EFFECT OF POST-ACTIVATION POTENTIATION (PAP) ON SWIM SPRINT PERFORMANCE

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ABSTRACT

Purpose: This study examined post-activation potentiation (PAP) and its effect on performance during sprint swimming. Following resistance exercise, the muscles are in a potentiated, as well as a fatigued state. Potentiation dissipates faster than fatigue, creating a window of opportunity for possible performance enhancement. It was hypothesized that (1) there will be an improvement in sprint performance as a result of a PAP loading protocol, and (2) that there will be a significantly greater improvement in males as a result of a PAP loading protocol. Methods: Subjects were 30 members (males, N=15; females, N=15) of the Cleveland State University Swim Team. Subjects performed two swim trials in a randomized order. The control trial involved a standard 900 meter freestyle swim warm up, followed by 6 minutes rest, followed by a maximal 100 meter freestyle swim effort. The PAP trial involved the same protocol; however a PAP loading protocol was completed prior to the 6 minutes rest. The PAP loading protocol involved the subjects completing four maximal 10 meter swims at a 1 minute interval while attached to a resistive Power Rack. The load (L) for the swims was derived by the formula $L = (0.2)(LBM)\left(\frac{100}{t}\right)$ where LBM is the subjects’ lean body mass and $t$ is their best 100 meter freestyle time. Fifty meter splits were also analyzed, as well as blood lactates. A repeated measures ANOVA was used to analyze the differences between trials, as well as compare the gender response. Results: There was a significant improvement in 100 meter freestyle time (.54sec) for the PAP trial versus the control trial.
(p=0.029). Both males and females improved during the PAP trial compared to the control trial for each performance measure: 100 meter, first 50 meter split, and last 50 meter, but there was no significant gender interaction (p=0.647). **Conclusion:** PAP has been shown to enhance 100 meter freestyle performance in collegiate sprint swimmers. Males and females have shown a similar response to a PAP loading stimulus, although other methods for loading should be explored.
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CHAPTER I
INTRODUCTION

1.1 Background Information

Understanding how the contractile properties of muscle fibers can influence performance can provide coaches and athletes with additional options when devising training programs. Of particular interest to this study is the concept of Post-Activation Potentiation (PAP), which has been shown to provide an ergogenic effect to athletic performance under certain conditions (15, 16, 22, 26). PAP is characterized by an increased rate of force development (RFD) (9) and has been observed following both voluntary and electrically-stimulated muscle contractions (13). The increased RFD observed while the muscles are under a potentiated condition is accompanied by a decreased time to peak force, and has been theorized to enhance performance in athletic activities that utilize the potentiated muscle groups.
The precise physiological mechanisms that contribute to PAP are somewhat unclear, although the dominant theory suggests that under the potentiated condition, an increase occurs in the phosphorylation of myosin regulatory light chains, leading to actin-myosin being more sensitive to Ca\(^{2+}\) (11). Increased neural activity, as a result of a maximal or near-maximal contraction, is also purported to contribute to PAP due to a greater ability to recruit and synchronize motor units for a subsequent athletic activity (1). In addition to increased synchronization of motor unit firing, Baker suggests that decreased inhibition from the golgi tendon organs aids the neural contribution to PAP (1). The pennation angle of the muscle is also suggested to contribute to PAP. The pennation angle of the muscle refers to the orientation of the muscle fibers relative to the bone and connective tissue and affects the way in which force is transferred from the muscles to the tendons and bones (30). A smaller pennation angle is purported to provide a greater PAP effect. A combination of metabolic and neural factors appears to contribute to PAP.

The practical application of PAP can be seen in the training philosophy known as *complex training*, which is said to provide both short- and long-term benefits (6, 16, 26). Complex training is practiced in numerous sports and involves loading the muscle with a resistive activity prior to performing a sport-specific activity using similar muscle groups. Following a maximal or near-maximal muscle contraction, the muscles are in both a fatigued and potentiated state (11). The potentiated state remains for a period of time after fatigue subsides, and provides a “window of opportunity” during which the athlete may be able to realize an ergogenic benefit from the potentiated state (11). The concept of the “window of opportunity” is depicted in Figure 1.
Figure 1. The Window of Opportunity Following a PAP loading Protocol.

A common example of complex training is that of using a squat protocol (either isometric or dynamic) as the loading mechanism, followed by a series of countermovement jumps (CMJ) (9, 22, 23, 31). Studies have been equivocal as to the performance benefit to be gained by using this protocol, with some showing a demonstrated increase in performance following the loading protocol (22) and others showing no increase (9, 23), or even a decline (31). The squat/CMJ protocol attempts to realize a delayed ergogenic effect, making it important to distinguish complex training using PAP (a delayed effect) from plyometric training that seeks a more immediate benefit.

The 100-meter freestyle is a swimming event that lasts for less than one minute at the elite level. Given its anaerobic nature, training methods for this event in recent years have begun to utilize complex protocols in order to enhance the potentiation possibilities for the athletes (27). The event was chosen for this study because it requires both anaerobic power and anaerobic capacity. While several prior studies have evaluated the longitudinal effects of resistance training on swim performance, it appears that this is the
first study to directly apply the immediate ergogenic effect of PAP to swimming performance.

1.2 Statement of the Problem

Based on the literature, complex training methods have the potential to enhance performance in athletic activities. Despite complex training methods being utilized in the sport of swimming, there is a need to determine the performance benefits to be derived from PAP for swimmers, while assessing any differences in the response to the loading protocol between genders.

1.3 Purpose of Study

The purpose of this study was to determine whether sprint performance in swimmers can be improved as a result of a post-activation potentiation (PAP) loading protocol, as well as to assess gender differences in this response.

1.4 Hypotheses

1. There will be an improvement in sprint swim performance as a result of the post-activation potentiation (PAP) loading protocol.

2. There will be a significantly greater improvement in males in sprint swim times as a result of the post-activation potentiation (PAP) loading protocol.
CHAPTER II
LITERATURE REVIEW

This study examined the potential for short-term benefits to swim performance as a result of post-activation potentiation (PAP). A summary of relevant literature is discussed in the following sections: Influential Factors, Types of Contractions, Performance, Duration, Gender Differences, and Swimming.

2.1 Influential Factors

Several factors are purported to influence the degree of potentiation including the type of conditioning exercise, the subsequent exercise, and the characteristics of the individual (30). Studies have shown varied effects of PAP, due in part to the highly varied loading methods employed (11). Individual characteristics of athletes’ muscular strength, muscle fiber distribution and training level influences the response to PAP (30). Individuals with a greater degree of muscular strength and a higher distribution of Type-II (fast twitch) muscle fibers have demonstrated a greater ability to achieve PAP (30), although Hodgson & Docherty stress that no relationship exists that demonstrates a direct
performance benefit as a result of an increased number of Type-II fibers (11). Training level is another factor that influences the PAP response, but its greatest benefit is in reducing the fatigue response (5). This suggests that a trained individual is less likely to fatigue from the loading protocol than an untrained individual, which allows for a greater window of opportunity for performance enhancement, even at the same degree of potentiation as an untrained athlete. The specificity of the subsequent exercise is an important consideration when designing a PAP loading protocol. Hodgson and Docherty stress that the muscle groups employed during the conditioning contraction should mirror the muscle groups used by the subsequent activity as closely as possible (11).

