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The Effects of Dynamic Versus Isometric Postactivation Potentiation on Collegiate Female Rowers

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THE EFFECTS OF DYNAMIC VERSUS ISOMETRIC POSTACTIVATION POTENTIATION ON COLLEGIATE FEMALE ROWERS

by

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ABSTRACT

Post-activation potentiation (PAP) has been shown to improve acute power-based performance, and the potential to enhance rowing performance. To examine PAP effects with rowing performance, 40 collegiate female rowers performed isometric potentiating (ISO), dynamic potentiating (DYN) and typical control (CON) warm-up protocols, after which they completed a three-minute all-out test (3MT) to evaluate their total distance, peak power, mean power, critical power, anaerobic working capacity (W') and stroke rate. Fifteen-second splits for distance and mean power were also analyzed. The PAP protocols were performed on a rowing ergometer, in a movement pattern that simulated rowing. ISO consisted of 5 × 5-second static muscle actions with the ergometer handle rendered immovable with a nylon boat-strap, while DYN consisted of 2 × 10-second all-out rowing bouts, separated by a 2-minute rest interval. A two-way (condition by experience level) interaction was found for distance, mean power and W' with significant differences (DYN > CON; 5.6 m, 5.9W and 1561.6 J) for more experienced rowers (>3.75 years; n=19) and no differences for less experienced rowers (n=18). A main effect for stroke rate was found with DYN>CON (1 s/min). Split analysis of mean power output revealed a two-way (condition by 15s split) interaction independent from experience level. Mean power in DYN was significantly greater than CON and ISO in the 15-30, 30-45, 45-60 and 60-75 second intervals. These results suggest that dynamic PAP may be beneficial for experienced rowers and that these strategies might benefit a greater power output over shorter distances regardless of experience. Future studies should investigate potential benefits of this protocol over a full race distance and identify the difference between experienced and less experienced rowers.

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CHAPTER ONE: INTRODUCTION

Enhancing acute exercise performance by performing prior high intensity activities of similar biomechanical characteristics is termed post-activation potentiation (PAP). For example, it has been shown that vertical jump height and sprint performance can be enhanced by a prior maximal or near-maximal single set or multiple sets of squats (Chiu et al., 2003; Evetovich, Conley, & McCawley, 2015; Hoffman, Ratamess, Faigenbaum, Mangine, & Kang, 2007; Okuno et al., 2013). The potentiating exercise or activity (e.g., squats in the previous example) is called the conditioning activity (CA) while the outcome variable is the performance measure of interest (e.g., jump or sprint in the previous example). The most obvious application of the PAP phenomenon would be the incorporation of a CA as part of a pre-competition warm-up, intended to augment subsequent performance (McGowan, Pyne, Thompson, & Rattray, 2015). Another possible application is the integration of strength-power potentiating complexes (i.e. coupling a strength exercise with a power exercise performed in succession) during training, in attempt to take advantage of the PAP phenomenon and enhance long term training adaptations (Comyns, Harrison, Hennessy, & Jensen, 2007; Seitz & Haff, 2015).

The contractile history of skeletal muscle influences subsequent performance. The most common effect observed manifests as musculoskeletal fatigue, which decreases subsequent performance, whereas the opposite effect, termed potentiation, serves to enhance performance. These opposing effects can co-exist (Rassier & MacIntosh, 2000) and the net-balance between fatigue and potentiation at a given moment following a CA will determine the resulting effect on performance (figure 1). If exercise-induced fatigue is greater than the induced potentiation, performance will be impaired, and vice versa. Furthermore, theoretically, if fatigue and potentiation are equal, performance will remain unchanged (Hodgson, Docherty, & Robbins, 2005; Rassier & MacIntosh, 2000; Seitz & Haff, 2016).

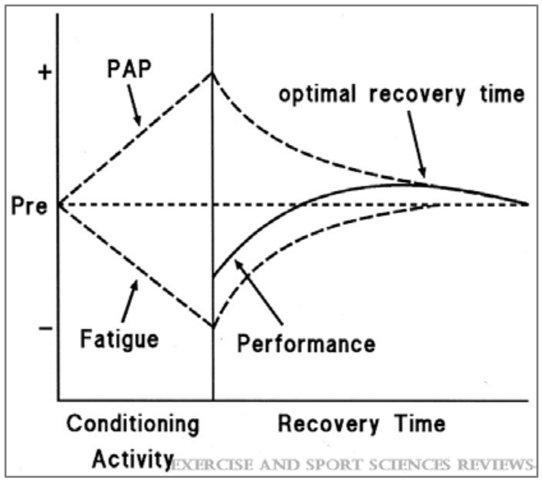

Figure 1: Net balance between fatigue and potentiation will decide observed performance. Figure from Sale (2002).

Post-activation potentiation research has yielded equivocal results which likely depend on a variety of modulating factors. In a recent meta-analysis by Dobbs and colleagues (2018), it was concluded that, although the cumulative results from 36 studies and 179 effects showed no effect of PAP on vertical jump performance (Hedges' d ES = 0.08, p = 0.197), effect size was greater (ES = 0.18; p = 0.007) for rest intervals of three to seven minutes between the CA and the performance measure of interest. The authors concluded that within this rest interval the muscle had recovered enough from residual fatigue while potentiation induced by the CA remained elevated enough to enhance performance. These results are in agreement with a meta-analysis by Seitz and Haff (2016) which identified various modulating factors of the PAP effect (e.g., rest interval, strength levels, number and intensity of CA sets, type of CA contraction). It is the general conclusion of multiple studies that the PAP response is highly individualized and should be tailored for each athlete according to their distinct physical/physiological characteristics (Batista, Roschel, Barroso, Ugrinowitsch, & Tricoli, 2011; Lim & Kong, 2013; Sarramian, Turner, & Greenhalgh, 2015; Seitz, de Villarreal, & Haff, 2014; Seitz & Haff, 2016; Till & Cooke, 2009). Additionally, it is believed that PAP non-responders exist (Evetovich et al., 2015; Mola, Bruce-Low, & Burnet, 2014); however, the precise mechanisms behind this phenomenon remain unknown.

Although PAP has been demonstrated in the laboratory environment using electrically induced muscle stimuli and muscle twitch force measurements (O'Leary, Hope, & Sale, 1997; Rassier & MacIntosh, 2000), its application using voluntary muscle actions and sport-specific movements are of particular interest to athletic performance. Traditionally, PAP induced via voluntary muscle action has been investigated in power-based activities (i.e. jumping, sprinting, throwing) because it has been shown to affect type II muscle fibers to a greater degree than type I muscle fibers (Sale, 2002) while resulting in increased rate of force development (RFD), which is vital for explosive movements (Tillin & Bishop, 2009). These PAP characteristics, combined with the knowledge that the effect seems to subside after several minutes (Seitz & Haff, 2016), contribute to the continued interest in evaluating CAs to improve power-based sport performance.

Endurance-based activities may also benefit from PAP, although the research in this area is quite limited. Sale (2002) suggested that PAP can increase force production of type I muscle fibers during prolonged activities and, if a submaximal pace is to be maintained, motor unit firing rate would decrease, allowing for a longer time to exhaustion. In support, PAP effects on an evoked muscle twitch have been reported in endurance trained, type I dominant athletes (triathletes) (Hamada, Sale, & Macdougall, 2000). Furthermore, a recent study suggested that a possible potentiation occurred during a 30 km running trial towards the end of the race, perhaps counteracting the accumulation of fatigue and preventing reductions in speed. In other words, the muscular contractions of the running itself served as a CA (Del Rosso et al., 2016). Although endurance trained athletes likely benefit from the PAP effects to a lesser extent than type II dominant power athletes (Feros, 2010), they may be able to sustain the potentiation for a longer period of time (Morana & Perrey, 2009).

Very few studies have examined endurance performance as the dependent variable (i.e., the main activity) following a CA. Silva and colleagues (2014) found that a CA comprised of four sets of 5RM in the leg press exercise resulted in 6.1% improvement in a 20 km cycling time trial ($p < 0.05$), greater cycling economy ($p < 0.01$), and power output in the first 10% of the trial (a trend, $p = 0.06$). Since the positive effects of PAP could only last minutes and can also increase RFD, it is also suggested that a warm up that includes CA could benefit shorter endurance activities that require a fast start such as rowing, swimming, and short distance running and cycling (Boullosa, Del Rosso, Behm, & Foster, 2018; Feros, Young, Rice, & Talpey, 2012; Hancock, Sparks, & Kullman, 2015; Sarramian et al., 2015). In particular, rowing is a high intensity sport that necessitates high levels of strength (Barrett & Manning, 2004; Hagerman, 1984) and aerobic endurance (Hagerman, 1984; Secher, 1983). Given the physiological and metabolic profile of rowing, it has been suggested that rowers can benefit from PAP by performing appropriate CAs (Feros, 2010). Feros et al., (2012) found an improvement in the first 500 meters out of a 1000 m rowing trial following a maximal isometric CA. The results showed improved mean power and stroke rate, and although performance time over the full distance was not statistically significant, there was a practical mean difference of 8.2 m, with one subject improving their results by 41.2 m. Another study by Doma, Sinclair, Hervert, and Leicht (2016) used a 10-second maximal rowing bout as the CA, followed six minutes later by another 10-second maximal rowing bout as the performance measure of interest, demonstrating improvements in average power output (+2.5%), peak power output (+1.5%), and first stroke power (+0.79%), which are important for the start of the race.

The existing PAP studies completed in rowers used different PAP protocols and different performance measures representing very specific physical qualities relevant to rowing. While providing beneficial information and promising results, the heterogeneity of the research methods makes it difficult to assess and compare the efficacy of the two protocols. Therefore, a single assessment relevant to the sport of rowing is needed to compare the previously examined PAP protocols appropriately. Evaluation of the power-duration relationship using the critical power (CP) test applied to rowing yields a number of key performance indicators including CP defined as the maximum power output an individual can tolerate for a relatively long period of time without fatigue, and W' defined as the finite work capacity available above CP (Cheng, Yang, Lin, Lee, & Wang, 2012; Kennedy & Bell, 2000; Shimoda & Kawakami, 2005; Vanhatalo, Jones, & Burnley, 2011). Critical power has predictive value for rowing events with subjects possessing higher CP values demonstrating better 2000 m rowing performance (Shimoda & Kawakami, 2005). Critical power and its velocity-based analogue, critical velocity, have been shown to be correlated with mean power ($r = 0.87$) and mean velocity ($r = 0.93$), respectively, during 2000 m time trials (Kennedy & Bell, 2000). The results from these studies suggest that the CP test is relevant to assessing rowing performance. Furthermore, the additional variables extracted from the CP test, such as mean power, peak power, and distance covered, may provide additional insight into the proposed PAP protocols. Therefore, the aim of this study is to use the CP framework as a standardized assessment method to compare isometric and dynamic PAP protocols in female collegiate rowing athletes.

Hypotheses

It is hypothesized that:

1. Mean power, peak power, and total distance during the three-minute all-out test will increase following both PAP protocols.
2. Dynamic PAP protocol will be superior to isometric PAP protocol in improving rowing performance as measured in the critical power test.

Limitations

1. All of the performance tests and intervention protocols rely on the participants' maximal effort and depend greatly on personal motivation.
2. There will be no measurement of force during the isometric PAP protocol.
3. There is no direct measurement of the existence of PAP (i.e., pre and post intervention evoked muscle twitch).
4. Strength levels (i.e., 1RM) will be collected from the athlete's coaching staff.

5. The study is not blinded. The participants knew that performance following the intervention is supposed to improve.

Operational Definitions

Postactivation potentiation (PAP) – every improvement in performance following a conditioning activity.

Conditioning activity (CA) – voluntary muscle contraction, either dynamic or isometric, performed prior to the main activity and designed to improve performance.

Performance measure\main activity – the dependent variable measured before and after the CA.

Critical power (CP) – the average value of the last 30 seconds of the 3-minutes all-out test (3MT).

Anaerobic work capacity (W') - work capacity available above CP, calculated as the area under the curve above CP.

Peak power – highest value of power attained during the 3MT.

Mean power – average power attained during the 3MT.

CHAPTER TWO: LITERATURE REVIEW

Post-activation Potentiation (PAP)

Evidence of the PAP phenomenon has been provided in both laboratory and field settings where muscle twitch peak force and rate of force development (RFD) have been shown to increase following prior voluntary contractions or electrically stimulated evoked contractions (Hodgson et al., 2005; Robbins, 2005). The increased force and RFD following PAP have led investigators to attempt to apply this mechanism in more applied settings. In particular, PAP has been examined to improve sports performance by having the athletes perform a voluntary maximal or near maximal muscle contraction utilizing similar biomechanical characteristics, either isometric or dynamic, prior to performing an explosive movement (e.g., jump, sprint or throw). However, although PAP has been repeatedly demonstrated in the laboratory using isolated muscle fibers, findings of studies investigating the PAP effects on subsequent human performance have yielded equivocal results (Hodgson et al., 2005). It appears that there are number of modulating factors determining the effectiveness of the CA on subsequent performance (e.g., intensity, volume, rest interval, training status and strength levels) (Dobbs, Tolusso, Fedewa, & Esco, 2018; Seitz & Haff, 2016) which will be discussed later in this section.

Mechanism

Muscle contraction has two opposing residual effects. The first effect is muscular fatigue, defined as decreased muscular force production, while the other effect is potentiation, which is the facilitation of greater force production. The resulting force production following a CA is dependent on the net balance between the two. The consensus from current literature is that the mechanism behind skeletal muscle potentiation is the phosphorylation of regulatory light chain (RLC) of myosin localized within the muscle, although some suggest that there might also be a neurogenic mechanism at the spinal level, with the potentiation of the H-reflex (i.e., increased motor neuron excitability in reaction to a constant stimulation intensity) (Hodgson et al., 2005; Tillin & Bishop, 2009).

<u>Sweeney, Bowman and Stull, 1993 (Sweeney, Bowman, & Stull, 1993)</u>

In this review, the authors discuss RLC phosphorylation and its effect on the rate of myosin and actin interactions, which lead to greater, more rapid force production. The RLC is located between the myosin head and the rod and provide modulation of Ca^{2+} activation. When Ca^{2+} is released from the sarcoplasmic reticulum it binds to calmodulin and the Ca^{2+}- calmodulin complex then binds to myosin light chain kinase (MLCK) and activates it. The activated MLCK phosphorylates the RLC and moves the myosin head into the force-producing state. Additionally, RLC phosphorylation facilitates the movement of the myosin heads farther from the myosin filament's surface and closer to the actin filament, reducing the time of the cross-bridge formation.

Although RLC phosphorylation plays a modulatory role in muscular contraction, it is not obligatory, since the process of RLC phosphorylation and dephosphorylation is relatively slow. The movement of the myosin head away from the myosin filament's surface towards the actin filament is considered to create increased sensitivity to Ca^{2+} which increases both force production and RFD. Phosphorylation of RLC can also cause a reduction of the frequency of motor unit firing while maintaining the same level of force and higher efficiency of Ca^{2+} would be attained since less Ca^{2+} is required for attainment of a given force output during continuous activity.

Rassier and MacIntosh, 2000

In this review by Rassier and MacIntosh (2000), the authors set to identify the mechanism of muscular fatigue and potentiation and demonstrate that they can coexist. Coexistence of fatigue and potentiation is defined as the simultaneous presence of the underlying causes of activity-dependent fatigue and potentiation. While skeletal muscle potentiation most likely results from RLC phosphorylation, activity-induced muscular fatigue, although multifactorial, is ultimately the result of either decreased concentrations of myoplasmic Ca^{2+} or decreased sensitivity to Ca^{2+}. An increased sensitivity to Ca2+ will result in a greater force production for the same level of Ca^{2+} while a decreased sensitivity to Ca^{2+} will result in the opposite response. However, when levels of Ca^{2+} are saturated, force output will not change.

