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Acute Effects of Complex Training Using Three Different Intracomplex Rest Intervals on Power Output in Recreationally Trained College Students

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Acute Effects of Complex training Using Three Different Intracomplex Rest Intervals on Power Output in Recreationally Trained College Students

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Dedication

This thesis is dedicated to my mom, my dad, and my brother. My family has been a consistent source of overwhelming support, patience, and love for me during this long and, at times, grueling journey. Not only during my academic career, but throughout my entire life, my family has always been by my side. I have grown as a leader, a scholar, a professional, and most importantly, as a human because of them. I am often "in over my head" when I take on big challenges like this degree. At times when I doubt myself the most, my family is right there to encourage, motivate, and provide me with guidance. They have seen me struggle, cry, laugh, and embrace, all the different challenges and obstacles I've faced in my 25-year journey around the sun. I am beyond fortunate to call them family and I savor each and every moment I share with them.

I know they will not read any of this thesis.

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Thank you again to my mom, my dad, and my brother. If you have read this far into the paper, this is just another area where I cannot verbalize the sheer amount of gratitude I feel for the constant love and support I receive from you all.

Abstract

Power is often referred to as explosiveness and is viewed as essential for many athletes within a wide range of sports. Power in sports is important in relation to its foundation in other specific abilities like first step-quickness, acceleration, and reaching top speeds (Cronin, Hansen, 2005). This research study examines the acute effects of complex training using three different intracomplex rest intervals (ICRI) on power output in recreationally trained college students. The goal of this study was to find the optimal ICRI for complex training (CT) by completing a countermovement jump on a force plate after a 3-RM back squat through the physiological process of post-activation potentiation (PAP). Power output was measured via Vertical Impulse (BW•s). Sixteen West Chester University students performed one baseline session and 3 experimental sessions. The experimental ICRI's that were tested were 1-minute, 2-minutes, and 4-minutes. Vertical Impulse (BW•s) data was measure and analyzed using a force plate and Bioware software. Results of the study revealed that the mean peak Vertical Impulse (BW•s) measured in units of BW•s of all three experimental sessions (1-minute = 3.241 BW•s, 2-minute = 3.394 BW•s, 4-minute = 3.556 BW•s) was significantly less than the baseline session (baseline = 4.183 BW•s). While our study was not able to determine an optimal ICRI, and more research is needed in this specific area, the results were in alignment with previous research reporting a diminished effect of complex training on less trained individuals.

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Chapter 1: Introduction

Since the dawn of competitive sports, humans have been searching for new and innovative methods to become faster, stronger, and overall more powerful. Strength and conditioning based training for athletics has been universally accepted as a method that can give athletes an advantage against their opponents. While many attributes are important for success in athletics and can be improved with a strength and conditioning program, power is critical to success in most sports and thus should be emphasized (Baker 2003). One recent training technique to optimize power output in training is known as Complex training (CT). Complex training is established on the physiological concept of post-activation potentiation (PAP), consisting of acute improvements in muscle force generation as a result of increased contractility (Chatzopolous, 2007). This causes increased motor unit recruitment, synchronization, and central input in the motor unit itself (Chatzopolous, 2007). Additional contributing factors to the acute power increase may include increased phosphorylation of the myosin light chain and should be considered as well (Chatzopolous, 2007). The increased phosphorylation leads to an increase in sensitivity to calcium within the myofilaments, but also a decrease in pre-synaptic inhibition which allows for a subsequent increased power output (Hoffman, 2007).

CT is a strength and conditioning method used to increase maximum power output. In 1986, Dr. Steve Fleck and Ken Kontor visited the Soviet Union and composed the first peer-reviewed complex training article. The authors describe the CT method as an operation performed by using a resistance exercise with a heavy load. This is immediately followed by a lighter load with a similar biomechanical movement pattern that is moved rapidly/ explosively. Fleck and Kontor deemed the heavy load as the conditioning activity. This conditioning activity can be done at either low speed-high load (5-RM back squat) or a high speed-moderate load exercise (power clean). Fleck and Kontor suggested that no matter what the exercise selection was, CT would result in performance benefits if the lighter load is less than the conditioning activity's load and moved rapidly. This results in higher power output and explosive movement for the lighter load (Fleck and Kontor, 1986). One theory of why this physiological phenomenon occurs is that there is excitation of the central nervous system (CNS) which produces an increase in contractile function due to a heavy load stimulus (Rixon, 2007). Specifically, strength training prior to plyometric exercises can cause increase in synaptic excitation within the spinal cord, which in turn increases post-synaptic potentials and subsequent increased force generating capacity of the involved muscle groups (Rassier, 2002). There is considerable support to the efficacy of CT and power output increases. Research by Baker, performed in 2003, took a look at the effects of acute-complex training on PAP in upper-body power output. Subjects were brought in to perform a bench press at 65% of 1-RM, then performed an explosive bench press throw. Baker found that PAP effects significantly increased by 4.5% in the experimental group using acute-CT training methods. Baker theorizes that the significant increases in power output can be attributed to both CNS excitation and mechanical adaptations (Baker, 2003). The physiological mechanisms behind CT are theorized, but how to best manipulate the intracomplex recovery, or rest between the heavy strength and subsequent power movement has yet to be determined.

One still unanswered question with PAP and complex training is the optimal recovery time between sets, also referred to as the Intracomplex Rest Interval (ICRI). Muscular contractions produce both PAP and fatigue. Muscle performance may improve if potentiation dominates over fatigue but may decrease if fatigue dominates over potentiation. Fatigue dominating over potentiation can be detrimental to power output, may lead to poor movement execution, and increase the risk of injury as well (Baechle, 2008, Carter, 2014, Ebben, 1998).