2.2 Types of Contractions

Potentiation has been observed as a result of both electrically stimulated and voluntary muscle contractions. Jubeau et al. examined potentiation activity in the muscles as a result of voluntary contractions compared to electrically stimulated contractions in the quadriceps muscles (13). Sixteen healthy men (age 23±2 years) who were habitually active but not sport-specifically trained were participants in the study. The study involved two separate experimental sessions, separated by 24 hours – one involving two maximal voluntary isometric contractions (MVIC) and one involving an electrically stimulated contraction followed by a MVIC. The electrically stimulated contraction was achieved using trans-cutaneous muscle stimulation to evoke a tetanic stimulated contraction in the quadriceps muscle. The duration of contractions in all trials was ~10 sec, with at least 10 minutes between the two trials each day. Femoral nerve stimulation was used to determine EMG and twitch torque before and after all conditioning contractions (13).
The results of the study showed a significant potentiation effect post-treatment for both the MVIC and the stimulated condition, although the degree of potentiation was significantly higher under the MVIC condition. The potentiated condition lasted longer for the MVIC than the stimulated condition, 240 sec to 30 sec, respectively. Jubeau et al. surmised that although each conditioning effect produced PAP, the MVIC condition allowed for the recruitment of additional peripheral motor units, whereas the electrical stimulation simply targeted the same units repeatedly (13).

Requena et al. examined the difference between a MVIC and two types of submaximal conditioning contractions at 25% of MVIC— one induced by percutaneous electrical stimulation (PES) and the other a voluntary contraction (VC) (21). The subjects for the study were 12 healthy men (age 21.7±0.7 years) who were recreationally active, but not specifically trained in a given sport. The procedure involved the subjects sitting with knee and ankle angles of 90° and 110°, respectively. Seven seconds was chosen as the duration for all conditioning contractions. The three trials were separated by at least 48 hours but not more than four days.

The results showed no twitch potentiation during the VC trial, but significant levels of twitch potentiation during the PES and MVIC trials. Additionally, the twitch potentiation for the MVIC trial was significantly greater than PES immediately following the conditioning contraction, with a sharp decline at one minute. By the third minute, the two conditions were similar in magnitude; but both were significantly higher than the baseline measurement. At 10 minutes, the MVIC twitch potentiation was no longer at a significant level, although the PES condition remained significantly higher than the baseline measurement (12). The study showed that a MVIC may be more effective in
creating a greater level of potentiation than a submax PES contraction, although the PES was able to maintain a significant level of potentiation for a longer period, possibly due to less fatigue (21).

Despite being typically associated with anaerobic activities, PAP has been observed in aerobically trained athletes as well. Hamada et al. examined 40 men who were divided into four groups of 10 subjects: Triathletes (22.3±1.6 years), distance runners (23.7±2.3 years), active controls (23.5±2.8 years), and sedentary controls (24.3±4.6 years). The active controls differed from the sedentary controls in that they completed a “recreational” upper and lower body weight training program three times per week on average. The triathletes and distance runners were competitive in their respective sports, and trained as such (8).

The subjects performed a 10sec MVIC of the elbow extensor and ankle plantarflexor muscles for the trial. Maximal twitch contractions were obtained pre- and post-contraction using PES. PAP was measured as the percentage change in peak twitch torque post-MVIC, and was compared to the sedentary group for data analysis purposes.

The results showed that triathletes had an enhanced PAP response (relative to the sedentary group) in both the upper and lower limbs. This is consistent with the fact that they train both their upper and lower bodies for their event. Distance runners, who mostly train lower body, had an enhanced PAP response in the plantarflexors only. The active controls, who maintain both upper and lower body fitness, had an enhanced PAP response compared to the sedentary group, although not to the degree of the triathletes (8). This study showed a PAP response to electrical stimulation, and also highlights the
importance of training level when seeking to induce PAP, particularly in the muscle
groups specific to an individual’s sport.

While Hamada at al. observed a PAP response following isometric conditioning
contractions (8), dynamic contractions may often be more practical in sports training and
competition settings. Rixon et al. examined improvements in jumping performance as a
result of isometric and dynamic conditioning protocols, as well as the impact of gender
and previous training experience (22). The subjects in the study included 15 men (age
23.1±2.4 years) and 15 women (age 23.4±3.1 years), who were considered anaerobically
untrained with the exception of one male and one female. The subjects were further sub-
divided into experienced (n=20) and inexperienced (n=10) weightlifters based upon their
ability to perform the dynamic squat protocol that was used in the dynamic loading
condition. The procedure involved testing the subject's performance during a
countermovement vertical jump (CMJ) with no conditioning activities before undergoing
the two conditioning contractions and then re-testing the CMJ performance after each
protocol. A 10 minute recovery period was provided following the baseline test, and 30
minutes was allotted between the two conditioning trials. The MVIC conditioning
contraction involved an isometric contraction against a squat machine bar and consisted
of three trials, each three seconds in length with two minutes rest between. The dynamic
contraction protocol (DS) was a set of 3 repetition maximum (3RM) dynamic squats
using the Smith Machine.

The results showed that the MVIC protocol provided significant increases in both
jump height and peak power across the entire sample of subjects, whereas the DS
protocol did not. This suggests that the MVIC was superior to the DS in terms of
producing PAP. Rixon et al. suggest that this is due in part to a lower metabolic cost needed to perform the isometric contraction, reducing the amount of residual fatigue as a result of the conditioning protocol (22). There was no significant interaction of gender or training in terms of the potentiating effect of the conditioning protocols. The study showed that CMJ performance can be significantly improved as a result of an isometric loading protocol, regardless of gender or training experience (22).

2.3 Performance

The effectiveness of PAP can be measured by whether it improves athletic performance following a loading protocol. Matthews et al. studied the effect of a resistance-training warm up on 20-meter sprint performance of professional male rugby players (16). Twenty male professional rugby players (age 23.6±3.5yrs) participated, and all possessed at least one year of sprint training and weight training. The subjects performed two trials – a control and a conditioning trial. Each trial began with a standardized dynamic warm up, after which a 20 meter sprint was performed. Under the control condition, a 10-minute rest period was observed before performing another 20-meter sprint. In the experimental condition, a weightlifting protocol consisting of a set of 5RM back squats was completed, after which a 10-minute rest period was observed before running the second 20-meter sprint.

The results of the study showed a significant improvement (3.3% faster) in the second run during the conditioning trial, which the researchers attributed to the athletes being in a potentiated state as a result of the weight-lifting protocol. This study demonstrated that PAP benefits can be observed in sprint performance and are not simply restricted to plyometric activities such as jumping (16).
Studies have been equivocal in their effectiveness when using PAP to achieve ergogenic effects. Robbins & Docherty examined the effectiveness of a 7 second MVIC in enhancing CMJ performance (23). Sixteen male college students (23.1±2.7 years) with some lifting experience participated in the study. The procedure involved two separate treatment conditions while assessing CMJ performance, which was measured by power indicators including jump height, peak force, rate to peak force, peak power, peak acceleration and peak velocity. Both trials began with a dynamic warm up, and then the subjects completed either the MVIC trial or the control trial. The control trial consisted of three sets of five consecutive CMJs at an interval of 8 minutes apart. The MVIC trial involved three complex sets of a 7-second MVIC, followed by a four minute rest interval, followed by five CMJs, spaced four minutes apart. This meant that the CMJs themselves were performed at the same 8 minute interval in both trials. The average values of the CMJs under each condition were used for data analysis.

The results showed no significant difference in performance between the two conditions. In this case, the loading procedure used by the researchers was insufficient to provide performance enhancement as a result of PAP. Robbins & Docherty speculate that this may be a result of performing only a single MVIC, which presents the possibility of insufficient neural activity to potentiate the muscles. Another reason given was the training background of the subjects – they possessed some lifting experience but were not trained weightlifters (23).

The PAP loading protocol can be detrimental to performance if it is overly fatiguing in its application. Bazett-Jones et al. took a different approach to examining performance increases resulting from PAP. The researchers examined range of motion
and peak force during a squat protocol under three conditions: control, controlled stretching and PAP (3). Ten male subjects (age 20.6±1.5yrs) who were NCAA Division III track athletes participated in the study. The squat test involved the subjects performing six isometric squats, as force data was collected electronically. Of the six trials, three focused on peak force (PF), in which the subject attained their maximal force after five seconds, and three focused on rate of force development (RFD), in which the subject attained maximal force as quickly as possible. For the control condition, the subjects sat in a chair for 10 minutes before performing the trial. For the stretching condition, the researcher manipulated each subject through a series of passive leg stretches before performing the test. The PAP condition involved three sets of three squats at 90% 1RM before performing the trial. Each set of three squats was separated by a three minute rest period. In all cases, the trial was performed within one minute of completing the treatment condition (3).

