Acute effect on vertical jump performance after two types of heavy squat exercises

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ACUTE EFFECT ON VERTICAL JUMP PERFORMANCE AFTER TWO TYPES
OF HEAVY SQUAT EXERCISES

by

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A thesis submitted in partial fulfillment
of the requirements for the

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ABSTRACT

Acute Effect on Vertical Jump Performance
After Two Types of Heavy Squat Exercises

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The purpose of this study was to compare vertical jump heights achieved before and after performing the half squat, or the quarter squat exercise. 10 male subjects experienced with the squat exercise performed 4 warm-up squat sets followed by 1 repetition with the weight of 90% of 1 RM half squat or quarter squat. No difference in jump heights after any of the three conditions including a control group (F = 3.096, p = 0.070) was found. Correlations between the relative strength ratio and the difference in averaged jump heights before and after the half and the quarter squat conditions were also tested, and no correlation was found (r = -0.128, p-value = 0.724; and r = -0.189, p-value = 0.601, respectively). Since the same five subjects increased jump height after both the half and the quarter squat exercises, it appears that there is a possibility of individual differences.
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CHAPTER I

INTRODUCTION

For many recreational athletes, the main purpose of a warm-up is to prevent injuries by increasing blood flow, body temperature, and extensibility of tissues. However, for competitive athletes, warm-up is something more than preventing injuries, it is key for enhancing their upcoming performance. Warm-up methods vary depending on each sport, team, or athlete. Optimal ways of warm-up have always been looked for by many athletes, coaches, and researchers to enhance performance. Recently, two well controlled studies revealed that performing heavy load exercise right before explosive activities enhance the performance of the bench press, the vertical jump, and the loaded counter movement jump (Gullich & Schmidtbleicher, 1996; Young et al., 1998). The increased abilities of the athletes in these studies after heavy load warm-up were accredited with posttetanic potentiation (PTP). In the strength training literature, PTP is a response by the muscle to contraction stimuli which results in enhanced muscle contraction ability. The physiological aspects of PTP are still not completely understood, and most researchers investigating the physiological aspects of PTP have been using animals, mostly cats or rats. Only limited research studies have investigated the effects of PTP on human performance (Gullich & Schmidtbleicher, 1996; Young et al, 1998; Radcliffe & Radcliffe, 1996; Hrysomallis & Kidgell, 2001). Recently, a few research
studies have been published demonstrating that increased speed strength performance associated with PTP (Young, 1998; Gullich & Schmidtbleicher, 1996; Radcliffe & Radcliffe, 1996). The results of these studies indicate PTP may be something that helps athletes who are involved in explosive, burst type of activities. Athletes can be observed using the concept of PTP in some warm-up situations in regular sporting activities. For example, baseball players may swing a bat with additional weight or simply swing multiple bats before taking their turn to hit. By using a heavier bat or multiple bats, the athlete is increasing the PTP of the muscles involved in hitting. Although the complete mechanism of this phenomenon is not well understood, some theories will be introduced in the literature review of this thesis (Chapter II).

Posttetanic Potentiation (PTP)

Potentiation generally refers to an increase in power, rate of force development, or the enhancement of contractile response. Tetanus is defined as the summation of all available motor units, which is usually brought about by intense muscular contraction or prolonged muscular contraction. Combining the definitions above, posttetanic potentiation (PTP) can be explained as the enhancement of power, force, or contractile response as the result of prior intense muscle activity. Sometimes researchers specify the name of potentiation depending on previous activities causing potentiation, such as postexercise potentiation (Trimble, 1998), or postactivation potentiation (PAP) (Hamada et al., 2000[a]; Hamada et al, 2000[b]). Muscle tetany is induced using a high frequency electrical stimulation and is painful. Most human studies use an isometric contraction or heavy isotonic contraction to produce muscle tetany (Hamada et al.,
Both isometric and isotonic exercises with heavy loads have been proven successful to increase short term power output and reported to evoke PTP (Young et al., 1998; Gullich & Schmidtbleicher, 1996; Radcliffe & Radcliffe, 1996; Hamada et al., 2000[a]; and Hamada et al., 2000[b]). Prior activity causes not only potentiation, but also fatigue, which can result in a decrease in performance due to previous muscle activity. Potentiation occurs when a brief period of repetitive stimulation results in an enhanced contractile response. Fatigue occurs when continued stimulation results in impaired or attenuated contractile response. It is reasonable to assume that PTP and fatigue are initiated when contractile activity is started and that they coexist during and for some time after repetitive stimulation (Rassier & MacIntosh, 2000). Therefore, performance may be enhanced when potentiation is predominant, and the opposite is true when fatigue is predominant.

Human muscles with shorter twitch contraction times and a higher percentage of Type II (fast twitch) muscle fibers are reported to exhibit greater PTP than Type I (slow twitch) muscle fibers (Hamada et al, 2000[a]; Hamada et al, 2000[b]; O’Leary et al., 1997). It is also reported that stronger individuals, those who lift more weight and trained athletes tend to exhibit greater PTP than weaker individuals or untrained individuals (Young et al., 1998; Gullich & Schmidtbleicher, 1996).

The effects of PTP (increase in power output) are usually apparent five seconds
after maximum voluntary contraction or during electrical stimulation of the muscle (Hamada et al., 2000[a]; Hamada et al., 2000[b]; O'Leary et al., 1997), but a study by Trimble & Harp (1998) displayed an initial depression of H-reflex. H-reflex is caused by stimulation of sensory neurons that result in afferent discharge causing an excitatory potential in the motor neuron pool. PTP is reported to last between 5 to 10 minutes (Hamada et al., 2000[a]; O'Leary et al., 1997) or even longer (Gullich & Schmidtbleicher, 1996).

Although the reason there is a potentiation following tetanus or heavy load resistance exercise is not fully understood, possible explanations include the role of regulatory light chain (RLC) phosphorylation. Positive correlation between the magnitude of potentiation and the magnitude of phosphorylation of RLC has been demonstrated (Manning & Stull, 1982; Moore & Stull, 1984). Phosphorylation of RLC occurs when myosin light chain kinase (MLCK) is activated (Rassier & MacIntosh, 2000). More MLCK activity can be found in fast twitch muscle fibers than it can be in slow twitch muscle fibers (Moore & Stull, 1984). This may be a reason why potentiation is exhibited more in fast twitch muscle fibers than in slow twitch muscle fibers (Hamada et al., 2000[a]; O'Leary et al., 1997).

Some other possible mechanisms include decreased inhibitionary effect of the Golge tendon organ (GTO) and psychological effects. The activation threshold of GTO can be decreased by heavy load (Baker, 2001). This decrease in the activation threshold of GTO could allow for the muscle to produce more force. Psychologically, people usually feel more comfortable to lift a load that is lighter than a load lifted in the previous set. This mental readiness may allow people to lift in a more explosive manner.
especially when the traces in the central nervous system from the heavy load still remain.

To date, most research has been directed at investigating the physiological mechanism of PTP. However, it is also important to determine what types of activities and at what intensity level will be beneficial during the warm-up period. Jumping was chosen for this research because it is an activity in almost every sport. Additionally, the use of the leg musculature for power and speed is also relevant to almost every sport and was also determined to be important for maximizing warm-up before activity. Therefore, comparing the PTP effects of two types of squat techniques, the half and the quarter, on vertical jump performance was the intent of this study. The results of this study will hopefully provide athletes with another option in their warm-up routine resulting in a better athletic performance.

Purpose of the Study

The purpose of this study was to investigate the effects of two different types of heavy squats (45° and 90°), as a cause of posttetanic potentiation (PTP), on vertical jump performance. Of particular interest in this study was the specific research question: Can athletes increase their vertical jump height after they perform 1 repetition of either the half or quarter squat at 90% of 1 repetitive maximum (RM) immediately prior to performing a vertical jump? If there is any improvement in the vertical jump, what improvement can be attributed to the half squat and what improvement can be attributed to the quarter squat?
Specific Research Hypothesis

1. Performing a 1 repetition half squat (90° of angle) at 90% of 1 RM will increase the jump height in counter movement jump due to PTP.

2. Performing a 1 repetition of the quarter squat (45° of angle) at 90% of 1 RM will increase the jump height in counter movement jump due to PTP.

3. The half squat will cause more PTP than the quarter squat; therefore, increase in jump height after the half squat will be higher than after the quarter squat.

Limitations of the Study

The following limitations apply to the study.

1. The depth of squat (either 45° or 90°) was measured visually by a strength and conditioning specialist certified by the National Strength and Conditioning Association, so no mechanical device such as an electrical goniometer was used.

2. Jump height was measured from the vertical force because about 97% of the total power (energy) exerted during vertical maximum effort jumps is used for pure vertical propulsion. The rest is lost in the form of internal segmental energy flows and non-vertical power components (Hatze, 1998).

3. External validity was limited due to the small sample size of ten subjects, strength level of the subjects, and proficiency level of the subjects.

4. Since the design of the study was concentrated on comparing the effects of two different squat styles, it is limited to investigate the physiological
mechanism of PTP.

5. Changing warm-up sequences for the half squat and the quarter squat condition may change the results of this study.

6. The amount of external control I may have over the subjects is limited. Such as the amount of sleep, exercise and time to eat.

Assumptions of the Study

All subjects were assumed to be injury free in the lower and upper extremities during the study. It was also assumed that all subjects performed each counter movement jump with their maximal effort as they were directed to do so by the researcher of the study. PTP was assumed to be predominant and fatigue was assumed to be minimal between the last squat set and the post-squat vertical jump. In a similar study, 3 minutes of rest was enough to cause PTP (Gullich & Schmidtbleicher, 1996; Radcliffe & Radcliffe, 1996). The Kistler force plate was zeroed before every jump and it was assumed to be accurate.

Definition of Terms

**Half squat** – The femur is parallel to the ground at the deepest position in squat movement (see a photo of the half squat in APPENDIX I)

**Quarter squat** – The femur and tibia form a 45° of angle to the ground at the deepest position in squat movement (See a photo of the quarter squat in APPENDIX I)

**RM** – Repetitive maximum. For example, 5 RM is the weight that can be lifted not more than and not less than 5 times.
Posttetanic potentiation – An increase in a force related parameter (power, rate of force
development, or force itself) and the enhancement of a contractile response after tetanic
contraction.

Tetanus – The summation of all available motor units, and is brought about by intense
muscular contractions or muscular contractions of long duration.

Displacement – The straight line distance between initial and final positions.

Acceleration – The change in velocity divided by the change in time.

Velocity – The change in displacement divided by the change in time.

Power – The rate of energy transfer. Work divided by time.

Relative strength ratio – The maximum weight lifted by a subject divided by the body
weight of a subject.