There should be a distinction between high and low frequency fatigue. High frequency fatigue will affect maximal contractions and could be a result of activity-induced or general fatigue, or a combination of both. While activity-based fatigue would not impact low-frequency force production, general fatigue will impact both high and low frequency force production. Therefore, the coexistence of potentiation and fatigue could be demonstrated by decrements in maximal force induced by high frequency stimulation coincident with increased muscle twitch force generation after fatiguing low-frequency stimulation. This situation was observed when twitch force was enhanced following a fatigue test (prolonged tetanic contraction of six minutes), indicating potentiation, while fatigue was observed with reduced post-test tetanic contraction (Rankin, Enoka, Volz, & Stuart, 1988). Interestingly, it was shown that fatigue lasted for a period of approximately 90 minutes while the twitch potentiated response dissipated after 10-14 minutes (Vergara, Rapoprot, & Nassar-Gentina, 1977).

Another way to demonstrate the coexistence of potentiation and fatigue is an altered relationship between RLC phosphorylation and potentiation. While there is correlation between RLC phosphorylation and the magnitude of potentiation, this relationship changes in a fatigued state compared to a rested muscle (p. 505). It is important to note, however, that these experiments were done with isolated skinned animal muscle fibers and did not involve human voluntary muscle contraction, although they can give insight of the mechanism behind the PAP phenomenon. The authors concluded that potentiation, caused by RLC phosphorylation, and fatigue, caused by low Ca^{2+} concentrations or decreased sensitivity to it, can coexist.

Sale, 2002

This review focused on the potential role of PAP in endurance athletes, by further developing the concept of low versus high frequency potentiation and fatigue. Submaximal force production may benefit from PAP due to its ability to affect force development during low frequency stimulation. Even though type II fiber types present greater potentiation than type I muscle fiber types, PAP has little effect on maximal force production during high frequency motor unit firing, where Ca^{2+} is saturated. When an athlete engages in an endurance activity, which requires maintaining sub-maximal force production, the increased muscle fiber force production from PAP may result in decreased motor unit firing rate, or potentially reduced motor unit recruitment to compensate for the increased force. This could, in turn, lead to an increased time to exhaustion or delayed low frequency fatigue. However, if the athlete then encounters a challenge that requires them to recruit high threshold motor units (e.g., hill climb or strategic sprint or change of pace), high frequency fatigue, which could not be compensated by PAP, will manifest. Furthermore, low frequency PAP could be generated during the endurance effort by the endurance effort itself, meaning that the muscular contractions of the activity will potentiate subsequent contractions, without the need for a specific CA. This was supported later by the reported increase in countermovement jump height during endurance running trials without performing a CA (Boullosa & Tuimil, 2009; Del Rosso et al., 2016). The co-existence of potentiation and fatigue is also presented with improvements in CMJ compared to baseline despite decreased speed and increased RPE during the trial (Del Rosso et al., 2016).

A potential advantage of endurance athletes is their increased resistance to fatigue, which can allow them to resist or recover faster from fatiguing CA, allowing them to exploit the potentiating effects before they dissipate. As for power activities, although PAP has limited effect on force production at the ends of the force spectrum (i.e., maximal force production), PAP will increase RFD and therefore will also likely increase power performance.

Modulating Factors

While studies using muscle twitch measures have repeatedly shown the existence of PAP, the literature regarding the effects of voluntary muscular CAs (e.g., dynamic squat or isometric knee extension) on subsequent performance (e.g., jump or sprint), seem to be equivocal (Hodgson et al., 2005; Tillin & Bishop, 2009). High interpersonal variability in the magnitude and ability to benefit from the PAP phenomenon exists, and the individual rest intervals required to recover from the fatigue induced by the CA while potentiation still persists further complicate this issue. As a result, different studies vary greatly in their methodology (i.e., CA type and intensity, rest intervals, training and strength status of subjects, type of contraction and dependent variables), making it difficult to draw conclusions on the PAP effect. Several meta-analyses tried to address this issue and will be discussed next.

Seitz and Haff, 2016

This review and meta-analysis by Seitz and Haff examined factors modulating PAP response of jump, sprint, throw and upper-body ballistic performances. It was found that the overall PAP effect was small for jump and throw (ES = 0.29 and 0.26 respectively) and upper-body ballistic activities (ES = 0.23), and moderate for sprint performance (ES = 0.51). Additionally, isometric CAs had a negative impact on performance (ES = -0.09) while dynamic high intensity and low intensity yielded positive effects (ES = 0.41 and ES = 0.19 respectively). The largest ES for recovery time was for 5-7 min (ES = 0.49), and multiple sets of CAs seem superior to single set CAs (0.69 vs. 0.24, respectively). Additionally, high intensity CAs seem to be superior to sub-maximal intensity CAs (0.51 vs. 0.34, respectively).

Furthermore, stronger individuals [one-repetition maximum (1RM) back squat greater than 1.75 × body weight for men and 1.5 × body weight for women] presented an ES = 0.41 compared to ES = 0.32 of the weaker individuals, and those with >2 years resistance training experience had ES = 0.53 compared to ES = 0.44 for those with less than two years resistance training experience and ES = 0.07 for those without any experience. However, when further analyzing the modulating factors by strength levels, it seems that stronger individuals will benefit the most from a single, high intensity set of CAs followed by a 5-7 min period of recovery, while weaker individuals will benefit the most from multiple sets of sub-maximal intensity CAs with rest intervals of 5-7 min (ES = 0.31) or more than 8 min (ES = 0.36).

Overall, the results of this meta-analysis suggest a high interpersonal variability of PAP responses, with strength levels being an important modulating factor. These conclusions are in general agreement with previous meta-analyses (Gouvêa, Fernandes, César, Silva, & Gomes, 2013; Hodgson et al., 2005; Tillin & Bishop, 2009; Wilson et al., 2013); however results vary. For example, Gouvea and colleagues (2013) found a larger ES for the 8-12 than the 4-7 rest interval following a CA (ES = 0.24 vs. ES = 0.15 respectively). Wilson et al., (2013) found no significant differences between dynamic CA and isometric CA (ES = 0.42 vs. ES = 0.35 respectively) in eliciting PAP, and 7-10 min as the most effective rest interval (ES = 0.70). Esformes et al., (2011) found only an isometric CA to improve peak power for upper body ballistic bench press throw while concentric, eccentric and dynamic (coupled concentric and eccentric) muscle actions did not result in significant performance improvements. As for CA intensity, it was concluded by several studies that maximal or near maximal intensity would result in a superior PAP effect (Dobbs et al., 2018; Gouvêa et al., 2013; Hodgson et al., 2005; Seitz & Haff, 2016; Tillin & Bishop, 2009) with one meta-analysis showing that moderate intensity CAs (60-84%) produced better PAP responses than heavy intensity CAs (ES = 1.06 vs. ES = 0.31 respectively) although these results were not analyzed by strength levels (Wilson et al., 2013).

Dobbs, Tolusso, Fedewa and Esco, 2018

The most recent meta-analysis examined the effects of PAP and its modulating factors on vertical jump. The authors included only studies that used trained subjects (>1 year training experience) and higher intensity CAs (>80% 1RM). When results were examined without considering the modulating factors, PAP did not improve vertical jump. However, significant heterogeneity was accounted for by CA mode (dynamic vs. isometric) and the rest interval. Isometric contraction CAs produced a negative effect (Hedges' d ES = -0.52) compared with a trivial effect size for dynamic contraction CAs (ES = 0.17), which confirms the findings of Seits and Haff (2016). Rest interval of 3-7 minutes produced the greatest effect size (ES = 0.18) compared with rest intervals of <3 min (ES = -0.16), 8-12 min (ES = 0.03) and >12 min (ES = 0.04). Overall, rest interval was the most significant modulator of the PAP effect. Furthermore, the authors suggest using CAs intensities of >80% 1RM to elicit PAP.

Endurance Performance

Very few studies examined PAP with the main activity being an endurance effort which is particularly relevant for the sport of rowing with its aerobic energy system requirements.

Silva et al., 2014

Silva and colleagues had 11 trained cyclists perform a 20 km time trial after a CA that consisted of four sets of maximal 5RM leg press exercise. The main finding from this study was an improved time of 6.1% ($p = 0.02$). Mean power output was higher by 3% (n.s.) and a trend was observed for higher mean power in the first 10% of the trial ($p = 0.06$), which could benefit a pacing strategy (i.e., starting the trial faster). The cadence was not affected by the CA as well as mean VO_2 and blood lactate. The authors argue that exercise economy improved ($p < 0.01$), however, exercise economy was only calculated during the warm up phase (pedaling at 100 W and 80 rpm) rather than the entire time trial.

Rowing

Rowing is a high intensity sport that necessitates high levels of strength (Barrett & Manning, 2004; Hagerman, 1984) and aerobic endurance (Hagerman, 1984; Secher, 1983). Rowing can be performed using one oar and two, four or eight rowers (sweep rowing) or by using two oars and a single rower, two or four rowers (sculling). A competition distance is typically 2000 m (Mahler, Nelson, & Hagerman, 1984).

Anthropometric Profile

Rowing performance is correlated to body height ($r = -0.81$), body mass ($r = -0.85$) and fat-free mass ($r = -0.91$) in both males and females. Sex differences exist, with females being slower than males with similar height and body mass (~9-10%), even when fat-free mass is matched (~4% difference) (Yoshiga & Higuchi, 2003). There are only two weight categories: lightweight (<59 kg for females and <72.5 for males) and heavyweight. Mean body mass for lightweight rowers is 70 kg and 57 for male and female rowers, respectively (Secher, 2000).

Physiological Profile

The 2000-meter event world record is 6:30 min for a single male rower, 7:07 min for a single woman rower, 5:18 min for a boat of eight male rowers and 5:54 min for a boat of eight female rowers. (http://www.worldrowing.com/events/statistics/). These data indicate an event duration which requires a large involvement of the aerobic system and indeed, the maximal oxygen uptake of oarsmen may reach 6.6 L/min (Secher, 1993). Maximal oxygen uptake has been correlated with 2000 m rowing times (r = -0.90) (Yoshiga & Higuchi, 2003) and velocity (r = 0.85), and VO_2max (L/min) was found to be the single best predictor of velocity during the 2000 m time trial, explaining 72% of the variance in rowing performance. The inclusion of blood lactate concentration, sampled five minutes following the performance, improved the model and explained 87% of the variance (Cosgrove, Wilson, Watt, & Grant, 1999). Accordingly, Secher (1993) estimated the relative contribution of the anaerobic energy systems to be 21% to 30% in an all-out rowing effort, which is somewhat consistent with the 25% to 30% estimated by Hagerman (1984) and 20-25% reported by Mazzone (1988). Thus, the fact that male and female rowers are characterized by 70 to 75% slow twitch skeletal muscle fibers (Secher, 1993) seem to align with the demands of the sport.

Although this data may place rowers in the endurance category, pacing strategies also require oarsmen and oarswomen to possess anaerobic qualities. A rowing event will start with a vigorous sprint which demands a high force and power outputs, both relying on anaerobic metabolism. The powerful start is followed by a steady-state aerobic intensity in the severe domain with an additional sprint at the end of the race (Hagerman, 1984; Mahler et al., 1984). Accordingly, blood lactate values as high as 17 mmol/L and pH as low as 7.1 were reported after an all-out rowing bout (Secher, 2000).

Biomechanical Profile

Biomechanically, rowing is a coordinated full-body effort, where both the upper and the lower body are required to exert force in a synchronized movement. Large muscle groups are engaged in repetitive, maximal force production to propel the boat over the water (Mazzone, 1988). The rowing motion can be divided into six stages which generally use the muscles in the body's posterior muscle chain, using a pull movement pattern of the upper body and a push movement pattern of the lower body, and are executed in a smooth transition and a repetitive cyclic fashion (Mazzone, 1988).

Critical Power

Critical power (CP) is defined as the maximum power output (or velocity) an individual can tolerate for a relatively long period of time without fatigue. Alternatively, CP has been described as the intensity point at which the body can sustain a maximal steady state of blood lactate and oxygen uptake, above which an inevitable eventual exercise intolerance will occur (A. M. Jones & Vanhatalo, 2017).

Critical power is particularly useful because it can provide valuable information for athletes, such as identification of the threshold point that separates 'heavy' exercise intensities from the 'severe' exercise intensities, much like the second ventilatory threshold (or respiratory compensation point) or the second blood lactate threshold. Above this threshold, exercise efficiency is reduced, muscle PCr and pH are reduced, blood lactate accumulates, and oxygen uptake increases to its maximum (A. M. Jones & Vanhatalo, 2017; A. M. Jones, Vanhatalo, Burnley, Morton, & Poole, 2010). As soon as the athlete surpasses the CP threshold, entering the ‘severe’ exercise intensity domain, they begin using the finite work capacity available above CP, termed W’. This information can also provide a prediction for time to exhaustion at different power outputs above CP while depleting W’ (Vanhatalo et al., 2011).

Critical Power Assessment

Critical power can be extracted from the hyperbolic relationship between power and time (P-t relationship) where time to exhaustion (TTE) decreases as power or velocity increases. Traditionally, the calculation of CP required three or four TTE trials at various high-intensity power outputs that would lead to exhaustion within 2-15 minutes (A. M. Jones et al., 2010). Total work (J) was then plotted against TTE (s), and the slope of a linear regression line would produce the CP. The intercept point of this line with the Y axis corresponds to W’ (figure X) (David G. Jenkins & Quigley, 1991; Monod & Scherrer, 1965). Critical power can also be extracted as the asymptote of the regression hyperbolic line when plotting power (W) against TTE, in which case the area under the curve above the CP will represent W’ (figure X). A third way to extrapolate CP and W’ is to plot power against the inverse of time. The slope of the linear regression line would then equal W’ and the y-intercept would represent CP (figure X) (A. M. Jones et al., 2010).

However, the necessity of several fatiguing tests to establish CP and W’ has proven to be cumbersome and rendered its use less applicable. Therefore, another method of identifying CP and W’ was needed, and an all-out test was used to find these variables in a single test. The three-minute all-out test (3MT) is a test in which the participant must produce sustained maximal power output, without pacing (i.e., reserving energy for the duration of the test). When the test is properly executed, CP can be calculated from the average power output in the last 30 seconds of the test as power output will plateau and the work performed in the 3MT above CP should equal W' (A. M. Jones et al., 2010). The 3MT was also tested specifically in rowing by Cheng et al., (2012) who found no significant differences in the CP estimated from the 3MT (referred to as "end test power") and CP determined from the traditional multi-trial method. However, W' from the 3MT (referred to as "work done above end test power") was found to be higher and did not significantly correlate to the W' found from the traditional method. Test-retest reliability for the different parameters was found to be moderate to high (ICC = 0.6 – 0.98, $p < 0.05$).

Critical Power and Rowing

According to Vanhatalo et al., (2011), the CP concept is most relevant to continuous activities that last between two and 30 min, including rowing, which could last approximately 6 – 8 minutes. The CP concept can be applied to rowing with power substituted with velocity and work with distance to yield critical velocity (CV) (Hill, Alain, & Kennedy, 2003; Kennedy & Bell, 2000). Critical velocity, calculated in shorter trials (e.g., 200 to 1200 m), can be used to predict performance in a 2000 m performance and CV has been shown to be highly correlated with velocity during a 2000 m time trial (Hill et al., 2003).

The value of CP is of great importance for endurance sports, and the W' concept can provide these athletes with information that can aid in pacing strategies. Athletes can plan a race strategy, utilizing their finite anaerobic work capacity when exceeding CP for a predetermined period of time and reducing their work rate below CP for longer period of time as necessary. For example, a rower can sprint (workload above CP) in the start of the race for 100 m and then reduce workloads to be close, but not exceeding CP for the majority of the race, and then sprint again at the end using the remnants of their anaerobic work capacity. The 3MT can also provide a temporal overview of rowing performance with changes in power output and distances covered throughout the assessment which may be impacted by CAs and PAP.

Post-activation Potentiation in Rowing

Given the physiological and metabolic profile of rowing, it has been suggested that rowers can benefit from PAP CAs (Feros, 2010). However, the area of PAP in endurance exercise in general, and rowing in particular has received little investigational attention (Boullosa et al., 2018) with only two studies investigating the effects of PAP on rowing performance.