The results showed no significant difference in PF between the three conditions, meaning that neither the stretching nor the PAP conditions improved performance (3). For RFD, the PAP trial produced significantly lower results than the control trial, meaning that the potentiation protocol decreased performance. Range of motion improvements were seen in the PAP trial, but not during the stretching trial, which was contrary to expectations. The researchers attributed the lack of RFD performance during the PAP trial to the fatiguing effects of the loading protocol (3). As has been established, the loading procedure for potentiation causes both a fatiguing and a potentiating effect (11). The researchers suggest that they erred by either making the loading procedure too
intense, or not allowing enough recovery time between the loading protocol and the test (3).

Stone et al. examined the performance of Olympic weightlifters as a result of strength-power-potentiating complexes (SPPCs) (26). Three female and four male (ages not provided) members of the 2003 U.S. National Weightlifting team participated in the study as a part of their training at the U.S. Olympic Training Center. Following their standard warm up, the athletes performed SPPCs involving “pulls” from mid-thigh which started at a light weight and increased to a target weight, followed by an unloading weight. The design of this experiment was unique in that the potentiating protocol was incorporated into the trials themselves. Men performed “pulls” at the following weights: 60, 140, 180, 220, and 140kg with each separated by 2 minutes. Women performed pulls at weights of 60, 80, 100, 120, and 80kg with the same rest intervals. Trials two and five were used for data analysis because the researchers had observed previously that 80kg and 140kg produced similar force measurements in women and men, respectively. Practically speaking, trial two served as the “control” condition, trials three and four served as the loading protocol, and trial five served as the “potentiated” condition.

The results showed a significant improvement in performance, measured by peak velocity, in trial five compared with trial two. This demonstrates that in these athletes the potentiating protocol was sufficient to enhance performance (26).

2.4 Duration

Post-activation potentiation (PAP) appears to be highly individualized in its effects, and as such it has been difficult to establish when the ideal “window of opportunity” for performance occurs following a potentiating treatment. Stone et al.
demonstrated that a two minute rest period was sufficient to allow the fatiguing effects of the loading protocol to subside and provide for a performance increase (26). It should be noted, however, that their subjects were elite athletes who are likely less prone to the fatiguing effects of the loading protocol than untrained individuals.

Studies have been devoted to discerning precisely how much time should elapse following the PAP treatment to allow for optimum performance. Kilduff et al. examined CMJ performance following bouts of heavy exercise at different recovery intervals compared with a baseline trial (15). Twenty professional male rugby players (25.4±4.8 years) with a minimum of three years weight training experience were the participants in the study. The trial consisted of the subjects undergoing a standard warm up routine before performing a CMJ, which was recorded as the baseline measurement. The subjects then observed a recovery period before performing three squats at 87% 1RM. Following the squats, the subjects performed more CMJs at the following intervals: ~15 sec after squats, 4min, 8min, 12min, 16min, 20min, and 24min. Power output, peak rate of force development (RFD), and jump height were observed as measures of performance during the jumps. To ensure that any potentiation was a result of the weight lifting, 10 of the participants performed CMJs four minutes apart following the warm up (without the weight training) to control for any fatiguing effects of the testing protocol itself (15).

The results of the study showed that 8 minutes of recovery time produced the optimum performance following a heavy weight lifting protocol, with a statistically significant performance improvement over baseline occurring at this time interval. Twelve of the subjects (70%) achieved their best measures for jump height, power output, and peak RFD during the 8 minute trial. Three more attained their peak measures
at 12 minutes, while the other three attained their peak at 4 minutes. There was a reduction in CMJ performance (~15sec) during the trial immediately following the squat protocol, demonstrating that fatigue outweighed potentiation immediately following the loading protocol (15).

Batista et al. used intermittent knee extension contractions to potentiate their subjects before observing the degree of PAP at varying time intervals thereafter (2). Ten physically active men (25.1±2.6 years) who were not strength-trained participated in the study. There were five trials total, each beginning with a conditioning protocol and concluding with a potentiation measurement at randomized time intervals. The conditioning protocol in this study involved the subjects performing 10 knee extensions separated by 30 seconds. The potentiation was measured during three additional knee extensions. Peak torque was assessed as the measure of performance. The rest intervals were 4, 6, 8, 10, and 12 minutes following the conditioning protocol.

The results of the study showed that the intermittent conditioning protocol was sufficient to induce PAP. There was no significant variation in the degree of PAP achieved across any of the time periods. The subjects in this study achieved similar levels of improvement in torque (as a result of PAP) at 4, 6, 8, 10 and 12 minutes compared to the baseline measurement. The baseline measurement for this study was the torque measurement of the first conditioning contraction for each particular day (2). This study demonstrated that PAP can be in effect for up to 12 minutes following the conditioning exercises, with the 4 minute minimum recovery time following the conditioning exercises seemingly sufficient to allow the fatiguing effects to subside.
2.5 Gender Differences

Few studies have directly assessed the gender response to PAP. Theories are contradictory with regards to how PAP may affect the genders. Anaerobically inclined individuals appear to reap the greatest performance benefits from PAP, given that its primary impact is observed in type II muscle fibers (33). Men have a greater muscle mass and thus more type II fibers than women, which would suggest that they would achieve a greater degree of PAP. Conversely, Rixon et al. hypothesized that women would see greater performance benefits than men, due to their greater resistance to fatigue during exercise (22). The theory is that this would provide a greater “window of opportunity” (see Figure 1) due to a lower degree of fatigue resulting from a given exercise load, although the results of their study did not support the hypothesis.

Witmer et al. examined changes in vertical jump performance as a result of using squats to elicit PAP (31). Gender responses to the PAP conditioning protocol were also evaluated. Twelve men (21.2±2.6 years) and 12 women (20.9±1.9 years), who were all active, participated in the study. The subjects performed two trials: a control and an experimental trial. Both trials involved a dynamic warm up, followed by a treatment (in the experimental trial), followed by a set of 10 CMJs which were separated by three minutes rest. In the control trial, the subjects immediately performed the CMJs. In the experimental trial, the subjects performed a PAP loading protocol before performing the CMJs. The loading protocol involved a series of squats as follows: 5 reps at 30%1RM, 4 reps at 50%1RM, and 3 reps at 70% 1RM. Following the loading protocol, the subjects proceeded to the CMJs. By spacing the jumps at three minute intervals, the researchers
aimed to negate the individualized responses that lead to individuals achieving the greatest PAP benefits at different time periods post-treatment (31).

The results of the study showed no significant improvement in performance as a result of the PAP squat protocol. While some individuals (both male and female) showed improvements in jump height as a result of the PAP condition, the sample as a whole actually showed a slight decline in jump height following the treatment. The researchers attributed this to the fatiguing effects of the loading protocol superseding the potentiating effects. Men and women responded in a similar fashion to the loading protocol of this study, with neither showing significant improvement in performance as a result of the PAP condition (31).

While not explicitly seeking to achieve a PAP effect, Radcliffe & Radcliffe observed an effect on males that may be attributable to PAP (20). Thirty-five Division 1A college athletes (24 males 11 females, 21±0.6 years) were subjects in the study. The subjects underwent five different warm up protocols before performing three countermovement horizontal jumps (CMHJ). The five warm ups were: standard warm up (baseline), warm-up plus four sets of four back squats at 85% 4RM, warm up plus four sets of four power snatch at 75-85%4RM, warm up plus four sets of four loaded jumps with 15% of bodyweight added, and warm up plus four sets of unloaded tuck jumps. Following the warm up protocol, a three minute rest interval was observed before the subjects completed the trial. The order of the warm ups was randomized among the subjects.