Therefore, finding the optimal balance between the two factors will determine the performance response. Power will be enhanced during the ICRI if the benefit of the potentiation is greater than the cost of fatigue. PAP will be reduced if the fatigue dominates over PAP or may remain unchanged if both fatigue and PAP are at the same level (Robbins, 2005). Since PAP and fatigue correlate, it is necessary to identify the optimal ICRI whereby the muscles have partially recovered from fatigue but remain in a potentiated state (Docherty and Hodgson, 2007). This may be deemed as the tradeoff between potentiation and recovery. Similar research (Bevan, Owen, Cunningham, Kingsley, Kilduf, 2009, Ebben 2002, Jensen and Ebben 2003, Jones and Lees, 2003) data suggests a wide range of results when it comes to the optimal ICRI. The ICRI's analyzed in these studies varied and utilized to find the optimal ICRI. The result of a study by Carter & Greenwood, (2014) looked at ICRI's and upper-extremity explosiveness ranging from fifteen seconds all the way to the maximum ICRI of twenty-four minutes. The result of the study found that eight minutes was the optimal ICRI for upper body explosiveness.

Researchers continue to further study the optimal ICRI. While the power increase is established in the literature (Bevan, 2009, Comyns, 2006), the optimal ICRI has yet to be established. Finding the ICRI that improves the subsequent power output the most, will allow strength and conditioning coaches to program more effectively and athletes to maximize power output. Therefore, the research question remains, what is the optimal ICRI to elicit the most benefit out of post-activation potentiation using acute-complex training methods. Our hypothesis for our research aligns with that of prior research (Comyns, Harrison, Hennessy, and Jensen, 2006) concluding that 4-minute ICRI could be considered the most effective ICRI time for acute-complex training for men. More recent research has looked to expanding the effects of PAP to include female subjects. Research by Ah Sue performed in 2016, observed the effects of PAP on

Division II female athletes. Ah Sue had female subjects perform single leg jumps after a heavy back squat with varied ICRI's. Ah Sue found significant improvements in power output post-CT style training within the experimental group compared to the control group (Ah Sue et al, 2016). The intention of this research study is to be able to determine optimal ICRI's to maximize power output while implementing complex training.

Chapter 2: Review of Literature

Power and its Importance in Sports

Power, by definition, is the rate of doing work. Strength and conditioning coaches often characterize a "powerful" athlete as an individual that is able to perform a movement at high velocity relative to the load they must overcome in an athletic movement.

Power is often referred to as explosiveness and is viewed as essential for many athletes within a wide range of sports. Power in sports is important in relation to its foundation in other specific abilities like first step-quickness, acceleration, and reaching top speeds (Cronin, Hansen, 2005). Power gives athletes the ability to generate force rapidly and dynamically in often high intensity settings. For example, sports like American football, hockey, tennis, baseball, weightlifting, and track and field, where moments of gameplay and competition last only seconds. Therefore, maximum and rapid power production is required to compete in competitive settings.

Complex Training and Post-Activation Potentiation

Complex training (CT) is a strength and conditioning method used to improve power output maximally while simultaneously improving an athlete's explosiveness. In 1986, Fleck and Contor visited the Soviet Union and composed the first peer-reviewed complex training article. The authors describe the CT method as an operation performed by using a resistance exercise with a heavy load, immediately followed by a lighter load with a similar biomechanical movement pattern and moved rapidly. Fleck and Contor deemed the heavy load as the conditioning activity. This conditioning activity can be done at either low speed-high load (5-RM back squat) or a high speed-moderate load exercise (power clean). Fleck and Contor suggests that no matter what the exercise selection was, CT would result in performance benefits if the lighter load is less than the conditioning activity's load, resulting in higher power output and explosive movement for the lighter load.

Exercises with similar biomechanical movements combined are often referred to as "complex pair." For example, a back squat followed by a countermovement jump. This led to the evolution of complex training. Another term used is a "Complex Triad," and is considered to be when three movements with similar biomechanics are combined in training (Ebben and Blackard, 1997). Theoretically, research suggests that many physiological responses can be elicited from CT (Baker 2003, Ebben and Watts 1998), including stimulating properties of the muscular, neurological, psychomotor systems, therefore, leading individuals to have increased power output and to move explosively (Baker 2003, Ebben and Watts, 1998). Complex training's physiological effects might lead to increases in motor unit excitability, resulting in increased motor unit recruitment, synchronization, and central input to the motor unit. Other physiological benefits that have been conjectured include increased phosphorylation of myosin light chain (Hoffman and Faigenbaum 2007). This increase in phosphorylation leads to an increase in the myofilament's sensitivity to calcium, as well as, a decrease in pre-synaptic inhibition, leading to power output development (Hoffman and Faigenbaum 2007). Current literature refers to this as post-activation potentiation (PAP).

CT and PAP Benefits – Support in Literature

The benefits of complex training are understood at this time, yet the physiological reasons behind the benefits to performance may not be. One hypothesis is that these improvements are caused by PAP. Complex training is established on PAP, consisting of acute improvements in muscle force generation as a result of increased contractility, known as a consequent physiological adaptation (Robbins et al, 2009). Increases in muscle force generated leads to increases in power output, translating into athletic performance. Research-based evidence suggests that PAP is elicited more in individuals with greater levels of strength (Baker, 2003). Baker analyzed sixteen rugby players, all with at least one-year of training experience. A positive correlation between maximal strength and power output was observed through multiple individuals with the highest power output when performing the explosive exercise by 6.2% post-completion of the heavy set. To compare, individuals with the lowest maximal strength only increased by 0.8% when performing the explosive movement (Baker, 2003). Other studies have also concluded the theory that the greater the individual's maximal strength, the greater the PAP benefits (Batista, Roschel, Barroso, Ugrinowitsch, Tricoli, 2011. Chatzopoulos, Giannakos, Patikas, Kotzamanidis, 2007).

The increase in power output that results from a heavy lift just prior has been measured in a variety of ways; including countermovement jumps (Comyns 2006, Jensen, Ebben 2003, Jones, Lees, 2003) depth jumps (Jones and Lees, 2003), medicine ball power drops, and explosive bench press style throws on a guided machine, hockey sprints and land sprints. (Baker 2003, Bevan and Owen 2009, Ebben and Jensen 2000). The results of these studies show that CT improves and individual's explosiveness and power output.

