to 1.0 lb. This enables a group of lifters to use the same analysis without having to consider differences in performance capability. Upon doing this, we need only remember that now we're dealing with "normalized" power. This is the approach we'll use in order to calibrate our analysis.

Upon setting $d$ = 1.0 ft, as discussed above, and setting $L_M$ = 1.0 lb to normalize the power, Eq. (3) becomes

$$P = \frac{fR}{T}, \tag{5}$$

where it must be kept in mind that we're now dealing with the normalized power per linear foot that the weights move. Lifters can later determine their true power outputs by multiplying Eq. (5) by their 1RM weights and the distances that they move the weights.

Another area of concern is that the Power Factor is computed for entire sets which include several repetitions that may be taken to momentary muscular failure [4]. During any set, rep-speed slows as fatigue grows, and thus the reps take longer to complete as the set progresses. This forces us to use an average time for the whole set! If you want to know how fatigue affects your power output throughout entire sets, then timing the whole set is fine. On the hand, if you want to know about your power output without interference from fatigue, then we need to find a different way to deal with time in our equations.

An easy way to eliminate the time problem is to make certain that every rep in the set takes the same amount of time, even if that means performing only 1 or 2 reps per set! Doing this affords a great simplification: when each repetition takes a small, yet equal amount of time $t$, we can put $T = Rt$, where $R$ is the number of repetitions performed during the set. Of course, simplifying the total time $T$ in this way brings constraints. Most obvious is that $t$ must remain constant for all repetitions throughout the set. In other words, your rep-speed must remain constant, or as nearly so as possible, throughout the set. This should be no problem for powerlifting routines wherein few reps are performed in each set, and for bodybuilding routines wherein working to momentary muscular failure is avoided. When momentary muscular failure is taken into account, or when you're lifting for speed, you must use the total time $T$ for the whole set.

Assuming that you can maintain a nearly constant rep-speed, Eq. (5) becomes

$$P = \frac{fR}{tR}. \tag{6}$$

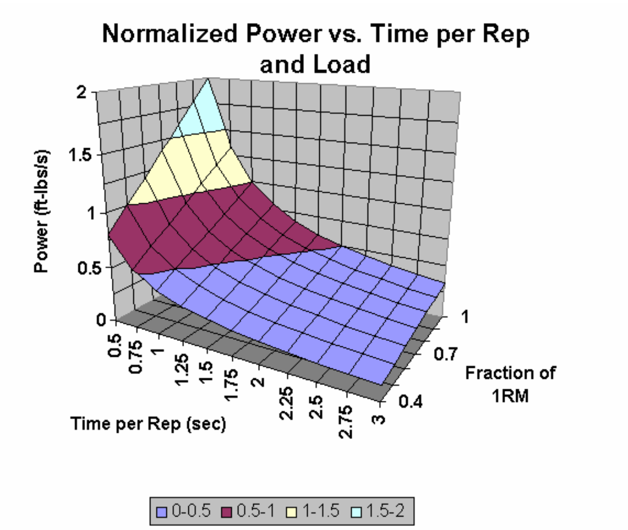
Upon canceling the $R$s in the numerator and denominator, we arrive at a very simple expression for the power:

$$P = \frac{f}{t}. \tag{7}$$

Although Eq. (7) appears very simple, it's somewhat complex because both $f$ and $t$ can take on different values independently of one another. Also, we must remember that the unit for power is ft-lbs/s; even though Eq. (7) is normalized, it still has the unit for power.

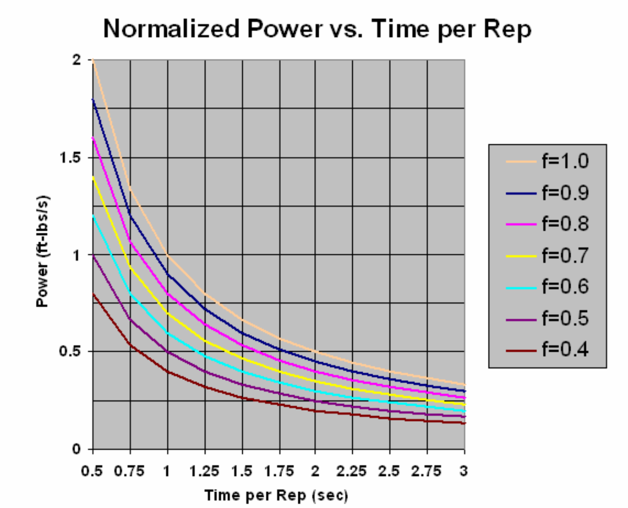
## Graphing Power versus Load and Time

A 3-dimensional surface graph of Eq. (7) is shown below. The surface graph illustrates the relationship between power, time, and load. The vertical values give the level of power performed for a single repetition. On the lower left-hand side are the time values; they represent various amounts of time that may be spent during a single repetition. The values on the lower right-hand side are the fractions of your 1RM weight; they represent various loads that may be lifted. The legend on the bottom indicates regions of the surface wherein the power falls within specific values. For example, the yellow region denotes values for the power ranging between 1.0-1.5 ft-lbs/s.