The results showed no significant change in performance for the CMHJs across all warm up protocols. When gender was examined separately, males showed a
significant increase in jump distance over other trials following the snatch warm up protocol (20). While the authors did not reference PAP as a possible catalyst, these results show characteristics of a performance increase resulting from PAP. The results also lend support to a dynamic, powerful loading protocol being more effective to induce PAP. The snatch exercise may be more likely to activate the upper body muscle groups (which are used in a horizontal jump) than the squats alone. This study also lends support to the notion of men being more responsive to a PAP protocol than women, although the smaller sample size of the women should be noted.

Several studies have directly assessed gender differences relating to sprint swimming (10, 18, 25), and the consensus is that the anaerobic power and anaerobic capacity characteristics of males allow them to perform better in sprint swimming than females. Further, Simmons et al. showed that “dry land” power (how “strong” a person is) is directly transferable into swimming “power” in males, but not for females (25).

2.6 Swimming

Post-activation potentiation (PAP) is typically associated with anaerobic and power-based activities such as jumping and sprinting. Power through the arm pull in freestyle sprinting has been observed as an important measure of swimming speed in elite swimmers (24), making sprint freestyle swimming a possible activity to benefit from a PAP loading protocol. Most studies relating to swimming and PAP or resistance training have been longitudinal in nature (12, 19, 24, 28, 29), and have not examined the potential of PAP to enhance immediate performance.

Complex training protocols are growing in popularity for the sport of swimming (27), however there has been little research directly examining the effects of resistance
protocols on swimming performance. Kilduff et al. used a squat protocol in an attempt to observe a PAP effect for sprint swimmers during the start of a sprint race, in the only study to directly examine the immediate effect of PAP on swimming performance (14). Nine (7 males; 2 females) international level sprint swimmers (22±2 years), who were within 5% of the National 50 meter freestyle record, were participants in the study. The subjects first performed a CMJ protocol to determine the optimal rest period following a PAP loading protocol, which consisted of 3 squat repetitions at 87% 1RM. All subjects showed the greatest PAP response (measured by CMJ performance) at 8 minutes following the loading stimulus, and as such this was the rest interval applied to the swimming trials (14).

The swimmers performed two trials in the pool from a dive start, using video equipment to measure their 15m start time. The control trial involved the athletes performing their individualized, race-specific warm up. The experimental trial involved the athletes performing the same 3-rep squat protocol at 87%1RM that had previously produced a PAP response as their warm up. Additionally, peak vertical force (PVF), and peak horizontal force (PHF) of the dive was quantified using video analysis.

The results showed no significant difference in 15-meter start time between the two trials, however there was a significant increase in PVF and PHF values following the PAP squat stimulus. The authors suggest that there may be merit to studying the PAP response in swimmers to improve certain biomechanical elements of a race, and that a combination of traditional swimming warm up and PAP may be an option for performance enhancement (14). In this case, the dive itself may have been more
powerful, but it did not translate into an overall better start, as represented by 15m swim time.

There are several longitudinal studies of note that are referenced in this section. Girol et al. assessed the long-term effect of resist/assist bands (Appendix A) on the performance of swimmers (7). This is notable because assist/resist bands are a resistance device that can be used to achieve immediate PAP. The study augmented a traditional swimming training program with one of three methods: dry-land strength (weight) routines, an in-water resist/assist routine, or no routine at all (control). Twenty one competitive swimmers (10 males, 11 females, age=16.5±3.5 years) were participants in the study. The subjects were randomly assigned into one of three groups: control; strength; or resist/assist. All three groups maintained the same basic aerobic conditioning in the pool, in addition to two, 45-minute sessions per week which focused on the specifically assigned activity. The control group simply completed a sub-maximal 90-minute cycle exercise to keep the training duration similar to the experimental groups. The strength group completed a traditional weight lifting protocol that targeted all major muscle groups and was periodized over the length of the study according to the athletes’ improvement. The resist/assist group was tethered to the starting block by surgical tubing during their session. They swam against the tubing until they either stopped moving or completed a length of the 25 meter pool. After 30 seconds of rest, they swam back, taking advantage of the tension in the tubing, which enabled them to achieve above-maximal speeds. Two sets of three repetitions were performed during each workout session.

This study examined several biomechanical markers related to sprint performance during a maximal 50-meter swim. Results were obtained at baseline, week six and week
12 and analyzed for improvement in the following areas: performance (time), muscular strength, stroke rate, stroke length, and stroke depth. No significant differences were observed between the groups at baseline, yet significant improvements in performance (time) were observed at week 12 for the strength and assist/resist groups. No significant change was observed in the control group at any point in the study. Other significant changes in week 12 occurred in stroke depth (significant improvement in strength and assist/resist groups compared with baseline), as well as stroke rate (significant improvement in assist/resist and strength groups compared with baseline) (7).

Pinchon et al. examined electrical stimulation as an alternative to weight training to enhance strength (and thereby swimming performance) in sprint swimmers (19). Fourteen competitive swimmers (no genders provided) were divided into two groups of seven: control (23.0±2.1 years) and electrostimulation (ES) (23.0±2.1 years). The swimming training was kept consistent between the groups, however the ES group received supplemental electrical stimulation training over a 3-week period. The ES training involved the subjects receiving ES to the latissimus dorsi muscles three times per week over the three week period. Each session involved 27 contractions lasting for ~6sec each, with 20sec rest between each contraction. Pre- and post-conditioning swimming tests were conducted. The first test was a 25 meter pull, which isolated the upper body muscles that received treatment. The second test was a 50 meter sprint swim in which the subjects were able to use their legs as they typically would during a competition.

The results showed that the ES group improved significantly over baseline for both swim tests, while the control group showed no significant improvement. The ES group improved by 0.19sec for the 25m pull, and by 0.38sec for the 50m swim, which the
authors attributed to strength gains resulting from the ES training regimen (19). Despite being longitudinal, this study is noteworthy because PAP has been achieved through ES (8, 13, 21), suggesting that swimmers may respond to an ES PAP protocol.

The power rack (Appendix B) is a series of connected pulleys that allow a swimmer to swim under a resistive state for a fixed distance of 10 meters. Wright et al. studied 18 competitive swimmers (10 males, 8 females, ages not provided) over a 5-week training protocol utilizing the power rack (32). Swimmers completed two supplemental training sessions per week using the power rack, in addition to their regular swim training. Initially, the load was set at 80% of peak power for eight repetitions, with the repetitions increased by two per session, such that 16 were used for the final training session.

The results showed that stroke power and stroke distance increased over the duration of the study when the swimmers were using the power rack (32). The study did not examine whether these factors translated to an improved performance while not using the power rack.

2.7 Summary

PAP has been observed following maximal muscle contractions of many varieties, including isometric, dynamic, and electrical stimulation (2, 13-16, 21, 22, 26). Factors affecting a person’s ability to achieve PAP include muscle fiber distribution, training background, and the specificity of the conditioning activity relative to the subsequent exercise. Studies are equivocal as to the effect of gender on PAP, although males have shown to have a greater capacity for sprint swimming performance than females. PAP has been observed following conditioning contractions of 4-10sec in duration in effect
from 4 to 12 minutes following the conditioning contraction. Although one study found no significant improvement in the swim start, no studies have directly examined the short- or long-term effect of complex training methods on swimming performance.
CHAPTER III

METHODS

3.1 Research Design

The study was an experimental design. The independent variables were the PAP loading protocol and gender. The dependent variables were 100 meter freestyle time, the first 50 meter freestyle split, the second 50 meter freestyle split, and blood lactate.