H-Reflex (Hoffmann Reflex) – “An electrical analogue of the monosynaptic stretch
reflex, elicited by bypassing the muscle spindle and directly stimulating the afferent
nerve. Studying H-reflex modulation provides insight into how the nervous system
centrally modulates stretch reflex response” (Ferris et al., 2001).
LITERATURE REVIEW

It must be remembered that posttetanic potentiation is also referred to as, postexercise potentiation, postactivation potentiation and so on, depending on the activity causing potentiation. Posttetanic potentiation studies will be broadly divided into the studies using humans and the studies using animals although the numbers of the human studies are limited at this point.

Studies Using Human Subjects

At the present time, there have been a few well controlled studies published on the effects of posttetanic potentiation on athletic performance and the human body (Gullich & Schmidtbleicher, 1996; Young et al., Hrysomallis & Kidgell, 2001; 1998; Hamada et al., 2000[a]; Hamada et al., 2000[b]; Trimble & Harp, 1998).

A posttetanic potentiation study done by Gullich & Schmidtbleicher (1996) investigated the acute effects of maximum voluntary contraction (MVC) on explosive force. Two investigations were carried out in this study. In the first study, speed strength performances of the bench press with guided barbell, vertical jumps, and drop jumps, prior to and immediately after MVCs were measured and compared. The second investigation was to evaluate parameters of neuromuscular activation, before and after
MVCs, and any changes in those parameters with time progression after MVCs. These parameters of neuromuscular activation after MVCs were compared with the parameters of the neuromuscular activation of the gross motor explosive strength output.

Additionally, the maximum H-reflex at the triceps surae muscle and the explosive force were measured during voluntary isometric plantar flexions.

Thirty-six athletes, who were involved in competitive speed strength type of sports, participated in the first study (34 athletes participated in both the bench press and the jumping tests). Several test units (different intensity of the same exercise) were carried out for both bench press and vertical jump. In the bench press test, the subjects were asked to push the guided barbell (16.9 kg) upward as explosively and as fast as possible. This movement was repeated five times before and after treatment (MVCs) with a rest interval of 30 seconds. Timing of this movement was measured by a contact free photoelectric measuring system. The five different activities prepared to cause PTP for the bench press were as follows: (1) 2 sets of 1 repetition at 100% of 1 RM with a rest interval of 5 minutes between each set, (2) 3 sets of 1 repetition at 100% of 1 RM with a rest interval of 5 minutes between each set, (3) 1 set of 3 repetition at 90% of 1 RM, (4) 5 sets of 5 second isometric contractions at 2.5 kg plus 1 RM with a rest of 1 minute between each set (The subjects were asked to raise the barbell by at least 1 cm and to hold it for 5 seconds). All subjects were successful in lifting the weight, but none of the subjects could hold it for 5 seconds), and (5) 1 set of 1 repetition at 100% of 1 RM. The post-test was initiated 3 minutes after finishing the treatment procedure in all five different test units. In the vertical jump test, the CMJs and DJs were performed on a KISTLER force plate. Eight jumps with an interval of 20 seconds between each jump
were performed before and after MVCs. During whole movement of each CMJ, the subjects were required to hold their hands at their waists. Flight height was measured using the flight time method ($S_f = S_i + V_i t + 0.5at^2$). Unilateral isometric leg-press trials of 5 seconds duration, at a hip angle of 95° and a knee angle of 120°, were used as MVCs for the lower extremity. The researchers prepared five different activities to cause PTP, but the description of the five activities were ambiguous.

For the second study, H-reflexes and explosive force plantar flexions before and after MVCs were compared. Seven sport students, who did not do any strength training and ten athletes who had participated in the first study were used as the subjects for H-reflex study. H-reflex was measured from the lateral gastrocnemius muscle (MGL) and the soleus muscle (SOL). The purpose of the H-reflex study was to see the peak-to-peak amplitude of the H-wave, which is a reflection of the number of activated motor units. Each subject had his H-reflex triggered 12 times, with a rest interval of 5 seconds. Eight of the ten trained competitive athletes took part in the measurement of the time course of explosive force behaviour during voluntary plantar flexion. The explosive force of plantar flexion was taken 3 times, with a rest interval of 30 seconds. In the second study, five sets of 5 seconds unilateral, isometric plantar flexions were used as MVCs. Monitor of H-reflex and explosive force plantar flexions were initiated immediately after MVCs (5 seconds) and continued to 13 minutes. For H-reflex experiment, the responses were observed up to more than 20 minutes for some individual cases.

The results of the first study indicate that all types of MVCs showed significantly positive effects on the rise in force. The greatest effects were produced by
1 to 3 MVCs using a 5-minute rest interval between MVCs. However, sub-MVCs (1 set of 3 repetitions with 90% of 1 RM) did not increase force significantly. In the vertical jump test, the subjects jumped on average 1.4 cm higher (3.3%, \( P < 0.001 \)) between 3 minutes and 5 minutes 20 seconds after the last MVC. A similar effect was also observed during the DJ from a drop height of 32 cm. The significantly increased flight height with almost unchanged contact times indicates evidence of a short time improvement in the neuromuscular performance output (\( p < 0.05 \)). However, athletes who had performed high anaerobic lactic acid loads on a day before the experiment did not showed as much increase as other athletes exhibited or some of them even showed a reduction of CMJ performance after MVCs. An average reduction of 3.1% was observed in subjects who performed high anaerobic load exercises. Therefore, the positive effects of short-term potentiation of speed-strength can not be expected under all circumstances.

In the H-reflex test, the potentiation between 4 and 11 minutes after MVCs was statistically significant (\( P < 0.05 \)). The highest reflex response after MVCs from each subject was found individually variable (= 8.7 minutes plus and minus 3.6 minutes; range: 2.5 to 12.5 minutes). Although the time course of the H-amplitude in the soleus muscle was similar to that of the lateral gastrocnemius, potentiation in the soleus was lower and of shorter duration. Potentiation behavior between the two groups of speed-strength athletes and sport student were also different. The trained athletes showed a significantly higher potentiation in the lateral gastrocnemius muscle and in the soleus muscle, and the potentiation in the speed strength-athletes lasted longer than that in sport student.
In the explosive force plantar flexion test, athletes initially exhibited a temporary reduction of explosive force after the MVCs. After approximately 2-3 minutes an increase in force reached the control level once again, and then was significantly higher between 4 and 13 minutes. As was observed in a H-reflex test, an individual variation was also demonstrated in the times of the highest explosive force performances. The highest explosive force performances were seen between 4.5 and 12.5 minutes depending on each subject. There was a positive correlation between the times of the highest expression of the H-reflex amplitude and the explosive force of voluntary plantar flexions ($r = 0.89$).

Practically, the athletes who had an early peak in the H-reflex also had their best post-MVC performance of explosive force early, while those who had a late peak in the H-reflex test also had a late peak in post-MVC performance of explosive force.

A study completed by Young et al. (1998) found that loaded counter movement jump (LCMJ) performance was enhanced immediately after performing heavy squatting. Subjects consisted of 10 males aged 18 – 31, who had experience in performing the half squat exercise. All subjects were required to attend 2 training sessions. In the first session, the goal was to familiarize subjects with the LCMJ. They performed the LCMJ with a 19 kg load resting on their shoulders. They used a modified Smith machine, which was 3 meters high (10-ft), so they could jump safely. Additionally, in the first training session they determined the subjects’ 5 RM load in the half squat exercise. The second session was held five days after the first session. The purpose of the second session was to assess the LCMJ performance before and after a set of half squats performed with a 5-RM load. All subjects performed a warm-up consisting of a
3-minute jog and stretches that targeted the muscles of the lower extremities. The rest of
the warm-up consisted of half-squats as follows: 10 reps at 50% of predetermined 5 RM
and 2 sets of 5 reps at 75% of predetermined 5 RM. Between these submaximum sets, a
3-minute rest period was provided to all subjects. After the warm-up squat sets, a testing
sequence was performed as follows; 2 sets of 5 reps LCMJ with 19 kg load, 1 set of 5
reps half squats with 5 RM load, and 1 set of 5 reps LCMJ with 19 kg load. A
four-minute rest period was provided between the testing sets.

The results showed that there was a significant difference between the second
set of LCMJ (right before performing half squat) and the third set of LCMJ (right after
performing half squat). The first set and the second set of LCMJ were not significantly
different. The third set of LCMJ was 2.8% greater than the second set of LCMJ, which
was statistically significant (p < 0.05). The subject who had the greatest increase in
mean jump height following the squat set (2.8 cm) also had the greatest 5-RM result
(246 kg). After the data was collected, the researchers decided to test the correlation
between the increased jump height and a subjects' 5 RM half squat test. The correlation
coefficient was 0.73, which is statistically significant (p = 0.02). This result indicated
that the stronger the individual, the greater the gain in jump height.

Radcliffe & Radcliffe (1996) reported a brief summary (abstract) of a study,
which investigated the effects of several warm-up protocols on horizontal counter
movement jump. Thirty-five college athletes (24 males and 11 females) participated in
this study. The best jump distance out of three horizontal counter movement jumps
before and after a specific warm-up protocol was compared. There were five warm-up
protocols, which each subject performed all five on non-consecutive days. The five
warm-up protocols were as follows: Standard warm-up (WU), WU plus four sets of four back squats at 75 – 85% of 4RM (WU+SQ), WU plus four sets of four power snatches at 75 – 85% of 4RM (WU+SN), WU plus four sets of four loaded jumps with 15 – 20% of the body weight added (WU+LJ), and WU plus four sets of four unloaded tuck jumps (WU+J). All subjects then performed horizontal countermovement jumps within three minutes after finishing the assigned warm-ups. The results revealed no significant effect for the warm-up protocol when male and female subjects were combined. However, when male subjects were analysed separately, the jump distance after warm-up plus four sets of power snatch exercises was significantly greater than after the standard warm-up alone. They concluded that incorporating the power snatch exercise to standard warm-up significantly improves the horizontal countermovement jump performance in collegiate athletes.

Hrysomallis & Kidgell (2001) studied effect of heavy resistive exercise on acute upper body power. Twelve healthy active male subjects were recruited for this study. Subjects participated on 3 separate occasions over a 3-week period. The 5 RM bench press was measured on the first visit. The purpose of the second and the third visits were to perform either explosive push-ups only or perform explosive push-ups 3 minutes after performing 5 repetitions of a 5 RM bench press load. The designation of performing push-ups only or performing bench press and push-ups, was randomly assigned to subjects. Explosive push-ups were executed on a custom built strain gauge force platform. To negate the subject’s weight, the output of the force plate was reset to zero when each subject placed the hands on the force plate with the elbow fully extended and their feet together. Each subject rapidly initiated descending phase of the push-up
on the command and the descending phase was continued until just short of contact of
the chest with the force plate. They then rapidly started ascending phase and pushed off
of the force plate with a maximal effort. Each subject completed 3 maximal effort
push-ups with 1.5-minute intervals between trials. An identical warm-up which
consisted of 5 minutes of moderate-intensity stationary cycling; two sets of 20-second
static stretch for the chest, shoulders, and arms; and a set of 8 push-ups, was performed
before the two conditions to ensure consistency.