A nice thing about the surface graph is that it clearly shows that the general trend is an increase in power whenever the load increases or the time per rep decreases. This is evident because the surface slopes upward as load values increase and as time values decrease. Despite this, the surface graph can be difficult to work with when we want to analyze our power output during training. It's much easier to graph the load and time separately.

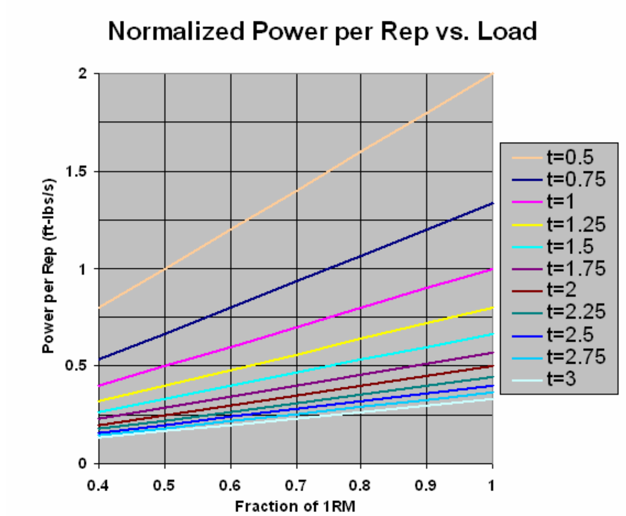
As you can see, the following graph shows the relationship between the normalized power and the amount of time taken to perform a single repetition.




The colored lines represent particular fractions of your 1RM weight. Notice that all the colored lines slope downwards as the time increases. This tells us that the longer you spend lifting any particular load, the lower is the power you perform during the lift! This drop happens regardless of how heavy the load seems during the lift.

The Power versus Time graph makes it easy to compare your power output for various loads and rep-times. For example, notice the upper-most sloping line that represents your 1RM weight (i.e., $f = 1.0$). According to the graph, if you spend 2 seconds lifting your 1RM weight, then you'll perform 0.5 ft-lbs/s of power. The graph also tells us that if you spend 1 second lifting 50% of your 1RM (i.e., $f = 0.5$), you'll also perform 0.5 ft-lbs/s of power. Clearly, lifting heavy weights doesn't guarantee that you're performing more power than when you lift lighter weights!

Let's take a look at another type of graph, which shows the relationship between the normalized power performed per repetition and the load you're lifting.




The Power versus Load graph contains essentially the same information as the previous graph, but the information is shown differently. The horizontal values are now fractions of your 1RM weight, and each of the colored lines represents a particular amount of time that you can spend lifting the various loads.

Notice the horizontal, black line which represents a power of 1.0 ft-lbs/s. For simplicity, we'll refer to this line as the "power-1 line." Okay, now notice that the power-1 line crosses over the three upper-most colored lines. The $t = 0.5$ line crosses the power-1 line at a point which coincides with a load of 0.5 of 1RM. Similarly, the $t = 0.75$ line crosses the power-1 line at about 0.75 of 1RM, and the $t = 1$ line crosses the power-1 line at 1.0 of 1RM. Based on this information, it's easy to see that your power output will be 1.0 ft-lbs/s when you lift 0.5 of your 1RM in 0.5 seconds. Your power output will also be 1.0 ft-lbs/s when you lift 0.75 of your 1RM in 0.75 seconds, or when you lift your 1RM in 1 second. It's interesting that the power output is the same for all three lifts even though the loads are so different!

## Analyzing Power in Multi-Rep Sets

Thus far we've been discussing power in terms of repetitions involving a variety of possible loads and times.

Now let's see how to apply what we know about power to human training subjects.