3.2 Subjects

A convenience sample of thirty healthy volunteers (n=15 males, n=15 females) from the Cleveland State University (CSU) Varsity Swim Team was used. The subjects possessed a wide variety of training and stroke backgrounds: Seven had a sprint training background, seven of the subjects had a distance training background, and 16 of the subjects had a mix of some sprint and some distance training. All 15 males and 11 of the females competed in the freestyle stroke in competitions. Four of the females did not train or compete in the freestyle stroke, yet were familiar with how to swim it for the purposes of this trial.
Only subjects deemed to be healthy and low-risk were invited to participate in the study. Each subject was administered the AHA/ACSM Pre-participation Screening Questionnaire (Appendix C) and were excluded if they selected “yes” to any question indicating a history of cardiovascular or respiratory disease. Subjects who had experienced dizziness, fainting or blackouts while exercising during the month preceding the study were also excluded. All participants were required to fill out an Informed Consent form (Appendix D) approved by the CSU Institutional Review Board (Appendix E), which outlined the study benefits, procedures, potential risks and voluntary participation.

3.3 Procedures

Testing occurred at the CSU Robert F. Busbey Natatorium in the 50-meter competition pool. The testing occurred during a conditioning phase of the swimming season, and the subjects were four weeks removed from any competitions at the time of the study. During the first session biometric data including height, weight and body composition was obtained in the CSU Human Performance Laboratory. Body composition was measured using a Bod Pod Body Composition Analyzer (COSMED, Rome, Italy). During sessions two and three, the subjects completed two separate swim trials with 48 hours between trials. A test/retest protocol was followed, which allowed the subjects to act as their own controls. To avoid order effect, half of the subjects performed the control trial first, and half performed the PAP trial first.

During the control trial, the subjects were administered a standard 900 meter swimming warm up similar to their pre-competition warm up. The warm up consisted of a sub-max 800 meter freestyle swim, followed by 4x25m freestyle sprints. Following a 6
minute rest interval, the subjects performed a 100-meter freestyle sprint from a dive start. During the PAP trial, the subjects were administered the same 900 meter freestyle warm up, and immediately moved to the PAP loading protocol. A 6 minute rest interval was again observed following the PAP loading protocol before the subject performed a 100-meter swim sprint. The 6 minute rest interval falls within the range of 4-12 minutes shown by previous studies to provide adequate recovery time in order to realize ergogenic effects as a result of PAP (2, 14, 15). Subjects performed a 100 meter cool down following each test.

3.3.1 Post-Activation Potentiation Loading Protocol:

The PAP loading protocol was designed to produce a window of opportunity (Figure 1), during which the subjects could realize an ergogenic effect on their performance. This was accomplished using dynamic, resistive sprints while attached to a Total Performance Power Rack (Appendix B). The power rack uses a pulley system which loads the muscles with weighted resistance as the subject swims 10 meters (Appendix F).

The desired duration of each conditioning swim was established based upon the literature and the prior experience of the subjects when using the power rack. A formula was derived from scratch in an attempt to prescribe an individualized load for each subject that would account for any differences in ability, as well as any differences between men and women when using the device. In short, the objective of the formula was to handicap each subject’s conditioning swim to ~7sec. The formula derived was:

\[ L = (0.2)(LB\text{M}) \left( \frac{100}{t} \right) \]

where \( L \) is the Load in kg, \( LB\text{M} \) is the lean body mass in kg and \( t \) is the subject’s best 100 meter freestyle time in seconds. Lean Body Mass (LBM) was
included in an effort to correct for the physiological differences between genders, and the subjects’ best time \((t)\) was included in an effort to correct for differing ability levels. As the denominator, \(t\) served the purpose of increasing the load for faster swimmers (smaller numbers), and decreasing the load for slower swimmers (larger numbers).

The formula was derived to target a time of \(\sim 7\) sec for each conditioning swim, because it is a duration the athletes were comfortable and familiar with as a result of their everyday power rack use. Tillin & Bishop cite studies that achieve PAP responses in timed contractions lasting anywhere from 4-10 seconds (30). Further, Requena et al. used \(\sim 7\) sec as the contraction duration and successfully achieved PAP, albeit for an isometric contraction (21). Robbins & Docherty used a \(\sim 7\) sec contraction time, but failed to achieve PAP, citing the fact that they only performed one conditioning contraction (23).

While the isometric contractions have a set contraction time, the conditioning procedure for this trial involved multiple contractions involving several muscle groups to complete the 10 meter swim. Once a basic structure for the formula was established, trial and error was used during the athletes’ practices to establish the correction factor of 0.2. The correction factor appeared to bring the largest sample of athletes in line with the target time of \(\sim 7\) sec.

Subjects performed four repetitions, one minute apart, to satisfy the loading protocol. The one minute interval is typical of one that is used regularly when using the device, and was expected to provide adequate recovery between conditioning swims.

The power rack contains 5lb weight increments, so once the desired load in kg was determined, a conversion was performed and a load was assigned in pounds, rounded to the nearest 5lb. The time for each repetition was measured by hand, with a stopwatch
starting when the athlete’s feet pushed off the wall, and stopping when the weight stack on the power rack reached the top of the device. Each athlete’s times for the four conditioning swims were averaged, with the means used for data analysis purposes.

3.3.2 Performance:

Time was the performance measure observed in this study. Times for the tests were obtained electronically using a System 6 electronic timing console (Appendix G), calibrated prior to testing and operated in a manner consistent with a standard swimming competition. Electronic touchpads (Appendix G) were used at both ends of the pool to analyze 50m splits. Data collected using the timing console included: total 100-meter freestyle time, first 50 meter split, and second 50 meter split. The 50 meter splits allowed for a more detailed analysis of the effects of PAP during various phases of the 100 meter effort.

3.3.3 Blood Lactate Analysis:

Post-test blood lactates were obtained two minutes after the completion of each trial using a micro technique. The micro technique involved drying and cleaning the subject’s finger with an alcohol swab. A Microtouch lancet was used to prick the subject’s finger to obtain a drop of blood, which was analyzed by a Lactate Plus analyzer (Nova Biomedical, Waltham, MA).

3.4 Data Analysis

Descriptive statistics were obtained for all measures. An independent t-test was used to analyze any differences between genders for both the load assigned and the time for each conditioning swim. A repeated measures analysis of variance (ANOVA) was used to examine differences in time between trials for the 100 meter time, first 50 meter
split, and last 50 meter split. The ANOVA also examined any differences between
genders in the response to the loading protocol. A paired samples t-test was used to
examine any differences in lactate measures between the two trials. SPSS (version 18)
was used for all analyses with .05 used as the level of significance.
CHAPTER IV
RESULTS & DISCUSSION

4.1 Descriptive Statistics

All subjects successfully completed the trials and no complications arose during the data collection process. Biometric data for the subjects is displayed in Table 1.

Table 1. Biometric Characteristics of Subjects (x ±SD).

<table>
<thead>
<tr>
<th></th>
<th>Males (N=15)</th>
<th>Females (N=15)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.1±1.0</td>
<td>20.0±0.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>78.1±6.0</td>
<td>68.3±6.8</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>180.0±4.6</td>
<td>167.5±7.5</td>
</tr>
<tr>
<td>Lean Body Mass (kg)</td>
<td>67.0±5.2</td>
<td>50.5±4.9</td>
</tr>
</tbody>
</table>

Lean Body Mass (LBM) was 67.0±5.2kg and 50.5±4.9kg for males and females, respectively, and was used to derive the load used for each subject in the study.

4.2 PAP Load and Duration of Conditioning Swims

Load Assigned for Conditioning Swims

Each athlete was assigned a load according to the methods described in Section 3.3.1. Means of these values were examined for men and women, and are shown in Table 2. The load for men was significantly higher (7.8kg) than for women.
Table 2. Mean Load Used for PAP Loading Protocol.

<table>
<thead>
<tr>
<th></th>
<th>Males (N=15)</th>
<th>Females (N=15)</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Load (kg)</td>
<td>23.7</td>
<td>16.0</td>
<td>.000*</td>
</tr>
<tr>
<td>Std. Deviation (kg)</td>
<td>2.1</td>
<td>1.9</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference (p<.05)

Duration of Conditioning Swims

The time for each conditioning swim undertaken during the loading protocol was recorded, and the mean of each athlete’s four repetitions was analyzed. The mean repetition time during the loading protocol for males and females is shown in Table 3.