The results revealed that there were no significant differences in average and
peak force when two conditions (the push-ups only, and the push-ups preceded by a set
of 5 RM bench press) were compared. Relative strength ratio (the 5 RM bench press
weight for each subject divided by their body weight) did not significantly correlate with
the difference in the push-up only condition and the push-up preceded by the 5 RM
bench press condition.

Unlike a study done by Gullich & Schmidtbleicher (1996), PTP in the upper
body did not occur in this study. While Gullich & Schmidtbleicher (1996) used heavier
weight and less repetition(s) in his five different conditions, this study used 5 RM bench
press weight. It is not certain that PTP in the upper body did not occur due to the weight
and repetition performed in this study. Young et al. (1998) observed PTP in loaded
counter movement jump (the lower body) by using 5 RM half squat weight, which was
the same in this study although the resting time between the treatment and performance
was 4 minutes in Young’s study while it was 3 minutes in this study.

A study done by O’Leary et al. (1997) investigated posttetanic potentiation
(PTP) of human dorsiflexors. Ten male and ten female subjects, between 19 and 23
years of age, participated in this study. They had no history of neuromuscular disorders and were not currently participating in a strength and/or endurance training programs. The subjects were required to refrain from consuming caffeine 24 hours prior to the experiment. Twitch response of the right ankle dorsiflexors were tested in a custom made apparatus that fixed the knee joint of the seated subject at 90° but allowed the ankle joint to be fixed and tested various joint angle. The common peroneal nerve was stimulated to activate the ankle dorsiflexors by lead plate electrodes overlying the head of the fibula (3 x 3 cm) and the proximal portion of the tibialis anterior (3.5 x 5 cm). A maximum pretetanic twitch response was obtained by increasing intensity after each single stimulus until a plateau of twitch torque and muscle compound action potential (M-wave) amplitude was established. The same stimulus intensity was used for tetanic stimulation and the posttetanic twitch responses. Two minutes after the pretetanic twitch had been established, tetanic stimulation was applied for 7 seconds with a frequency of 100 Hz. This intensity created a maximum pretetanic twitch response. Posttetanic twitches were elicited 5 seconds after tetanus and continued every 30 seconds for 8 minutes after the original tetanus response. Eight minutes after the tetanus, a posttetanic twitch was elicited every minute for 20 minutes after the tetanus. Two minutes after the last posttetanic twitch was obtained, subjects were asked to perform three isometric maximum voluntary contractions (MVCs) of the dorsiflexor muscles for 5 seconds with 2-minute intervals between each MVC.

The results showed that torque decreased 15% during tetany. Twitch peak torque had increased 45% 5 seconds after tetany. Potentiation declined to 28% at 1 minute after tetanus, then rose slightly to 33% at 2 minutes, and declined slowly with
potentiation still 25% after 5 minutes. However, the researchers recognized there was a large intersubject variation in the amount of potentiation (5 – 140%) and its persistence (5 to > 20 minutes). Recognition of the inter-subject variation in posttetanic potentiation effects is consistent with a study done by Gullich & Schmidtbleicher (1996).

Unlike the changes in torque, the muscle compound action potential (M-wave) did not change significantly from pre-tetanic value at 5 seconds after tetanus but increased sharply (26%) at 2 minutes and then subsided. Twitch half relaxation time (the time required for relaxation to half-maximal twitch tension) decreased significantly (23%), more than twitch rise time (13%) 5 seconds after the tetanus, then recovered slowly. Both twitch rates of torque development (75%) and relaxation (71%) increased in a similar manner at 5 seconds after tetanus and remained elevated (up to 25%) at 5 minutes. The extent of twitch torque potentiation was inversely correlated with pre-tetanic twitch rise time \( (r = -0.69) \), half relaxation time \( (r = -0.61) \), and twitch to tetanus ratio \( (r = -0.66) \). All were statistically significant.

The data indicate that twitch half relaxation time compared to time to peak torque is affected more by PTP, and PTP is more prominent in muscles with a short twitch time course and small twitch to tetanus ratio. Subjects with a shorter twitch rise time and shorter half-relaxation time tended to have greater PTP in this study. This inverse correlation within one muscle is in agreement with previous research indicating fast-contracting muscles consisting of a high percentage of fast twitch (type II) fibers tend to have greater PTP compared to slow twitch muscles (Hamada et al., 2000[1]; Moore & Stull, 1984).

O’Leary et al. researched types of stimulation (electrical stimulation, or
maximum voluntary contraction) to get potentiation. Since voluntary muscle contraction depends on a subject’s effort while electrical stimulation can deliver a maximal and constant level of contraction, the researchers assumed they could decrease intersubject variation by using electrical stimulation. However, the potentiation they observed in the dorsiflexors using tetanic stimulation was less. Additionally, the inter-subject variation was not less than the potentiation induced by MVCs. Therefore, it was found that intersubject variability was not due to the level of effort from each subject. However, the reason for the greater potentiation with voluntary contraction over with electrical stimulation is not explained in this study.

Hamada, et al. (2000[a]) investigated the relationship between postactivation potentiation (PAP) and fiber type distribution. Twenty young men, who were free of neuromuscular disorders and participated in recreational activity 3 – 4 times a week, participated in this study. They were required to refrain from consuming caffeine during the 24 hours prior to the experiment. Postactivation potentiation in the right knee extensors was tested. Subjects were required to rest for 30 minutes after they arrived at the laboratory. After resting for 30 minutes, a maximum twitch response was elicited in knee extensors by delivering a series of single stimuli of increasing intensity with indirect percutaneous nerve stimulation until a plateau of twitch torque and muscle compound action potential (M wave) amplitude were established. The same stimulus intensity was used for twitches evoked after the MVC. Five minutes after the pre-MVC maximal twitch response was obtained, the subjects performed MVC for 10 seconds. Post-MVC twitch responses were measured immediately (5 seconds) after MVC, at 30 seconds post-MVC, and at 30-second intervals for 5 minutes post-MVC. In this study,
MVC, twitch, and EMG response were measured. Twitch measurements included peak torque, time to peak torque (TPT), and half-relaxation time (HRT). The peak-to-peak amplitude, duration, and area of the M wave associated with each twitch response were measured. The four subjects with the highest post-activation potentiation (HPAP) and the four subjects with the lowest post-activation potentiation (LPAP) were identified out of the twenty subjects. Biopsies of vastus lateralis from these eight subjects were taken by percutaneous needle to examine subjects' fiber type distribution.

The results showed the PAP of twitch peak torque 5 seconds after the 10 seconds MVC ranged from 34% to 114%, with a mean standard deviation of 70.6% ± 22.5%. From the initial maximum value, peak torque started to decline rapidly, but was still elevated (~ 12%) above the pre MVC value after 5 minutes. On the other hand, the immediate maximum potentiation of M-wave amplitude was much smaller, and its elevation was not significant beyond the first minute. An initial decrease of TPT and HRT were observed, followed by increases to within a few percent of the pre-MVC values after 5 minutes. A significant negative correlation between PAP and TPT was observed. Correlation statistics between PAP and HRT, however, were not significant. A significant negative correlation between PAP and pre-MVC twitch to MVC peak torque ratio (r = - 0.73, P < 0.001) was observed. There was a significant positive correlation between PAP and MVC peak torque expressed (r = 0.48, P < 0.05) although the correlation was not significant when peak torque was related per kilogram of body mass. Negative correlations between PAP and pre-MVC twitch to MVC peak torque ratio in this study were very similar to the correlations in the study done by O'Leary et al. (1997). In contrast to the O'Leary study, the negative correlation between PAP and HRT

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in this study was not significant although it showed similar tendencies to the O'Leary study.

Similar to the result in Young et al. (1998), stronger individuals tended to gain more PAP in this study. When two groups of four subjects with the lowest (LPAP) and highest (HPAP) PAP immediately after MVC were compared, LPAP had greater (22%) twitch peak torque, whereas HPAP had shorter TPT (29%). There were no differences in HRT or M-wave characteristics when two groups (LPAP and HPAP) were compared. LPAP had a greater twitch to MVC peak torque ratio. Muscle biopsy revealed LPAP and HPAP did not differ significantly in type I fiber area of the vastus lateralis, but it revealed that HPAP had greater type II (36%), IIA (32%), IIB (40%), and mean (I + II, 23%) fiber areas and a greater II to I area ratio than LPAP. It was significant that HPAP had a greater percentage of type II, IIA, and IIB fibers as well as a greater percent type II fiber area. These findings in humans are in agreement with observations in small mammals done by Moore & Stull (1984), which showed that fast twitch muscle fibers gain more potentiation than slow twitch muscle fibers.

Trimble & Harp (1998) conducted a study to investigate the effects of an intense bout of volitional resistance exercise on the H-reflexes of the lateral gastrocnemius (LG) and the soleus (S) muscles. The author was attempting to determine if a potentiation of the H-reflex could be induced with physiological stimuli. Ten college age subjects (5 male and 5 female) participated in this study where lateral gastrocnemius and soleus H-reflexes were obtained before and after a vigorous bout (eight sets of 10 repetitions with a 20 seconds rest interval between each set) of concentric-eccentric triceps surae exercises.
The results showed that all subjects displayed an initial depression of the LG (P < 0.01) and S H-reflex (P < 0.05) immediately after the exercise. As a group, significant potentiation of the LG H/M ratio was observed following the initial depression. Five of the ten subjects demonstrated this potentiation, which often lasted 10 minutes after exercise. The other five subjects displayed a longer and more obvious early depression of the H-reflexes followed by a return to baseline levels. At least two overlapping processes, (a brief depression followed by or superimposed over a longer lasting potentiation), were identified from this data. Although postactivation depression of the H-reflex was observed in all of the subjects, those who had a brief period of depression (10 – 60 seconds) demonstrated a subsequent potentiation and those who had a longer period of depression (2 – 3 minutes) did not demonstrate appreciable potentiation.

There are different theories about how the postactivation depression occurs.

