Acute Strength Increases in Submaximal Loads via Exposure to Near Maximal Loads

A Thesis submitted in partial fulfillment of the requirements
For the degree of Master of Science
in Kinesiology

By

Cameron Lewis McGarr

August 2012
The thesis of Cameron Lewis McGarr is approved:

__________________________________________
Dr. Kimberly A. Henige
Date

__________________________________________
Dr. Shane D. Stecyk
Date

__________________________________________
Dr. Sean P. Flanagan, Chair
Date

California State University, Northridge
# Table of Contents

- Signature Page ii
- Abstract iv
- Introduction 1
- Purpose and Hypothesis 12
- Methods 13
- Results 16
- Discussion 18
- References 23
- Appendix A 25
Abstract

Acute Strength Increases in Submaximal Loads via Exposure to Near Maximal Loads

By
Cameron Lewis McGarr

Master of Science in Kinesiology

Post Activation Potentiation has been shown to be effective at increasing power performance in vertical jump height and sprint speed. The purpose of this study was to determine if this phenomenon could be used to obtain the same increase in performance in a high-force, low-velocity application. As this is the basis for the training protocol known as wave loading, it was important to determine if a heavy load will lead to improved performance with a submaximal load. 50 male subjects took part in this pretest post-test, randomized intervention study. The testing was conducted on 2 separate days. Each day the subjects determined their 6RM. After four minutes rest they either performed one repetition with a 2RM load or one repetition with that same 6RM load. After another four minutes rest, subjects attempted a repetition maximum with a 3% increase to their original 6RM load.

For group mean data, no significant difference in the number of repetitions performed was found between conditions (4.12 +/- 1.18 vs. 3.84 +/- 1.36). However, the results indicate that certain individuals had an improvement in the number of repetitions, while others did not. It appears there may be some merit for using PAP in a strength-training program, however, since the conditions for eliciting PAP are highly individual and difficult to predict there would likely be a considerable amount of trial and error.
Introduction

According to recent research, there may be a way to acutely increase power performance through exposure to heavy loads [(Baker (2003), McBride et al. (2005), Weber et al. (2008), and Yetter and Moir (2008)]. Popularly known as complex or contrast training, this procedure pairs a heavy resistance exercise with a power movement to increase muscular activation. This phenomenon is known as post activation potentiation (PAP). Several studies using heavy loads have been able to improve performance in exercises such as a vertical jump or 40 yard sprint [Weber et al. (2008), McBride et al. (2005), and Yetter and Moir (2008)]. After this exposure, muscle activation - either through heightened neurological activity or chemical changes - is said to be increased (Docherty et al. (2004)). However, fatigue is also present, decreasing performance (Jensen et al. (2003)). The questions are whether or not this acute enhancement in force production can outweigh fatigue, and under which conditions this will be most obvious. Typically, this training method is used for improving performance of activities such as a vertical jump or an explosive push up. However, because this phenomenon appears to be movement specific and is sensitive to the length of rest periods, its use for acutely improving athletic power performance is limited. Therefore, it may be beneficial, and perhaps more applicable, to investigate whether or not this phenomenon can be used to increase performance in strength activities. The training protocol known as wave loading attempts to take advantage of this phenomenon. The purpose of this thesis is to determine if PAP can be used to increase strength in sub maximal loads and if this increase is superior to what is gained from traditional methods.
**Increased Force Production**

Acute enhancement in force development has been shown to improve power performance (Weber et al. (2008)). If this acute increase in force production can be achieved during training sessions, over time with the increase in training volume, a chronic increase in strength and performance can likely be achieved. According to Weber et al. (2008), using loading parameters of 85% 1RM will have a significant increase in jump height. Twelve Division I male track and field athletes were asked to perform seven consecutive squat jumps, tested under two randomized conditions, and finally retested for an additional seven squat jumps. One condition was five repetitions of a back squat at 85% 1RM, while the other was five unloaded squat jumps. For both conditions, the heights of the first seven jumps were compared to the heights of the last seven. The heavy back squat condition elicited an increase in peak jump height as well as mean jump height; however, the squat jump condition actually showed a decrease for both. What was not tested was how the subjects would react if no condition were administered between tests. Similarly, McBride et al. (2005) used a back squat of 90% (HS) 1RM, which was compared to a loaded counter movement jump (LCMJ). The LCMJ condition used a load of 30% 1RM and maximal effort was accounted for on each attempt. Under both conditions three reps were used. Unlike the study by Weber et al. (2008), a control group was also used to account for fatigue. Instead of testing jump height, a 40-yard dash was the dependent variable. The subjects were again male athletes at the college level (15 Division III football players). A rest period of four minutes was given following each condition. Both conditions showed improvements over the control group, but only the HS group showed a significant improvement. Since the LCMJ group
was exerting maximal effort, one might speculate that a load near 1RM is needed for a full exploitation of acute force production enhancement.