The mean repetition time was significantly faster for men (1.29sec) than for women (p=.001).

Table 3. Mean Repetition Time During the Loading Protocol.

<table>
<thead>
<tr>
<th></th>
<th>TOTAL (N=30)</th>
<th>Males (N=15)</th>
<th>Females (N=15)</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Repetition Swim Time (sec)</td>
<td>7.30</td>
<td>6.66</td>
<td>7.95</td>
<td>.001*</td>
</tr>
<tr>
<td>Std. Deviation (sec)</td>
<td>1.13</td>
<td>0.59</td>
<td>1.18</td>
<td></td>
</tr>
</tbody>
</table>

*Significant difference (p<.05)

4.3 Performance Measures for Control and PAP Trials

Comparison of 100 Meter Times

Times for all subjects (N=30) for the control and PAP trials are represented in Table 4. The time during the PAP trial was significantly faster (.54 sec) than the control trial (p=.029).
Table 4. Comparison of 100 Meter Freestyle Times (\( \bar{x} \pm SD \)).

<table>
<thead>
<tr>
<th>Subjects</th>
<th>100 Meter Time (sec)</th>
<th>Std. Deviation (sec)</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Trial</td>
<td>N=30</td>
<td>63.45</td>
<td>5.37</td>
</tr>
<tr>
<td>PAP Trial</td>
<td>N=30</td>
<td>62.91</td>
<td>5.06</td>
</tr>
</tbody>
</table>

*Significant difference (p<.05)

Comparison of Times for First 50 Meter Split

Times for the first 50m of each 100m swim for all subjects (N=30) are shown in Table 5. The time for the PAP trial was faster (.26 sec) than the control trial, although this difference was not significant (p=.051)

Table 5. Comparison of First 50 Meter Times (\( \bar{x} \pm SD \)).

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Mean Time (sec)</th>
<th>Std. Deviation (sec)</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Trial</td>
<td>N=30</td>
<td>29.78</td>
<td>2.48</td>
</tr>
<tr>
<td>PAP Trial</td>
<td>N=30</td>
<td>29.52</td>
<td>2.34</td>
</tr>
</tbody>
</table>

Comparison of Times for Second 50 Meter Split

Times for the second 50m of each 100m swim for all subjects (N=30) are shown in Table 6. The time for the PAP trial was faster (.27 sec) than the control trial, although this difference was not significant (p=.058)

Table 6. Comparison of Second 50 Meter Times (\( \bar{x} \pm SD \)).

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Mean Time (sec)</th>
<th>Std. Deviation (sec)</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Trial</td>
<td>N=30</td>
<td>33.67</td>
<td>2.93</td>
</tr>
<tr>
<td>PAP Trial</td>
<td>N=30</td>
<td>33.40</td>
<td>2.78</td>
</tr>
</tbody>
</table>
4.4 Gender Comparisons

The differences in performance for each gender in response to the loading protocol are shown in Table 7. For all measures (100m, 1st 50m, 2nd 50m), males and females were faster during the PAP trial than their respective control trials.

Table 7. Gender Response to Loading Protocol ($\bar{x} \pm SD$).

<table>
<thead>
<tr>
<th></th>
<th>Gender</th>
<th>Control Time (sec)</th>
<th>Std. Deviation (sec)</th>
<th>PAP Time (sec)</th>
<th>Std. Deviation (sec)</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>100 Meter Swim</strong></td>
<td>Males (N=15)</td>
<td>59.47</td>
<td>2.56</td>
<td>59.05</td>
<td>2.55</td>
<td>.647</td>
</tr>
<tr>
<td></td>
<td>Females (N=15)</td>
<td>67.42</td>
<td>4.39</td>
<td>66.78</td>
<td>3.80</td>
<td></td>
</tr>
<tr>
<td><strong>1st 50 Meter Split</strong></td>
<td>Males (N=15)</td>
<td>27.89</td>
<td>1.07</td>
<td>27.67</td>
<td>1.18</td>
<td>.740</td>
</tr>
<tr>
<td></td>
<td>Females (N=15)</td>
<td>31.67</td>
<td>1.98</td>
<td>31.36</td>
<td>1.61</td>
<td></td>
</tr>
<tr>
<td><strong>2nd 50 Meter Split</strong></td>
<td>Males (N=15)</td>
<td>31.59</td>
<td>1.56</td>
<td>31.38</td>
<td>1.52</td>
<td>.645</td>
</tr>
<tr>
<td></td>
<td>Females (N=15)</td>
<td>35.75</td>
<td>2.46</td>
<td>35.42</td>
<td>2.24</td>
<td></td>
</tr>
</tbody>
</table>

Interaction p-values of .647, .740 and .645 for the 100 meter, first 50 meter split and second 50 meter split, respectively, show no significant difference in the gender response to the PAP loading protocol. The interaction between males and females for the 100 meter swim is shown in Figure 2, illustrating that no significant interaction between genders (p=.647) to the loading protocol was observed.
Figure 2. Gender Response to PAP Loading Protocol for the 100 Meter Swim.

4.5 Blood Lactate

Comparison of Blood Lactate

Post-test blood lactate results for the control and PAP trials are shown in Table 8. Lactate readings were higher during the PAP trial than the control trial (0.8mMol/dl), although not significantly (p=.099).

Table 8. Comparison of Blood Lactates (\(\bar{x} \pm SD\)).

<table>
<thead>
<tr>
<th></th>
<th>Subjects</th>
<th>Mean (mMol/dl)</th>
<th>Std. Deviation (mMol/dl)</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Trial</td>
<td>N=30</td>
<td>11.5</td>
<td>3.3</td>
<td>.099</td>
</tr>
<tr>
<td>PAP Trial</td>
<td>N=30</td>
<td>12.3</td>
<td>3.4</td>
<td></td>
</tr>
</tbody>
</table>
4.6 Discussion

4.6.1 PAP Load and Duration of Conditioning Swims

Based upon the literature, a target time for the conditioning swims of ~7 sec was sought. The mean contraction time produced during this study was 7.30 sec, which is within a desirable range to satisfy a ~7 sec target. Robbins and Docherty used a contraction length of ~7 sec, but failed to induce PAP due to using only one conditioning contraction (23). The present study attempted to remedy that error by using four “contractions”, or conditioning swims. Requena et al. achieved PAP using a ~7 sec duration, although not for a dynamic protocol (21). The present study differed from Kilduff et al. in that it combined the PAP loading protocol with the traditional swimming warm up during the PAP trial, the lack of which was highlighted by Kilduff as a weakness in their study (14).

The formula of $L = (0.2) (LBM) \left( \frac{100}{t} \right)$ was derived to produce a load tailored to the individual, that would allow for a contraction time of ~7 sec. The concern when devising the formula was that LBM would not correct enough for the performance differences between males and females when using the power rack, particularly given the studies showing men being better suited to anaerobic performance in the pool (10, 18, 25). The mean contraction time for males was 6.66 ± 0.59 sec, significantly faster than the time of 7.95 ± 1.18 sec recorded for females. Further, a much larger standard deviation for females indicates a greater degree of variability in the loading times. Boelk et al. found that the power rack was insufficient to improve the power characteristics of female sprinters compared with a non-power rack swim (4), which begs the question as to
whether there may be a more effective method of PAP loading for females than the power rack.

The formula provided an average load of 23.7±2.1kg for men, which was significantly higher than the load of 16.0±1.9kg for women. With regards to the load output, a significant difference between the genders was expected, given that the purpose of the formula was to provide different loads for different subjects in order to achieve a common outcome (ie. ~7sec). To that effect, the formula appears to have served its purpose.