As cited in Trimble & Harp (1998), a study done by Hultborn et al. (1996) suggested that a presynaptic depletion of neurotransmitter associated with repetitive activation of the homonymous la afferents likely cause postactivation depression. On the other hand, Schieppati & Musazzi (1984) claimed that postactivation depression is due to autogenic inhibition related to descending influences controlling the termination of activity. In this study, the potentiation of an H-reflex was determined to occur after the initial depression and the shorter depression period resulted in an increased potentiation while long depression period tended to result in a decreased or no potentiation.

A study conducted by Hamada et al. (2000[b]) investigated the postactivation potentiation (PAP) in the endurance trained muscles of male athletes. The subjects in
this study were triathletes (TRI), distance runners (RUN), active controls (AC) whose main activity was recreational upper and lower weight training, and sedentary control subjects (SED). Each of three groups consisted of 10 male subjects. Both upper and lower body muscle groups, the elbow extensors (triceps brachii for upper) and ankle plantarflexors (triceps surae for lower) were studied. Subjects were asked to refrain from caffeine intake for the 24 hours prior to the test. The plantarflexors were tested first, and elbow extensors were tested after a 30 minutes rest period from the first testing procedure. Electrical stimulation was used to stimulate the muscles being studied. A maximum pre-voluntary contraction (MVC) twitch response was elicited by delivering a series of single stimuli of increasing intensity until twitch torque stopped increasing. A stimulus intensity that was 20 – 30% higher than the intensity needed for the maximal twitch response was used for post-MVC twitch responses. Five minutes after establishing the pre-MVC twitch response, the subjects performed a 10-second isometric MVC. Twitch responses were tested at 5 seconds, 1 minutes, 3 minutes, and 5 minutes after MVC to see if there was any effect on PAP.

The results showed that TRI and AC, who trained both upper and lower body, increased PAP in both the triceps brachii and the triceps surae compared to sedentary subjects. Runners, who trained lower body, increased PAP only in triceps surae. Generally, TRI and RUN had the greatest PAP during the 5 minutes after MVC and followed by AC and then SED. All groups had a significant PAP 5 seconds after MVC, and a depression of twitch peak torque rather than increase was observed at 3 minutes and 5 minutes after MVC. The depression in the triceps brachii was more obvious because an average peak torque actually went below pre-MVC level after 3 minutes of
the MVC. The depression was smallest in TRI group. The researchers also measured
the correlation between PAP and pre-MVC twitch time to peak torque and half
relaxation time. Negative correlations between PAP and pre-MVC twitch time to peak
torque and half relaxation time in both the triceps brachii and the triceps surae were
reported. This indicates a shorter time to peak torque and shorter half relaxation time
was associated with greater PAP. This negative correlation was also reported in a study
done by O'Leary et al. (1997). Shorter time to peak torque and half relaxation time
indicated higher distribution rate of type II muscle fibers. Hamada et al (2000[a]),
O'Leary et al. (1997) also reported greater PAP in higher distribution rate of fast twitch
muscles. It is important to note that PAP started to decline only after 3 minutes of MVC
and an average peak torque of the biceps brachii did not remain above control level
(pre-MVC level) after 3 minutes. Other studies report longer potentiation effects such
4.5 – 12.5 minutes (Gullich & Schmidtbleicher, 1996) and 5 – 20 minutes (O'Leary et al.,
1997). It was also interesting that the subjects in this study did not have as much
variation in the length (time traces) of the potentiation effects as in other studies (Gullich
& Schmidtbleicher, 1996; O'Leary et al., 1997).

Gossen & Sale (2000) studied the effects of postactivation potentiation (PAP)
on dynamic knee extension performance. The purpose of their study was to test the
effects of PAP on the load-velocity relation (with intermediate loads) in the quadriceps
muscles in humans. Ten subjects, six male and four female, between 22 and 35 years old
and were moderately active participated in this study. Subjects were required to avoid
any heavy lower leg exercises or caffeine intake 24 hours prior to the testing. The
experiment consisted of 5 sessions. The first session was a familiarization session in
which the subjects experienced electrical stimulation of the knee extensors and performed isometric contractions and maximal dynamic contractions. Each subject was tested for the maximum isometric torque for the knee extensor in this session. The other four sessions were designed for testing the effects of PAP with 15%, 30%, 45%, or 60% done in random order of maximum isometric knee extension torque after a 10-second maximal voluntary isometric contraction (MVC). The dynamic extensions were performed with and without PAP. The dynamic knee extensions without PAP were used as the control. An electromyographic (EMG) technique was used to record activation of the vastus medialis muscle during MVC. The order of the PAP trials was as follows: isometric twitch – 10 seconds MVC (control did nothing during this period) – isometric twitch – dynamic knee extension – isometric twitch – dynamic knee extension – isometric twitch. This cycle was completed in 60 seconds and an interval between MVC and the first dynamic knee extension was 15 seconds. Isometric twitch response was evoked four times in one cycle of protocol to monitor the extent of PAP during the test. Besides the PAP trials, there was a protocol called the twitch control trials which were identical to the PAP trials except that isometric twitches were evoked when the dynamic knee extensions would have been performed in the PAP and control group.

The results revealed that PAP, measured as the increase in evoked twitch torque, was 53% and 43% respectively at the time of the first and second extensions with each load. In dynamic knee extension, however, PAP did not increase peak velocity nor peak power with any load, and there was a tendency for peak velocity to decrease in the first extension after MVC. The EMG data recorded from the vastus medialis muscle did not show any difference between control and PAP trials. The researcher concluded that
15-second recovery period was not enough to recover from 10 seconds MVC. Young et al. (1998) gave 4-minute rest while Radcliffe & Radcliffe (1996) and Gullich & Schmidtbleicher (1996) gave 3 minutes rest for their subjects after inducing MVC. Therefore, it seems that at least 2 to 3 minute recovery period is needed after the stimuli that induce PTP or PAP such as squat exercise, or isometric MVC.

Studies Using Animals

Most of the studies using animals focus on investigating the physiological aspects of posttetanic potentiation (PTP). The mechanism of PTP is still not fully understood and it is difficult and dangerous to use human subjects to study physiological aspects of PTP. This difficulty is due to involvement of dissections and vigorous tetanic stimulation of muscles. Research using animals is the primary method to provide answers regarding PTP and what is happening physiologically during PTP. Although not all the results from animal studies readily transfer to athletic performance and muscle activities of humans, results from animal studies provide some idea or hint about the physiological aspects of PTP in humans.

Abbate et al. (2000) investigated the effects of high-frequency initial pulses (HFIP) and PTP on mechanical power output during concentric contractions and to determine if the effects were velocity dependent. The medial gastrocnemius muscles of the rats were used in this study. Two types of high-frequency initial pulses (HFIP), two pulses of 200 Hz (D200) and three pulses of 400 Hz (T400), were used to study the effects of HFIP on mechanical power output. HFIP was immediately followed by a stimulation of either 80, 120, or 200 Hz. Force data obtained before and after HFIP were
compared to study the effects of HFIP. To investigate the effects of PTP on mechanical power output, potentiation was evoked with a tetanus of 1 second at 160 Hz. The potentiating tetanus was followed by three concentric contractions, which were 2 seconds apart. Three different frequencies were used randomly for three concentric contractions after a tetanus stimuli. The velocity of concentric contractions, applied after both HFIP and potentiating tetanus, was either 0, 25, 50, 75, 100, 125, 150, or 200 mm/s and were randomly applied. Isometric contractions before and after HFIP and potentiating tetanus were also tested in this study.

The results showed that during isometric contractions, both D200 and T400 of HFIP increased the rate of force development (T400 increased more than D200 did). However, peak force remained unchanged with the frequencies of 80 and 120 Hz. Frequency of 200 Hz did not increase the rate of force development or peak force. During concentric contractions, HFIP increased power output at 75 mm/s or higher contraction velocities when a frequency of 80 or 120 Hz followed HFIP.

Similar to the results of HFIP, no effects on peak force were observed at any frequencies during isometric contractions after PTP although increase in the rate of force development was observed after PTP. The effects of PTP during concentric contractions were very similar to the effects of HFIP. PTP increased power output with shortening velocity of 75 mm/s or higher when a frequency was either 80 or 120 Hz. In this study, HFIP and PTP were reported to have similar effects on post HFIP or PTP contractions. An increase in power output was observed in both HFIP and PTP at high velocity (75 mm/s) while no effect on peak force was determined in both HFIP and PTP during isometric contractions. In any type of contractions, a frequency of 200 Hz appeared too
high to get any positive effects from both HFIP and PTP.

Williams (1990) investigated antagonizing calcium influx via calcium removal and calcium channel antagonists inhibited PTP. Whole sartorius and semitendinosus muscles and muscle bundles from both muscles dissected from a frog were mounted at optimal length in a normal Ringer solution (NR). To measure PTP, isometric twitches were evoked every 10 seconds for 2 minutes before and immediately after a 2.5-second tetanic contraction at 80 Hz. To antagonize calcium influx, the following four solutions were prepared: low-calcium Ringer (LCR), NR plus diltiazem, NR plus nifedipine, and NR plus D 600. These four calcium antagonistic solutions were used before the 2.5-second tetanus. The addition of Dilt, Nif, and D 600 to post-tetanized muscle was also attempted.

The results indicated that responses of whole muscles and fiber bundles were similar. The four calcium influx antagonist solutions did not have significant influences on pre-tetanic twitches or on maximal tension produced during the tetanus. However, the antagonists also caused a noticeable decrease in tension at the end of the tetanus. Under NR conditions, twitches evoked immediately after the 2.5 seconds tetanus were increased by $49.5 \pm 0.4\%$ with the peak rate of tension development increased by $44.9 \pm 0.5\%$ ($P < 0.05$). In contrast to NR conditions, low-calcium Ringer (LCR), NR plus diltiazem, NR plus nifedipine, and NR plus D 600 (antagonizing calcium influx solutions) decreased the PTP response by $59.8 \pm 6.2$, $55.9 \pm 10.1$, $73.2 \pm 6.8$, and $29.8 \pm 3.6\%$ respectively ($P < 0.05$) and increased the peak rate of tension development by $65.8 \pm 11.1$, $45.7 \pm 8.6$, $55.6 \pm 4.4\%$ and $49.0 \pm 10.5\%$ respectively ($P < 0.05$). The addition of Dilt, Nif, and D 600 immediately after the tetanus also reduced PTP slightly. These
three solutions also had a tendency to increase the rate at which the potentiated twitch returned to control levels. The results indicate that antagonism of calcium influx via calcium removal or via calcium antagonists significantly reduce PTP effects. Therefore, calcium influx is assumed to have some influence on PTP phenomenon. It is known that Dilt, Nif, and D 600 inhibit calcium influx through the slow channels rather than the fast channels (Almers et al., 1985). For this reason, the researcher in this study suggests that the slow channels are involved in PTP while they do not identify a role of the fast channels in PTP.