Ferso et al., 2012

Feros et al. (2012) used an isometric CA, before a 1000 m time-trial. The CA consisted of five sets of five-second isometric muscle actions on the rowing ergometer, pulling an immovable handle (two seconds of gradual force increase immediately followed by three seconds of all-out contraction) separated by 15-second recovery intervals. After four minutes of rest, the 1000 m time trial was performed. The authors found a significant increase in mean power output by 6.6% and mean stroke rate by 5.2% over the first 500 m resulting in time reduction of 1.9% over the first 500 m only. The time over the full 1000m was improved by 0.8% (n.s.); however a practical difference of 8.2 m was observed, with one of the subjects improving their results by 41.2 m (and two subjects not benefiting from the intervention). The study used highly trained rowers (Australian national level) and a familiar position within the rowing motion to engage in the CA. The chosen CA is of highly external and practical validity, since it is utilizing the rowing ergometer, rather than a strength exercise, and can potentially be applied in a race setting. This study is also one of the few studies using an endurance effort as the performance measure of interest following a CA to assess PAP. However, results may have been better if, according to recent meta-analyses, recovery time had been longer, and the contraction mode had been dynamic rather than isometric (Dobbs et al., 2018; Gouvêa et al., 2013; Seitz & Haff, 2016).

Doma et al., 2016

The second study used a very different methodology which consisted of a 10-second maximal rowing bout as both the CA and the performance measure of interest, which were separated by a six-minute recovery period (Doma, Sinclair, Hervert, & Leicht, 2016). The results showed a 2.5% increase in average power output, 1.5% in peak power output and 0.79% in first stroke power. The authors concluded that a dynamic 10-second CA can increase rowing sprint ability and may assist in the start of the race. However, additional research is needed to assess whether this kind of CA could elicit PAP that will improve performance for the duration of the race. Additionally, the rowers may benefit from multiple sets of CA rather than performing a single set (Seitz & Haff, 2016).

CHAPTER THREE: METHODOLOGY

Study Design

This investigation used an experimental crossover design. A minimum sample size of 17 participants was calculated for 80% power, $\alpha = 0.05$, and an anticipated effect size of 0.63 from 500m split time data provided by Feros et al. (2012) using power analysis software (G*Power 3.1.9.2, Dusseldorf, Germany).

Following an informed consent and initial screening (T1), participants were assessed for their height and weight and were familiarized with the testing procedures (T2). Additionally, the participants were asked for their rowing experience in years and their current squad placement (performance, development or novice). Personal best 2000 m indoor rowing times and strength measures (estimated 1RM in front squat and push press) were obtained from the team's coaching staff. Familiarization and testing sessions were performed in the crew team's training facility (i.e., boathouse) in a group setting. Participants were then randomized into three groups while maintaining an equal number of the performance squad athletes and development\novice squad athletes between groups. The next three visits (T3, T4, T5) were counter-balanced to try to account for a learning effect, and each group performed one of the testing conditions on each day (i.e., control, dynamic PAP and isometric PAP) followed by the three-minute all-out test (3MT). The final visit (T6) included body composition assessment and a graded exercise test to assess maximal aerobic capacity. T1 and T2 were done on the same day, T3, T4, and T5 were separated by 48 hours, and T6 took place three weeks later. Participants were asked to maintain their usual eating habits, and refrain from strenuous exercise and alcohol consumption for 24 hours prior to testing. Table 1 shows a timeline of the study.

Table 1: Study timeline overview.

T1	T2	T3	T4	T5	T6
Consent and screening	Anthropometrics Familiarization	CON\ISO\DYN 7 MIN 3MT	CON\ISO\DYN 7 min 3MT	CON\ISO\DYN 7 min 3MT	Body Composition VO_2max

Notes: T1 and T2 were done on the same day. T3, T4, and T5 were separated by 48 hours. T6 took place three weeks after T5.

Participants

Forty female collegiate rowers, between the ages of 18 and 22 years old were recruited to participate in this investigation (age = 20 ± 1.4 years; height = 171.79 ± 5.16 centimeters; body mass 75.38 ± 10.17 kilograms, rowing experience 4.3 ± 3.29 years, VO_{2peak} 46.12 ± 5.25 ml/kg/min). This study was approved by the Institutional Board of the University of Central Florida. All participants completed a written form of consent (Appendix C), PAR-Q (appendix D) and medical history questionnaire (appendix E) prior to beginning of the study. The participants were recruited from the University of Central Florida's crew team. Of the 40 participants, 28 were part of the performance (i.e., competitive) squad, and 12 were part of the development\novice (i.e., non-competitive) squad. During the investigation, three participants missed one of the testing days (T3, T4, T5) due to illness or injury (which were unrelated to the study's procedures). Therefore, 37 participants were used for the final repeated measures analysis. Three participants missed T6 (which included body composition and VO_2max testing). Two participants missed T6 due to injury, and one participant was cut from the team due to unsatisfactory performance. Table 3 and 4 provide descriptive and performance values for the entire sample and by experience levels.

Procedure

Initial screening (T1)

Potential study participants were informed of the study during a regularly scheduled rowing training session during the month of January 2019, following the academic winter break. All study procedures, risks, and benefits were explained to the group, and any questions were answered. Each volunteer provided their written informed consent to participate in the study and filled out a Physical Activity Readiness Questionnaire (PAR-Q) and a medical and activity history questionnaire to assess their physical ability to participate in the study.

Assessment and Familiarization (T2)

Anthropometrics

Immediately after consent and screening, participants were assessed for their anthropometrics. First, height was measured using a stadiometer (Patient Weighing Scale, Model 500 KL, Pelstar, Alsip, IL, USA). The participant removed their shoes and stood with their back to the measuring stick. The investigator placed the top part of the measuring stick on top of the participant's head and recorded their height in centimeters. Next, weight was recorded in kg using a scale (InBody 770, Biospace Co, Ltd. Seoul, Korea).

Familiarization

Familiarization took place upon completion of the anthropometric assessments during T2. Participants completed the entire isometric (ISO) and the dynamic (DYN) PAP protocols followed by the 3MT.

Testing Days Procedure (T3, T4, T5)

Forty-eight hours after T2, the first group arrived at the boathouse at approximately 06:00 am, the second group at 06:30 and the third group at 07:00. All testing days were separated by 48 hours and total visit time for each athlete lasted 60 minutes. For the testing days, all active ergometers (Model D with a PM5 monitor, Concept 2, Morrisville, VT, USA) were connected in series to a laptop and were controlled by Venue Race application (Concept2, Inc.). Maximal and mean heart rate (HR) were recorded for the performance team only, using the team’s HR monitor system (Polar Electro, Finland). The damper/resistance lever on the ergometers was set between three and four, to elicit a drag factor of 112 for all procedures throughout the study.

Immediately after a standardized warm-up, which was created with the assistance of the coaching staff and lasted 20-25 minutes (appendix B), the participants performed either the control (CON), dynamic (DYN) or isometric (ISO) condition and were assessed for their peak power, mean power, critical power (CP) and critical velocity (CV). Anaerobic work capacity (W’) was calculated in joules and meters as the work done above CP in the 3MT (Cheng et al., 2012; Vanhatalo, Doust, & Burnley, 2007). Additionally, total distance was recorded, and mean power and distance were calculated for 15 seconds intervals.

Three-minute all-out test (3MT)

After the warm-up (in the control condition) or the PAP protocols, participants rested for seven minutes, seated on the rowing ergometer. No static stretching was allowed between the warm-up and the 3MT in order to limit the potential impairment of power production resulting from static stretching adjacent to exercise (Behm & Chaouachi, 2011; Young & Behm, 2002). During the 3MT, all ergometers were controlled by the laptop and were set for a 3-min trial. The resistance control dial on all ergometers was set to elicit a drag factor of 112, according to the team's normal settings. The participants performed the all-out 3-min effort with strong verbal encouragement of their peer coxswains. During all testing days, each participant sat in the same place surrounded by the same participants and coxswain, to maintain the testing conditions as similar as possible. To prevent pacing during the test, participants were not able to see any of the monitor's information, nor were they informed of the elapsed time. In attempts to ensure an all-out effort, participants were instructed to maintain their stroke rates and power output as high as possible at all times throughout the test (Cheng et al., 2012).

Pace (in seconds for 500 meters) was recorded every 0.5 seconds by the Venue Race software, and power output was calculated using the following equation, obtained from the Concept2 website (https://www.concept2.com/indoor-rowers/training/calculators/watts-calculator):

$$Power\ (W) = \frac{2.8}{(pace \backslash 500)^3} \quad (1)$$

The CP value was calculated as the average power output for the final 30 seconds of the test. W' was calculated in joules and meters as the power – time integral above the CP (Cheng et al., 2012; Vanhatalo et al., 2007), by subtracting the product of the CP and the duration of the test (180 sec) from the product of mean power and duration. W' (J) calculation is expressed in the following equation:

$$W'(J) = Mean\,power \times 180 - CP \times 180 \quad (2)$$

To allow for a better practical understanding of W' for rowing, W' was also calculated in meters by subtracting the product of the critical velocity (CV) and 180 (seconds) from the total distance. The equation can be expressed as follows:

$$\boldsymbol{W'(m) = Distance - (CV * 180)} \quad (3)$$

Peak power was the highest value attained during the test and mean power was calculated as the average power attained during the 3MT. Critical velocity was calculated as the average velocity of the last 30 seconds of the test, by dividing the distance covered in that time by 30 seconds.

The group that performed the control condition performed the warm-up, followed by a seven-minute recovery interval and then the 3MT. The groups that performed the PAP protocols (ISO and DYN) performed the warm-up, followed by a two-minute rest period, in which the procedure instructions were explained to them, after which the PAP protocol was executed. After a seven-minute recovery interval, the groups performed the 3MT. The rest interval between the PAP protocol and the 3MT was selected according to findings of two meta-analyses (Dobbs et al., 2018; Seitz & Haff, 2016).

Isometric PAP Protocol (ISO)

The ISO was originally described by Feros (2010) and Feros et al. (2012). To allow for an isometric contraction, the handle on the ergometer was made immobile by a heavy-duty nylon boat-strap (Vespoli USA Inc., New Haven, CT) that was wrapped around the ergometer's body (i.e., the column of the flywheel). The strap was adjusted for each participant so that the knee angle was approximately 110 degrees (with complete extension equal to 180 degrees) and the participants were sitting in an upright position known to them as "quarter slide" (figure 2). The ISO protocol consisted of five sets, separated by 15-second rest intervals. Each set consisted of two seconds of submaximal contraction where the force applied to the handle was gradually increased, immediately followed by three seconds of maximal isometric contraction (see table 2). The participants were informed of the steps during the procedure (i.e., "go," "stop," etc.) using a recorded audio instruction. The recording started with a 5-second countdown followed by "go, max, stop." The participants were made aware beforehand that they should pull on the handle on "go," gradually increase the force and reach maximal force production on "max," and completely relax on "stop." For the 15-second recovery period, there were no instructions during the first 10 seconds, and then a 5-second countdown was given before the next set began. After all five sets were completed, a seven-minute passive recovery period began as previously suggested (Dobbs et al., 2018; Seitz & Haff, 2016; Wilson et al., 2013), as opposed to the four minutes used in the original protocol (Feros, 2010; Feros et al., 2012), in which the participants remained seated on the ergometer, and no static stretching was allowed.

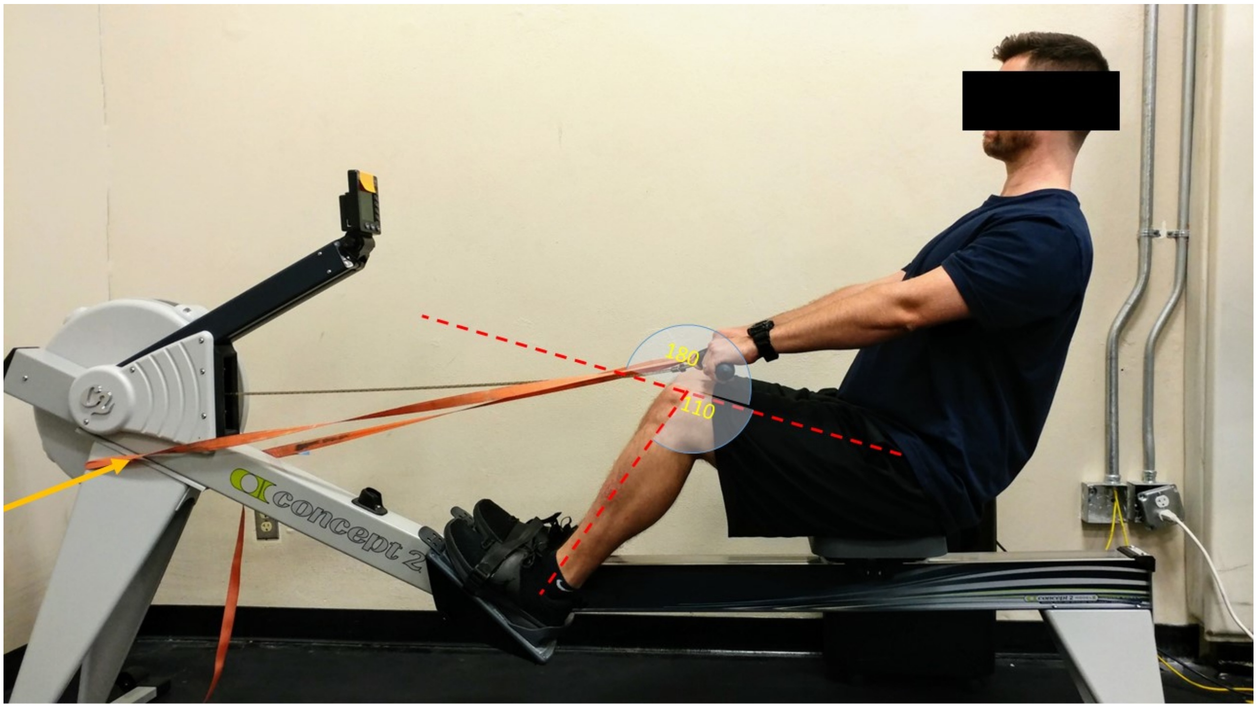

Figure 2: Isometric PAP protocol setup. The participants set in a "quarter slide" position, with their knees bent at 110 degrees. The ergometer's handle was fixed using a heavy-duty nylon boat strap. Protocol was used by Feros et al., 2012.

<u>Dynamic PAP Protocol (DYN)</u>

The dynamic PAP protocol was adopted from Doma et al., (2016) and slightly modified. The protocol consisted of two sets of all-out 10-second rowing bouts on the ergometer. The sets were separated by a two-minute recovery interval. Doma et al. (2016) used a single set as the CA; however, in order to better approximate the time under tension of the ISO and DYN protocols, the protocol was extended. The DYN protocol consisted of a total of 20 seconds of all-out effort while the ISO protocol consisted of 25 seconds of effort, out of which 15 seconds were maximal (tables 2). Additionally, potentiation might be increased using multiple sets as a result of the staircase effect, as was demonstrated in a meta-analysis by Seitz and Haff (2016). Similar to the ISO protocol, a drag factor of 112 was used, and the participants were given a seven-minute recovery period on the ergometer without static stretching, after which the 3MT was performed. Peak power and distance were recorded during the DYN PAP protocol.

Table 2 : PAP protocols comparison.

	DYN	**ISO**
Intensity and duration	10 seconds maximal	0-2 seconds: sub-maximal 2-5 seconds: maximal
Number of sets	2	5
Time under tension	20 seconds maximal	25 seconds total 15 seconds maximal 10 seconds sub-maximal
Recovery between sets	2 minutes	15 seconds
Total protocol duration	2:20 min	1:25 min
Recovery before 3MT	7 minutes	7 minutes

Notes –DYN protocol adapted from Doma et al., (2016) and modified. ISO protocol adapted from Feros (2010).

Maximal Aerobic Capacity and Body Composition (T6)

For the last testing day, each participant arrived individually to the Human Performance Laboratory. First, the participants were assessed for body composition using a multi-frequency bioelectrical impedance analysis device (InBody 770, Biospace Co, Ltd. Seoul, Korea). Participants were asked to remove any jewelry, their footwear, including socks, and wear only light athletic attire. Then they were asked to stand on a platform while holding two handles out to the side. This position was held as the device sent a minute electrical current through the body, to determine body composition (expressed as fat percentage). Participants were asked to be at least two-hours fasted for this assessment.