The significant difference in the time of the loading swims is of concern, because the loading formula intended to avoid this outcome. Further, the increased variability for females suggests that the results are less than ideal, and supports Boelk et al.’s conclusion that the power rack may be an insufficient resistive device for females. Despite the time of the conditioning swims being less than ideal, the true test of the effectiveness of the loading protocol is whether PAP was achieved, and performance enhanced as a result, which is discussed in the next section.

4.6.2. Performance Measures for Control and PAP Trials

This study sought to measure the difference in 100 meter freestyle performance as the result of a resistance loading protocol designed to induce post-activation potentiation (PAP). 11 females and 10 males improved their time on the PAP. The mean time for the PAP trial (62.91sec) was significantly faster than the mean time for the control trial (63.45sec) by .54sec. Therefore, it can be surmised that the PAP loading protocol was sufficient to produce a state of PAP in the subjects that improved their performance. This is consistent with the results from other studies which found that a resistance loading
protocol was sufficient to produce PAP (2, 13-16, 21, 22, 26), which subsequently enhanced performance (15, 16, 20, 22, 26). The improvement of .54sec is a very significant margin in competitive swimming, and precisely represents the difference between 1st place and 7th place in the men’s 100 meter freestyle at the 2012 Olympic Games (17).

The 50 meter splits of each trial were also examined in order to determine whether the performance effect of PAP is achieved at a specific phase of a race. For example, a major difference between the PAP response during each 50m split could guide future research towards different events such as the 50 meter freestyle (which requires more power), or the 200 meter freestyle (which requires more anaerobic endurance).

The PAP trial showed an improvement in the first 50 meters of 0.26sec over the control trial, but this was not statistically significant. However, 0.26sec is a large margin in sprint swimming, where races are routinely decided by tenths and hundredths of a second. The results for the second 50 meter split were similar, with the PAP trial being .27sec faster than the control trial. This improvement in time was also not significant, but again represents a margin that could decide sprint races.

The 6 minute rest interval used in this study was sufficient to allow the subjects to reap the performance benefits associated with PAP. This agrees with the range of 4-12 minutes cited by several studies (2, 14, 15) as being sufficient to realize performance gains following a PAP conditioning protocol.

4.6.3 Gender Comparisons

The significant difference in the times of the conditioning swims between genders suggests a significant gender difference in the effect of the conditioning load. Upon
observing this difference, the decision was made to conduct an analysis of variance to examine the interaction between gender and the loading protocol. The loading protocol produced improvements during the PAP trial compared with the control for both males and females for the 100 meter swim, 0.43sec and 0.64sec, respectively, but there was no significant gender interaction. The loading protocol also produced an improvement on the first 50 meter split of the PAP trial compared to the control trial for males and females, 0.22sec and 0.31sec, respectively, and again there was no significant gender interaction. The second 50 meter split also showed an improvement in the PAP trial in both males and females, 0.21sec and 0.33sec, respectively, with no significant gender interaction. A lack of interaction in the gender response to the loading protocol is in agreement with Witmer et al. (31), although in that study, neither gender improved CMJ performance as a result of PAP, which is contrary to the present results. Rixon et al. hypothesized that females would see performance benefits resulting from PAP due to greater resistance to fatigue than males, which may explain why women improved in this study despite the longer duration of their conditioning swims.
5.1 Summary

Post-activation potentiation (PAP) is a physiological state that has the potential to enhance athletic performance. Research has shown that following resistive exercise, the muscles are in both a fatigued as well as a potentiated state. Fatigue dissipates at a more rapid rate than potentiation, which creates a window of opportunity during which an athlete may realize an ergogenic effect on performance. This has been confirmed by previous studies. The results of the present study support previous literature suggesting that a resistance loading protocol can create a potentiated state that enhances subsequent athletic performance.

5.2 Conclusion

Based on the results of this study, swim sprint performance was significantly improved as a result of PAP loading protocol; therefore the primary hypothesis was supported. The 100 meter freestyle time of the subjects improved by an average of 0.54sec, which can be a major difference in a sport that routinely has races decided by
hundredths of a second. No significant improvement was seen for either 50 meter split between the PAP and control trials. A formula was developed to prescribe significantly different loads for the subjects, with the aim of all subjects subsequently performing the conditioning swims in ~7sec. There was a significant difference between genders in the average time of the conditioning swims, however no significant interaction between gender and protocol was observed in their subsequent 100 meter trials. Therefore, the secondary hypothesis, that there would be a significantly greater improvement in males as a result of the post-activation potentiation loading protocol, was not supported.

5.3 Limitations

The study was conducted with the aim of keeping as much consistency as possible between subjects and trials, including swimming at the same time of day and swimming in the same lane in the pool to mitigate any current effects. The diet and sleep habits of the subjects were not monitored, and there may have been variability between the trials for certain subjects. The subjects were instructed to perform a maximal 100 meter sprint, but the possibility exists that some efforts were less than maximal despite instruction to the contrary.

This study was conducted at a time of the season when the athletes were not at peak fitness, and this factor may have had an effect on the results. The literature suggests that it is possible that the PAP effects may have been even stronger if this study had been conducted during a period of peak fitness for the subjects.

Some of the subjects do not compete in freestyle as a legitimate competitive stroke, which may have negatively affected their performance, particularly during the loading protocol. Although 100m freestyle best times were considered in deriving the
loads, subjects who were uncomfortable swimming the freestyle stroke may have underperformed on the power rack.

5.4 Future Research Recommendations

Further research is necessary to determine the best way to harness PAP as a competitive tool for swimmers. For loading on the power rack, the loading formula should be adjusted in order to reduce some of the variability in load times. Refinement of the loading formula should examine other options to correct for gender differences, as well as a correction factor for stroke specialties if the swimmer is performing a stroke that is not one of their primary strokes. Other options for loading should also be examined, such as whether an isometric protocol that targets specific muscle groups may be more effective, as was observed in some cases in the literature. A broader range of distances and strokes should be examined, to see if PAP provides greater benefits for particular events.

5.5 Application

This study has shown that a post-activation potentiation (PAP) loading protocol can enhance sprint performance in swimmers when performed six minutes prior to the event. The power rack is costly and relatively immovable, however similar effects might be seen by using resistance parachutes (Appendix H) or assist/resist cords (Appendix A), which are both relatively inexpensive and portable. Coaches and swimmers should examine ways to incorporate PAP loading protocols at competitions to take advantage of the ergogenic potential of PAP.
BIBLIOGRAPHY


APPENDICES
Appendix A

Assist/Resist Swimming Cords

Swimming Assist/Resist Tether (Finis USA, Livermore CA)
Appendix B

Power Rack

Total Performance Power Rack (Total Performance, Inc., Mansfield OH)
Appendix C

Name ______________________  Date ____________

AHA/ACSM Pre-participation Screening Questionnaire

Assess Your Health Needs by Marking all **true** statements

**History**

_You have had:_
- □ A heart attack
- □ Heart Surgery
- □ Cardiac Catheterization
- □ Coronary angioplasty (PTCA)
- □ Pacemaker/implantable cardiac
- □ Defibrillator/rhythm disturbance
- □ Heart valve disease
- □ Heart failure
- □ Heart transplantation
- □ Congenital heart disease

**Recommendations:**
If you marked any of the statements in this section, consult your healthcare provider before engaging in exercise. You may need to use a facility with a medically qualified staff.

**Other health issues:**
- □ You have musculoskeletal problems. *(Specify on back)*
- □ You have concerns about the safety of exercise. *(Specify on back)*
- □ You take prescription medication(s). *(specify on back)*
- □ You are pregnant

**Symptoms**
- □ You experience chest discomfort with exertion.
- □ You experience unreasonable breathlessness.
- □ You experience dizziness, fainting, blackouts
- □ You take heart medications.