Still, other studies have shown that favorable results can be achieved with as little as 65% 1RM. Baker (2003) took 16 rugby players with at least one year of training experience and tested their upper body power output. Rather than adjust load to relative strength, a constant load of 50kg was selected. Pre- and post- tests consisted of a Smith machine bench press throw. The experimental group performed six repetitions on the bench press with 65% 1RM load between pre- and post- tests. A control group was used - eliminating any potential for improvement through test familiarity. The experimental group had a significant improvement on the post-test. In this case, a 4.5% increase was achieved. The rest periods used here were consistent with the previous studies using a four-minute rest.

In a study by Smilios et al. (2005) using loads of 30% to 60% 1RM in the back squat, less favorable results were seen but significant improvements were still noted. Several key points regarding acute enhancement of force production are revealed when examined closely. Ten recreationally-active men, who were familiar with resistance training, were tested on both a counter movement jump and a squat jump after four different conditions. The first condition was a half squat with 30% 1RM, which saw virtually no improvement on either variable; the other three conditions were a half squat with 60% 1RM and a jump squat with both a 30% and 60% 1RM. Though some improvements were noted even with a lighter load than used in other studies, some similarities remain constant. The countermovement jump improved with the 30% and 60% jump squat condition and with the 60% half squat condition. What is noticed is that
the exercise requiring the most muscle activation had the greatest enhancement of force production. This study went a step further and continued to test performance after multiple sets of exposure on the independent variables. Not only did the 60% jump squat condition show the most improvement, but the improvements continued into the third set, suggesting that more muscle activation will bring forth a greater enhancement of force production.

Another study (Yetter and Moir 2008), suggesting that acute enhancement of force production can be achieved during strength training sessions, compared the back squat to the front squat and a control group. Here, subjects (10 men roughly 22 years of age) performed one of the three previously noted conditions, took a four minute rest, and then performed a 40 meter dash. This study had two very telling outcomes: the back squat resulted in a significantly greater improvement over both the front squat and control condition. But more importantly, the improvement did not come within the first 10 meters. The significant differences were seen between 10 and 20 meters, suggesting that acute enhancement in force production is useful to some degree for improving rate of force development in exercises of more than one repetition.

The technique for creating this acute enhancement in force development is known as complex or contrast training. The increased force production is known as Postactivation Potentiation (PAP). This phenomenon occurs when force production is acutely enhanced by a prior lift. Advocates of PAP suggest that if an explosive movement is preceded by a heavy lift, then performance could be enhanced and this could lead to acute as well as chronic improvements in sport performance. Several possible reasons ranging from increased neural activation, better synchronization of
motor units, and chemical changes in the muscle cell have been offered as to the physiological effects of PAP (Docherty et al. (2004)). The theory that seems to be the most readily accepted is Regulatory Light Chain (RLC) phosphorylation. In brief, this theory states that after a brief muscle contraction there is an increase in Ca$^{2+}$ in the sarcoplasmic reticulum. This increases myosin light chain kinase, which in turn increases the availability of ATP within the muscle (Docherty et al. (2004)). This causes the actin and myosin crossbridge to become more sensitive to the Ca$^{2+}$ and thus increases force production at low levels of Ca$^{2+}$.

As of yet, PAP has only been investigated in its relationship to improving performance in explosive movements such as vertical jump or short sprint. It has not been researched in its ability to improve maximal muscle contraction or repeated near maximal contractions for acute improvements in strength. Yetter and Moir (2008) gives some indication that PAP should be investigated in this way, as improvements were seen beyond a single effort.