Participants then performed a graded exercise test (GXT) to volitional exhaustion on a rowing ergometer (Model E with a PM5 monitor, Concept 2, Morrisville, VT, USA) to detect their peak oxygen consumption (ml/min and ml/kg/min). Prior to testing, participants completed a ten-minute warm up at a self-selected pace on the rowing ergometer and were allowed to perform their preferred stretching routine. The participants were fitted with a heart rate monitor (Garmin Ltd., Canton of Schaffhausen, Switzerland) to record HR and a mask that covers their nose and mouth (Hans Rudolph, Inc., Kansas City, MO). Since the rowing ergometer is non-motorized, the participants were asked to match the required power output for each stage of the test. The GXT protocol consisted of two minutes at an initial workload of 125 watts, then increased to 150 watts for two minutes, and then increased by 25 watts every minute until exhaustion or until the participant could not match the required power output for one minute despite strong verbal encouragement. (Kendall, Fukuda, Smith, Cramer, & Stout, 2012). The damper level on the ergometer's flywheel was set between three and four to achieve a drag factor of 112 during the test, which was the drag factor the rowers used for training. Participants were not able to see their time, distance, or heart rate during the GXT but were able to see their power output and stroke rate. Stroke by stroke data collection during the VO_2max test was done using ErgData app (Concept2, Inc.) and an Apple iPad (Apple, Cupertino, CA, USA).

A wearable metabolic system with an in-line gas collection system (COSMED K5 portable metabolic system, Rome, Italy) was used to analyze oxygen and carbon dioxide parameters in order to estimate rate of consumed oxygen (VO_2) (ml/kg/min and ml/min) by sampling and analyzing breath-by-breath expired gases. Calibration was performed prior to every test in accordance with manufacturer's instructions. The unit was mounted on the participant's body using the original K5 harness. The unit, including the battery, weighed 900 grams. The software used for the VO_2max testing was Cosmed Omnia cardiopulmonary diagnostic software.

Respiratory measures (VO_2, VCO_2, and RER) and heart rate were monitored continuously throughout the test. The highest 30 seconds average value during the last stage of the GXT before exhaustion was considered VO_{2peak} if it coincided with at least two of the following criteria: (a) plateau in VO_2 despite an increase in power output; (b) respiratory exchange ratio (RER) of at least 1.15 and/or (c) heart rate within 10% of age-predicted maximal heart rate (calculated as 220 - age).

Statistical analysis

All statistical analyses were conducted via JASP statistical software (JASP Team, Version 0.9, 2018). Results were analyzed for the entire sample and by participant's experience level, with the sample split by the median experience (3.75 years) into more (n=20) and less (n=20) experienced groups. An independent samples t test was used to compare anthropometric and performance measures between the two experience groups. Dependent variables were assessed for normality using the Shapiro-Wilk test. Mann-Whitney test was used for the variables that were not normally distributed.

A three-way [condition (DYN vs. ISO vs. CON) × experience (more experienced vs. less experienced) × 15s splits (0-15s vs. 15-30s vs. 30-45s…135-150s vs. 150-165s vs. 165-180s) repeated measures analysis of variance (ANOVA) with Holm post-hoc analyses was used evaluate distance covered, mean power, mean power in the first 105s, stroke rate, while a two-way (condition × experience) ANOVA was used to evaluate CP, W', and PP. Mean power was analyzed for the first 105 seconds of the 3MT (approximately 500 m) to allow comparison with previous studies. Mauchly's test was used to test for sphericity, and Greenhouse-Geisser correction was used when the assumption of sphericity was violated.

Total distance was compared between testing days (T3, T4, T5), independent of testing condition, using a one-way ANOVA to rule out a possible learning effect of the intervention. Additionally, a testing order effect (the order in which each participant performed the different conditions) was evaluated using a 3-way repeated measures ANOVA (order x condition x experience).

In order to evaluate effort level during the 3MT trials, peak power was compared between the 10s maximal rowing bouts performed during the DYN protocol (DYN PP) and the 3MT trials (3MT PP), with a one-way repeated measures ANOVA. Relevant correlation analyses were also conducted. A criterion alpha level of $p < 0.05$ was used to determine statistical significance. All data are reported as mean ± SD.

CHAPTER FOUR: RESULTS

Descriptive statistics for study participants are provided in Table 3. Years of rowing experience (p<0.001) and 2000m times reported by the coaching staff (p=0.006) were significantly different between the more and less experienced rowing athletes. No other differences were found between groups.

Table 3: Descriptive statistics (mean ± SD) for the more experienced (Exp high), less experienced (Exp low), and overall (Combined) groups of female rowing athletes

	n	Combined	n	Exp Low	n	Exp High
Height (cm)	40	171.8 ± 5.16	20	171.6 ± 5.88	20	172 ± 4.46
Weight (kg)	40	75.38 ± 10.17	20	74.57 ± 9.76	20	76.19 ± 10.75
BMI	40	25.26 ± 2.4	20	25.26 ± 2.4	20	25.69 ± 2.9
Fat %	37	27.2 ± 4.3	18	26.34 ± 3.8	19	28.01 ± 4.7
Age (years)	40	20 ± 1.4	20	19.9 ± 1.5	20	20.1 ± 1.3
Experience (years)	40	4.3 ±3.3	20	1.5 ± 1.2	20	7.1 ± 2.1 *
2000 m (sec)	39	464.2 ± 29.5	19	476.8 ± 34	20	452.3 ± 18.3 *
VO2max (ml\kg\min)	37	46.12 ± 5.25	18	45.04 ± 4.45	19	47.14 ± 5.83
VO2max (ml\min)	37	3446 ± 484.5	18	3335 ± 515.7	19	3552 ± 440.7
Front Squat 1RM (kg)	24	59.05 ± 12	8	58.39 ± 10.76	16	59.38 ± 12.91
SQ\BW	24	0.77 ± 0.21	8	0.75 ± 0.19	16	0.78 ± 0.23
Push Press 1RM (kg)	23	41.31 ± 8.05	7	42.76 ± 6.73	16	40.68 ± 8.7

Notes: Exp Low – experience < 3.75 years; Exp High – experience > 3.75 years; SQ\BW = ratio of weight lifted in the front squat exercise to body weight; 2000 m = time in seconds to complete an indoor 2000 m on a rowing ergometer; * different between groups.

Table 4: Dependent variables (mean±SD) for the more experienced (Exp high; n=19), less experienced (Exp low; n=18), and overall (Combined; n=37) groups of female rowing athletes

	CON			ISO			DYN		
	Combined	*Exp high*	*Exp low*	*Combined*	*Exp high*	*Exp low*	*Combined*	*Exp high*	*Exp low*
Distance (m)	800.2 ± 44.18	813.9 ± 35.7	792.2 ± 44.52	797.1 ± 45.24	813 ± 32.28	789.4 ± 46.17	804.9 ± 42.4 **	819.5 ± 34.55 *,**	791 ± 47.11
Mean Power (W)	260.7 ± 37.34	268.8 ± 35	252.2 ± 39.42	258.3 ± 36.94	267.2 ± 31.38	249 ± 40.84	263 ± 39.12 **	274.7 ± 34.17 *,**	250.6 ± 41.09
Peak Power (W)	376.8 ± 58.13	372.2 ± 53.61	381.6 ± 63.76	364.8 ± 57.45	358.1 ± 49.66	371.9 ± 65.39	381.9 ± 64.44 **	383 ± 54.6	380.7 ± 75.05
Critical Power (W)	220.7 ± 39.09	234.5 ± 32.89	206 ± 40.6	219.7 ± 37.31	236.4 ± 28.74	202.1 ± 37.85	217.9 ± 37.21	231.7 ± 27.68	203.4 ± 41.07
W' (J)	7060 ± 2824	6084 ± 2709	8089 ± 2634	6851 ± 3087	5455 ± 2824	8324 ± 2696	7995 ± 2840 **	7646 ± 2803 *,**	8364 ± 2913
W' (m)	36.46 ± 16.96	30.74 ± 15.4	42.49 ± 16.82	34.17 ± 18.43	24.98 ± 16.14	43.87 ± 15.78	40.70 ± 16.86 **	36.87 ± 14.9 **	44.74 ± 18.26
Stroke Rate (s/min)	35.73 ± 2.86	36.47 ± 3.07	34.95 ± 2.4	36.26 ± 3.18 *	36.98 ± 3.1	35.49 ± 3.1	36.75 ± 2.9 *,**	37.43 ± 2.9 *	36.03 ± 2.79 *

CON=control; ISO=isometric protocol; DYN=dynamic protocol

*** Different from CON; ** Different from ISO; ሰ Different between experience groups; Exp high – rowing experience>3.75 years; Exp low – rowing experience<3.75 years**

Distance

A main effect for condition (F=4.91, p=0.01) in total distance covered during the 3MT was found with ISO being less than DYN (p=0.009; d=0.523). No differences were found between CON and ISO (p=0.601; d=0.214) or DYN (p=0.243; d=0.295).

A significant experience × condition interaction (F=3.16, p=0.048) was found for total distance covered with the more experienced rowers showing greater values during DYN compared to ISO (p=0.002; d=0.936) and CON (p=0.015; d=0.735) and no differences between conditions for the less experienced rowers. No main effect for experience was found, however, a trend was noted (d=-0.306, p=0.071), (figure3).

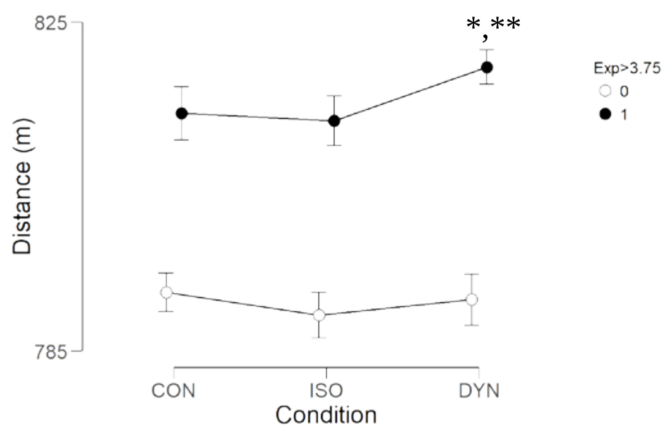

Figure 3: Distance covered in the 3MT by testing condition and by experience levels. Black circles represent high experience, and white circles represent low experience. * DYN>CON; ** DYN>ISO.

An individual analysis of the change in distance covered between CON and ISO revealed a wide range of change, between -19.7 m to 18 m, with 15 athletes who improved their scores, out of which three athletes improved their scores in more than 10 meters and 20 athletes who remained within 5 meters of their control scores (gained or lost). Similarly, an individual comparison between CON and DYN revealed a range between -16.4 m to 17.1 m, with 25 athletes who improved their scores, seven athletes who improved their scores in more than 10 meters, and 19 athletes who remained within 5 meters of their control scores (figure 4).

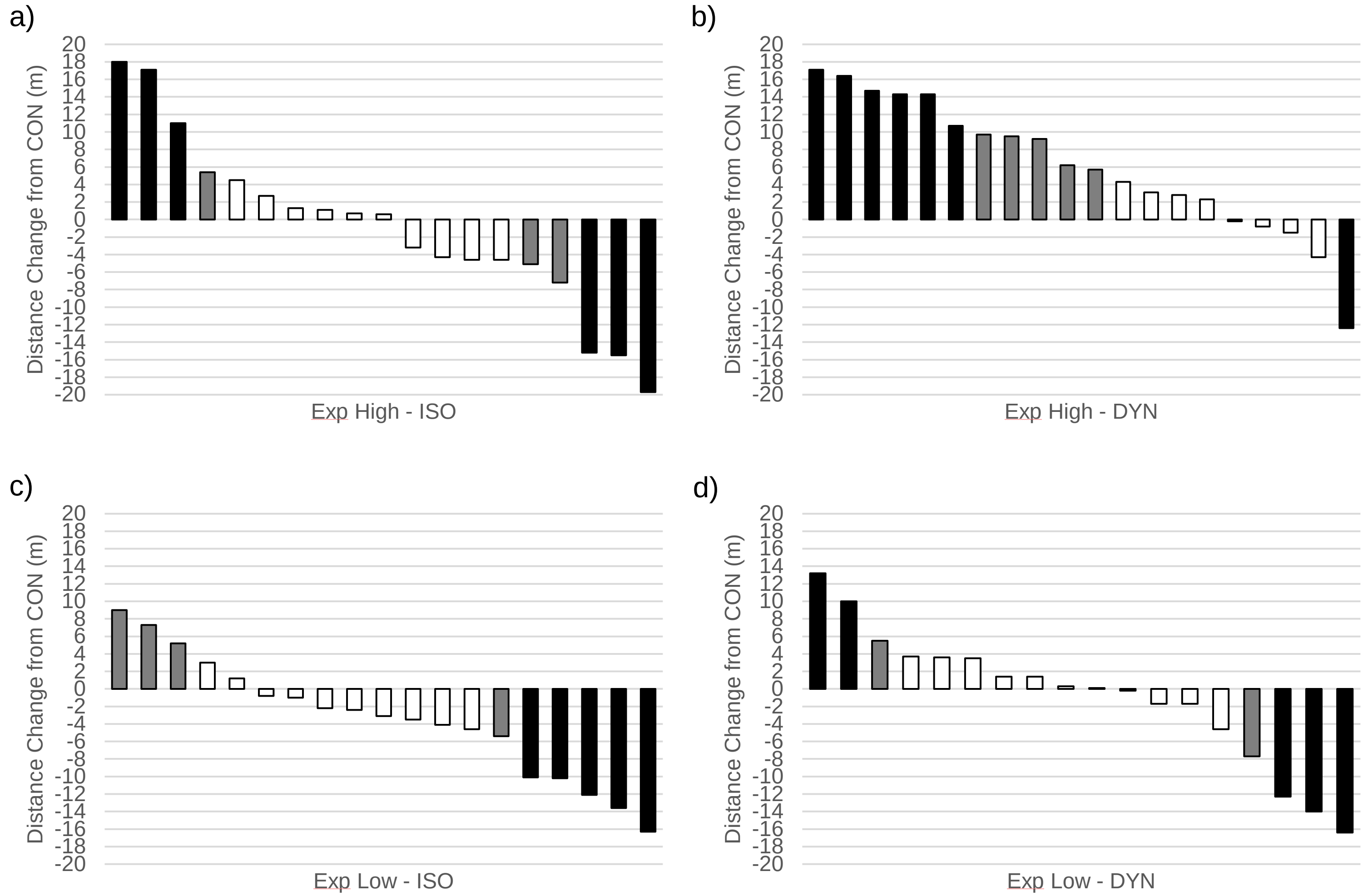

Figure 4: Changes from CON in distance covered during the 3MT for a) ISO and b) DYN for the more experienced rowers (Exp High; n=19), and c) ISO and d) DYN for the less experienced rowers (Exp Low; n=18). Bars in black indicate changes of ≥ 10m. Bars in white indicate changes of ≤ 5.

A main effect for 15s split (F=152.77, p < 0.001) in distance covered was found with distance peaking in the 15-30s split, and then declining gradually and significantly every subsequent 15s interval. The 120-135s split was no different from the 135-150s split, indicating that the performance momentarily leveled off, but then continued to decline again. Figure 5 presents distance covered every 15 seconds by testing conditions.

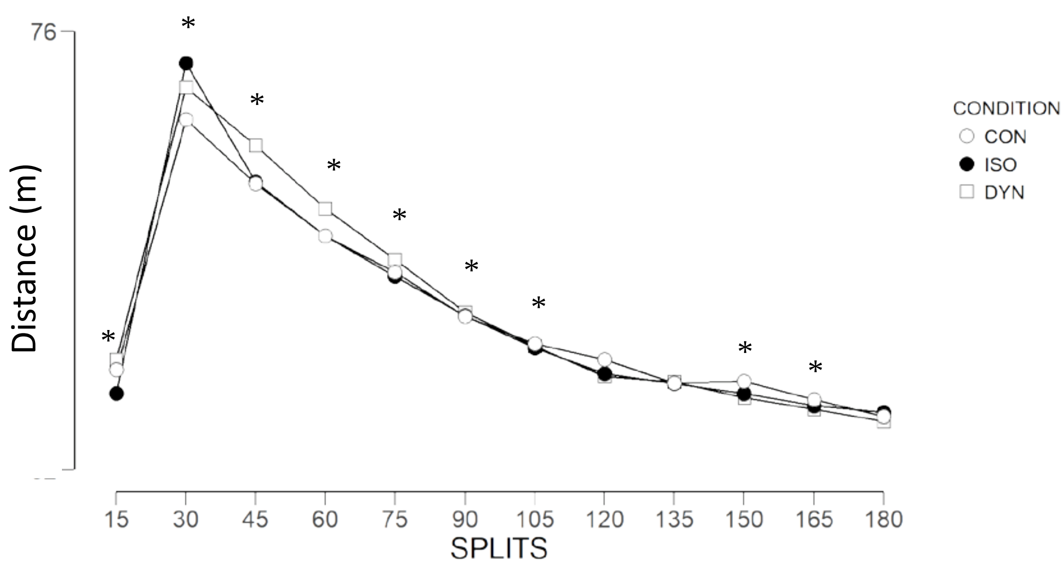

Figure 5: Distance covered (m) for every 15 seconds split and testing condition. * indicates difference from following split.