**Cardiovascular risk factors**
- □ You are a man older than 45 years.
- □ You are a woman older than 55 years or you have had a hysterectomy or you are postmenopausal.
- □ You smoke.
- □ Your blood pressure is greater than 140/90 mm Hg.
- □ You don’t know your blood pressure.
- □ You take blood pressure medication.
- □ You don’t know your cholesterol level.
- □ You have a blood cholesterol >240 mg/dl.
- □ You have a blood relative who had a heart attack before age 55 *(father/brother)* or 65 *(mother/sister)*.
- □ You are diabetic or take medicine to control your blood sugar.
- □ You are physically inactive *(i.e., you get less than 30 minutes of physical activity on at least 3 days/week).*
- □ You are more than 20 pounds overweight.
- □ None of the above is true.

You should be able to exercise safely without consultation of your healthcare provider in almost any facility that meets your needs.

- Proceed with test if musculoskeletal problems are minor, concerns about safety of exercise are normal, and prescription medications are not for cardiac, pulmonary, or metabolic disease.

**Risk Status (Low, Moderate, High):** ____________________
Appendix D

Informed Consent Form

The Effect of Post-Activation Potentiation on Performance in Short-term Sprinting in Competitive Swimmers

This study is being conducted by Andrew Hancock and supervised by Dr. Kenneth Sparks, Director of the Human Performance Laboratory from Cleveland State University, Department of Health, Physical Education, Recreation and Dance and Health Sciences.

Purpose of the Study
I understand that the purpose of the study is to examine the improvement in sprinting performance (if any) that occurs in swimmers as a result of a loading protocol designed to induce post-activation potentiation.

I understand that I will be asked my age and required to complete the American Heart Association/American College of Sports Medicine prescreening questionnaire to determine whether I am at low risk for the occurrence of a cardiovascular problem as a result of exercise. If I am found to be at anything other than a low risk level, I will not be allowed to participate in this study.

I understand that I will come to Cleveland State University for two separate testing sessions, separated by at least 24 hours. I understand that the first session will last approximately 45 minutes, and the second session will last for approximately 30 minutes, for a total time commitment of 1 hour and 15 minutes. I also understand that I will be using a Total Performance Inc. Power Rack in each of the testing sessions.

Procedures
I understand that testing will occur at Cleveland State University’s Robert F. Busbey Natatorium. I understand that I will be subjected to two separate tests with a minimum of 24 hours of recovery between the two. I understand that the test protocols will differ and the order of each protocol will differ among the test subjects. I understand that before the first test, I will report to the Cleveland State University Human Performance Laboratory, where my body composition will be measured using a Bod Pod.

Control Trial
I understand that the control trial will involve the participants completing the following swimming warm up: 800 meter swim easy, and 4x25 swim fast with 20 seconds rest in between each. At the conclusion of the warm up and following a 3-minute rest interval, I will be asked to complete a maximal 100-meter freestyle swimming effort. Following the effort I will be asked to complete a 100 meter cool down.

In addition, my blood lactate, a blood marker of exercise intensity, will be measured both before and after this test (prior to the cool down). Blood will be taken using a finger prick with a blood lancet to acquire a small drop of blood. My finger will be cleaned prior to
the stick with alcohol and dried with gauze. A bandage will be placed over the wound until bleeding has stopped.

**Post-activation Potentiation Trial**

I understand that during the post-activation potentiation trial, I will complete the same 1,000 meter swimming warm up. Immediately following the warm up, I will complete a loading protocol involving four 10.5 yard sprints under resistance with 1 minute rest between each. The resistance will be supplied by a *Total Performance Power Rack*, and will be prescribed according to the following formula: 

\[ L = 0.2(LBM)(100/t) \]

where \(L\) is the Load in kg, \(LBM\) is the lean body mass in kg and \(t\) is my best 100 meter freestyle time in seconds. Following a 6 minute rest period, I will complete the same 100-meter freestyle maximal effort and cool down.

**Risks and Benefits**

I understand the potential risks associated with this study include mild muscle soreness resulting from sprint swimming and discomfort experienced from giving finger sticks for obtaining blood lactate. I also understand that during exercise testing, there exists the possibility of certain changes occurring; these include abnormal blood pressure, fainting, disorders of the heart rhythm, and rare instances of heart attack, stroke or death (1:20,000 exercise tests). I understand the Natatorium has emergency procedures in place and every effort will be made to minimize these risks. The Natatorium is equipped with an AED and all staff are trained in CPR and First Aid. If necessary, an Emergency Action Plan would be administered by the Aquatic Supervisor on duty and may involve directing EMS to the pool area. CPR/First aid will be administered until EMS arrives. Emergency procedures are posted throughout the Natatorium. I also know that I can voluntarily stop exercise if I experience any problems.

**Responsibilities of the Participant**

I will need to complete a medical history using the American Heart Association/American College of Sports Medicine prescreening questionnaire. This screening tool is used to ascertain that I am at a low risk of experiencing cardiovascular problems as a result of exercising. The information I submit and that is contained therein will be used in the determination of my eligibility to participate in this study.

**Confidentiality**

I understand that any information obtained during my testing will be treated as confidential and will not be revealed to any individual without my consent. However, information obtained during my test may be used for research purposes with my right to privacy retained.

The medical and research information recorded about me will be used within Cleveland State University as part of this research. Tests and procedures done solely for this research study may be placed in my file to indicate my participation in this study. Upon completion of the study, I will have access to the research information recorded about me. Any publication of data will only use group data and not identify me by name.
**Freedom of Consent**
My participation in this study is voluntary. I know that I am free to stop at any time, if I so desire.

**Contacts and Questions**
The researchers conducting this study are Kenneth Sparks and Andrew Hancock. I may ask them any questions concerning this research study. If I have additional questions at a later time, I can reach Kenneth Sparks at 216-687-4831 or k.sparks@csuohio.edu, or Andrew Hancock at 216-687-4812 or a.p.hancock@csuohio.edu

**Participation**
I understand that participation in this study is voluntary and that I have the right to withdraw at any time with no consequences.

I understand that if I have any questions about my rights as a research participant, I can contact Cleveland State University's Review Board at (216) 687-3630.

**Patient Acknowledgement**
The procedures, purposes, known discomforts and risks and possible benefits to me and to others have been explained to me. I have read the consent form or it has been read to me and I understand it. I have had an opportunity to ask questions that have been answered to my satisfaction. I voluntarily consent to participate in this study and I have been given a copy of this consent form.

____________________________________  ______________________
Signature of Participant                 Printed Name

____________________________
Date

____________________________________  ______________________
Signature of Witness                   Printed Name

____________________________
Date
Appendix E

Institutional Review Board Approval Letter

Memorandum

Institutional Review Board

To: Kenneth Sparks
    HPERD

From: Barbara Bryant
    IRB Recording Secretary

Date: March 19, 2012
Re: Results of IRB Review of your project number: #29533-SPA-HS
    Co-Investigator: Andrew Hancock
    Entitled: The effect of post-activation potentiation on performance in short-term sprinting in competitive swimmers

The IRB has reviewed and approved your application for the above named project, under the category noted below. Approval for use of human subjects in this research is for one year from today. If your study extends beyond this approval period, you must contact this office to initiate an annual review of this research.

By accepting this decision, you agree to notify the IRB of: (1) any additions to or changes in procedures for your study that modify the subjects’ risk in any way; and (2) any events that affect that safety or well-being of subjects. Notify the IRB of any revisions to the protocol, including the addition of researchers, prior to implementation.

Thank you for your efforts to maintain compliance with the federal regulations for the protection of human subjects.

Approval Category: Expedition Review: Project approved, Expedited Category 2

cc: Project file
Appendix F

Power Rack in Use by Swimmer

Swimmer attached to Power Rack, swimming away (photo taken during testing)
Appendix G

Colorado System 6 Timer and Touchpad

(Colorado Time Systems, Loveland CO)
Appendix H

Resistance Parachute

Swimming Parachute (NZ Manufacturing, Tallmadge OH)