Further research demonstrates that maximal or high intensity dynamic exercises increases both power output and jump height, including both vertical and horizontal jump performance (Gourgoulis, Kasimatis, Mavromatis, and Garas, 2003. Guillich and Schmidtbleicher, 1996. Young, Jenner, and Griffiths, 1998). As stated, these improvements in performance are theorized to be caused by PAP. PAP is defined as the enhanced neuromuscular contraction in skeletal muscle after an initial bout using a near max load (Weber, Brown, Coburn, and Zinder, 2008).

Ojeda et al (2016) performed a study aimed to determine the acute effects of CT on 30-meter sprint times in military athletes. The session consisted of 4 sets of 5 repetitions at 30% 1-RM + 4 repetitions at 60% 1-RM + 3 repetitions of 30-meter sprints with a 120-second rest. The measured variables were the 30-meter sprint time and the average power output and peak power of squats. Results of the study determined that there was a positive relationship between acute CT and 30-meter sprint, showing there was a significant reduction in sprint times for all subjects involved in the study (Ojeda et al, 2016). The practical application of the study of CT in a military setting was described as a viable conditioning method that increases explosive power levels as well as general strength. The authors also emphasized the importance of both the heavy load and explosive movements and the fastest speed possible to fully stimulate the nervous system (Ojeda et al, 2016).

Additionally, Lee et al (2014) examined the efficiency of continuous CT on skating abilities in ice hockey players. Ice hockey is characterized by high intensity intermittent skating and rapid changes in direction and velocity, as well as periodic body contact. The study included 20 players total, with 10 male ice hockey players that participated in 12 weeks of CT and skating training, and the other 10 players only participating in 12 weeks of skate training only. Both groups performed a series of on-ice skating assessments including a 5-time 18-meter shuttle, a t-test, a rink dash repeated 5 times, and a line drill performed before, during, and after the 12-week period. The players in the CT group showed improved skating abilities, including stopping ability, agility, and ability to change direction, and endurance when compared to the group that did not participate in CT training. These findings support the effectiveness of CT in high intensity sports, as well as demonstrated the versatility of CT. CT demonstrates its ability to lead to acute improvements in power output but also allows chronic adaptations in explosive performance over time (Lee, Lee, & Yoo, 2014).

Rest Periods

One of the largest factors effecting PAP in complex training is recovery between sets. This is also known as Intracomplex Rest Interval (ICRI). Muscular contractions produce both PAP and fatigue, therefore, finding a balance between these two factors with determine the performance response. This response maybe enhanced, reduced, or unchanged (Robbins, 2005). Muscle performance during ICRI may improve if potentiation dominates and fatigue is reduced. PAP will be reduced if the fatigue dominates over PAP or may remain unchanged if both fatigue and PAP are at the same level (Robbins, 2005).

Since PAP and fatigue correlate it is necessary to identify the optimal ICRI whereby the muscles have partially recovered from fatigue but remains in a potentiated state (Docherty and Hodgson, 2007). This made be deemed as the tradeoff between performance and recovery. When it comes to recovery, studies have shown that minimal rest periods, anything below 30-seconds is detrimental to power output development (Bevan and Owen 2009, Jensen and Ebben, 2003). This leads to overall poor performance. Similar research (Bevan, Owen, Cunningham, Kingsley, Kilduf, 2009, Ebben 2002, Jensen and Ebben 2003, Jones and Lees, 2003) data suggests a wide range of results when it comes to ICRI effectiveness on power output in acute-CT. The times used in these studies ranged from 10-seconds, to 5-minutes, to a maximum of 24-minutes.

There have been several different approaches to ICRI. One study performed by Comyns et al. observed the acute effects of CT using ICRIs of 30-seconds, 2-minutes, 4 minutes, and 6-

minutes in the combination of a 5-RM back squat and countermovement jumps in both male and female populations. Only men displayed improvements in performance when using 4-minute ICRI. Researchers (Comyns, Harrison, Hennessy, and Jensen, 2006) therefore concluded that 4-minute ICRI could be considered the most effective ICRI time for acute-complex training for both men and women. Additionally, the data collected using both the lowest and highest ICRI's, 30-seconds and 6-minutes, have been suggesting a decrease or recovery to baseline jumping performance (Comyns, Harrison, Hennessy, and Jensen, 2006).

Since there has not been a theorized timeframe in which PAP is at its most effective point. Further research is needed to expand understanding on the most effective time PAP is able to optimize explosive performance and power production.

Male vs. Female

Most recent literature findings suggest CT to have more significant PAP effects on males than females (Baechle, Earle, and Wathen, 2008. Chiu, Fry, Weiss, Schilling, Brown, and Smith, 2003). Only a small neuromuscular response has been elicited in females. Mihalik et al. (2008) has shown that males have higher absolute countermovement jump height power production than females. Authors cited multiple studies displaying that females are capable of producing about two-thirds power as men, leading to lower response to CT comparatively to males (Docherty, Robbins, and Hodgson, 2004. Duthie, Young, and Aitken, 2002).

On the other hand, some studies have shown that gender does not affect ICRI in complex training. Jensen and Ebben (2003) studied both genders, using 11 males and 10 female division 1 athletes in their response to CT. Consisting of a 5-RM back squat followed by a countermovement countermovement jump. The ICRI's implemented were 10-seconds, 1,2,3 ad

4-minutes. Their data observed conflicting findings, that gender does not play a role in the effectiveness of CT training and that ICRI's ranging from 1-4-minutes does not either improve nor impair countermovement jump performance.

Training Level – Trained vs. Untrained

Various studies support Baker's (2003) findings that trained individuals with greater maximal strength respond better to CT training and PAP. While other studies have found different outcomes (Jensen and Ebben 2003). A study by Jensen and Ebben (2003) found no difference in response to performance for a countermovement jump after a 5-RM heavy squat between stronger and weaker individuals. Matthews et al (Matthews, O'Conchuir, and Comfort, 2009) showed analogous results that did not show any variation in performance between trained and untrained individuals when applying the CT method. However, researchers of the latter study emphasized the fact that their subjects were not "strong" due to being untrained (Matthews, Comfort, and Crebin, 2010). Resulting in training level being a determining factor in CT effectiveness.