**Rest Protocols**

The benefits of PAP are not universally accepted. After a maximal or near maximal muscle contraction, fatigue is present and will limit performance. Both fatigue and PAP are present after a muscle contraction, and both will decline as the rest interval progresses. Initially, fatigue will mask any physiological improvement in muscular activation. However, some studies show that the effects of fatigue diminish at a faster rate than PAP, thus allowing for an improved performance. Essentially, if too little rest is allotted, PAP will be overshadowed by fatigue; but if too much rest is present, PAP will
be lost as well. There appears to be a window in which sufficient PAP will be present to show an increase in performance.

Before optimal rest periods for eliciting PAP can be discussed, it is necessary to determine the rest periods allow for the greatest muscular endurance, as well as full recovery for absolute strength. This will establish a baseline for recovery from which potentiation can later be manipulated without being masked by fatigue. Miranda et al. (2007) looked at the effect of two different rest periods on the number of repetitions completed. This study also compared the two rest periods on total volume over the entire training session. The two rest periods chosen were one minute and three minutes. The one-minute rest period protocol resulted in significantly lower repetitions and total volumes than the three-minute protocol. What may be noteworthy, however, is that the results for every set were significantly lower than the first set of the training session, indicating cumulative fatigue even for different exercises. Even with three minutes rest, full recovery was not achieved. Rest periods of four minutes may be necessary for PAP to overshadow fatigue with muscular endurance applications. This study demonstrates that muscular endurance decreases with repeated bouts of the same exercise and is dependent on the length of the rest periods.

Though muscular endurance cannot fully recover after short rest periods, it is possible for maximal strength to recover after one-minute rest. Matuszak et al. (2003) examined the effects of one, three, and five minute rest periods on repeated 1RM strength. Seventeen men with at least two years of weight training experience attempted repeated 1RMs with each of the three rest periods. Conditions were randomized and subjects were tested over multiple visits, each visit being 48 hours apart. The completion
of the second attempt was achieved by 13 of 17 subjects after one-minute rest. The results remain similar with the previous study, in that when three minutes rest was given, 16 of the 17 subjects were able to successfully complete the second attempt. As in the previous study, rest periods of three minutes were superior to one minute. With five minutes rest, only 15 of the 17 were successful, indicating that PAP may begin to return to levels mirroring fatigue when approaching five minutes. A key point about the subjects is that they all were able to squat at least one and a half times their bodyweight, indicating that they were already able to recruit a large amount of muscle fibers, which may be necessary for a favorable PAP response.

Knowing how fatigue affects muscular endurance and absolute strength, along with the best rest protocols for managing fatigue, it is possible to look into what conditions are most favorable to PAP. Jensen et al. (2003) looked at several different rest periods and the resultant vertical jump height following a 5RM back squat. This study investigated five different rest periods: 10 seconds, one, two, three, and four minutes. Unlike other studies, the independent variables were not tested over multiple test days but rather at separate intervals on the same day following the 5RM back squat. All 21 subjects were male and female Division I athletes, again suggesting that relative strength levels were somewhat high. The 10 second-rest condition was significantly lower than all other conditions, demonstrating that fatigue will overshadow PAP with very short rest periods. All three of the remaining intervals did not show a difference between them. More importantly, none of the mean jump heights per condition returned to pretest levels. This suggests that fatigue will overshadow PAP and a difference in PAP will not be seen between one, two, three, and four minutes rest; however, this can not be determined
conclusively using the methods of this study. Since all data were collected in a single testing session, the reality is that only one minute rest was ever really experienced with this study. It is possible that each vertical jump attempt added to fatigue and masked the real potential of PAP at the different rest intervals.

Conversely, Comyns et al. (2006) performed a similar study using rest periods of 30 seconds, two, four, and six minutes, but the conditions were tested over two different days. Athletically active male and female subjects from anaerobic sports were used. Countermovement jumps were tested along with ground reaction force. With a rest period shorter than one minute, a significant decrease in performance was noted. Unfortunately, performance was not increased enough under any of the other conditions for results to have been significant; however, a small improvement was seen with a four-minute rest. A study by Smilios et al. (2005), which was covered in more detail earlier, showed different results in performance at one, five and 10-minute rest intervals. All conditions were performed for three sets with the dependent variables of a squat jump (SJ) and a countermovement jump (CMJ) tested after one-minute rest. The results for the dependent variables were discussed in the previous section but the information concerning recovery will be covered here. After the initial tests had been completed, the subjects were asked to perform the SJ and CMJ both five and 10 minutes post stimulus. Across all conditions, performance was significantly decreased after five minutes of recovery. Almost identical results occurred after 10 minutes, supporting the premise that beyond four minutes post stimulus PAP will have abated.