Tang & Zucker (1997) conducted a study to investigate whether mitochondria and endoplasmic reticulum (ER) are involved in maintaining sufficient level of the elevation of posttetanic presynaptic [Ca\(^{2+}\)] after the tetanus to cause PTP. The excitatory (glutamatergic) neuromuscular junctions on crayfish leg opener muscles were used in this study. PTP was produced by stimulating the motor axon for 7 – 10 minutes at 20 – 33 Hz. Excitatory junction potentiations (EJPs) were recorded before and after the tetanus at 0.2 – 0.33 Hz, as well as during tetanus. Presynaptic [Ca\(^{2+}\)], was also measured before, during, and after tetanus in most experiments. TTP\(^{4+}\), CCCP, or ruthenium red was used to block mitochondrial Ca\(^{2+}\) sequestration and release. A role for ER was investigated by blocking the Ca\(^{2+}\)-ATPase responsible for Ca\(^{2+}\) influx into ER with endoplasmic reticulum (ER) Ca\(^{2+}\) pump inhibitors (thapsigargin (K\(_i\) < 1 nM) or BHQ (K\(_i\) = 400 nM)).

The results revealed that mitochondrial Ca\(^{2+}\) uptake and release inhibitors (TTP\(^{4+}\), CCCP, and ruthenium red) significantly decreased EJPs 1 minute after tetanus although increase in EJPs during tetanus with TTP\(^{4+}\), CCCP, and ruthenium red was also
observed. PTP was blocked by all three mitochondrial Ca\textsuperscript{2+} uptake and release inhibitors while endoplasmic reticulum Ca\textsuperscript{2+} pump inhibitors had no effects. Results of this study indicate that mitochondria play a significant role in the activation of PTP, while ER does not have any effect on PTP.

Moore & Stull (1984) examined the effects of a wide range of frequencies and durations of stimulations on myosin phosphorylatable light chain (P-light chain) phosphorylation and dephosphorylation in the slow twitch soleus muscle and the high and low oxidative portions of the predominantly fast twitch gastrocnemius muscle in rats. The correlation between isometric twitch tension potentiation and P-light chain phosphorylation was also investigated.

They found that the white portion of the gastrocnemius muscle contained 2.2 and 3.5 times more myosin light chain kinase activity than did the red portion of the gastrocnemius muscle and the soleus muscle, respectively. On the other hand, they found that the red portion of the gastrocnemius muscle and the soleus muscle contained 3.5 times more succinate dehydrogenase (a mitochondrial marker enzyme) activity than did the white portion of the gastrocnemius muscle. The white portion of the gastrocnemius muscle was stimulated repetitively at several low frequencies (0.5, 5.0, 10 Hz) to see the effects on P-light chain phosphorylation. Muscle stimulation at 0.5, 5.0, and 10 Hz was sufficient to increase in P-light chain phosphate content in the white portion of the gastrocnemius muscle. The stimulation at 10 Hz produced P-light chain phosphorylation 2.6 and 12.3 times faster than the stimulations at 5 and 0.5 Hz, respectively.

Compared to the production of P-light chain phosphate in the white

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gastrocnemius muscle, the P-light chain phosphate content under similar conditions of muscle stimulation in the red portion of the gastrocnemius was smaller. However, the rate of onset of twitch tension potentiation in the red portion of the gastrocnemius was found frequency dependent like in the white portion of the gastrocnemius muscle. The effect of 10 seconds of tetanic stimulation at 100 Hz on the rate of P-light chain phosphorylation in the white portion of the gastrocnemius muscle was also investigated. It was found that the rate of P-light chain phosphorylation was 2.2, 5.8, and 27 times greater than the initial rates of P-light chain phosphorylation observed when the muscle was stimulated at 10, 5, and 0.5 Hz, respectively. A second tetanic contraction, which occurred 20 seconds after the first tetanus, further increased in the extent of P-light chain phosphate content. Isometric twitch tension potentiation after the first and second tetanic contractions was observed and it was correlated with the rate of P-light chain phosphorylation.

In the soleus muscle (slow twitch), stimulation at low frequencies (1 and 5 Hz) did not result in an increase in P-light chain phosphate content while long duration high frequency stimulation (30 Hz for 60 seconds, and 100 Hz for 15 seconds) caused a small increase in P-light chain phosphate content. The rate of P-light chain dephosphorylation was four times faster in slow muscle than in fast white muscle. The researchers assumed that the greater extent of P-light chain phosphorylation in the white portion of the gastrocnemius muscle may be due in the presence of more kinase and less phosphatase activities. The researchers concluded that the physiological consequences of P-light chain phosphorylation are likely to be of greatest importance in fast-twitch white muscle. The results of this study indicate that the faster the P-light chain phosphorylation is
produced, the more potentiation is achieved. Since fast twitch muscles have more kinase activities, the faster rate of P-light chain phosphorylation is possible.

Rassier & Walter (2002) investigated the effects of pH on the length-dependent twitch potentiation in skeletal muscle. Fiber bundles of extensor digitorum longus muscles (EDL) dissected from the mouse were used in this study. Isometric twitch contractions of the fiber bundle were performed before and after 10 seconds of 10 Hz stimulation at five different lengths. The five different lengths of muscle bundles ranged from optimal length for maximal force production ($L_o$) to $L_o + 1.2$ mm ($L_o$, $L_o + 0.3$ mm, $L_o + 0.6$ mm, $L_o + 0.9$ mm, and $L_o + 1.2$ mm). The average length of $L_o$ was $12 \pm 0.7$ mm. Solutions of pH 6.6, 7.4, and 7.8 were prepared to measure the level of potentiation in different pH levels (the levels of pH were changed by altering the CO$_2$ concentration of the bath solutions).

The results showed that the potentiation was greater at a pH 7.4 than at 6.6. Contractions at pH 7.8 were similar to the contractions at pH 7.6. As length of the fiber bundle increased, the degree of potentiation at pH 7.4 and 7.8 showed a linear decrease ($r^2 = 0.95$ and $r^2 = 0.99$ respectively). However, a change in potentiation did not occur as length increased at pH 6.6, and the slope of the length-potentiation relationship was not different from $L_o$ (0 mm) ($r^2 = 0.05$). This study found that increasing pH level causes increase in potentiation, and the length dependent potentiation is abolished by low pH level (pH 6.6). It is known that a decrease in intramuscular pH decreases Ca$^{2+}$ sensitivity (Martyn & Gordon, 1988), so it is understandable that a higher pH level increases the level of potentiation. The researchers concluded that the mechanism of the length-dependent potentiation might be closely related to the length dependence of Ca$^{2+}$.
sensitivity.

From the studies completed on animals, calcium was found to be a key for PTP. PTP was significantly reduced by antagonism of calcium influx though the slow channels via calcium removal or via calcium antagonists (Williams, 1990). More specifically, inhibiting mitochondrial Ca\(^{2+}\) uptake and release blocked PTP while inhibiting endoplasmic reticulum Ca\(^{2+}\) activities had no effect on PTP (Tang & Zucker, 1997). The rate of P-light chain phosphate production is also found to have some effects on PTP. The faster rate of phosphorylation was found to cause higher PTP (Moore & Stull, 1984). This positive correlation explains why PTP is more prominent in type II (fast twitch) muscle fibers. Simply, type II muscle fibers have more kinase activities which allows the faster production of P-light chain phosphorylation. Therefore, type II muscle fibers have higher rate of P-light chain phosphorylation and so as higher PTP (Moore & Stull, 1984). Rassier & Walter (2002) found a positive correlation in pH level and PTP. Since it is known that a decrease in pH level decreases Ca\(^{2+}\) sensitivity (Martyn & Gordon, 1988), the results of Rassier & Walter (2002) were indirectly affected by a decrease in Ca\(^{2+}\) uptake level that was caused by a decrease in pH level.
CHAPTER III

METHODS

The purpose of this study was to compare the effects of two different types of squats, as a cause of PTP, on vertical jump height. Specifically, the efficacy of using two different types of heavy squats (the half squat and the quarter squat) to increase CMJ performance through the elicitation of PTP was examined.

Subjects

Initially, 11 experienced weight lifters were recruited for this study, but one subject was withdrawn due to an injury unrelated to this study between the second and the third sessions. Therefore, 10 subjects (age = 23.4 ± 2.0 yr; height = 177.0 ± 5.0 cm; weight = 83.1 ± 9.7 kg; the maximum half squat weight = 304.0 ± 51.3 lb; the maximum quarter squat weight = 379.0 ± 53.2 lb) completed all the sessions in the experiment, and the data from these 10 subjects were used. To be eligible for participation, one year experience with the squat exercise and ability to perform the half squat were required. The average experience of the 10 subjects in squat exercise was 7.3 ± 3.3 yr. The average squat exercise performed by these subjects in a week was 1.2 ± 0.4 times / week. The means and standard deviations (SD) for the max half squat weight and the quarter squat weight were 304.0 ± 51.3 lb, and 379.0 ± 53.2 lb, respectively. The means and
SDs for 90% of the max half squat weight and the quarter squat weight used in the study were 274.0 ± 46.4 lb, and 341.4 ± 47.5 lb, respectively. Prior to participating in this study, subjects read and signed an informed consent form (APPENDIX IV) approved by the office of Protection of Human Subjects Review Committee at the University of Nevada, Las Vegas.

**Instrumentation**

Vertical ground reaction force (GRF) data during the CMJ were measured and recorded for 4 seconds at the sample frequency of 1000Hz with the Kistler force plate (model 9281B11). BioWare software (version 3.21) was used for the acquisition of data from the Kistler force plate. A Gateway E-3000 (Intel Pentinum MMX processor) was used to run the BioWare software. All raw data were subsequently exported to a Microsoft Excel (2002) spreadsheet for processing.

**Experimental Protocol**

All subjects were asked to report to the Sports Injury Research Center at UNLV on three separate occasions. The subjects were also asked to refrain from heavy lower extremity exercises 48 hours prior to each session. In the three occasions, each subject was required to sit down for 30 minutes before starting any exercise to minimize fatigue. The purpose of the first session was to perform 2 sets of 3 maximal CMJs and to determine the 1 RM in the half squat and the quarter squat. As a warm-up, each subject was required to run on a treadmill for three minutes at 5 mph and perform 3 submaximal CMJs before starting experiment. A 2-minute rest period between the end
of the warm-up and the beginning of the next exercise was required of all subjects. This warm-up routine remained the same on the 2\textsuperscript{nd} and 3\textsuperscript{rd} day of the experiment. The 2 sets of 3 maximum CMJs obtained on the first day were used as a control measure.