Untrained individuals may not have the prerequisite levels of strength required for CT and may only show very limited results in power output. Baker (2003) suggests that the NSCA's prerequisites for plyometric training may serve as a baseline to implement CT. Yet these have since been removed. Alternatively, Lim et al (2016) determined multiple guidelines for the practical application of PAP. Some of these guidelines include an individual being considered a moderate to highly trained athlete and having resistance training experience greater than 2-years.

Chapter 3: Methods

Experimental Approach

This study was approved by the Institutional Review Board of West Chester University of Pennsylvania. The acute approach of this study aimed to keep the sessions within a two-week timeframe. The experimental design consists of four different sessions that were separated by 72 hours of rest, and were scheduled ahead of time in accordance with subject's schedules. This allotted time between sessions was purposefully enacted to prevent any muscle fatigue from the previous session from interacting with the next experimental session. The study included a standardized dynamic warm-up that was performed at the beginning of every session and lasted 8 to 10 minutes. Along with the dynamic warm-up, a more specific, barbell (BB), warm-up was included.

The first session, considered the baseline session, allowed subjects to fully understand the purpose of the study by providing them with all required Informed Consent and PAR-Q along with anthropometric and baseline measurements. Each subject was provided a cue sheet on how to perform both the back squat and countermovement jump. In addition to written instructions and cues for both movements, the main researchers also coached subjects either in a small group or one-on-one basis during the baseline session prior to any measured movements. After performing the standardized warm-up and receiving coaching and cueing for both movements, each subject was asked to step up on the force plate to measure body weight (BW in lbs) and perform the countermovement jump to establish a baseline power output. Data collection for the VJ was performed so that the subjects were given a countdown of 3 before stepping on the plate to ensure the Bioware software was collecting data before the participant jumped, getting set, and performing the countermovement jump. The baseline session was slightly different from the experimental sessions, as the VJ proceeded the heavy load back squat set. This was done to ensure the countermovement jump was not impacted by PAP. The heavy load, high bar back squat (3-RM) was determined using a 3-RM back squat protocol, loosely based on the NSCA's 1-RM testing protocol. The attained 3-RM of each subject was used in the sessions following as the heavy strength set to elicit the potentiation. This warmup consisted of 8 warm-up sets. The weight was increased by 10% percent each set, and the repetitions were decreased by 3-reps with every 10% increase, again loosely based on the NSCA 1-RM protocol. The test was concluded, and the 3-RM recorded when the subject failed a fourth rep attempt, subject could not maintain proper squat mechanics, or the subject failed to hit parallel or below.

The subsequent data collection sessions were all similar in nature, and only differed by the ICRI between the heavy load back squat and the countermovement jump on the force plate. Each session started with the same standardized, dynamic warm-up, followed by the progressive barbell warm-up building up to each individual subject's previously determined 3-RM weight. The barbell warm-up used was the same as the warn-up used in the initial session when determining each subjects 3-RM. Each session consisted of the warm-up, and then 4 working sets; two sets of the heavy load back squat for 3 repetitions, the ICRI of 1, 2, or 4 minutes, and the two sets of the countermovement jump on the force plate. Each subject was given 5 minutes of rest before performing the heavy squat and the countermovement jump the second time to allow for complete recovery. The sessions were structured to allow two different ICRI's to be tested in each session. Each ICRI was performed first in one session and second in another. This, along with the five-minute rest between the first and second complex combinations, was to ensure independence. The four sessions consisted of the following:

- Session One: Body weight (BW), Countermovement jump (VJ), baseline testing for back squat (3-RM).
- Session Two: 2 experimental sets consisting of performing a heavy 3-RM back squat, an ICRI interval, 1 countermovement jump on the force plate, and a five-minute recovery before repeating the heavy back squat set and countermovement jump using a different ICRI. ICRI's used were 1-minute and 2-minute between back squat and countermovement jump.
- Session Three: 2 sets consisting of 3-RM back squat followed by 1 countermovement jump each. ICRI's used were 2-minute and 4-minute between back squat and countermovement jump.
- Session Four: 2 sets consisting of 3-RM back squat followed by 1 countermovement jump each. ICRI's used were 4-minute and 1-minute between back squat and countermovement jump.

Subjects

A total of 30 subjects were recruited as volunteers to participate in this study. 14 subjects were dropped due to corrupted data or unforeseen scheduling conflicts. Specifically, there were 7 male subjects and 9 female subjects, all recreationally trained 3-times per week at minimum. This was mandated and asked during the first session when subjects filed out the informed consent and PAR-Q. To ensure validity and consistency within this research, any subjects with missing data or any subject data that experienced technical difficulties were removed prior to data interpretation and analysis.

Procedures

Instrumentation

The equipment used in this research consisted of a standard Olympic-barbell and plates in pounds, and an in-ground force plate (Kistler 5691A, 0.6 m x 0.9 m, Winterthur, Switzerland) collecting at 1000 Hz. No training belts were provided, requested, or used in this study.

Statistical Analysis

The statistical approach of the results was computerized and performed using Microsoft Excel. Each jump was recorded using the Bioware software on the force plate, and the files were time-sliced together to record the take-off phase of each VJ. For each take off phase, the impulse generated through the subject's feet was recorded and calculated in units of body weight•seconds (BW•s) in the Bioware software, as describe below. Due to technical difficulties observed while using the force plate, some files showed an offset that was not representative of the subject's body weight (BW). An offset is when the software shows weight below or above zero, which will either add or subtract to the subject's true body weight. To ensure proper data collection, all files were normalized and corrected using individualized BW. The analytical procedure is explained below:

1. Each file was carefully analyzed for artifacts and potential offset measurements.
2. Offset measurements were normalized to BW and corrected to start from the 0 value.
3. The average force produced during takeoff was measured and recorded in body weight of force (BW) via the bioware software. BW is a dimensionless measure; the SI units would be Newtons divided by mass, multiplied by gravity (N/mg).
4. The time interval during the takeoff phase was measured to the 1000th of a second.