One additional point of difference is that, unlike studies to be covered in the next section, all these contrast training studies [with the exception of Smilios et al. (2005)]
used a repetition maximum. Smilios’ study was also the only study to show favorable results to PAP. This lends support to the notion that PAP is best elicited with a sub-maximal effort. The window for PAP appears to be in excess of 65% and under 100% maximum efforts.

Other Variables

Training Age

Almost all studies observed used trained subjects. Few studies actually looked at the difference training age has on PAP. One such study done by Chiu et al. (2003) looked specifically at the different effect with training age. This study took 24 total subjects, 7 athletically trained and 17 recreationally trained individuals (athletically trained being defined as current active participation in competitive sport). Twelve subjects were male and 12 were female. Subjects performed both rebound jumps and concentric movement only jumps with different loads. No effects were noticed for any conditions until the groups were separated by training age. Once this had been done, the athletically trained individuals had a significant improvement in almost every post-test showing that a higher training age aided PAP. This is supported in a study by Rixon et al. (2007). Thirty subjects were tested, 20 were experienced trainees while 10 were not. Subjects were tested three times on a countermovement jump. The first test set the baseline values for jump height. The second and third tests came after an isometric contraction and dynamic squat condition. The experienced lifters responded to both conditions with slightly better results than did the inexperienced lifters; however, results did not reach significance. Though results were not significant in this study, the outcome was similar to the results found by Chiu et al. (2003). In conjunction with these findings,
of the other studies investigated, the studies showing the best results for PAP all used college-aged, well-trained athletes involved in competitive sport.

**Movement Specificity**

After a proper rest period has been determined and the correct load selected, successful exploitation of PAP appears to rely on at least one more variable, movement specificity. Masamoto et al. (2003) found that when a 1RM squat was preceded by a depth jump there was a greater improvement than when it was preceded by a tuck jump. Twelve men were tested for their 1RM in the back squat. Six days later, they returned and were retested on the 1RM after either three tuck jumps or two depth jumps. The subjects came back on a third and final occasion to complete the other condition. 1RM squat attempts took place 30 seconds following each condition. To ensure that each condition was clear from the effects of the other, a four-minute rest was given between attempts and order was randomized. Only the depth jump condition resulted in a significant improvement in 1RM strength. A possible reason for this outcome is the increased eccentric tension placed on the muscles by the depth jump. A more telling study for movement specificity is the Yetter and Moir (2008) study. As explained earlier, a heavy back squat (HBS) was compared to a heavy front squat (HFS) and a control (four minute walk) on 40 meter sprint times. The study found that HBS had a significant improvement over the other two conditions. This outcome can be explained by looking at the muscle involvement of both the back squat and the 40 meter sprint. During the back squat, the torso is less vertical than the front squat. The position in which the torso is further forward allows for more involvement of hip extensor muscles. Similarly, the motion during the 40 meter sprint also requires a great deal of hip extension. Since the
weight used for the front squat was based off of 80% of the back squat weight, intensity was relative across both conditions. Therefore the improvement can be attributed to the similarity in muscle recruitment rather than load.

The study by Comyns et al. (2006) explained earlier, tested single leg jump height after a 5RM squat. The performance test was done on a sledge that had the subjects in a position similar to sitting in a chair. Unfortunately, this limited the involvement of hip extension during the test. Considering these muscles are critical to squat strength it could be argued that a significant amount of increased muscle recruitment occurred in the hip extensors. Likewise, jump height is highly dependent on hip extension; this provides a possible explanation as to why this study did not see a significant improvement in performance. All studies testing for PAP used an eccentric component with the testing conditions. Therefore, we are led to believe that the stretch shortening cycle might need to be involved to take advantage of the previous overload.

**Fiber Type**

According to Hamada et al. (2000), PAP will be most exploitable among athletes with a higher percentage of Type II muscle fibers. Twenty subjects performed a 10 second maximal voluntary contraction (MVC) and were then tested for PAP. Muscle biopsies were given to eight subjects, the four with the highest and four with the lowest display of PAP. The four subjects that displayed the most PAP had a significantly higher ratio of Type II muscle fibers than did the four that displayed the least amount of PAP. This is consistent with the premise of contrast training: using a heavy load to excite the high threshold muscle fibers (Type II) in order to glean the benefits for an explosive movement. This seems logical in that more muscle activation should equal an
improvement in force production. The four subjects with the most PAP did in fact have a higher degree of motor unit activation, 89.7% as opposed to 81.5% for the four with the least PAP. Inducing PAP would be of little use to an endurance athlete since high force production is not necessary.