No significant difference was found for total distance covered between testing days (F=0.33, p=0.71) or order groups (F=1.49, p=0.216) indicating limited learning effects or adverse motivational issues and order effects, respectively.

Peak power

A main effect for condition (F=5.84, p=0.004) in peak power was found with DYN being greater than ISO by 17.081 W (t=-3.812, d=0.627, p=0.002). No differences were found between DYN and CON (d=0.152, p=0.36) or ISO and CON (d=0.376, p=0.057). No main effect for experience was found (d=0.060, p=0.719), (figure 6).

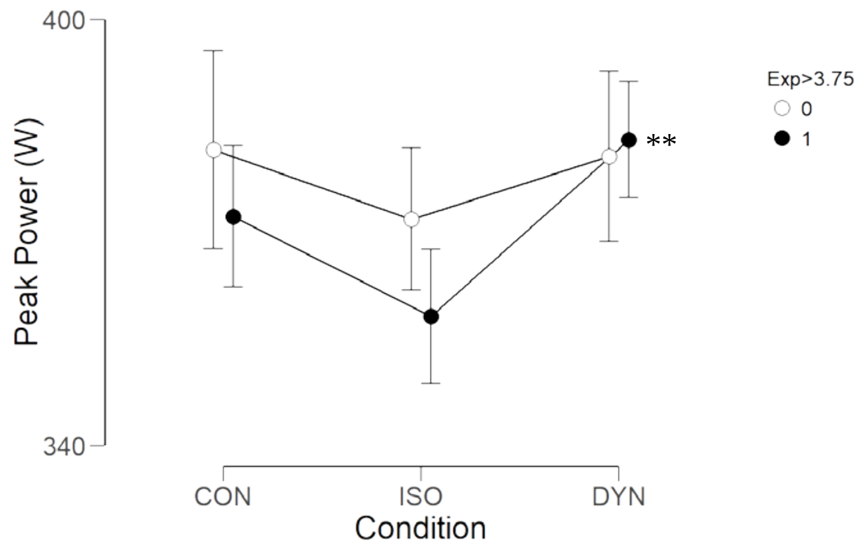

Figure 6: Peak power by testing condition. Error bars represent 95% confidence intervals. ** DYN>ISO.

The peak power obtained in both sets of CA during the DYN protocol (DYN PP) was significantly higher than the values obtained during the 3MT (3MT PP) in all three testing days (figure 7).

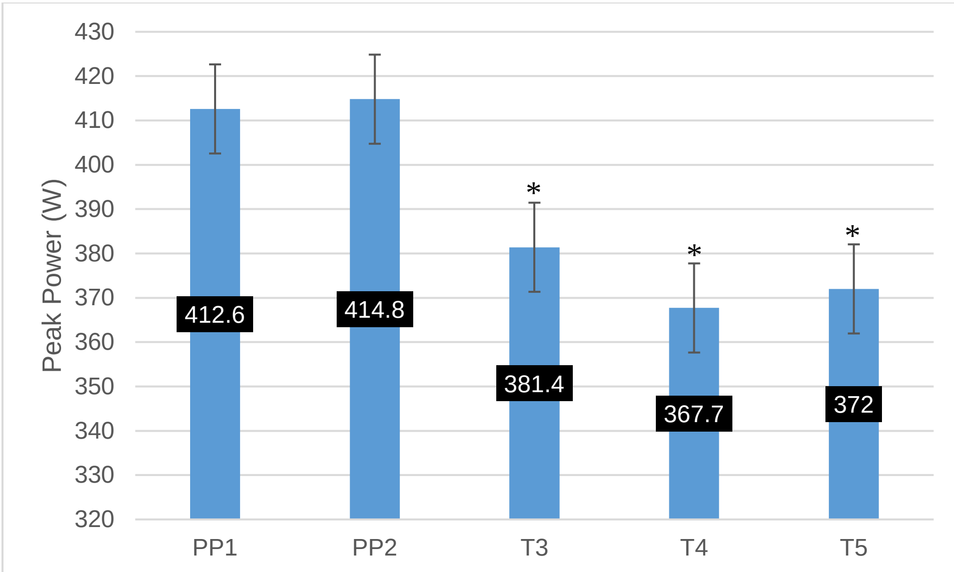

Figure 7: A comparison of peak power obtained during DYN and each testing day. PP1 – peak power in the first set of the DYN; PP2 – peak power in the 2nd set of the DYN. * - Different from PP1 and PP2. Error bars represent standard error.

<u>Mean power</u>

A main effect for condition (F=4.67, p=0.012) was found for mean power with DYN greater than ISO (d=0.52, p=0.008). A condition × experience interaction (F=3.57, p=0.033) was found with DYN being greater than CON (d=0.747, p=0.009) and ISO (d=1.057, p<0.001) for more experienced rowers and no differences between conditions for less experienced rowers (figure 8). No main effect for experience was found (d=0.267, p=0.113).

A main effect for condition (F=12.593, p<0.001) was found for mean power in the first 105s with DYN greater than CON by 7.2 w, a 2.5% difference (d=0.6, p=0.002) and ISO (d=0.762, p<0.001). A condition x experience interaction (F=4.75, p=0.012) was found with DYN being greater than CON by 11.5 w (d=0.942, p=0.001) and ISO by 14.95 w (d=1.24, p<0.001) for the more experienced rowers and no differences for the less experienced rowers (figure 9).

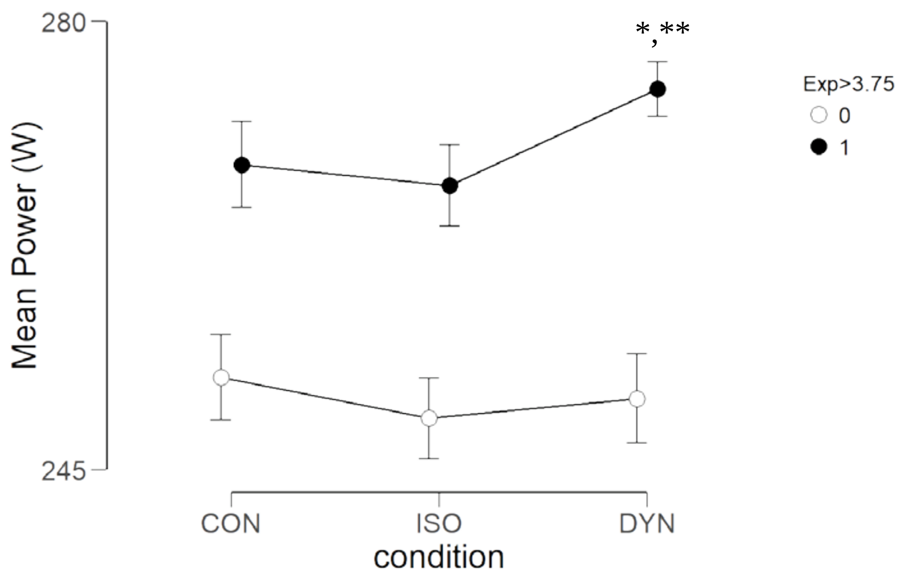

Figure 8: Mean power comparisons of testing conditions by experience level. The black circles represent the high experience group, and the white circles represent the low experience group. Error bars represent 95% confidence intervals. * DYN>CON; ** DYN>ISO.

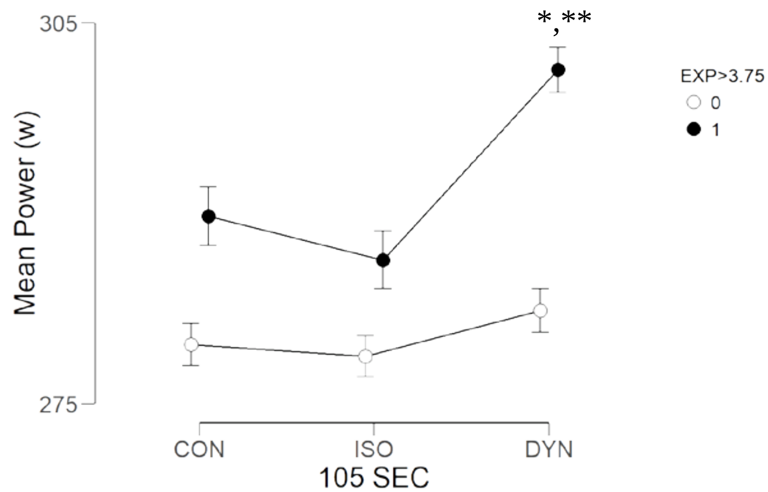

Figure 9: mean power in the first 105 seconds by testing condition. Black circles represent high experience group, and white circles represent low experience group. Error bars represent 95% confidence intervals. * DYN>CON; ** DYN>ISO.

A main effect for 15s split (F=232.26, p<0.001) was shown with mean power being significantly different between all the 15s splits except for 0-15s and 30-45s, and 135-150s and 150-165s. A condition × 15s split (F=6.42, p<0.001) interaction was found for mean power, and a trend was noted for condition × experience (F=3.045, p=0.054). Mean power was greater in DYN than CON for 15-30s, 30-45s, 45-60s and 60-75s seconds splits (p<0.05), (figure 10).

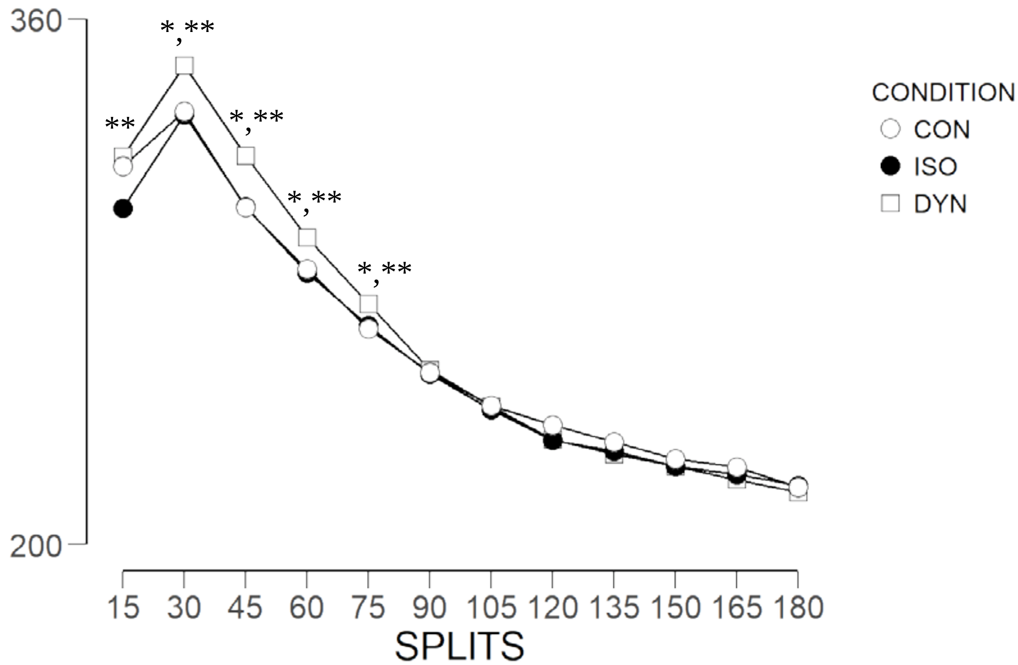

Figure 10: mean power analyzed by 15-second splits and categorized by condition. * DYN>CON.; ** DYN>ISO.

<u>Stroke Rate</u>

A significant main effect for condition (F=10.704, p<0.001; figure 12) and a condition × 15s split interaction (F=4.273, p<0.001) was found for stroke rate. Stroke rate for DYN was greater than CON and ISO (p<0.001, d=0.868 and p=0.05, d=-0.348 respectively), and ISO was also greater than CON (d=0.385, p=0.05). Stroke rate was higher for DYN for every 15 seconds split from 0 to 135 seconds (figure 11). No main effect for experience was found (d=0.26, p=0.124).

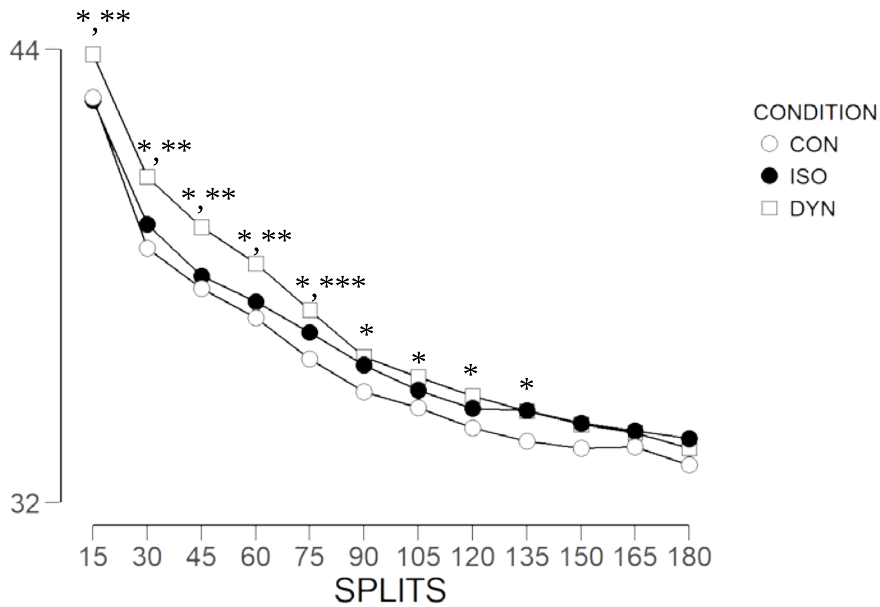

Figure 11: Stroke rate for every 15 seconds splits by testing condition. * DYN>CON; ** DYN>ISO; * ISO>CON**

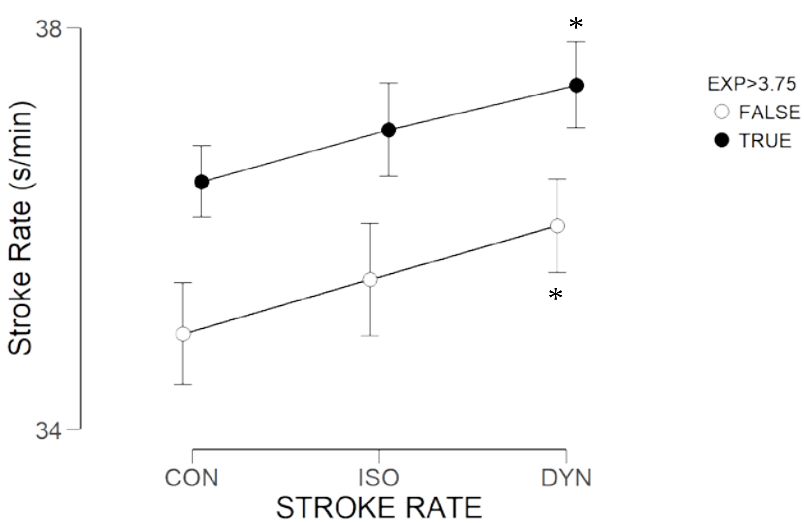

Figure 12: Mean stroke rate by testing condition and experience levels. Black circles represent high experience, and white circles represent low experience. * DYN>CON.