After all the individual files were collected, analyzed, and processed, IBM SPSS software was used to report means and standard deviation of the conditions. A series of t-tests on each trial was performed to confirm independence of each ICRI. Effect Size was additionally calculated via SPSS software and included for practical application for Strength and conditioning professionals.

Effect size represents the difference between two means divided by the variability among the sample. Reported in standard deviation units, an ES of 0.5 represents a difference of ½ of a standard deviation. Emphasizing the size of effect promotes a more scientific approach and unlike significance tests, effect size is independent of sample size (McLeod, 2019). *Cohen's d* is an appropriate effect size for the comparison between two means, for example, to accompany the reporting of t-tests and ANOVA results. Therefore, the effect size (*Cohens-d*) was calculated for practicality. Cohen suggests that an ES of 0.2 is considered to be a small effect size, 0.5 represents a medium effect size, and 0.8 a large effect size. This means that if the means of two groups do not differ by 0.2 standard deviations or more, the difference is trivial, even if it is statistically significant (McLeod, 2019).

Chapter 4: Results

Subject Data

Sixteen subjects were recruited for this research and were students at West Chester University. Specifically, there were 7 male subjects and 9 female subjects. All of the volunteers were apprised of the risks and benefits of participation, signed consent forms and completed all parts of the study. Subject characteristics are listed in Table 1 below.

Table 1. Subject Mean Characteristics

	Mean Age (yrs)	**Mean Bodyweight (lbs.)**	**Mean Height (cm.)**	**Mean 3-RM (lbs.)**
Subjects	22	160.813	159.56	179.063

Descriptive Statistics

Descriptive statistics were calculated using SPSS statistics software. All Vertical Impulse (BW•s) data for each ICRI was analyzed and interpreted in Table 2. Any significant outliers were not included into the descriptive statistics. The Vertical Impulse (BW•s) mean of the baseline session (4.18 BW•s) was significantly higher than those of the experimental sessions (1-minute = 3.241 BW•s, 2-minute = 3.394 BW•s, 4-minute = 3.556 BW•s).

Table 2. Descriptive Statistics for Vertical Impulse (BW•s) and ICRI

VERT. IMPULSE (BW•S) VALUES	N	MEAN (BW•S)	STD. DEVIATION (BW•S)	STD. ERROR	95% CONFIDENCE INTERVAL FOR MEAN		MIN. (BW•S)	MAX. (BW•S)
					Lower Bound	Upper Bound		
BASELINE	16	4.1831	1.08984	0.27246	3.6024	4.7639	2.24	6.5
1MIN ICRI	32	3.2416	0.78882	0.13944	2.9572	3.526	1.63	4.95
2MIN ICRI	32	3.3941	0.85256	0.15071	3.0867	3.7014	2.09	5.29
4MIN ICRI	32	3.5569	1.06332	0.18797	3.1735	3.9402	1.86	5.69

Independent Samples T-Tests

The experimental design is assuming that the first lift has no influence on the second. We make each experimental trial as independent as possible by allowing total recovery between the 2 lifts. Additionally, that is also the reason that we varied which ICRI came first in each session, to eliminate the argument that the first lift might impact the second. A series of independent samples T-tests were run amongst the experimental trials to confirm independence. The results of these T-tests are seen below in Table 2. Observing the p-value and Levene’s Test for each experimental ICRI, we can conclude the above statement deems true.

Table 3. Results of the Independent Samples T-Tests

		LEVENE'S TEST FOR EQUALITY OF VARIANCES		**T-TEST FOR EQUALITY OF MEANS**						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	99% Confidence Interval of the Difference	
									Lower	Upper
MINUTE-1	Equal variances assumed	2.89	0.099	-0.264	30	0.794	-0.07625	0.28873	-0.87025	0.71775
MINUTE-2	Equal variances assumed	0.415	0.524	1.561	30	0.129	0.4625	0.29633	-0.3524	1.2774
MINUTE-4	Equal variances assumed	1.047	0.314	0.41	30	0.685	0.15625	0.38109	-0.89174	1.20424

One-Way ANOVA

After running the independent samples t-test, a One-Way ANOVA test was conducted (Table 3/Appendix D) to test for significant difference between ICRIs. The significance value of p=0.012, which is below p=0.05, therefore there is a statistically significant in the mean between the ICRI trials. To find out which specific groups differed, a Tukey Post-HOC test of multiple comparisons was conducted (Appendix D).

Table 4. One-Way ANOVA Table

	Means Square	**F**	**Sig.**
Between Groups	3.352	3.823	0.012
Within Group			
Total	0.887		

Means Comparison

Once confidence in data validity was achieved, a comparison of the Vertical Impulse (BW•S) from each ICRI was conducted. Table 4 and Figure 1 display the comparison of means over each ICRI experimental trial. Baseline (B) Vertical Impulse (BW•S) mean = 4.18 BW•s with a standard deviation (SD) = 1.08 this is significantly greater compared to the 1-minute ICRI = 3.24 BW•s, 2-minute ICRI = 3.39 BW•s, and 4-minute ICRI of 3.55 BW•s.

Figure 1. ANOVA Graph displaying Means of Vertical Impulse (BW•s) per ICRI.

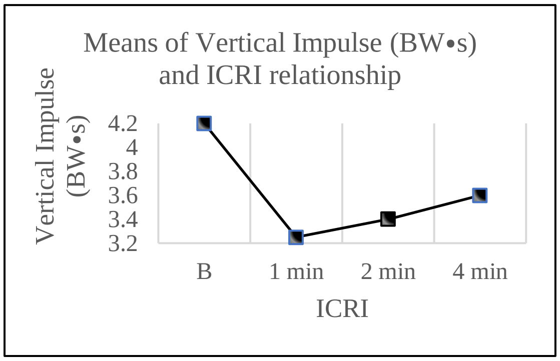

Table 5. Vertical Impulse (BW•s) per ICRI condition.