**Summary**

Although the best approach for using PAP to increase athletic performance still seems to be in question, it is clear that some benefits can be elicited from its use. It appears that an increase in force production, through increased motor unit activation is a possible cause for the success of PAP. Moreover, RFD and muscle recruitment are key factors in power and maximal strength respectively. PAP has been shown to successfully improve maximal strength when applied to a 1RM attempt when preceded by a power movement (Masamoto et al. (2003)), and recovery from a 1RM attempt is possible within a training session if sufficient rest is allowed (Miranda et al. (2007)). Given this information it becomes clear that research is needed to investigate the application of PAP for increasing strength.

**Purpose and Hypothesis**

The purpose of this study was to investigate the effect of utilizing a heavy load on acute strength increases with sub maximal loads. Based on previous research, it was hypothesized that after exposure to a heavy set, the subjects would have enough Post activation Potentiation (PAP) to successfully complete more repetitions with a 3% increase in load, than without such an exposure.
Methods

Participants

Fifty male, trained subjects were selected. In order to be eligible for inclusion, all subjects had to have at least one year resistance training experience, in which they have used both, heavy lifts and the bench press exercise. Subjects were excluded from the study if they had any musculoskeletal injuries to the upper body within the last 6 months or had a layoff from resistance training of more than 10 days. The age range for inclusion was adults over the age of 18 years. Male subjects were used both to provide a homogeneous sample and eliminate the added variable of gender differences experienced in relative max lifts.

Instruments

The instruments used in the testing procedure were a standard Bench Press apparatus. The metrics of the bench were 45.72 centimeters high. The bar used was a 20.45 kg bar, seven foot Olympic Bar. It was loaded with Standard Barbell weight plates (including .57 kg weight plates, .34 weight plates and .23 kg weight plates so adjustments could be made to the nearest .23 kg for accuracy).

Procedures and Data Collection

Approval for testing with human subjects was obtained through the institution prior to beginning data collection. The testing methods occurred over three separate days. A written consent form was given to subjects 24 hours in advance of the initial testing day and returned to the tester immediately prior to beginning the testing protocol.

Day one of testing was used for three reasons: first, to establish a baseline for subjects’ 6RM load; second, to ensure all subjects could perform two repetitions with
112% of their 6RM load; and third, so that subjects would be familiar with how the lifts were to be performed. On day one, all subjects determined their 6 repetition maximum (RM) on the bench press. Before determining the 6RM, subjects warmed up by performing two sets of six repetitions, one with 50% and one with 75% of their proposed 6RM. Next, subjects attempted to perform their proposed 6 RM. If they were able to complete an additional rep (seven) they were stopped, given a four-minute rest, 2.28 kg was added to the bar and the subject again attempted to complete six reps. This step was repeated until the 6RM was determined. If the subject was unable to complete six repetitions on their first attempt they were given a four-minute rest, the weight was lowered 2.28 kg if they missed by one repetition and 4.54 kg if they missed by more than one repetition. After the 6RM had been determined, subjects were given a four-minute rest before attempting a two-repetition maximum (2RM). This number was determined based on 112% of the subjects’ 6RM. If the subjects were successful in the 2RM attempt, testing was completed for day one. If the subjects were unsuccessful in the 2RM attempt, they were given an additional four-minute rest and reattempted their 2 RM with 2.28 kg decrease in weight.

Subjects were instructed to lower bar in a controlled manner. Control was defined as keeping both feet in full contact with the floor, keeping the head, shoulders, and hips in contact with the bench, and lowering the bar to within 2.54 centimeters of, but not touching the chest, on each and every repetition. This was done for both the safety of the subject, as well as efficacy of the study. In order to control this variable, the test proctor gave audible cues to the lifter, and if the lifter was not compliant with the test protocol
they were stopped, given further instruction, and after a four-minute rest they again attempted the test.