Critical power (CP)

No main effect for condition (F=0.696, p=0.5) or any interactions were found for CP. A main effect for experience was found (d=0.445, p=0.01) with the high experience group being greater than the low experience group (figure 13).

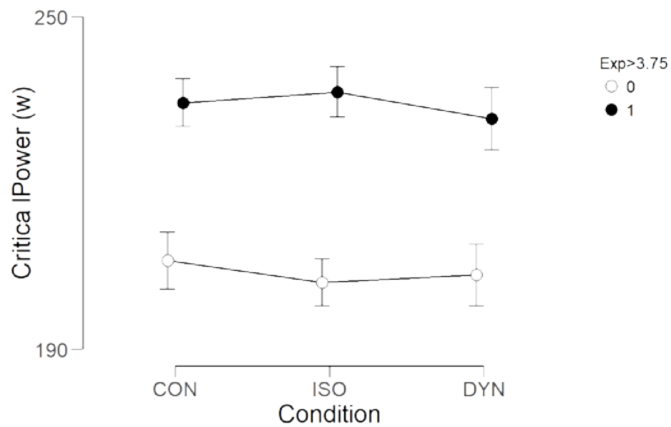

Figure 13: Critical power by condition and experience levels. Black circles represent high experience, and white circles represent low experience.

Anaerobic working capacity (W')

A main effect for condition (F=4.232, p=0.018) was found for W' with DYN being greater than ISO (d=0.434, p=0.037). A condition × experience interaction (F=3.49, p=0.036) was found with the more experienced rowers with DYN being greater than CON (d=0.611, p=0.032) and ISO (d=0.792, p=0.009) and no differences were found between conditions for the less experienced rowers. A main effect for experience was found (d=0.394, p=0.22) with the low experience group being greater than the high experience group (figure 14).

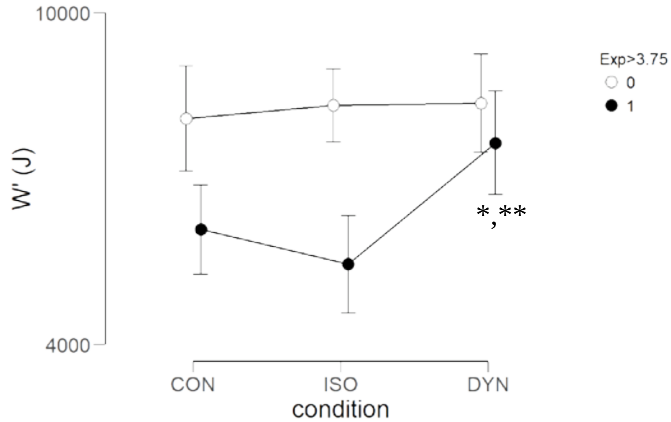

Figure 14: Comparison of W' (J) by testing condition for experience groups. The black circles represent the high experience group, and the white circles represent the low experience group. Error bars represent 95% confidence intervals. * DYN>CON; ** DYN>ISO.

Correlations

Total distance (r=-0.956, p<0.001), CP (r=-0.925, p<0.001), 3MT peak power (r=-0.605, p<0.001) and mean power (r=-0.928, p<0.001) were all negatively correlated with 2000 m performance times. Additionally, peak power in the DYN protocol (i.e., 10 seconds all-out) was negatively correlated with 2000 m performance (r=-0.642, p<0.001), while strength measures were not significantly correlated with 2000 m performance.

Distance covered in the 3MT was significantly positively correlated with CP (r=0.936, p<0.001), 3MT PP (r=0.706, p<0.001), 3MT MP (r=0.992, p<0.001), DYN PP (r=0.634, p<0.001) and with estimated push press 1RM (r=0.432, p=0.04). 3MT MP was significantly correlated with estimated push press 1RM (r=0.436, p=0.037) and DYN PP (r=0.632, p<0.001). Critical power was significantly positively correlated with 3MT PP (r=0.558, p<0.001), 3MT MP (r=0.923, p<0.001), and DYN PP (r=0.544, p<0.001). Anaerobic working capacity (W' in J) was only correlated with 3MT PP (r=0.374, p=0.019).

CHAPTER FIVE: DISCUSSION

The purpose of this study was to compare the effects of isometric and dynamic post-activation potentiation (PAP) protocols on rowing performance, as measured during the three-minute all-out test (3MT), in collegiate female rowers. The primary finding of this investigation was that the dynamic PAP protocol (DYN) improved total distance, mean power and anaerobic work capacity (in joules) for more experienced rowers, while DYN improved mean stroke rate in the 3MT for all participants. Mean power output was also greater in DYN over CON in the first 105 seconds (approximately 500 m) for all participants; however, this difference originated from the high experience group only. The first stated hypothesis was partially supported since only DYN improved rowing performance for some of the participants. Additionally, some benefits were found for all participant, but only in the earlier stages of the trial. The second stated hypothesis was also supported since DYN was more effective than ISO in improving rowing performance.

Isometric Protocol

The current findings somewhat contradict previous studies which showed improved rowing performance following an isometric conditioning activity (CA) (Feros et al., 2012). Feros et al. (2012) used a different performance measurement (i.e., 1000 m time trial versus three-minute all-out test, respectively); however, both trials covered similar distance on average (1000 m versus approximately 800 m in the 3MT, respectively) and were completed within similar timeframes (approximately 172 seconds and 180 seconds, respectively). Neither investigation showed significant improvements over the full distance. Similar results were reported by

Guevara et al. (2018) which used a single set of isometric wall-sits as CA followed by a seven-minute rest interval before a 1000 m rowing time trial. Notably, Feros et al. (2012) reported increased mean power output (6.6%) and stroke rate (5.2%) along with a 1.9% improvement in time to complete the first 500 m, whereas limited changes were observed following the isometric protocol in the current study.

Female Athletes, Strength, and Fatigability

In contrast to the currently utilized sample of female athletes, the participants in the Feros et al., (2012) study were mostly males (nine males and one female), elite level athletes (compared to collegiate level in the current study) with higher VO_2peak (68.7 ± 3.1 vs. 46.1 ± 5.2), and a resistance training background of at least 5 years (no actual strength measures were reported). Additionally, participants were older (24.8 ± 2.6 vs. 20 ± 1.4 years). Although resistance training background information was not recorded in the current study, information about strength levels was gathered from the performance team's training logs (table 4). The information suggested strength levels below those recommended by Seitz and Haff (2016) (i.e., back squat 1RM of 1.5 times the body weight for women) to elicit PAP effects. Future studies should assess the true 1RM of the participants in relevant exercises and at time points that are closer to the intervention.

Several studies investigating power-based as opposed to endurance-based PAP effects have included female participants. While Evetovich et al. (2015) showed enhancements in power-based performance in females, Sygulla and Fountaine (2014) showed no such effect in static squat jumps. A meta-analysis by Wilson et al. (2013) showed a lower effect size for females (ES = 0.20) than males (ES = 0.42); however, this difference was not statistically significant. It is unclear if true sex differences in the PAP response exist or if these differences are simply related to strength levels. In accordance with a review by Tillin and Bishop (2009) and a recent study by Kontou, Berberidou, Pilianidis, Mantzouranis and Methenitis (2018), Seitz and Haff (2016) reported a larger effect size in stronger individuals and those with more resistance training experience, independent of sex.

Further support for the importance of strength and sex differences comes from fatigability studies. While some studies had shown no sex differences in fatigability when men and women were matched for strength or power (Hunter, Critchlow, Shin, & Enoka, 2004a; K. J. Smith & Billaut, 2012), other studies have found contrasting results (Hunter, Critchlow, Shin, & Enoka, 2004b). Females have been shown to be less fatigable and recover faster than males (Hunter, 2014, 2016; Hunter et al., 2004b; Laurent et al., 2010). However, this effect is lessened during dynamic contractions compared to isometric contractions, in high speed contractions compared with lower speed contractions, and in higher intensities compared with medium or low intensities (Hunter, 2014, 2016). If women are less fatigable, then eliciting a meaningful PAP response would require more fatiguing protocols, while a faster recovery response would likely require shorter recovery times. Future studies could use an evoked muscle twitch response before and after the CA to verify the existence of local muscle PAP before performing the performance trial (MacIntosh, 2010).

Since the manifested PAP effect results from the net balance between fatigue and potentiation, the duration of the recovery interval may be crucial. In addition to differences in the study samples, the recovery interval between the CA and the performance measure was longer in the current investigation compared to Feros et al. (2012). The ideal recovery interval changes between individuals, and is probably affected by strength levels and training experience (Seitz et al., 2014; Seitz & Haff, 2016). Considering the variability in responsiveness during the current study, the conclusion from this data is that the PAP protocol should be tailored for each individual according to their own characteristics.

Although the recovery interval in this study was selected based on several meta-analyses, reporting the greatest effect size for rest interval of 5-7 minutes (Dobbs et al., 2018; Gouvêa et al., 2013; Seitz & Haff, 2016; Wilson et al., 2013), it is possible that the recovery time used was not ideal for the intensity of the CAs, the population, or a combination of both factors. If the intensity of the CAs used was not high enough to justify seven minutes of recovery, then the potentiating effect of the CA might have either dissipated before the beginning of the measured performance (i.e., the 3MT), or the CA may not have generated the intended effect. Since high intensities CAs have been shown to elicit greater PAP than lower intensity CAs (Dobbs et al., 2018; Seitz & Haff, 2016), a maximal effort was required in this protocol; however, due to limitations with the available instrumentation such effort was not verified in the current study. Additionally, the participants in this study were not specifically trained in maximal isometric contractions, which could have affected their ability to generate sufficient isometric force to elicit a meaningful PAP response.

Dynamic Protocol

Doma et al., (2016) used a 10-sec maximal dynamic rowing bout as both the CA and the performance outcome, separated by six minutes. While the performance outcome was different from the current study, the recovery intervals were similar, and the peak power achieved early in the 3MT (usually in the first 10 seconds) can be used for the purpose of comparison. There was no significant difference in peak power between the CON and DYN in the current study (d=0.152, p=0.36); however, there was approximately a 5 W difference which was equal to 1.3% (of CON peak power). While not significant, the differences in peak power between CON and DYN (+5 watts or 1.3%) resemble the significant results reported by Doma et al. (2016) which found a 6 w or 1.5% difference.

With respect to mean power output, Doma et al. (2016) also found a significant difference of 2.5% between the two 10-seconds bouts. Mean power during the first 15 seconds in the current investigation was not different between CON and DYN; however, these calculations may have been affected by the inability to calculate power for the first ~4 seconds because the software used did not display this information. Notably, a significant difference was found for DYN over CON for the first 105 seconds (approximately 500 m). This suggests that DYN PAP would be beneficial for the first stages of a rowing trial. The results are similar to previous studies completed with anaerobically trained male cyclists. Doma et al. (2018) found that a 10-second overloaded cycling sprint improved mean power in a subsequent Wingate anaerobic power test, but not peak power (though a trend was noted, p=0.06).

Rowing Experience

The study found DYN to be significantly higher thanCON over the full duration of the 3MT in distance, mean power output and W’ for the more experienced rowers, but not for less experienced rowers, or for the entire sample. Several studies have shown that experienced athletes benefited more from PAP, and found training status to be a modulator of PAP response (Chiu et al., 2003; Gouvêa et al., 2013; Rixon, Lamont, & Bemben, 2007; Seitz & Haff, 2016; Wilson et al., 2013). The more experienced rowers in the current sample may have benefited from additional exposure to structured strength and conditioning programs. A stronger and more experienced athlete would potentially better maintain the balance between fatigue and potentiation; however, no strength data was available for the less experienced group in this study in order to make this comparison. Therefore, future studies should measure strength as a part of the protocol and take strength levels into consideration.

More experienced athletes have been shown to endure pain and discomfort associated with all-out efforts better than inexperienced athletes and non-athletes (Assa, Geva, Zarkh, & Defrin, 2018; Geva & Defrin, 2013; Tesarz, Schuster, Hartmann, Gerhardt, & Eich, 2012). The more experienced group had higher CP values than the less experienced group. Since aerobic capacity was not different between the groups, differences in CP may have been due to other unknown factors, such as mental toughness or pain resistance, which could lead to better endurance performance and possibly a benefit from PAP.

Endurance Efforts

There is a lack of research examining longer duration, endurance efforts as the performance outcome (Boullosa et al., 2018). Similar to findings of Feros et al., (2012), the results from the current study tend to support the notion that the effect of PAP is more prominent in the earlier stages of the performance. While the more experienced rowers demonstrated improved distance, mean power output, and anaerobic working capacity for the full duration of the test (three minutes and approximately 800 meters) following DYN, it seems that the majority of the differences in distance and mean power were accumulated in the first part of the test, as differences between the conditions became smaller and smaller for every 15 seconds interval after peaking. In addition, when analyzing the entire sample, some differences were found in the first 105 seconds for mean power output. However, these differences were not sufficient to create a significant difference over the full trial. Despite providing some support and justification for the use of PAP in longer duration efforts with experienced athletes, further investigations are required to establish whether this method would provide any benefits for longer duration efforts, such as the 2000 m rowing event, which lasts 7-8 minutes for female collegiate rowers. One study examined a longer duration effort with experienced male cyclists and showed potential for such improvements (Silva et al., 2014). The participants performed four sets of 5RM leg press exercises, prior to a 20 km cycling time trial. Results showed a 6.1% ($p<0.05$) improvement in time to complete the distance. Interestingly, the authors also reported a trend ($p=0.06$) of mean power increase in the first 10% of the trial (2k and approximately 3 minutes) but not over the full distance, similar to the current findings. Longer endurance efforts might also be enhanced by prior heavy exercise via different mechanisms than PAP, such as priming , which is a phenomenon in which endurance efforts are enhanced by changes in oxygen uptake kinetics (i.e. earlier engagement of the aerobic energy system) (Bailey, Vanhatalo, Wilkerson, DiMenna, & Jones, 2009; Birnbaumer, Müller, Tschakert, Sattler, & Hofmann, 2018; M. Burnley, Doust, & Jones, 2005; Caritá et al., 2015; Caritá, Greco, & Denadai, 2014; McGowan et al., 2015; Palmer, Jones, Kennedy, & Cotter, 2009).

The proposed mechanism of the PAP phenomenon, phosphorylation of the regulatory myosin light chains, was suggested by Sale (2002) to be beneficial for endurance efforts that are submaximal in nature. The potentiation of the muscle fibers would allow for a greater force output for each muscular contraction for a longer duration at constant submaximal intensities via enhanced efficiency due to decreased motor unit firing rate/frequency. Since the 3MT used in the current study called for a maximal effort for a predetermined duration (i.e., three minutes), it is difficult to address this theory. Since the 3MT was designed to measure CP, which by definition is the highest power output that can be maintained at a steady state without fatigue, it can be argued that when reaching the CP, the athletes are rowing at a submaximal level. However, the CP output is only reached near the end of the test, after the athlete has exercise at maximal or supra-maximal intensities, designed to deplete their anaerobic working capacity (W'). As such, the test requires activation of both higher and lower frequency motor units at different stages of the test.

If higher frequency motor units are engaged, PAP may not compensate for this type of fatigue, and force output would be decreased. However, speed of contraction and rate of force development could be increased for these motor units, thereby increasing power output (Sale, 2002). As the test continues and high frequency fatigue sets in, the athlete must use their low threshold motor units, in which PAP is more prominent, thereby delaying fatigue (Sale, 2002). The first part of this theory was not supported by the results since peak power did not increase following both PAP protocols, which is in contrast to findings by Doma et al., (2016). However, mean power output did increase for experienced rowers following DYN, suggesting these rowers could maintain submaximal intensities for a longer duration. It is possible that the PAP effects from DYN offset the low frequency fatigue, as suggested by Sale (2002). Sale (2002) also suggested that repeated contractions during endurance efforts themselves serve as CA and elicit PAP. This was supported in a study by Del Rosso et al., (2016) during which an increased vertical jump values were shown during different stages of a 30 km run, indicating that the muscular contractions from the run itself created a PAP effect. This may explain why small differences are found between CON and the two PAP protocols. If the endurance effort itself produces PAP, then this should occur for both the control condition and the CAs, with little added benefits for the later stages of the effort.