	Baseline	ICRI 1-minute	ICRI 2-minute	ICRI 4-minute
Mean (BW•s)	4.18	3.24	3.39	3.55
SD (BW•s)	1.08	0.78	0.85	1.06

Effect Size

Looking at the ES (Figure 2), both the 1-minute and 2-minute ICRI showed a significant decrease in Vertical Impulse (BW•s). The ES of the 1-minute ICRI was 0.98 and the 2-minute was 0.80. The ES of the 4-minute ICRI was 0.58, displaying a moderate, positive, significance.

Fig 2. Effect size per condition.

	Effect Size *(ES)*
Baseline vs. 1-minute	0.98
Baseline vs. 2-minute	0.80
Baseline vs. 4-minute	0.58

Chapter 5: Discussion and Conclusions

CT is believed to lead to increased muscle motor-unit excitation, which accounts for the potentiation and greater power output. We hypothesized that individuals would significantly improve their power output by performing an acute CT procedure involving a heavy back squat (3-RM) followed by a countermovement jump. Additionally, we hypothesized that the 4-minute ICRI would be the most effective ICRI for acute-complex training. All subjects showed significant decreases in Vertical Impulse (BW•S) when performing the acute-CT procedure. While all the ICRI's resulted in a decrease in acute Vertical Impulse (BW•S), the 4-minute ICRI showed the least decrease.

Use of Recreationally Trained Subjects

Other physiological reasons could be behind why we did not see increases in Vertical Impulse (BW•s). A study performed by Chiu et al, examined the effects of PAP on power output in both athletically trained and recreationally trained subjects. The results of this study showed a significant increase in power output in the athletically trained ($p<0.05$) group, but no statistically significant increases within the recreationally trained group; supporting the theory that acute-PAP might be a viable option to enhance explosive strength in athletically trained individuals, but not recreationally trained individuals. (Chiu, L.A., Fry, A.C., Weiss, L.W., Schilling, B.K., Rown, L.E., Smith, S.L. 2003). Our research aligns with and supports Chiu et al's research. This could be a possible limitation to our own research conducted. Recreationally trained individuals have less muscular conditioning which could lead to diminished effects or lack thereof CNS-excitation. Athletes tend to have greater CNS-excitation due to continued muscular conditioning and being frequently trained at a more consistent and higher intensity (Chiu et al, 2003). Athletes also have a physiological tendency to resist fatigue (Chiu et al, 2003). Baker's (2003) findings state that trained individuals with greater maximal strength respond better to CT training and PAP. If we had limited our population to athletically trained individuals, our research might have been more consistent with previous studies that did limit their subject population to college athletes.

Effects of PAP - Male vs. Female

Another possible reason our research did not show an increase in Vertical Impulse (BW•s) with any of the tested ICRI's could be the difference between the sexes. Rixon et al. looked at 30-young men and women who are recreationally trained with previous Olympic weightlifting experience to examine the effects of PAP on power output via countermovement jumps. The results of Rixon's research concluded that men had a greater statistically significant increase in power output when engaging in complex training than women (Rixon et al, 2007). Perhaps the fact that more than half of our subjects were women contributed, along with the use of only recreationally trained subjects, to the outcome of our research study. Rixon et al states that there is no clear answer and further research is needed to determine why women see less PAP effects than their male counterparts (Rixon et al, 2007). Mihalik et al. (2008) has shown that males have higher relative increases in power production after a heavy strength set than females. Most recent literature findings suggest CT to have more significant PAP effects on males than females (Baechle, Earle, and Wathen, 2008. Chiu, Fry, Weiss, Schilling, Brown, and Smith, 2003). In our research, we combined our male and female data into groups and did not separate data by biological sex.

ICRI's Utilized

Current findings have shown that an ICRI of 30-seconds or below proves to be detrimental to power output generation (Ebbens, 1998), thus 30-seconds was an excluded ICRI from this study.

Comyns et al. 2010 suggests that using a 240-second (4-minute) ICRI is optimal for exploiting PAP, while allowing proper recovery, but this timeframe was unsuccessful in this study. In our study, the 240-second ICRI showed the least decrease in power output. Perhaps if we had used male athletes rather than male and female recreationally trained subjects, our findings may have been different. Beaven et al, also suggests that the most efficient ICRI to reap the physiological benefits of PAP to be between 4 and 8-minutes (Bevan et al, 2009). Within our study we used shorter ICRIs, this could have affected our results because of the possibility that we did not give the body enough time to elicit the benefits of PAP. Perhaps the longer ICRIs are even more important for recreational athletes who might need even more time than athletes between the heavy strength set and power movement because they are less resistant to fatigue. A study by Jensen and Ebben (2003) found no difference in response to performance for a countermovement jump after a 5-RM heavy squat between stronger and weaker individuals. This results in training level being a determining factor in CT effectiveness. Untrained individuals may not have the prerequisite levels of strength required for CT and may only show very limited results in power output.

Warm-up Protocol

Another possible reason why the current study did not find results consistent with most other studies showing significant gains in power using complex training (Baker, 2003, Bevan et al, 2009, Ebbens, 1998) was our specific warm-up protocol may have been too lengthy. In an effort to ensure our subjects were adequately warmed-up, we may have implemented too many specific warm-up sets in the squat, leading to the onset of fatigue prior to the heavy strength set, which could possibly lower the resulting potentiation or lengthen the recovery period needed prior to the power movement.

Limitations

The main limitations of this study were technical factors. From a technical perspective, the Bioware software utilized in data collection crashed multiple times throughout the study. Corrupted data resulted in subjects being excluded from the data analysis and interpretation, therefore reducing the N-value.