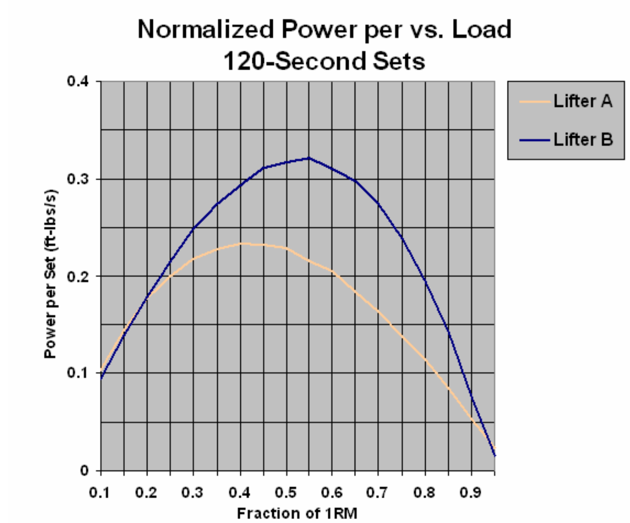
Recall the two lifters, A and B, mentioned above, and how we couldn't use the Power Factor to directly compare their performance [4]. Well, now we're going to go ahead and compare their power performance by normalizing their 1RM weights to calibrate our analysis. Suppose lifter A has a 1RM weight of 316 lbs for Squats, and lifter B has a 1RM weight of 333 lbs for the same exercise. With these values in hand, it's straightforward to determine the weights for each lifter that correspond to the fractional values we'll use for the analysis. Table 1 lists the fractional values of interest and the corresponding weights that each lifter will use during the performance test.

| *f* | Weights Lifter A | No. Reps 120 Sec. | Weights Lifter B | No. Reps 120 Sec. |
|---|---|---|---|---|
| 0.1 | 32 | 125 | 33 | 114 |
| 0.15 | 47 | 115 | 50 | 111 |
| 0.2 | 63 | 106 | 67 | 107 |
| 0.25 | 79 | 96 | 83 | 103 |
| 0.3 | 95 | 87 | 100 | 99 |
| 0.35 | 111 | 78 | 117 | 92 |
| 0.4 | 126 | 70 | 133 | 88 |
| 0.45 | 142 | 62 | 150 | 83 |
| 0.5 | 158 | 55 | 167 | 76 |
| 0.55 | 174 | 47 | 183 | 70 |
| 0.6 | 190 | 41 | 200 | 62 |
| 0.65 | 205 | 34 | 216 | 55 |
| 0.7 | 221 | 28 | 233 | 47 |
| 0.75 | 237 | 22 | 250 | 38 |
| 0.8 | 253 | 17 | 266 | 29 |
| 0.85 | 269 | 12 | 283 | 20 |
| 0.9 | 284 | 7 | 300 | 10 |
| 0.95 | 300 | 3 | 316 | 2 |

**<u>Table 1: Performance Data for Lifters A and B</u>**

Once you know how much weight to use for each fractional value, you can begin testing the lifters' performance. For each fractional value, the corresponding weight is lifted for as many repetitions as possible within a time period of 120 seconds. We'll suppose that the numbers of reps listed in Table 1 were actually performed by lifters A and B.

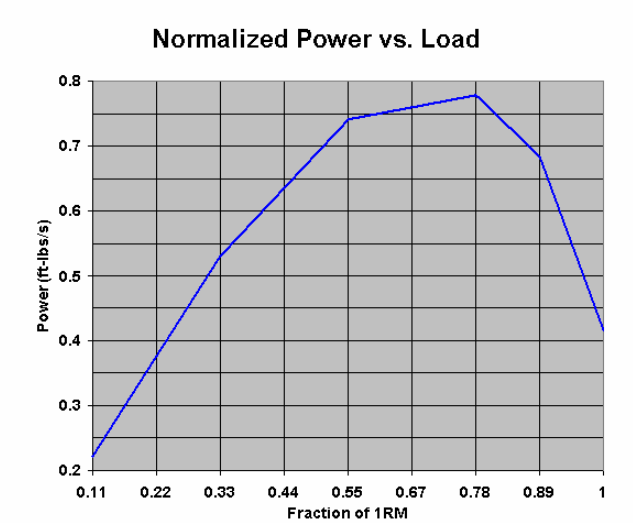
Since the lifters performed multi-rep sets that last for 120 seconds, we must use Eq. (5) to determine the power output of the lifters for each fractional value of interest. Carrying this out with the data listed in Table 1 leads to the following Power versus Load graph.




Now that we have a calibrated graph, we can directly compare the performance of lifters A and B! The first thing to notice is that lifter A's power output peaks when using loads between about 40-45% of 1RM, whereas lifter B's power peaks when using a load of about 55% of 1RM. No doubt, this difference is due to fatigue increasing during the long, 2-minute sets. Another thing to notice is the power output when the lifters use a load below about 0.2 of 1RM and above about 0.93 of 1RM. In both cases, lifter A performed a bit more power than did lifter B. These little shifts in performance would not be apparent if the analysis wasn't calibrated.