Critical Power and Anaerobic Work Capacity

The 3MT used in this study was previously used to evaluate critical power (CP) and anaerobic working capacity (W') in cycling (Mark Burnley, Doust, & Vanhatalo, 2006; Vanhatalo et al., 2007; Vanhatalo, Doust, & Burnley, 2008) and rowing (Cheng et al., 2012). While CP is the highest work rate that can be sustained at a steady state without fatigue, it has been suggested that W' is fixed and finite, indicating individual tolerance to exercise in the severe intensity domain above CP (A. M. Jones & Vanhatalo, 2017). Various factors have been proposed to explain the mechanism behind W'. Although the use of the term 'anaerobic' suggests that W' is related to substrate availability, this may be an oversimplification, as other possible explanations exist (A. M. Jones et al., 2010). Interestingly, changes in CP are inversely related to changes in W' and the two seem to be dependent, or at least related, to each other. Therefore, these variables cannot be perceived as independent aerobic and anaerobic entities (A. M. Jones et al., 2010). For example, endurance training, as well as hyperoxic environment, increased CP but at the same time reduced W' (D. G. Jenkins & Quigley, 1992; Vanhatalo et al., 2008; Vanhatalo, Fulford, DiMenna, & Jones, 2010). W' was reduced by glycogen depletion (Miura, Sato, Sato, hipp, & Fukuba, 2000) and increased after short term sprint-interval training (D. G. Jenkins & Quigley, 1993) and creatine supplementation (Miura et al., 1999; J. C. Smith, Stephens, Hall, Jackson, & Earnest, 1998); However, the magnitude of W' might also be related to the accumulation of fatigue-induced metabolites (e.g., H^+ and P_i) (Fitts, 1994).

The results from this study showed no change in CP and an increase in W' following DYN, for experienced rowers only. Since CP is a highly related to aerobic capacity, it was not expected to change following the interventions. It can be argued that the magnitude of change in W' simply increased due to the increase in mean power in the first stages of the test. Such an increase could originate from the PAP intervention by increasing the rate of force development in the muscular level. W' has also been shown to increase following six minutes of heavy-intensity exercise (A. Jones, Wilkerson, Burnley, & Koppo, 2003), potentially due to a priming effect via changes in oxygen uptake kinetics and energy system contribution (i.e., greater contribution of the oxidative system). However, this is speculative and may not be the case in the current study since the nature of the CA was short in duration.

Modulating Factors

PAP response is apparently affected by various factors such as strength, training status, recovery interval, contraction type, fiber type composition, intensity and volume of the CA, etc. (Dobbs et al., 2018; Rixon et al., 2007; Seitz & Haff, 2016; Wilson et al., 2013) A meta-analysis by Seitz and Haff (2016) analyzed modulating factors by strength levels. Results showed several differences between stronger and weaker individuals. For example, the stronger individuals showed a larger effect size for high intensity CA while weaker individuals benefited more from sub-maximal CAs. Similarly, stronger individuals benefited more from a rest interval of 5-7 minutes while the weaker individuals showed the greatest effect size for rest intervals of eight minutes or more. Therefore, PAP interventions should either be individually designed or the sample studied should be homogeneous enough to benefit from a single intervention. Considering the above, “non-responders” to PAP may simply be a result of implementing a non-ideal intervention for the population investigated, meaning, they simply “did not respond” to the specific intervention used, and might respond to a different intervention (Pickering & Kiely, 2018). However, drawing conclusions based upon the aforementioned meta-analysis should be taken with caution since it has only examined studies relating to power-based performance outcomes (i.e., jumping, sprinting and throwing) rather than endurance-based performance, such as the 3MT evaluated during the current investigation.

Potential Limitations

The use of experienced collegiate athletes as participants presented some limitations to the study, primarily due to scheduling and limiting the impact on training loads. The study had to be conducted within a narrow time window shortly after the athletes came back to training after a month-long winter break. The testing days had to be scheduled 48 hours apart, while the athletes were still training with the team, which could have caused accumulated fatigue. The potential ability of the more experienced athletes to recover faster and tolerate the training loads better compared to less experienced athletes, both after the break and in general, may have contributed to the observed differences.

Due to equipment limitations, we did not measure the existence of muscle twitch PAP before the performance. Therefore, we can only assume that perceived performance improvements were due to PAP elicited from the intervention. Additionally, the force produced in ISO was not measured, as it would have been with an isometric mid-thigh pull, for example. A potential limitation that exists in every study that requires maximal effort is motivation. However, the presence of peer teammates and the strong verbal encouragement given, as well as the fact that the participants were competitive athletes, decreased the probability for the occurrence of this issue. The use of a subjective rating of perceived exertion (RPE) scale to assess the intensity of the intervention and performance might be useful for future studies.

Practical Applications

This investigation found both statistically significant and practical differences for the DYN PAP protocol in improving total distance, mean power output and anaerobic rowing capacity in experienced female rowers. A 5.6 m difference over a three-minute rowing bout may translate to valuable results over the duration of a competitive race. Additionally, the DYN PAP protocol could be easily implemented in the natural environment of the rowers by completing short, all-out bouts on rowing ergometers or in the boat on water prior to racing. The use of this equipment saves the need for heavy and cumbersome resistance training equipment which is commonly used to elicit PAP. This intervention may serve as a simple, low-risk, cost-effective method to improve rowing performance. However, it is important to note that this investigation used a fixed-duration trial, as opposed to a fixed-distance trial, which is typically used during official rowing competitions. Additionally, the distance covered in this investigation was approximately 800 m and lasted three minutes, as opposed to 2000 m and approximately 7:30 min during these competitive events.

Considering the high correlations found between personal record individual 2000 m indoor rowing times and CP and distance covered during the 3MT, the 3MT used in the investigation could be a useful tool for coaches when a shorter test is needed for screening athletes.

Conclusions and Future Studies

Our results showed that DYN increased distance, mean power and W' for experienced collegiate female rowers. Additionally, Mean power increased in the first 105s (~500 m), and stroke rate increased for rowers of all experience levels. This study supports the use of PAP in short-duration endurance-based efforts and adds to the limited body of knowledge in that area, particularly with female athletes. Since rowing experience was shown to be a significant modulator of the PAP response, future studies should try to identify the mechanism behind this effect. In that regard, psychological measure (e.g., mental toughness questionnaire) could be used as part of the effort to identify differences between experienced and inexperienced athletes. Finally, future studies should also try to implement a more personalized protocol for each athlete to maximize the effects of PAP, and identify modulating factors for PAP in endurance efforts.

APPENDIX A: APPROVAL LETTER

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **David Fukuda** and Co-PI: **Idan Harat**

Date: **November 20, 2018**

Dear Researcher:

On 11/20/2018 the IRB approved the following human participant research until 11/19/2019 inclusive:

Type of Review:	UCF Initial Review Submission Form Expedited Review
Project Title:	The Effects of Isometric versus Dynamic Postactivation Potentiation Protocols on Rowing Performance in Female Collegiate Rowers
Investigator:	David Fukuda
IRB Number:	SBE-18-14520
Funding Agency:	
Grant Title:	
Research ID:	N / A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30 days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 11/19/2019, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

This letter is signed by:

Signature applied by Racine Jacques on 11/20/2018 02:15:47 PM EST

Designated Reviewer

APPENDIX B: GENERAL WARM UP

Rowing PAP General Warm-Up

- 5 min sub-max erg (power at 125-175). No sprints or all out strokes allowed.
- Knee hugs alternating x 10
- Quad stretch alternating x 10
- World's greatest stretch alternating x 6 (3 each side)
- Open the gate x 10
- Close the gate x 10
- Arm circles x 10
- Arm swings x 10
- Forward leg swings x 5 each leg
- Side leg swings x 5 each leg
- Squats x 10
- Lunges with twist x 10 (5 each leg)
- Push ups to cobra x 5
- 10 min sub-max erg (power at 125-175). No sprints or all out strokes allowed.

APPENDIX C: CONSENT FORM

The Effects of Isometric versus Dynamic Postactivation Potentiation Protocols on Rowing Performance in Female Collegiate Rowers

Informed Consent

Principal Investigator: David Fukuda, Ph.D.

Co-Investigator: Idan Harat, B.A

Sub-Investigators: Michael J. Redd, Ph.D.
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College of Health Professions and Sciences
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IRB EXPIRATION DATE: 11/19/2019

Why am I being invited to take part in a research study?

We invite you to take part in a research study because you are part of UCF's collegiate women's rowing team.

You must be between the ages of 18 and 35, a woman, be a part of the rowing team and able to perform high intensity physical activity to participate in this study.

What should I know about a research study?

- Someone will explain this research study to you.
- Whether or not you take part is up to you.
- You can choose not to take part.
- You can agree to take part and later change your mind.
- Your decision will not be held against you.
- You can ask all the questions you want before you decide.

Who can I talk to?

If you have questions, concerns, or complaints, or think the research has hurt you, talk to Mr. Idan Harat, Co-Investigator, (407) 823-2367, idanharat@knights.ucf.edu or Dr. David Fukuda, Principal Investigator, (407) 823-0442, David.fukuda@ucf.edu.

This research has been reviewed and approved by an Institutional Review Board ("IRB"). You may talk to them at 407-823-2901or irb@ucf.edu if:

- Your questions, concerns, or complaints are not being answered by the research team.
- You cannot reach the research team.
- You want to talk to someone besides the research team.
- You have questions about your rights as a research subject.
- You want to get information or provide input about this research.

Why is this research being done?

Post-activation potentiation (PAP) is a way to acutely increase performance by performing high intensity exercise prior to the main performance. For example, a set of heavy squats can increase subsequent vertical jump height or improve sprint performance. In rowing, isometric and dynamic potentiating activities were shown to improve some aspects of subsequent rowing performance. However, these studies have evaluated only a single PAP protocol at a time and used different performance measures (1000 m and 10 second all-out effort). The differences of existing PAP research methodologies within the sport of rowing make it difficult to compare protocols between studies.

Therefore, the purpose of this study is to evaluate and compare the effects of isometric versus dynamic PAP protocols on rowing performance of collegiate rowers.

How long will the research last?

We expect that you will be in this research study for 6 testing days (a screening and consent visit and an additional 5 testing visits). Testing visits should be interspersed by at least 48 hours.

How many people will be studied?

We expect a minimum of 20 people will be in this research study and a maximum of 50.

What happens if I say yes, I want to be in this research?

- Complete the Physical Activity Readiness Questionnaire (PAR-Q+) and Medical History Questionnaire.
- Read and sign this study Informed Consent Form.
- Following enrollment into the study you will report to the testing location on five additional occasions. All testing visit will be in the presence of the study investigators. Some or all of the visits may be held in a group settings. If a testing session takes place in the boathouse, a member of the coaching staff will be there to provide access to the facility.
- Testing location for each testing day may be either in the Strength and Conditioning Laboratory or the rowing team's training facility. The location will depend on scheduling and availability.
- On your next visit (T2), you will be assessed for anthropometric measures and be familiarized with further testing procedures (PAP protocols and 3-min all-out test). For this visit you should be two hours fasted.
- Anthropometric measures that will be assessed are height, weight, leg length and body composition. Additional information required is your age, strength training and rowing experience, best 2000 m performance times and maximal strength data (1RM in relevant exercises). This information will be obtained from the team's coaching staff.
- Body composition and weight will be assessed using bioelectrical impedance analysis. You will be asked to remove your footwear, including socks, and wear only light athletic attire. Then you will be asked to stand on a platform while holding two handles out to the side. You will hold this position as the bioelectrical impedance analysis sends a minute electrical current (that is safe and cannot be seen or felt) through the body to determine body composition. There are no risks or discomforts associated with the use of bioelectrical impedance analysis.
- During the third visit (T3) you will be assessed for your maximal 3-minute all-out test (3MT). This visit will take place in the rowing team's training facility in a group setting.
    - The 3MT requires you to row with maximal stroke rate and power output for 3 minutes without pacing. The ergometer's damper will be set to the highest setting. Additionally, the ergometer's monitor screen will be covered and no information will be given to you while rowing.
- The next two visits (T4 and T5) will assess the PAP protocols and will be done in the team's training facility. After a warm up (10 minutes on the erg and dynamic stretching), you will perform either the dynamic or the isometric PAP protocol in a randomized fashion. After seven minutes of rest, you will perform the 3MT. If you performed the dynamic protocol on T4 then you will perform the isometric protocol on T5, and vice versa.
- The isometric PAP protocol consists of 5 sets of isometric contraction on the rowing ergometer. The handle of the ergometer will be fixed by using a non-flexible strap tied around the body of the ergometer. The strap's length will be adjusted so that you will be seated upright with your knees bent approximately to 110 degrees (180 degrees is when the knees are fully extended). Each set of isometric contractions will begin with two seconds of gradually increasing force immediately followed by 3 seconds of maximal contraction. Sets will be separated by 15-second recovery intervals.
- The dynamic PAP protocol is comprised of two sets of 10-second all-out rowing bouts, separated by two-minute rest intervals.
- On the final visit (T6) you will be assessed for maximal aerobic capacity (VO_2max).
- Maximal aerobic capacity test is a graded exercise rowing test to assess aerobic abilities. In this test you will be rowing on a rowing ergometer while wearing a mask covering your mouth and nose to sample expired oxygen. The mask will be connected to a small portable gas analyzer which will be mounted on a wearable harness. Additionally, you will be fitted with a heart rate monitor (a light flexible strap that is wrapped around the body, just under the chest). You will

be asked to row at an increasing power output until volitional exhaustion or until you cannot keep up with the required power.

- We estimate that no visit will exceed 60 minutes.

T1	T2		T3		T4		T5		T6
Informed consent	Anthropometrics Familiarization	48 hrs	3MT	48 hrs	ISO\DYN 3MT	48 hrs	ISO\DYN 3MT	48 hrs	VO_2max
30 min	30 min		30 min		60 min		60 min		30 min

What happens if I do not want to be in this research?

Participation in research is completely voluntary. You can decide to participate or not to participate. Your participation in this study is voluntary. You are free to withdraw your consent and discontinue participation in this study at any time without prejudice or penalty. Your decision to participate or not participate in this study will in no way affect your continued enrollment, grades, employment or your relationship with the individuals who may have an interest in this study.

What happens if I say yes, but I change my mind later?

You can leave the research at any time and it will not be held against you. If at any time during the study you do not wish to continue, you are encouraged to inform the researcher. Discontinuation of participation may occur at any time. You have the right to discontinue participation without penalty, regardless of the status of the study. Data obtained until the point of withdrawal may or may not be used in the final analysis.

Is there any way being in this study could be bad for me?

High intensity physical exercise may present a risk of musculoskeletal injuries (e.g muscle strains) and temporary discomfort from perceived effort. Additionally, you may feel temporary nausea from maximal effort exercises. Rise in heart rate and blood pressure associated with exercise may also occur. After completion of these tests you may experience feelings of muscle soreness and fatigue which are a normal outcome of physical exercise.

Participants' physical risks will be minimized by having each testing session conducted by qualified investigators. All testing procedures will be done in a controlled manner in the presence of certified strength and conditioning and basic life support personnel.

Will being in this study help me in any way?

We cannot promise any benefits to you or others from your taking part in this research. However, possible benefits include gaining information about your cardiovascular endurance and body composition. Additionally, you may gain information that could benefit your training regimen towards your primary sport.

What happens to the information collected for the research?

Efforts will be made to limit the use and disclosure of your personal information, including research study records, to people who have a need to review this information. We cannot promise complete secrecy. Organizations that may inspect and copy your information include the IRB and other representatives of this organization. Individual results may be shared with your coaches upon their request.

Can I be removed from the research without my OK?

The person in charge of the research study can remove you from the research study without your approval. Possible reasons for removal include inability to follow the study protocol.

What else do I need to know?

If you need medical care because of taking part in this research study, contact the investigator and medical care will be made available. Generally, this care will be billed to you, your insurance, or other third party. The University of Central Florida has no program to pay for medical care for research-related injury.

Taking part in this research study may lead to added costs to you. In the event that you do not have a valid permit to park on UCF's main campus, you may need to pay for a temporary parking pass for testing visits. Garage parking costs are $3-$5/day for visitors.

Your signature documents your permission to take part in this research.