Implications for Further Research

More research needs done to find the optimal ICRI when implementing complex training. Future research could focus on separating the trained and untrained populations. Furthermore, more research needs done to see if the optimal ICRI needs to be longer in less trained or recreational individuals. Additionally, more research needs to be done to see if the optimal ICRI is different for males vs. females. The results of this study do not support other research concluding that acute-CT is a viable method for improving power output. However, this study does support the theory that complex training is not as effective on recreationally trained individuals.

This leaves an open opportunity to examine these same ICRI's for athletically trained individuals. With research supporting stronger PAP benefits from athletes, future research could expand on the optimal ICRI levels for recreationally trained individuals. The development of CT programs and an increased understanding of the physiological effects of PAP through research continue to further our understanding in the hopes that one day new scientifically proven styles of training can one day be practically applied with the universal goal of making athletes faster, more powerful, and reduce injuries.

References

Ah Sue, R., Adams, K. J., & DeBeliso, M. (2016). Optimal Timing for Post-Activation Potentiation in Women Collegiate Volleyball Players. *Sports (Basel, Switzerland)*, *4*(2), 27. https://doi.org/10.3390/sports4020027

Baechle, T.R., Earle, R.W., and Wathen, D., Champaign, I.L., (2008). Resistance training. In: Essentials of Strength Training and Conditioning. *Human Kinetics*. pp. 381–411.

Baker, D. (2003). Acute effect of alternating heavy and light resistances on power output during upper body complex power training. *J Strength Cond Res 17*: 493–497.

Baker, D., Newton, R. (2005). Acute effect on power output on alternating an agonist and antagonist muscle exercise during complex training. *J Strength Cond Res 19*: 202–205.

Batista, M.A.B., Roschel, H., Barroso, R., Ugrinowitsch, C., Tricoli, V. (2011). Influence of strength training background on postactivation potentiation response. *J Strength Cond Res 25*: 2496–2502.

Bauer, Pascal1; Sansone, Pierpaolo2; Mitter, Benedikt1; Makivic, Bojan3; Seitz, Laurent B.4; Tschan, Harald1 Acute Effects of Back Squats on Countermovement Jump Performance Across Multiple Sets of a Contrast Training Protocol in Resistance-Trained Men, *Journal of Strength and conditioning Research: April 2019 - Volume 33 - Issue 4* - p 995-1000 doi: 10.1519/JSC.0000000000002422

Beaven, C.M., Cook, C.J., Gill, N.D. (2008). Significant strength gains observed in rugby players following specific RE protocols based on individual salivary testosterone responses. *J Strength Cond Res 22*: 419–425.

Beaven, C.M., Gill, N.D., Cook, C.J. (2008). Salivary testosterone and cortisol responses following four resistance training protocols in professional rugby players. *J Strength Cond Res 22*: 426–432.

Beaven, C.M., Gill, N.D., Ingram, J.R., Hopkins, W.G. (2011). Acute salivary hormone responses to complex exercise bouts. *J Strength Cond Res 25*: 1072–1078.

Bevan, H.R., Owen, N.J., Cunningham, D.J., Kingsley, M.I.C., Kilduff, L.P. (2009). Complex training in professional rugby players: Influence of recovery time on upper-body power output. *J Strength Cond Res 23*:1780–1785.

Burger, T. (1999). *Complex training compared to a combined weight training and plyometric training program*.

Carter, J., & Greenwood, M. (2014). Complex training Reexamined: Review and Recommendations to Improve Strength and Power. *Strength and conditioning Journal, 36:*(2), 11.

Chatzopoulos, M., Giannakos, A.P., Antonopoulos, K. (2007). Post Activation Potentiation Effects After Heavy Resistance Exercise On Running Speed. *Journal of Strength and conditioning Research, 21:*(4), 1278-1281.

Chiu, L., Fry, Z., Schilling, F., Johnson, A., & Weiss, C. (2004). Neuromuscular fatigue and potentiation following two successive high intensity resistance exercise sessions. *European Journal of Applied Physiology, 92:*(4), 385-392.

Chiu, L.A., Fry, A.C., Weiss, L.W., Schilling, B.K., Rown, L.E., Smith, S.L. (2003). Postactivation potentiation response in athletic and recreationally trained individuals. *J Strength Cond Res 17*: 671–677.

Comyns, T.M., Harrison, A.J., Hennessy, L.K. (2010) Effect of squatting on sprinting performance and repeated exposure to complex training in male rugby players. *J Strength Cond Res 24*: 610–618.

Comyns, T.M., Harrison, A.J., Hennessy, L.K., Jensen, R.L. (2006). The optimal complex training rest interval for athletes from anaerobic sports. *J Strength Cond Res 20*: 471–476.

Cronin, J., Hansen, K. (2005). Strength and Power Predictors of Sports Speed. *Journal of Strength and conditioning Research 19*:(2), 349-357.

Docherty, D., Robbins, D., Hodgson, M. (2004). Complex training revisited: A review of its current status as a viable training approach. *J Strength Cond Res 26*: 52–57.

Docherty, D., Hodgson, M. (2007). The Application of Postactivation Potentlation to Elite Sport. *International Journal of Sports Physiology and Performance (IJSPP), 2*(4), 439-44.

Dodd, D.J., Alvar, B.A. (2007). Analysis of acute explosive training modalities to improve lower body power in baseball players. *J Strength Cond Res 21*: 1177–1182.

Duthie, G.M., Young, W.B., Aitken, D.A. (2002). The acute effects of heavy loads on jumpsquat performance: An evaluation of the complex and contrast methods of power development. *J Strength Cond Res 16*: 530–538.

Ebben, W.P. (2002). Complex training: A brief review. *J Sports Sci Med 1*: 42–46.

Ebben, W.P., Blackard, D.O. (1997). Complex training with combined explosive weight training and plyometric exercises. *Olympic Coach 7*: 11–12.

Ebben, W.P., Jensen, R.L., Blackard, D.O. (2000). Electromyographic and kinetic analysis of complex training variables. *J Strength Cond Res 14*: 451–456.

Ebben, W.P., Watts, P.B. (1998). A review of combined weight training and plyometric training modes: Complex training. *J Strength Cond Res 20*: 18–27.