The second and third days of testing were held approximately 48 and 96 hours after the first, respectively. On these days, subjects performed the same warm up with the same weight as the first day. After the warm up, subjects determined their 6RM for that day using the same protocol as day one. Subjects served as their own controls and testing order was randomized. After a four-minute rest period, the subjects were either exposed to a heavy set (1 repetition with their 2 rep max) or they performed the control protocol (1 repetition with their 6RM load). This was done to maintain uniformity in rest periods across both conditions. After an additional four-minute rest, subjects attempted to perform as many repetitions as possible with a 3% increase in load to their 6RM. On the third day of testing, subjects performed the testing protocol they did not attempt on the previous day. Figure 1 represents a flow chart of each condition.

Figure 1. Flow diagram of the study protocols.
Statistical Analysis

A paired t-test was used to analyze the data and confirm a statistical significance of the results (p>0.05).

Results

No statistically significant difference in the number of repetitions performed was found between conditions. The heavy set condition had a mean of 4.12 +/- 1.81 repetitions on the post-test, while the control condition had a mean of 3.84 +/- 1.36 repetitions. When compared to the control condition, 21 subjects showed an improvement as a result of the heavy-set intervention, 19 subjects showed a decrease in performance, and 10 subjects showed no difference in performance.

However, 23 subjects did not have a stable 6RM from one test day to the next, which may have influenced the results. Therefore, subjects were grouped into one of nine categories:

**Category 1:** an increase in 6-RM compared to the control day and a decrease in repetitions compared to the control day

**Category 2:** an increase in 6-RM compared to the control day and no change in repetitions compared to the control day

**Category 3:** an increase in 6-RM compared to the control day and an increase in repetitions compared to the control day

**Category 4:** a decrease in 6-RM compared to the control day and a decrease in repetitions compared to the control day

**Category 5:** a decrease in 6-RM compared to the control day and no change in repetitions compared to the control day
Category 6: a decrease in 6-RM compared to the control day and an increase in repetitions compared to the control day

Category 7: no change in 6-RM compared to the control day and a decrease in repetitions compared to the control day

Category 8: no change in 6-RM compared to the control day and no change in repetitions compared to the control day

Category 9: no change in 6-RM compared to the control day and an increase in repetitions compared to the control day

The distribution of subjects in each category is presented in Table 1.

Table 1. Distribution Table of Categories

<table>
<thead>
<tr>
<th></th>
<th>Increase in 6-RM</th>
<th>Decrease in 6-RM</th>
<th>No Change in 6-RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decrease in Reps</td>
<td>7</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>No Change in Reps</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Increase in Reps</td>
<td>4</td>
<td>5</td>
<td>12</td>
</tr>
</tbody>
</table>

Further analyses were conducted on those subjects with a stable 6-RM. A frequency distribution of subjects, based on the change in repetitions, is presented in Figure 2. To see if there were any distinguishing characteristics of the subjects for whom this protocol was beneficial or detrimental (Categories 9 and 7, respectively), the following group means were compared: height, weight, 6RM strength, and strength to mass ratio. No statistically significant differences were found for any variable (all p < 0.05).
Figure 2. Frequency distribution for the change between conditions in the number repetitions performed post-stimulus.

**Discussion**

To our knowledge, this is the first study to search for the PAP phenomenon in a high-force, low-velocity movement (i.e. bench press) as opposed to a high-velocity, power movement (e.g. vertical jump, sprint). As this is the basis for the training protocol known as wave loading, it was important to determine if a heavy load will lead to improved performance with a submaximal load. The results indicate that the protocol used in this investigation elicited improved force production for some subjects, while producing no effect or a decrease in performance with others. However, we were not able to predict, based on anthropometric and strength data, the characteristics of the person who would benefit from this protocol.

Even with explosive activities, PAP has not been found to be a universally observed phenomenon. Some studies have shown an increase [(Baker (2003), McBride...
et al. (2005), Weber et al. (2008), and Yetter and Moir (2008)] while others have seen no change [(Smilios et al. (2003)], or even a decrement in performance under certain conditions [(Comyns et al. (2006) and Jensen et al. (2003)]. It is important to note that these studies examined group mean data; therefore individual improvements are not considered. Few studies have examined the results on an individual basis. Chiu et al. (2003) found that training status has an impact on PAP. McCann and Flanagan (2010) showed that even with a group of trained individuals, the protocol that elicits the greatest PAP is highly individualized. Roughly half the subjects used in the current study were athletically trained, meaning they were currently involved in, and training for, competitive sport. The other subjects were recreationally trained, weight training regularly but not involved in competitive sport. No observable differences were noted between how the different protocols affected each groups.

