Some answers to the questions concerning Power and Strength:

In discussing the possibilities of strength gain, we can breakdown the gains in strength into two components the neural (short-term) component and the hypertrophic (long-term) component.

The neural factors that improve strength gains within the short-term include (1) the recruitment of additional motor units for greater force production, (2) changes in the discharge rates of motor units, (3) the counteraction of autogenic inhibition that allows for greater force production, and (4) the reduction of coactivation of agonist and antagonist muscles. These changes are incorporated into what we would characterize as the short-term effects of strength training and strength gain.

In the first case: recruitment of additional motor units - As the external force exceeds the normal homeostatic contractile force of the muscle, the neural system must increase the recruitment of motor units, which in turn stimulates the contraction of more muscle fibers within the contracting muscle. The greater the external force, the greater the number of motor neurons recruited. The orderly recruitment of motor neurons is based on the size of the motor neuron. Smaller neurons with the lowest stimulus threshold are recruited first and as the demand (external force) for stronger contractions increase, the larger motor neurons are recruited. This means that those motor neurons that are small in size and have the lowest threshold are innervated at the onset of the contraction, followed by the mid-size motor neurons, and finally the large motor neurons if necessary. The small motor neurons with low thresholds are found in the Type I (slow twitch) fibers, and the largest motor neurons with the highest stimulus threshold are found in the type IIb (fast twitch-glycolytic) fibers. With this in mind, strength training will always recruit the slow twitch fibers upon contraction, and will only recruit the fast twitch fibers when necessary. In other words, contraction of slow twitch fibers is easily achieved, but the contraction of the fast twitch type IIb fibers is very hard to achieve. This is an important concept, because in the orderly recruitment of motor neurons, both the slow twitch (type I) and fast twitch (type IIa and IIb) are recruited to cause a contraction dependent on the external force. Since muscle hypertrophy occurs at its greatest level in the type IIb fibers, the external force must be great enough to recruit the type IIb fibers. This also means that increases in both Type I and Type II fiber hypertrophy are evident in resistance training. Now, what about a beginning weight lifter? With the beginning weightlifter, increased recruitment of motor neurons is disrupted according to Selye's first phase of GAS. Instead of methodically recruiting motor neuron by motor neuron until the necessary contractile force is supplied to overcome the external force, all motor neurons are recruited so that all of the fibers are innervated to cause a contraction; the fight or flight response. The neural adaptation process for Stage II of Selye’s theory is to enhance the force feedback loop from the muscle to the central nervous system and gain control of the motor unit recruitment so that the neural response is an orderly recruitment of
only those neurons that are necessary to produce a contractile force greater than the external force. This adaptation process usually begins immediately upon training and reaches completion within 4 – 6 weeks.

The second part of the motor neuron activation of muscle fibers deals with changes in the discharge or firing rate of the motor neuron. A firing rate describes the number of impulses or stimuli per length of time. A general description would be that as the external force increases, the firing rate of the motor neuron increases, which in turn increases contractile force. However, to be specific, the contribution of the firing rate of the motor neuron is dependent on muscle size, the maximum contractile force of the muscle and motor neuron recruitment. In small muscles, the firing rate begins contributing to the muscle contraction after the force of contraction reaches approximately 50% of the maximum contractile force of the muscle. Once the force of the contraction exceeds 50% of the maximum contractile force the muscle can generate, then the firing rate is the major contributor to generation of contractile force up to the maximum contractile force. In large muscles, the firing rate does not contribute significantly to the muscle contraction until the force of contraction reaches 80% of the muscle’s maximum achievable contractile force. To achieve adaptation of the firing rate in large muscles, the force of contraction must exceed 80% of the muscle’s maximum contractile force, therefore, adaptation of the firing rate will occur after motor neuron recruitment is achieved and the force of contraction exceeds 80% of maximum contractile force.

To put the first two factors of neural adaptation into perspective, let us look at a large proximal muscle such as the bicep. As we begin a weight lifting program using biceps curls, the main factor for the development of contractile force is the recruitment of motor neurons up to 100% of the muscle’s maximum contractile force which can be approximated by a 1RM lift. After the external force exceeds 80% of 1RM then, the firing rate increases to improve contractile force in conjunction with the recruitment of the large motor neurons. Therefore, in most strength training programs, firing rate adaptations occur after the adaptations of motor neuron recruitment.

The final area of neural adaptations that occur in the latter part of training program (4–16 weeks) is the reduction in inhibitory responses and antagonistic muscular contractions. The inhibitory response is the reaction of the central system due to feedback either from the Golgi tendon or from pain receptors. Increases in muscular tension as “measured” by the Golgi tendon causes a feedback loop that inhibits the stimulation of the motor neurons thereby limiting contractile force. As the Golgi tendon adapts to the presence of the tension, the inhibitory response is lessened and the corresponding motor neuron stimuli is improved which in turn increases the contractile force of the muscle. The second part of the central feedback loop is the activation of agonist and antagonist muscle groups for control. As the muscle adapts to the strength training program, the neural feedback for control is diminished, and certain antagonistic
muscles are no longer receive contractile stimuli. When this happens, the internal stress of the primary working muscle is increased thereby improving the adaptation process of the contracting muscle (In other words, the primary contracting muscle no longer receives help from other secondary controlling muscles). Notice in figure 1.0 that the neural adaptation response declines as a percentage of strength (force development) as time in training increases.