Signature of subject	Date
Printed name of subject	
Signature of person obtaining consent	Date
Printed name of person obtaining consent	
Printed name of person witnessing consent process	

APPENDIX D: PAR-Q

2017 PAR-Q+

The Physical Activity Readiness Questionnaire for Everyone

The health benefits of regular physical activity are clear; more people should engage in physical activity every day of the week. Participating in physical activity is very safe for MOST people. This questionnaire will tell you whether it is necessary for you to seek further advice from your doctor OR a qualified exercise professional before becoming more physically active.

GENERAL HEALTH QUESTIONS

Please read the 7 questions below carefully and answer each one honestly: check YES or NO.	YES	NO
1) Has your doctor ever said that you have a heart condition ☐ OR high blood pressure ☐?	☐	☐
2) Do you feel pain in your chest at rest, during your daily activities of living, **OR** when you do physical activity?	☐	☐
3) Do you lose balance because of dizziness **OR** have you lost consciousness in the last 12 months? Please answer **NO** if your dizziness was associated with over-breathing (including during vigorous exercise).	☐	☐
4) Have you ever been diagnosed with another chronic medical condition (other than heart disease or high blood pressure)? **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
5) Are you currently taking prescribed medications for a chronic medical condition? **PLEASE LIST CONDITION(S) AND MEDICATIONS HERE:** ______	☐	☐
6) Do you currently have (or have had within the past 12 months) a bone, joint, or soft tissue (muscle, ligament, or tendon) problem that could be made worse by becoming more physically active? Please answer **NO** if you had a problem in the past, but it ***does not limit your current ability*** to be physically active. **PLEASE LIST CONDITION(S) HERE:** ______	☐	☐
7) Has your doctor ever said that you should only do medically supervised physical activity?	☐	☐

If you answered NO to all of the questions above, you are cleared for physical activity.
Go to Page 4 to sign the PARTICIPANT DECLARATION. You do not need to complete Pages 2 and 3.

- Start becoming much more physically active – start slowly and build up gradually.
- Follow International Physical Activity Guidelines for your age (www.who.int/dietphysicalactivity/en/).
- You may take part in a health and fitness appraisal.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.
- If you have any further questions, contact a qualified exercise professional.

If you answered YES to one or more of the questions above, COMPLETE PAGES 2 AND 3.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ at **www.eparmedx.com** before becoming more physically active.
- Your health changes - answer the questions on Pages 2 and 3 of this document and/or talk to your doctor or a qualified exercise professional before continuing with any physical activity program.

2017 PAR-Q+

FOLLOW-UP QUESTIONS ABOUT YOUR MEDICAL CONDITION(S)

1.	**Do you have Arthritis, Osteoporosis, or Back Problems?** If the above condition(s) is/are present, answer questions 1a-1c	If **NO** ☐ go to question 2
1a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
1b.	Do you have joint problems causing pain, a recent fracture or fracture caused by osteoporosis or cancer, displaced vertebra (e.g., spondylolisthesis), and/or spondylolysis/pars defect (a crack in the bony ring on the back of the spinal column)?	**YES** ☐ **NO** ☐
1c.	Have you had steroid injections or taken steroid tablets regularly for more than 3 months?	**YES** ☐ **NO** ☐
2.	**Do you currently have Cancer of any kind?** If the above condition(s) is/are present, answer questions 2a-2b	If **NO** ☐ go to question 3
2a.	Does your cancer diagnosis include any of the following types: lung/bronchogenic, multiple myeloma (cancer of plasma cells), head, and/or neck?	**YES** ☐ **NO** ☐
2b.	Are you currently receiving cancer therapy (such as chemotheraphy or radiotherapy)?	**YES** ☐ **NO** ☐
3.	**Do you have a Heart or Cardiovascular Condition?** *This includes Coronary Artery Disease, Heart Failure, Diagnosed Abnormality of Heart Rhythm* If the above condition(s) is/are present, answer questions 3a-3d	If **NO** ☐ go to question 4
3a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
3b.	Do you have an irregular heart beat that requires medical management? (e.g., atrial fibrillation, premature ventricular contraction)	**YES** ☐ **NO** ☐
3c.	Do you have chronic heart failure?	**YES** ☐ **NO** ☐
3d.	Do you have diagnosed coronary artery (cardiovascular) disease and have not participated in regular physical activity in the last 2 months?	**YES** ☐ **NO** ☐
4.	**Do you have High Blood Pressure?** If the above condition(s) is/are present, answer questions 4a-4b	If **NO** ☐ go to question 5
4a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	**YES** ☐ **NO** ☐
4b.	Do you have a resting blood pressure equal to or greater than 160/90 mmHg with or without medication? (Answer **YES** if you do not know your resting blood pressure)	**YES** ☐ **NO** ☐
5.	**Do you have any Metabolic Conditions?** *This includes Type 1 Diabetes, Type 2 Diabetes, Pre-Diabetes* If the above condition(s) is/are present, answer questions 5a-5e	If **NO** ☐ go to question 6
5a.	Do you often have difficulty controlling your blood sugar levels with foods, medications, or other physician-prescribed therapies?	**YES** ☐ **NO** ☐
5b.	Do you often suffer from signs and symptoms of low blood sugar (hypoglycemia) following exercise and/or during activities of daily living? Signs of hypoglycemia may include shakiness, nervousness, unusual irritability, abnormal sweating, dizziness or light-headedness, mental confusion, difficulty speaking, weakness, or sleepiness.	**YES** ☐ **NO** ☐
5c.	Do you have any signs or symptoms of diabetes complications such as heart or vascular disease and/or complications affecting your eyes, kidneys, **OR** the sensation in your toes and feet?	**YES** ☐ **NO** ☐
5d.	Do you have other metabolic conditions (such as current pregnancy-related diabetes, chronic kidney disease, or liver problems)?	**YES** ☐ **NO** ☐
5e.	Are you planning to engage in what for you is unusually high (or vigorous) intensity exercise in the near future?	**YES** ☐ **NO** ☐

2017 PAR-Q+

6. Do you have any Mental Health Problems or Learning Difficulties? *This includes Alzheimer's, Dementia, Depression, Anxiety Disorder, Eating Disorder, Psychotic Disorder, Intellectual Disability, Down Syndrome*

If the above condition(s) is/are present, answer questions 6a-6b — If **NO** ☐ go to question 7

6a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
6b.	Do you have Down Syndrome **AND** back problems affecting nerves or muscles?	YES ☐ NO ☐

7. Do you have a Respiratory Disease? *This includes Chronic Obstructive Pulmonary Disease, Asthma, Pulmonary High Blood Pressure*

If the above condition(s) is/are present, answer questions 7a-7d — If **NO** ☐ go to question 8

7a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
7b.	Has your doctor ever said your blood oxygen level is low at rest or during exercise and/or that you require supplemental oxygen therapy?	YES ☐ NO ☐
7c.	If asthmatic, do you currently have symptoms of chest tightness, wheezing, laboured breathing, consistent cough (more than 2 days/week), or have you used your rescue medication more than twice in the last week?	YES ☐ NO ☐
7d.	Has your doctor ever said you have high blood pressure in the blood vessels of your lungs?	YES ☐ NO ☐

8. Do you have a Spinal Cord Injury? *This includes Tetraplegia and Paraplegia*

If the above condition(s) is/are present, answer questions 8a-8c — If **NO** ☐ go to question 9

8a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
8b.	Do you commonly exhibit low resting blood pressure significant enough to cause dizziness, light-headedness, and/or fainting?	YES ☐ NO ☐
8c.	Has your physician indicated that you exhibit sudden bouts of high blood pressure (known as Autonomic Dysreflexia)?	YES ☐ NO ☐

9. Have you had a Stroke? *This includes Transient Ischemic Attack (TIA) or Cerebrovascular Event*

If the above condition(s) is/are present, answer questions 9a-9c — If **NO** ☐ go to question 10

9a.	Do you have difficulty controlling your condition with medications or other physician-prescribed therapies? (Answer **NO** if you are not currently taking medications or other treatments)	YES ☐ NO ☐
9b.	Do you have any impairment in walking or mobility?	YES ☐ NO ☐
9c.	Have you experienced a stroke or impairment in nerves or muscles in the past 6 months?	YES ☐ NO ☐

10. Do you have any other medical condition not listed above or do you have two or more medical conditions?

If you have other medical conditions, answer questions 10a-10c — If **NO** ☐ read the Page 4 recommendations

10a.	Have you experienced a blackout, fainted, or lost consciousness as a result of a head injury within the last 12 months **OR** have you had a diagnosed concussion within the last 12 months?	YES ☐ NO ☐
10b.	Do you have a medical condition that is not listed (such as epilepsy, neurological conditions, kidney problems)?	YES ☐ NO ☐
10c.	Do you currently live with two or more medical conditions?	YES ☐ NO ☐

PLEASE LIST YOUR MEDICAL CONDITION(S) AND ANY RELATED MEDICATIONS HERE: ______________________

____

GO to Page 4 for recommendations about your current medical condition(s) and sign the PARTICIPANT DECLARATION.

2017 PAR-Q+

If you answered NO to all of the follow-up questions about your medical condition, you are ready to become more physically active - sign the PARTICIPANT DECLARATION below:

- It is advised that you consult a qualified exercise professional to help you develop a safe and effective physical activity plan to meet your health needs.
- You are encouraged to start slowly and build up gradually - 20 to 60 minutes of low to moderate intensity exercise, 3-5 days per week including aerobic and muscle strengthening exercises.
- As you progress, you should aim to accumulate 150 minutes or more of moderate intensity physical activity per week.
- If you are over the age of 45 yr and **NOT** accustomed to regular vigorous to maximal effort exercise, consult a qualified exercise professional before engaging in this intensity of exercise.

If you answered **YES** to **one or more of the follow-up questions** about your medical condition:

You should seek further information before becoming more physically active or engaging in a fitness appraisal. You should complete the specially designed online screening and exercise recommendations program - the **ePARmed-X+ at www.eparmedx.com** and/or visit a qualified exercise professional to work through the ePARmed-X+ and for further information.

Delay becoming more active if:

- You have a temporary illness such as a cold or fever; it is best to wait until you feel better.
- You are pregnant - talk to your health care practitioner, your physician, a qualified exercise professional, and/or complete the ePARmed-X+ **at www.eparmedx.com** before becoming more physically active.
- Your health changes - talk to your doctor or qualified exercise professional before continuing with any physical activity program.

- You are encouraged to photocopy the PAR-Q+. You must use the entire questionnaire and NO changes are permitted.
- The authors, the PAR-Q+ Collaboration, partner organizations, and their agents assume no liability for persons who undertake physical activity and/or make use of the PAR-Q+ or ePARmed-X+. If in doubt after completing the questionnaire, consult your doctor prior to physical activity.

PARTICIPANT DECLARATION

- All persons who have completed the PAR-Q+ please read and sign the declaration below.
- If you are less than the legal age required for consent or require the assent of a care provider, your parent, guardian or care provider must also sign this form.

I, the undersigned, have read, understood to my full satisfaction and completed this questionnaire. I acknowledge that this physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if my condition changes. I also acknowledge that a Trustee (such as my employer, community/fitness centre, health care provider, or other designate) may retain a copy of this form for their records. In these instances, the Trustee will be required to adhere to local, national, and international guidelines regarding the storage of personal health information ensuring that the Trustee maintains the privacy of the information and does not misuse or wrongfully disclose such information.

PARTICIPANT ID______________________________ DATE ______________________________

SIGNATURE OF PARENT/GUARDIAN/CARE PROVIDER ______________________________

For more information, please contact
www.eparmedx.com
Email: eparmedx@gmail.com

Citation for PAR-Q+
Warburton DER, Jamnik VK, Bredin SSD, and Gledhill N on behalf of the PAR-Q+ Collaboration. The Physical Activity Readiness Questionnaire for Everyone (PAR-Q+) and Electronic Physical Activity Readiness Medical Examination (ePARmed-X+). Health & Fitness Journal of Canada 4(2):3-23, 2011.

The PAR-Q+ was created using the evidence-based AGREE process (1) by the PAR-Q+ Collaboration chaired by Dr. Darren E. R. Warburton with Dr. Norman Gledhill, Dr. Veronica Jamnik, and Dr. Donald C. McKenzie (2). Production of this document has been made possible through financial contributions from the Public Health Agency of Canada and the BC Ministry of Health Services. The views expressed herein do not necessarily represent the views of the Public Health Agency of Canada or the BC Ministry of Health Services.

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01-01-2017

APPENDIX E: MEDICAL HISTORY QUESTIONNAIRE

Confidential Medical History Questionnaire

Subject #__________

When was your last physical examination? ______________________________

1. **List any prescription medications you currently take or have taken in the last month**:

Medication | Reason for medication

________________________ ____

________________________ ____

________________________ ____

________________________ ____

2. **Are you allergic to any medications? If yes, please list medications and reaction**.

____
____
____
____

3. **Please list any other allergies – including food allergies – that you may have.**

____
____
____
____

4. **Have you ever been hospitalized? If yes, please explain**.

Year of hospitalization   Reason

____________________ ____

____________________ ____

____________________ ____

5. **Please list any chronic (long-term) illnesses that have caused you to seek medical care.**

____
____
____
____
____
____
____

From the list below, please indicate if you have had (or currently have/are experiencing):

Anorexia nervosa or bulimia	Yes	No
Diabetes mellitus or insipidus	Yes	No
Hypoglycemia	Yes	No
Amenorrhea	Yes	No
Menopause	Yes	No
Anemia	Yes	No
Sickle cell anemia	Yes	No
Cystic fibrosis	Yes	No
Water retention problems	Yes	No
Gastrointestinal disorder	Yes	No
Heart pacemaker	Yes	No
Epilepsy/convulsions/seizures	Yes	No

Dizziness/fainting/unconsciousness	Yes	No
Asthma	Yes	No
Shortness of breath	Yes	No
Emphysema or chronic respiratory disorder	Yes	No
Chronic headaches	Yes	No
Bronchitis or chronic cough	Yes	No
Chronic sinus problem	Yes	No
High blood pressure	Yes	No
Heart murmur	Yes	No
High cholesterol	Yes	No
Rheumatic fever	Yes	No
Hepatitis	Yes	No
Kidney disease	Yes	No
Bladder problems	Yes	No
Tuberculosis (positive skin test)	Yes	No
Jaundice	Yes	No
Auto immune deficiency	Yes	No
Endotoxemia	Yes	No
Thyroid disorders	Yes	No
Hyperprolactinemia	Yes	No
Arthritis	Yes	No
Hepatic encephalopathy	Yes	No
Mania/hypermania	Yes	No

Any others (please specify below):

____

____

Do you smoke cigarettes or use any other tobacco product?	Yes	No
Do you use alcohol?		
If 'Yes', how much & how often?	Yes	No

____

Do you use caffeine?		
If 'Yes', how much & how often?	Yes	No

____

Do you have a history of drug or alcohol dependency?	Yes	No
Are you pregnant?	Yes	No
Is there a chance that you may be pregnant?	Yes	No

For women: When was the first day of your last period?

Do you ever have any pain in your chest?	Yes	No
Are you ever bothered by racing of your heart?	Yes	No
Do you ever notice abnormal or skipped heartbeats?	Yes	No
Do you ever have any arm or jaw discomfort, nausea, or vomiting associated with cardiac symptoms?	Yes	No
Do you ever have difficulty breathing?	Yes	No
Have you ever had tingling or numbness in your arms or legs?	Yes	No
Has a member of your immediate family died of a heart problem or sudden death before the age of 50?	Yes	No
Has a health care provider ever denied or restricted your participation in sports for any problem?	Yes	No

If 'Yes', please explain below:

____

____

____

Are you presently taking any nutritional supplements or ergogenic aids?	Yes	No

If 'Yes', please provide details in the space below:

____

____

____

Have you had any recent injuries or surgeries that might prevent you from performing high intensity, all-out physical exercises? *Please specify below:* Yes No

____

____

____

APPENDIX F: FIGURE USE APPROVAL LETTER

WOLTERS KLUWER HEALTH, INC. LICENSE
TERMS AND CONDITIONS

Mar 20, 2019

This Agreement between Mr. Idan Harat ("You") and Wolters Kluwer Health, Inc. ("Wolters Kluwer Health, Inc.") consists of your license details and the terms and conditions provided by Wolters Kluwer Health, Inc. and Copyright Clearance Center.

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