One limitation of this study was that the 6-RM was not stable for 23 subjects. Fifteen subjects had a heavier 6RM on the heavy-set condition and eight subjects had a heavier 6RM on the control condition. Of the subjects with a heavier 6RM on the heavy-set condition, seven subjects performed fewer repetitions with the heavy-set condition. However, of the subjects who had a lighter 6RM on the heavy-set condition no subjects performed fewer repetitions than they did on the control condition. Poliquin (1988) stated that strength levels may vary from day to day by as much as 20 percent. Moreover, recent text has stated that there has been no reliability testing on the bench press exercise, [Moir, G.L. (2012)]. With the changes in RM and small changes in the number of repetitions performed, it appears to be that finding the correct combination of loading and rest periods will be difficult.
The PAP stimulus must be large enough to elicit the desired stimulus, but not so large as to allow fatigue to overcome PAP. Studies have used loads ranging from 30% RM up to a relative maximum. Comyns et al. (2006), used a 5RM and did not elicit a positive PAP response, whereas McBride et al. (2005) used a relative load of 90% and saw a more favorable outcome. Baker (2003) saw a positive result with a load of 65% maximum, while Smilios et al. (2005) did not see an improvement when using a load of 30% 1RM. Our protocol used a 2-RM load for 1 repetition, approximately 95% RM. This load was selected in order to prevent a complete fatigue in the intervention. However, given the lack of reliability in RM testing, this load may have been relatively higher for some subjects, putting this load outside the optimal parameters for maximal PAP.

The other variable concerning PAP is the rest period between the stimulus and performance. PAP has been shown with as little as 1 minute (Jensen et al. 2003) or as long as 18.5 minutes rest (Chiu et al. 2003). The rest period used in this study was four minutes, which was chosen because it was similar to what was successful in other investigations. As is seen with intensity, the rest period must represent a delicate balance: it must be long enough to abate fatigue effects, while not too long as to also abate the PAP effects. This again may be highly individualized. Since several subjects had a positive response to the experimental protocol and several subjects did not, a case could be made that the rest period needs to be tailored to the individual. If attempting to use a wave loading protocol in a practical setting, the strength and conditioning professional must determine whether it is appropriate for each individual. That is, if the
rest periods are excessively long, or, if multiple exercise sessions are used to determine an individual’s optimal rest period, the use of wave loading would not be beneficial.

The use of PAP on strength applications, though not clearly demonstrated here, could have positive results. Training volume is the key component when training for muscle mass, while training intensity is the key component for increasing maximal strength. The possible benefit of using loading parameters similar to the one in this study is the ability to keep the overall volume high enough to train for muscle mass while being exposed to intensities sufficient to increase maximal strength. The increased intensity provided by the wave loading model could have a more profound impact on the chronic effects of resistance training if single session, weekly and monthly volumes are the same as seen in a traditional model and recovery time between exercise bouts is unchanged. No studies taking advantage of the type of loading parameters used in this study were found. However, given what is known about training volumes and intensities, there may be a use for this type of loading parameter in a strength-training program. A limitation to this protocol is the individualization that is required.

When looking at the single-subject analysis several subjects did show an improvement during the heavy-set condition. Most subjects had a difference of one or two repetitions; however, an improvement of five repetitions was also observed during the heavy-set intervention. This improvement was not universally observed. Since PAP was present in many subjects, sub analyses were conducted based on the additional measures collected during this study. Subjects were analyzed based on height, weight, strength, and strength to mass ratio. These measures did not give any indication to who would best benefit from PAP in a wave loading model.
It appears there may be some merit for using PAP in a strength-training program. However, since the conditions for eliciting PAP are highly individual and difficult to predict, there would likely be a considerable amount of trial and error. Professionals intending to include this protocol in a strength training program need to first consider the trade off for possible strength gains from using this model as opposed to a traditional model, and length of time available for any given exercise session. Further studies are needed to determine who may best benefit from PAP. In addition, further investigation is needed to determine the optimal relative loads to elicit maximal PAP. Furthermore, investigation is needed to determine if this protocol can be beneficial for chronic effects of increasing strength and if these effects are superior to strength training programs that do not rely on the PAP phenomenon.
References


Informed Consent

Appendix A

Project Title

Acute Strength Increases in Submaximal Loads via Exposure to Near Maximal Loads is a study conducted by Cameron McGarr while attending California State University, Northridge working toward a Master’s of Science in Kinesiology with an emphasis in Biomechanics. The purpose of this study is to investigate the appropriateness of utilizing a heavy load to gain an immediate increase in strength on sub maximal loads.