At subsequent testing sessions, each subject was required to sit and rest for 15 minutes between the 2 sets of 3 maximal CMJs. Since it took about 15 minutes to complete the squat exercises on the 2\textsuperscript{nd} and 3\textsuperscript{rd} days of the experiment, 15 minutes rest was appropriate to simulate the time frame of the two other treatment conditions. The rest interval between jumps was 30 seconds, and this interval remained constant for all treatment conditions performed on the different days. Immediately after finishing the second set of maximal CMJs, 1 RM testing with a free weight Olympic barbell was performed in a squat rack with safety bars on each side. The subject's 1 RM of the half squat was determined first followed by the 1 RM test in the quarter squat. All subjects were required to warm-up for the squat exercise by performing the following progression with 2-minute rest intervals between sets.

For measuring 1 RM of half squat:

Set 1 - 6 reps at 50\% of expected 1 RM half squat
Set 2 - 4 reps at 65\% of expected 1 RM half squat
Set 3 - 2 reps at 80\% of expected 1 RM half squat
Set 4 - 1 rep at 85\% of expected 1 RM half squat
Set 5 - 1 rep at 90\% of expected 1 RM half squat

The rest period was extended from 2 minutes to 3 minutes after the 5\textsuperscript{th} squat set. As the subject performed the half squat to determine their 1 RM, the weight added to a load that was too light was between 5 - 50 lbs. The addition of weight was determined by
each subject and the primary investigator, who is a strength and conditioning specialist (CSCS) certified by the National Strength and Conditioning Association, and depended on the efforts required to complete the previous lift. This routine was continued until 1 RM of the half squat was found. After finding 1 RM of the half squat, subsequent lifts were performed to determine the 1 RM of the quarter squat as well.

Finding 1 RM of the quarter squat:

Three minutes after achieving 1 RM of the half squat, the process to determine the 1 RM of the quarter squat was initiated with 3-minute rest intervals. To determine the 1 RM of the quarter squat, the weight of the 1 RM half squat was used as the starting weight. Each subject and the researcher of the study selected an additional weight between 5 – 50 lbs, which depended on the efforts required to complete the previous lift. This routine was continued until 1 RM of the quarter squat was determined.

The second session was conducted 3 to 5 days after Session 1, and the third session was held three to five days after Session 2. All subjects were required to report to subsequent testing sessions without any muscle soreness in the legs from the previous session. How long muscle soreness remained in subjects’ legs was assumed to be relative to each subject, therefore a 3 – 5 day window of resting was prepared. The purpose of Session 2 and Session 3 was to investigate if performing the half squat and/or the quarter squat could increase the counter movement jump height. During these two sessions, the order of testing was counter balanced to control for order effects. In Session 2, subject 1, 3, 5, 7, and 9 performed the half squat and subject 2, 4, 6, 8, and 10 performed the quarter squat. The numbers assigned to the subjects represent the order of testing. Likewise, in Session 3 the subjects who performed the half squat in
Session 2 performed the quarter squat, and the subjects who performed the quarter squat in Session 2 performed the half squat in Session 3. The warm-up routine before starting Session 2 and Session 3 was identical to the warm-up in Session 1. In both Session 2 and Session 3, 2 minutes after warm-up, each subject performed three maximal CMJ with 30 seconds interval between jumps. The researcher reminded each subject to jump as high as possible during each maximal CMJ performed. Immediately after performing the last maximal CMJ, each subject performed either the half squat or the quarter squat depending on what was assigned for him in each session. To perform 90% of 1 RM for each type of squat, the following progression was conducted with 2-minute rest intervals between sets. Each subject was required to sit down during the 2-minute rest intervals.

Set 1 - 6 reps at 50% of 1 RM of assigned type of squat
Set 2 - 4 reps at 65% of 1 RM of assigned type of squat
Set 3 - 2 reps at 80% of 1 RM of assigned type of squat
Set 4 - 1 rep at 85% of 1 RM of assigned type of squat
Set 5 - 1 rep at 90% of 1 RM of assigned type of squat

3 minutes after performing 1 repetition at 90% of the assigned type of squat, each subject performed three maximal CMJs with 30-second intervals between jumps. Each subject was asked to sit down during the 3 minute resting period before performing 3 maximal CMJs.

Data Reduction

Vertical ground reaction force (GRF), measured in Newtons (N) was recorded.
during each jump via the Kistler force plate. Data from the force plate was used to calculate CMJ height. All raw data were subsequently exported to the Microsoft Excel spreadsheet for data reduction and processing. Acceleration, velocity, and displacement of CMJ were derived from the vertical GRF data. Acceleration was calculated from the vertical GRF with the following equation: \[ a = \frac{(F_z - \text{Body Weight})}{m}. \] Body weight is mass of the body times gravity (9.81 m/s^2). The vertical GRF measured during the time between the start of data collection and right before the beginning of jump movement was used as the force of the body. Therefore, the length of sample time for the force of the body varied depending on the timing of the initiation of movement. Velocity was calculated from acceleration with the following equation: \[ V_f = a \Delta t + V_i. \] Displacement was calculated from velocity with the following equation: \[ S_f = v \Delta t + S. \] The maximum displacement, which was the jump height for each jump, was measured with the above calculations. An average height of the three CMJs performed before and after the 15 minutes rest, the half squat, and the quarter squat was then calculated. These average CMJ heights were used to represent each condition.

Statistical Analysis

There were three levels of independent variables, which were control (15-minute rest), the half squat, and the quarter squat. The dependent variable was the vertical jump height difference between pre and post control, the half squat, and the quarter squat conditions. The mean and standard deviations of the average jump heights from all ten subjects in each condition were calculated. The dependent variable was analyzed using one way repeated measure ANOVA to determine if differences
existed in the CMJ height achieved before and after the 15 minutes resting (control), the half squat exercise, and the quarter squat exercise. The Pearson correlation was also performed to see if there was any correlation between relative strength ratio (the maximum weight lifted by a subject divided by the body weight of a subject) and the difference in CMJ height before and after two treatments (the half squat and the quarter squat).
CHAPTER IV

RESULTS

There was no difference in CMJ performance after any of the three testing conditions; 15-minute resting, the half squat and the quarter squat ($F = 3.096, p = 0.070$).

Mean and standard error for vertical jump height difference before and after each condition across subjects are illustrated in Table 1 and are represented graphically in Figure 1.

Table 1  Mean and Standard Error for CMJ Height Difference Before and After Each Condition Across Subjects (Each Subject Completed 3 CMJs Before and After Each Condition)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean Difference (cm)</th>
<th>Standard Error (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>-1.3</td>
<td>0.65</td>
</tr>
<tr>
<td>Half Squat</td>
<td>0.6</td>
<td>0.74</td>
</tr>
<tr>
<td>Quarter Squat</td>
<td>-0.1</td>
<td>0.39</td>
</tr>
</tbody>
</table>
Figure 1. Mean CMJ Height Differences for Before and After Treatment Across Subjects

The mean and standard deviation across subjects for vertical jump height in each condition are shown in Table 2 and are represented graphically in Figure 2.

Table 2 Mean + SD for CMJ Height Across Subjects (Each Subject Completed 3 CMJs Before and After Each Condition)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Average CMJ Height (cm)</th>
<th>Standard Error</th>
<th>STDEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Control</td>
<td>62.7</td>
<td>1.85</td>
<td>5.85</td>
</tr>
<tr>
<td>After Control</td>
<td>61.4</td>
<td>1.78</td>
<td>5.62</td>
</tr>
<tr>
<td>Before Half Squat</td>
<td>63.3</td>
<td>2.61</td>
<td>8.25</td>
</tr>
<tr>
<td>After Half Squat</td>
<td>63.9</td>
<td>2.33</td>
<td>7.36</td>
</tr>
<tr>
<td>Before Quarter Squat</td>
<td>63.5</td>
<td>2.27</td>
<td>7.18</td>
</tr>
<tr>
<td>After Quarter Squat</td>
<td>63.3</td>
<td>2.08</td>
<td>6.58</td>
</tr>
</tbody>
</table>

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There was no correlation between strength ratio and vertical jump height differences for the half squat condition ($r = -0.138$ and p-value $= 0.704$) and for the quarter squat condition ($r = -0.173$ and p-value $= 0.632$).
DISCUSSION

The primary interest of this study was to compare CMJ height before and after performing the half squat and the quarter squat exercises. In this study, no significant difference in vertical jump performance was found in any of the three conditions, including a control condition. Therefore, a PTP effect, which is hypothesized to increase power output, was not observed in this study unlike other similar studies (Gullich & Schmidtbleicher, 1996; Young et al., 1998; Radcliffe & Radcliffe, 1996).

Several factors could explain why PTP did not occur in this study, but some of all the possible factors seem to have more impact than the others. One argument is the length of the rest interval between the last squat set and the first CMJ in the second set. A 3-minute rest period was selected for this study based on published research by Gullich & Schmidtbleicher (1996) and Radcliffe & Radcliffe (1996), who succeeded in creating PTP by implementing a 3-minute resting period between heavy resistant warm-up and jump performance. Young et al. (1998) succeeded in creating PTP by using a 4-minute rest period between a 5-RM half squat set and a loaded CMJ. In this study, repetitions of the squat exercises were kept low, therefore fatigue from the squat exercises were assumed to be minimal after 3 minutes of resting. Additionally, subjects were asked to sit still during the 2 minute rest intervals between squat sets, and during
3-minute rest period, which was the time between the completion of the last squat set and the first CMJ in the second set. Gullich & Schmidtbleicher (1996), Young et al. (1998), and Radcliffe & Radcliffe (1996), did not outline how their subjects spent their assigned resting time, i.e. sitting, standing, or slow walking in the testing area.

Understanding how subjects utilized their rest time during the testing, i.e. sitting or walking around, is as important as knowing how long the rest period was during the experiment, because the rate of blood flow would change depending on their resting manner. Increased blood flow theoretically could aid in recovery by delivering nutrients and removing any lactic acid from the previous activity. Therefore, resting manner could be the one of the important factors affecting the production of PTP.

Another explanation for the lack of findings in this study is the amount of weight lifted and repetitions performed. It was found that performing 1 repetition of 90 % of maximum half squat and quarter squat does not have any effect on vertical jump performance. Changing any lifting parameters may or may not have effects on vertical jump performance. In another words, one study is not enough to find how heavy is heavy enough, and what volume is enough or too much to cause PTP. The optimal combination of weight and volume to cause PTP can only be found by conducting more research.