**Figure 1.0. Neural and Hypertrophic Adaptations as a Percentage of Strength Gains Over Time**

Now what about muscle hypertrophy? Muscle hypertrophy can be described as transient (immediate) or chronic. Transient hypertrophy describes the pumping up of the muscle during a single exercise bout due to fluid accumulation from the blood plasma into the interstitial spaces of the muscle. Chronic hypertrophy describes the increase in muscle size after long-term resistance training due to changes in muscle fiber number (fiber hyperplasia) or muscle fiber size (fiber hypertrophy). Muscle fiber hypertrophy is the increase in the numbers of myofibrils and actin and myosin filaments that result in more cross-bridges. The muscle protein synthesis that aids in the increase in fiber size increases during the post-exercise period of a training regimen. Training at higher intensities appears to cause greater fiber hypertrophy than training at lower intensities. Notices in figure 2.0 that training at loads above 85% of 1RM accomplishes hypertrophy in both type I and type II muscle fibers. More on this in the power discussion below.
So the next question becomes what about power? Power, as discussed in the discussion area is the interrelationship of force generation and the speed of contraction. From reading the above material, you can then surmise that power development requires improving force generation from neural adaptations and hypertrophy as well as contractile speed associated with fiber recruitment and rate coding of the neural stimuli. So one question you may ask is; why do some researchers report that training for power occurs between 40% and 70% of 1RM, when in fact this would lead to the recruitment of only Type I fibers? One hypothesis is: As you add hypertrophy, which increases the strength component (review figure 1.0), you change neural recruitment strategies of the muscle fiber. By working at the lower loads, you allow the neural system to adapt to new recruitment strategies in response to the added hypertrophy. This is a plausible hypothesis, except that it does not incorporate the relationship between recruitment and fiber contractility speed. Remember that Type I slow twitch fibers are thus named because they have slower contractile speed than Type II fast twitch fibers. And as discussed above, slow twitch fibers are recruited before fast twitch fibers. So how do we explain this quandary? My thought on this is that training at 40% to 70% improves the type I fiber contractile speeds improving power. I think the researchers have in general forgotten that power has a relationship between the external mass being moved relative to the absolute force generation of the muscle fiber, contractile speed of the muscle fiber, and the rate coding of the motor unit. An example of this would be if you had two 100kg individuals, each lifting 100 kg. The velocity (distance/time) at which they can lift that weight is proportional to the absolute force generation of the muscle, the contractile speed of the recruited fibers, and absolute rate coding of the recruited fibers. Look back at the power lab that each of you posted. Explain
why some individuals were able to lift at higher speeds than others, or a better question, is why some people were unable to lift the weights at all? The answer is that they did not have the requisite force generation relative to the weight. So back to the general discussion of power. How do you improve power? You improve power by increasing the strength of the individual. Another example of this is if you have two 75kg athletes running a 100 meter sprint. One male could squat 100 kg while the other could squat 200 kg. The faster sprinter would be the one that could squat 200 kg because the mass that is being moved is at a lower percentage of the actual force that the legs can generate. This is an over simplified example, but I think that it explains the power issue. Two studies that we have done here at UTPB corroborate this example. We increase approach velocity of pole vaulters by increasing their strength: The greater force generation of the legs, the faster the approach velocity. Pole vaulters now can estimate their vault height by their approach velocity, and can estimate approach velocity from the relationship between body weight and leg strength. Looking at college football players, we found that over a four training year period, the athletes improved strength and power linearly, and that at the end of four years the athletes were still improving on strength power. The final example is when we take elderly patients and progressively weight train them over a four year period. We see gains in bench press strength of 400% and gains in power of 200%.

So what is the “best” training program? I have attached an excel file that has the basic program. The percentages and progressions can be used for any muscle group (not only those I included). The program allows the athlete to workout 4 days a week. I usually have them lift Monday upper body, Tuesday lower body, take off Wednesday for repair, work Thursday upper body, Friday lower body and then take off the weekend for repair. At the end of the twelve week cycle, the athlete tests the 1 RM and then begins the program over with new weights determined from the new 1 rm. At the end of each cycle (12 weeks) you can expect to see on average 20% – 40% gain in 1 RM. Some points on the program:
Finish each set of lifts even if you need a spotters help (Recruitment and rate coding adaptations)
Always start the next cycle at the 50%/60% lifts (again Recruitment and rate coding adaptations for power improvement)

Now your final question, and my rant of the year is this: Why have we been so slow at developing the research for strength? (Note that weight training has only been around in the exercise physiology realm for about 20 years). The two most noted exercise physiologist who study strength are Zatiersky and Kraemer. My thoughts on this question are that most of the exercise physiologists between 1930 and 1990 were all long distance runners and had very little knowledge or desire to expand on the relative knowledge of strength and power. Most were focused on improving endurance because that was the area at which they were more comfortable. I believe in the next twenty years we will see more absolute knowledge of strength and power as more and more exercise physiologists
become intrigued by the research of the muscle. Also, it helps that technology is making it less invasive to study the muscle and its neural pathways.

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