Description of Research

This research will add to the already high number of studies done on increasing strength in athletes. This study may provide a new and effective way of combining different weights to increase strength. You will be asked to attend testing on three separate days. These days should be no more than 48 hours apart.

You will be expected to show up to Equinox Fitness @ Woodland Hills for three days of testing. On the first day of testing you will give the tester your proposed six repetition maximum (6RM). You will then perform two sets of 6 repetitions, one with 50% and one with 75% of your proposed 6 RM. Then you will attempt to lift your proposed 6 RM. All repetitions, both warm up and test repetitions, will be done under the following protocol: The weight must be lowered to within one inch of, but not touching, the chest. Your feet must remain in contact with the floor and your hips must remain in contact with the bench. The weight can be lifted off the chest as fast as possible. If said protocol is not followed you will be stopped, given additional instruction, and after a four minute rest you will be allowed to repeat the attempt. If you are able to perform more repetitions you will be stopped and more weight will be added to the bar. You will be asked to put forth an all out effort. If you are unable to lift the weight for six repetitions, you will be given a four minute rest, the weight will be reduced and you will be given another attempt to complete six repetitions. It may take multiple sets to establish your 6RM. You will complete as many sets as necessary to establish your 6RM.

On the second day of testing you will perform the warm up exactly as you did on day one. After your warm up you will
determine your 6RM for that day the same ways as you did on day one. After a four minute rest period you will either be asked to lift your two repetition maximum (2RM) one time or you will be asked to lift your 6RM weight one time. You will then be given an additional 4 minute rest period then asked to perform as many repetitions as possible with a 3% increase in weight.

On the third day of testing you will perform the testing protocol you did not perform on day two.

There is an inherent risk with lifting weights. This risk increases as the load gets closer to your maximum strength. A potential risk is that you may not be able to lift the selected load. In order to combat this risk a spotter will be placed at each end of the bar. If you are unable to lift the bar off your chest the spotters will remove the bar. If the bar begins to descend after the initial upward movement the spotters will remove the bar for you. Another potential risk is the possibility of muscle strain. It is understood that this risk is lower due to the fact that you are an experienced lifter. Adequate warm up before all sets will also decrease the injury potential. Another major risk factor with weight lifting, especially in the bench press, is the desire to bounce the weight off the chest in order to successfully lift more weight. You will not be allowed to touch the bar to your chest.

**Confidentiality**

Testing will take place during the hours of club operation when multiple fitness professionals will be present. If an injury occurs and treatment is necessary, standard EMS protocol for the testing site will be followed. In the event of an injury, each subject will be referred to their primary care physician at their own cost. The test proctor will not treat the subjects if an injury occurs.

**Concerns**

The names of participants will be kept confidential, using alpha-numeric codes instead of names. Data will be kept by the investigator, and any information linking the participant to the code will be destroyed at the end of this study. Results will only be published in aggregate form, and no identifying information of the individual participants will be published.

**Voluntary Participation**

If you wish to voice a concern about the research, you may direct your question(s) to Research and Sponsored Projects, 18111 Nordhoff Street, California State University, Northridge, Northridge, CA 91330-8232, and by phone at 818-677-2901. If you have
specific questions about the study you may contact Dr. Sean Flanagan, faculty advisor, 18111 Nordhoff Street, Northridge, CA 91330-8287, and by phone at 818-677-7507

Participating in this study is completely voluntary and you do so at your own will. You may drop out of this study at any time and without explanation.

I have read the above and understand the conditions outlined for participation in the described study. I have been provided with a copy of this consent form to keep and I give informed consent to participate in the study.

Name  ________________________________________

Last              First

MI

Age _______ Years _________Months

Signature  ________________________________________

Date ______

Researcher’s signature  __________________________

Date ______

If you have signed this form, please return one copy in an envelope by mail to:

Dr.  Sean Flanagan
Department of  Kinesiology
California State University, Northridge
18111 Nordhoff Street
Northridge, CA 91330-8287

or give this form to  Cameron McGarr.