The design of this study in which using high intensity isotonic contraction with less repetition to cause PTP was unique compared to other similar studies. Gullich & Schmidtbleicher (1996) used multiple sets of maximal isometric voluntary contraction for 5 seconds, Young et al. (1998) and Hrysomallis & Kidgell (2001) used 1 set of 5 repetitions with 5 RM weight, and Radcliffe & Radcliffe (1996) used four sets of four
power snatches at 75 – 85% of 4RM. Similar to the studies by Young et al. (1998), Radcliffe & Radcliffe (1996), and Hrysomallis & Kidgell (2001), free weights were implemented in this study while the weight used in this study (90% of each subject’s max) was greater than the others. The repetitions were less in comparison to Young et al (1998), Hrysomallis & Kidgell (2001), and Radcliffe & Radcliffe (1996) studies. However, lifting parameters used in this study had no effect on vertical jump performance.

Practical Recommendations

Although statistics showed no difference in any of 3 conditions, including the control condition, half of the subjects in this study increased CMJ height after performing the half squat and the quarter squat exercises. Interestingly, half of the subjects who increased their performance after the half squat were the same subjects who increased performance after the quarter squat. The other five subjects, who did not increase their performance, decreased their performance after the half squat, and they also decreased their performance after the quarter squat except one subject did not change jump height before and after the quarter squat. Individual performance in each condition is shown in Table 3.
Table 3  Mean Difference in CMJ performance of Each Subject Before and After Each
Condition Within Each Subject

<table>
<thead>
<tr>
<th>Subject</th>
<th>Control (cm)</th>
<th>Half Squat (cm)</th>
<th>Quarter Squat (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.5</td>
<td>1.3</td>
<td>0.6</td>
</tr>
<tr>
<td>2</td>
<td>-0.5</td>
<td>2.5</td>
<td>1.3</td>
</tr>
<tr>
<td>3</td>
<td>-0.8</td>
<td>-1.1</td>
<td>-0.1</td>
</tr>
<tr>
<td>4</td>
<td>-3.7</td>
<td>-1.0</td>
<td>-0.5</td>
</tr>
<tr>
<td>5</td>
<td>-3.6</td>
<td>5.9</td>
<td>0.8</td>
</tr>
<tr>
<td>6</td>
<td>-0.1</td>
<td>-1.3</td>
<td>-2.1</td>
</tr>
<tr>
<td>7</td>
<td>0.7</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td>8</td>
<td>1.6</td>
<td>1.3</td>
<td>0.1</td>
</tr>
<tr>
<td>9</td>
<td>-1.3</td>
<td>-1.4</td>
<td>-2.0</td>
</tr>
<tr>
<td>10</td>
<td>-4.6</td>
<td>-1.2</td>
<td>-1.3</td>
</tr>
</tbody>
</table>

In terms of statistics, the result of this study was not significant, but this interesting observation may not be ignored because there is a possibility of individual differences. If individual difference exists, it is important to understand for athletes who consider utilizing the heavy resistance warm-up. While this study showed no difference in vertical jump performance after performing 1 repetition of 90% of maximum squat weight, some athletes still may use heavy resistance lifting as a part of their warm-up routine because other similar studies support the idea of using heavy weight as a warm-up for better performance (Gullich & Schmidtbleicher, 1996; Young et al., 1998; Radcliffe & Radcliffe, 1996). My recommendation to those athletes would be to try out several combinations of different lifting parameters to find out their own optimal routine.

Future Study Considerations

More investigations are needed to examine different lifting parameters, such as...
repetition, weight being lifted, or resting time, to find an optimal warm-up routine for better performance. Although the purpose of this study was to compare an acute effect on vertical jump performance after performing two types of squat exercise in a group of 10 subjects, and no difference was found, the possibility of individual difference in responding to the same warm-up routine using heavy resistance lifting was indicated. Therefore, single subject results might be considered in future research.
APPENDIX I

PICTURES OF THE HALF SQUAT AND THE QUARTER SQUAT
Above pictures show the deepest point in the half squat (a) and the quarter squat (b).
Subject: 1

Age: 25
Height: 175.5 cm
Weight: 86.3 kg
Experience in Weight Lifting: 9 years
Experience in Squat Exercise: 9 years
Number of Workout(s) in a Week: 5 times
Number of Squat Workout(s) in a Week: 1 time
Maximum Weight Lifted in the Half Squat: 315 lb.
Maximum Weight Lifted in the Quarter Squat: 385 lb.
Strength Ratio in the Half Squat: 3.65 lb./1kg
Strength Ratio in the Quarter Squat: 4.46 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

| Summary of Subject 1 (Unit used for the numbers in these boxes is cm) |
|-----------------|----------------|----------------|----------------|----------------|----------------|
| Condition       | Before/After  | 1st CMJ       | 2nd CMJ       | 3rd CMJ       | Average       | Difference    |
| Control         | Before        | 58.7          | 56.2          | 55.3          | 56.7          | -0.5          |
|                 | After         | 59.0          | 54.8          | 54.9          | 56.2          |
| Half Squat      | Before        | 53.4          | 55.7          | 56.6          | 55.2          | 1.3           |
|                 | After         | 58.4          | 57.8          | 53.3          | 56.5          |
| Quarter Squat   | Before        | 58.8          | 55.3          | 55.2          | 56.4          | 0.6           |
|                 | After         | 58.6          | 54.3          | 58.1          | 57.0          |
Subject: 2

Age: 25
Height: 174.0 cm
Weight: 83.5 kg
Experience in Weight Lifting: 6 years
Experience in Squat Exercise: 6 years
Number of Workout(s) in a Week: 3-4 times
Number of Squat Workout(s) in a Week: 1 time
Maximum Weight Lifted in the Half Squat: 330 lb.
Maximum Weight Lifted in the Quarter Squat: 435 lb.
Strength Ratio in the Half Squat: 3.95 lb./1kg
Strength Ratio in the Quarter Squat: 5.21 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
<th>Average</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Before</td>
<td>62.7</td>
<td>68.7</td>
<td>66.1</td>
<td>65.8</td>
<td>-0.5</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>64.3</td>
<td>64.4</td>
<td>67.3</td>
<td>65.3</td>
<td></td>
</tr>
<tr>
<td>Half Squat</td>
<td>Before</td>
<td>71.5</td>
<td>72.0</td>
<td>67.7</td>
<td>70.4</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>71.1</td>
<td>74.2</td>
<td>73.3</td>
<td>72.9</td>
<td></td>
</tr>
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<td>Quarter Squat</td>
<td>Before</td>
<td>64.2</td>
<td>65.9</td>
<td>67.6</td>
<td>65.9</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>68.4</td>
<td>68.1</td>
<td>65.1</td>
<td>67.2</td>
<td></td>
</tr>
</tbody>
</table>

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Subject: 3

Age: 28
Height: 175.5 cm
Weight: 77.5 kg
Experience in Weight Lifting: 13 years
Experience in Squat Exercise: 13 years
Number of Workout(s) in a Week: 4 times
Number of Squat Workout(s) in a Week: 2 times
Maximum Weight Lifted in the Half Squat: 310 lb.
Maximum Weight Lifted in the Quarter Squat: 375 lb.
Strength Ratio in the Half Squat: 4.00 lb./1kg
Strength Ratio in the Quarter Squat: 4.84 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
<th>Average</th>
<th>Difference</th>
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</thead>
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<tr>
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<td>After</td>
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<td>62.1</td>
<td>64.4</td>
<td>63.7</td>
<td></td>
</tr>
<tr>
<td>Half Squat</td>
<td>Before</td>
<td>66.3</td>
<td>63.1</td>
<td>66.3</td>
<td>65.2</td>
<td>-1.1</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>63.8</td>
<td>63.3</td>
<td>65.3</td>
<td>64.1</td>
<td></td>
</tr>
<tr>
<td>Quarter Squat</td>
<td>Before</td>
<td>63.5</td>
<td>65.0</td>
<td>63.8</td>
<td>64.1</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>After</td>
<td>65.3</td>
<td>63.2</td>
<td>63.7</td>
<td>64.1</td>
<td></td>
</tr>
</tbody>
</table>

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Subject: 4

Age: 24
Height: 187.0 cm
Weight: 89.3 kg
Experience in Weight Lifting: 9 years and 6 months
Experience in Squat Exercise: 9 years and 6 months
Number of Workout(s) in a Week: 5 times
Number of Squat Workout(s) in a Week: 2 times
Maximum Weight Lifted in the Half Squat: 355 lb.
Maximum Weight Lifted in the Quarter Squat: 425 lb.
Strength Ratio in the Half Squat: 3.98 lb./1kg
Strength Ratio in the Quarter Squat: 4.76 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
<th>Average</th>
<th>Difference</th>
</tr>
</thead>
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<td>Before</td>
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<td>76.2</td>
<td>75.3</td>
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</tr>
<tr>
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<td>After</td>
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<td>74.1</td>
<td>76.1</td>
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<tr>
<td>Quarter Squat</td>
<td>Before</td>
<td>73.6</td>
<td>73.4</td>
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<tr>
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<td>After</td>
<td>72.2</td>
<td>74.1</td>
<td>74.2</td>
<td>73.5</td>
<td></td>
</tr>
</tbody>
</table>
Subject: 5

Age: 22
Height: 181.0 cm
Weight: 105.0 kg
Experience in Weight Lifting: 9 years
Experience in Squat Exercise: 9 years
Number of Workout(s) in a Week: 3-5 times
Number of Squat Workout(s) in a Week: 1 time
Maximum Weight Lifted in the Half Squat: 365 lb.
Maximum Weight Lifted in the Quarter Squat: 420 lb.
Strength Ratio in the Half Squat: 3.48 lb./1kg
Strength Ratio in the Quarter Squat: 4.00 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
<th>Average</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Before</td>
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<td>59.1</td>
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<td>-3.6</td>
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<td>56.3</td>
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<tr>
<td>Half Squat</td>
<td>Before</td>
<td>49.0</td>
<td>53.4</td>
<td>52.2</td>
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<tr>
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<td>After</td>
<td>59.1</td>
<td>56.5</td>
<td>56.5</td>
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<td>Quarter Squat</td>
<td>Before</td>
<td>57.1</td>
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<td>58.3</td>
<td>57.8</td>
<td>59.0</td>
<td></td>
</tr>
</tbody>
</table>
Subject: 6

Age: 22
Height: 183.0 cm
Weight: 75.4 kg
Experience in Weight Lifting: 6 years and 6 months
Experience in Squat Exercise: 2 years
Number of Workout(s) in a Week: 4 times
Number of Squat Workout(s) in a Week: 1 time
Maximum Weight Lifted in the Half Squat: 210 lb.
Maximum Weight Lifted in the Quarter Squat: 335 lb.
Strength Ratio in the Half Squat: 2.79 lb./1kg
Strength Ratio in the Quarter Squat: 4.44 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
<th>Average</th>
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<td>68.2</td>
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<td>68.1</td>
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<td>67.7</td>
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<td>67.0</td>
<td>67.5</td>
<td>66.8</td>
<td></td>
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</tbody>
</table>
Subject: 7