## Analyzing Power in Single-Rep Sets

The methods presented above for determining the power are clearly affected by the presence of fatigue on the part of the lifters. One way to substantially eliminate fatigue is to perform only 1 repetition with each weight being tested. Of course, we all know that the time it takes to lift a load depends on weight of the load. In essence, the heavier the load, the longer it takes to lift the load. So, what happens when we lift various loads as fast as we can, but perform only 1 rep with each weight? Dr. Frederick Hatfield (a.k.a. "Dr. Squat") has done considerable research into this subject and has determined that for any lifter performing any exercise, the power performed appears to follow an inverted U-shaped path when graphed as a function of load [6]. This is illustrated in the following graph.




The above graph is the result of using Eq. (7) with some of Dr. Hatfield's research data. The following table lists some of the fractional values and rep-times offered in [6] and used with Eq. (7) to produce the Power versus Load graph.

| **Fractional Values (*f*)** | **Time per Rep (*t*-seconds)** |
|---|---|
| 0.11 | 0.5 |
| 0.33 | 0.63 |
| 0.55 | 0.75 |
| 0.78 | 1.0 |
| 0.89 | 1.3 |
| 1.0 | 2.4 |

As illustrated in the graph, the power does indeed follow an inverted U-shaped path when the rep-speed is maximal and fatigue is not a factor. Moreover, the power performed clearly peaks when the load is between 0.55 and 0.85 of the 1RM weight. When lifting loads less 0.55, power suffers because the loads are simply too light relative to the amount of time taken to lift these loads. And, when lifting loads heavier than 0.85, power suffers again because the weights are too heavy relative to the amount of time taken to lift these weights. In essence, loads below 0.55 of 1RM are too light, and loads above 0.85 are too heavy; we simply cannot move these loads fast enough to perform optimal levels of power. With loads between 0.55 and 0.85, however, the load and time appear to be more optimally associated with one another. As a consequence, the load range between about 0.55 and 0.85 of the 1RM weight is considered to be a preferred "training zone" [6].

## Simple Procedure for Testing Power

Many aspects of determining the power in our training have been presented in the sections above. So, is there a straightforward procedure for determining your power output, or that of your clients? Well, yes; let's take a look.

The first step is to determine a 1RM weight for each lifter, as well as for each exercise under consideration. Once you know the 1RM weight, you can determine the fractional values (*f*) [2-3] and the corresponding weights you'll use during the performance test. If you're determining your own power, you needn't worry about normalization; but if you'll be comparing the performance of more than one lifter, normalizing the power is crucial. This can be done by simply setting the 1RM weight equal to 1.0 lb later, when you analyze the performance data. Also, you should set the distance the weight moves (*d*) equal to 1.0 ft. You'll then be working with the normalized power per linear foot that the weights move. If you want to determine your true power output, you can do this by multiplying the power by the true 1RM weight and the distance that the weight moves.

Next, you're ready to perform timed rep-tests with the various weights that you determined. This involves loading the bar with weight and then recording the time it takes to perform a desired number of reps, or recording the total number of reps performed during a fixed period of time. You have a couple of options, here. If you're interested in your performance during multi-repetition sets that include fatigue, you can record the total time required to perform the entire set. On the other hand, if you want to eliminate fatigue, you can either record the time required to perform single-rep sets or make certain that your rep-speed remains constant throughout multi-rep sets.

| **Multi-Rep Sets with Fatigue** | **Singles or Multi-Reps with Constant Rep-Speed** |
|---|---|
| Determine 1RM weight for each lifter and/or exercise. | Determine 1RM weight for each lifter and/or exercise. |
| Determine fractional values (*f*) and corresponding weights. | Determine fractional values (*f*) and corresponding weights. |
| Normalize the 1RM weight and the distance the weights move. | Normalize the 1RM weight and the distance the weights move. |
| Record the total time (*T*) to complete each set of rep (*R*). | Record or determine the time (*t*) to complete each rep. |
| Determine power values by using $P = \frac{fR}{T}$. | Determine power values by using $P = \frac{f}{t}$. |

**<u>Table 2: Procedure for Testing Power</u>**

The manner in which you record time determines which form of power equation that you'll use. You can Eq. (5) to determine power values if you recorded the time for entire sets that include fatigue on the part of the lifter. If you recorded the time for single-rep sets, or you kept the rep-speed essentially constant throughout multi-rep sets, then you can use Eq. (7) to determine the power values. Note that when you record the total time for a multi-rep set, you must divide the total time by the number of reps before using Eq. (7). Table 2 summarizes the steps required to test your power output, or that of your clients.

## References


[1] Ridgely, Charles T., "Techniques for Analyzing Work in our Training," Part 1 of "Physics and Training with Weights," *Bodybuilding.com*, October 2004, http://www.bodybuilding.com/fun/ridgely7.htm

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[4] Sisco, Peter N., *Train Smart: Pete Sisco's Secrets to Gaining up to 40 Pounds of Muscle – Fast!*, http://www.precisiontraining.com

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