Age: 24
Height: 172.5 cm
Weight: 69.4 kg
Experience in Weight Lifting: 5 years
Experience in Squat Exercise: 5 years
Number of Workout(s) in a Week: 6 times
Number of Squat Workout(s) in a Week: 1 time
Maximum Weight Lifted in the Half Squat: 255 lb.
Maximum Weight Lifted in the Quarter Squat: 310 lb.
Strength Ratio in the Half Squat: 3.67 lb./1kg
Strength Ratio in the Quarter Squat: 4.47 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th></th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
<th>Average</th>
<th>Difference</th>
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<tr>
<td>Before</td>
<td>55.0</td>
<td>54.0</td>
<td>57.9</td>
<td>55.6</td>
<td></td>
<td>0.7</td>
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<tr>
<td>After</td>
<td>52.6</td>
<td>59.6</td>
<td>56.7</td>
<td>56.3</td>
<td></td>
<td></td>
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<tr>
<td><strong>Half Squat</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>55.4</td>
<td>56.4</td>
<td>55.8</td>
<td>55.9</td>
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<td>After</td>
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<tr>
<td><strong>Quarter Squat</strong></td>
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<td></td>
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<tr>
<td>Before</td>
<td>55.8</td>
<td>51.4</td>
<td>55.9</td>
<td>54.4</td>
<td></td>
<td>1.3</td>
</tr>
<tr>
<td>After</td>
<td>56.7</td>
<td>52.1</td>
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<td>55.7</td>
<td></td>
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</table>

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Subject: 8

Age: 21
Height: 169.5 cm
Weight: 74.0 kg
Experience in Weight Lifting: 2 years
Experience in Squat Exercise: 2 years
Number of Workout(s) in a Week: 3-4 times
Number of Squat Workout(s) in a Week: 1 time
Maximum Weight Lifted in the Half Squat: 235 lb.
Maximum Weight Lifted in the Quarter Squat: 275 lb.
Strength Ratio in the Half Squat: 3.18 lb./1kg
Strength Ratio in the Quarter Squat: 3.72 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
<th>Average</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>Before</td>
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<td></td>
<td>After</td>
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<td>58.6</td>
<td>58.9</td>
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<tr>
<td>Half Squat</td>
<td>Before</td>
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<td>65.7</td>
<td>63.6</td>
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<tr>
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<tr>
<td>Quarter Squat</td>
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<td>64.2</td>
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<tr>
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<td>After</td>
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<td>64.1</td>
<td>61.7</td>
<td>63.2</td>
<td></td>
</tr>
</tbody>
</table>

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Subject: 9

Age: 21
Height: 176.0 cm
Weight: 80.7 kg
Experience in Weight Lifting: 8 years
Experience in Squat Exercise: 8 years
Number of Workout(s) in a Week: 4 times
Number of Squat Workout(s) in a Week: 1 time
Maximum Weight Lifted in the Half Squat: 360 lb.
Maximum Weight Lifted in the Quarter Squat: 440 lb.
Strength Ratio in the Half Squat: 4.46 lb./1kg
Strength Ratio in the Quarter Squat: 5.45 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
<th>Average</th>
<th>Difference</th>
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<td>68.9</td>
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<td>71.7</td>
<td>70.9</td>
<td>71.7</td>
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<td>70.3</td>
<td>70.3</td>
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<td>73.8</td>
<td>74.8</td>
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</tbody>
</table>

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Subject: 10

Age: 21
Height: 175.5 cm
Weight: 90.2 kg
Experience in Weight Lifting: 9 years
Experience in Squat Exercise: 9 years
Number of Workout(s) in a Week: 4-5 times
Number of Squat Workout(s) in a Week: 1 time
Maximum Weight Lifted in the Half Squat: 305 lb.
Maximum Weight Lifted in the Quarter Squat: 390 lb.
Strength Ratio in the Half Squat: 3.38 lb./1kg
Strength Ratio in the Quarter Squat: 4.32 lb./1kg

All the Counter Movement Jump Heights Performed Before and After Each Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before/After</th>
<th>1st CMJ</th>
<th>2nd CMJ</th>
<th>3rd CMJ</th>
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<tr>
<td>Half Squat</td>
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<td>58.4</td>
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Results of One Way Factorial ANOVA

Tests of Within-Subjects Effects

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<th>Source</th>
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<th>Mean Square</th>
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Correlations

Summary of Correlations Between the Half Squat and the Strength Ratio

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<th>CMJDIFF</th>
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<td>.704</td>
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<td>Sig. (2-tailed)</td>
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<td></td>
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<tr>
<td>N</td>
<td>10</td>
<td>10</td>
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</table>

Correlation Chart Between The Half Squat and The Strength Ratio
Summary of Correlations Between The Quarter Squat and The Strength Ratio

<table>
<thead>
<tr>
<th></th>
<th>RATIO</th>
<th>Correlation</th>
<th>Sig. (2-tailed)</th>
<th>N</th>
<th>CMJDIFF</th>
<th>Pearson</th>
<th>Correlation</th>
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<td>CMJDIFF</td>
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</table>

Correlation Chart Between The Quarter Squat and The Strength Ratio

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APPENDIX IV

INFORMED CONSENT
PROJECT TITLE: Acute Effect on Vertical Jump Performance After Two Types of Heavy Squat Exercises

General Information:

I am Masai Takahashi from the Department of Kinesiology. I am the researcher on this project. You are invited to participate in a research study. The study will investigate the effect of two different types of squat on your performance of a counter movement jump.

Procedure:

If you decide to participate in this study, you will be asked to do the following: your height and weight will be recorded prior to testing and this informed consent will be signed. An investigator will explain the procedures and tasks you will perform and any questions you might have may be asked at this time.

Prior to recording any trials, general warm-up will be performed. The warm-up will include 3 minutes stationary biking, and three submaximal counter movement jumps (CMJ). This general warm-up allows you to increase blood flow in your body (especially in the legs), and get feeling of jumps. You are aware that you should have some skill in executing a basic half and quarter squat. Routine for each session will be following:

In the 1st session (two sets of 3 CMJs without treatment and 1 RM half squat test). As a general warm-up, subjects will perform 3 minutes stationary biking, and three submaximal CMJs (This warm-up routine will be used before starting each session throughout this research). 1 minute after the general warm-up, you will perform two sets of 3 CMJs. The interval between these two sets will be 15 minutes, and the interval for each jump will be 30 seconds. You will be required to sit down during the 15 minutes of rest. After 15 minutes of rest, you will perform the second set of three maximal CMJs. Average of three CMJs will be used to represent a CMJ from each set. The difference between before and after rest will be compared and used to be a control group (no treatment). After performing two sets of three CMJs, you will be tested for 1 repetitive max (RM) half squat. The routine to find 1 RM half squat will be set as followings: 6 reps at 50% of estimated 1 RM half squat, 4 reps at 65%, 2 reps at 80%, 1 rep at 85%, 1 rep at 90%, 1 rep at 95%, 1 rep at 100%, 1 rep at 100% plus 5 – 20 pounds as needed and repeated this until 1 RM half squat is found. The resting time between each squat set will be 2 – 3 minutes.

In the 2nd session (treatment will be either one of two types of squatting) After 4 – 6 days of measuring 1 RM half squat, you will perform either one of two different hip angles of squats in this session. You will start with a general warm-up,
then you will perform three CMJs 1 minute after general warm-up. The resting
between each jump will be 30 seconds. 2 minutes after performing the last CMJ in the
first set, you will perform either one type of squat as followings: 6 reps at 50% of 1 RM,
4 reps at 65%, 2 reps at 80%, 1 rep at 85%, and perform 1 rep of 90% of 1 RM half squat.
2 minutes after the last set of squat, which will be 90% of 1RM half squat, you will
perform another three CMJs and the interval between each jump will remain 30 seconds.
Average of three CMJ will be used to represent a CMJ from each set.

**In the 3rd session** (treatment will be either one of two types of squats that subjects have
not performed).
3 – 5 days after the 2nd session, you will come in for the 3rd session. Every routine will
be exactly same as the routine in the 2nd session except the squatting style. You will
perform either half squats or quarter squats whichever you did not perform in the 2nd
session.

**Benefits of Participation:**

By participating in this research you will be contributing to the ongoing investigation of
sports performance and potential finding of advanced warm-up method for explosive
activities. The anticipated benefits of the study will be to determine whether different
types of squat have an effect on performance of counter movement jump. You may also
benefit from correcting squat form by certified strength and conditioning specialist if
you do not have correct squat technique. Your data is an important part of the
investigation and hopefully you will receive satisfaction from participating in a
research project.

**Risks:**

A “half squat” is generally assumed to contain increased potential risk over the “quarter
squat”. The half squat, which is bending the knees to a 90 degree angle while standing,
in general may have a slightly greater chance to get cause muscular strain or knee
ligament damage if it is not performed correctly. The potential risks to the participants
in this study include; back muscle strain from improper squat positioning, ankle sprain
from improper landing in performing the counter movement jumps. However, all the
participants in this study will have experience in performing the squat exercise prior to
their participation. A certified strength and conditioning specialist will be supervising
each subject throughout the experimental protocol. Each session will start with a
general warm-to include jumping with the intent of reducing the potential ankle injury.
Therefore, the overall risks to the participant in this study are the same as what people
would expect while weight lifting or any type of jumping activity in a public gym.

**Contact:**
If you have any questions about the study or if you experience adverse effects as a result of participation in this study, you may contact the researchers, Masai Takahashi at 895-4494 or Dr. Mangus at 895-3158. For questions regarding the rights of the research subjects, you may contact the UNLV Office for the Protection of Human Subjects at 895-2794.

**Participation:**

Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study and you may withdraw at any time without prejudice to your relations with the University. You are encouraged to ask questions about this study prior to the beginning or at any time during the study. You will be given a copy of this form.

**Confidentiality:**

All information gathered in this study will be kept completely confidential. Consent forms will be stored in a locked file cabinet for at least three years. No reference will be made in written or oral materials, which could link you to this study.

**Consent:**

I have read the above information and agree to participate in this study.

____________________________________  ________________
Signature of Participant                Date

____________________________________  ________________
Signature of Researcher                 Date
REFERENCES


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calcium and calcium channel antagonists.” *The American Physiological Society.* 1093-1097.

VITA

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Thesis Examination Committee:
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   Committee Member, Dr. John Mercer, Ph.D.
   Committee Member, Dr. William Holcomb, Ph.D.
   Graduate Faculty Representative, Dr. J. Wesley McWhorter, Ph.D.