Esformes, J.I., Bampouras, T.M. (2013). Effect of back squat depth on lower body postactivation potentiation. *J Strength Cond Res 27*: 2997–3000.

Evetovich, Tammy K.; Conley, Donovan S.; McCawley, Paul F. Postactivation Potentiation Enhances Upper- and Lower-Body Athletic Performance in Collegiate Male and Female Athletes, *The Journal of Strength & Conditioning Research*: February 2015 - Volume 29 - Issue 2 - p 336-342 doi: 10.1519/JSC.0000000000000728

Fleck, S., Kontor, K. (1986). Soviet strength and conditioning: Complex training. *J Strength Cond Res 8*: 66–68.

Gilbert, G., Lees, A., Graham-Smith,, P. (2001). Temporal profile of post-tetanic potentiation of muscle force characteristics after repeated maximal exercise. *Journal of Sports Sciences, 19*(1), 6.

Gourgoulis V.A.N., Kasimatis, P., Mavromatis, G., Garas, A. (2003). Effect of submaximal halfsquat warm-up program on countermovement jumping ability. *J Strength Cond Res 17*: 342–344.

Guillich, A., Schmidtbleicher, D. (1996). MVC induced short-term potentiation of explosive force. *N Stud Athlete 11*: 67–81.

Hodgson, M., Dochery, D., Robbins, D. (2005). Post-activation potentiation: Underlying physiology and implications for motor performance. *Sports Med 35*: 585–595.

Hoffman, J., Faigenbaum, A., Brown, L.E. Champaign, I.L. (2007). Intermediate programs. In: Strength Training. *Human Kinetics*. pp. 293–306.

Jensen, R.L., Ebben, W.P. (2003). Kinetic analysis of complex training rest interval effect on countermovement jump performance. *J Strength Cond Res 17*: 345–349.

Johnson, D.L., Bahamonde, R. (1996). Power output estimate in university athletes. *J Strength Cond Res 10*: 161-1666.

Jones P., Lees, A. (2003). A biomechanical analysis of the acute effects of complex training using lower limb exercises. *J Strength Cond Res 17*: 694–700.

Larson, G.S. (2003). The effects of plyometric training with a weight vest on lower extremity power in volleyball players. Master's thesis, *The University of North Carolina, Chapel Hill*.

Lee C., Lee S., Yoo, J. (2014). The Effect of a Complex training Program on Skating Abilities in Ice Hockey Players. *Journal of Physical Therapy Science*, *26*(4), 533–537. http://doi.org/10.1589/jpts.26.533

Lim J., Barley C. (2016). Complex training for Power Development: Practical Applications for Program Design. *Strength and conditioning Journal*, *38*(6), 33-43.

MacDonald, C.J., Lamont, H.S., Garner, J.C. (2011). The effects of 3 different modes f training upon measures of CMVJ performance. *J Strength Cond Res 25*: S7.

MacDonald, C.J., Lamont, H.S., Garner J.C. (2012). A comparison of the effects of 6 weeks of traditional resistance training, plyometric training, and complex training on measures of strength and anthropometrics. *J Strength Cond Res 26*: 422–431.

Matthews, M., Comfort, P. (2008). Applying complex training principles to boxing: A practical approach. *J Strength Cond Res 30*:12–15.

Matthews, M.J., Comfort, P., Crebin, R. (2010). Complex training in ice hockey: The effects of a heavy resisted sprint on subsequent ice-hockey sprint performance. *J Strength Cond Res 24*: 2883–2887.

Matthews, M., O'Conchuir, C., Comfort, P. (2009). The acute effects of heavy and light resistances on the flight time of a basketball push-pass during upper body complex training. *J Strength Cond Res 23*: 1988–1995.

May, C.A., Cipriani, D., Lorenz, K.A. (2010). Power development through complex training for the Division I collegiate athlete. *J Strength Cond Res 32*: 30–43.

McGuigan, M. (2017). Developing Power. *Human Kinetics*.

Mihalik, J.P., Libby, J.J., Battaglini, C.L., McMurray, R.G. (2008). Comparing short-term complex and compound training programs on countermovement jump height and power output. *J Strength Cond Res 22*: 47–53.

Nibali, M., Chapman, D.W., Robergs, R., Drinkwater, E. (2013). Validation of jump squats as a practical measure of post-activation potentiation. *Applied Physiology, Nutrition, and Metabolism*, *38*(3), 306-313.

Ojeda, Á.H., Ríos, L.C., Barrilao, R.G., Serrano, P.C. (2016). Acute effect of a complex training protocol of back squats on 30-m sprint times of elite male military athletes. *Journal of Physical Therapy Science*, *28*(3), 752–756. http://doi.org/10.1589/jpts.28.752

Potach, D.H., Chu, D.A. (2008). Plyometric training. In: Essentials of Strength Training and Conditioning. *Human Kinetics*. pp. 413–456.

Rassier DEHerzog W. Force enhancement following an active stretch in skeletal muscle. *J Electromyogr Kinesiol*. 2002;12(6):471–477 [PubMed] [Google Scholar]

Rixon, K.P., Lamont, H.S., Bemben, M.G. (2007). Influence of type of muscle contraction, gender, and lifting experience on postactivation potentiation performance. *J Strength Cond Res* 21: 500–505,

Robbins, D.W. (2005). Post-activation potentiation and its practical applicability: A brief review. *J Strength Cond Res 19*: 453–458.

Robbins, D.W., Young, W.B., Behm, D.G., Payne, W.R. (2009). Effects of agonist-antagonist complex resistance training on upper body strength and power development. *J Sports Sci 27*: 1617–1625.

Robbins, D.W., Young, W.B., Behm, D.G., Payne, W.R. (2010). Agonist-antagonist paired set resistance training: A brief review. *J Strength Cond Res* 24: 2873–2882.

Robbins, D.W., Young, W.B., Behm, D.G., Wayne, W.R. (2010). The effect of a complex agonist and antagonist resistance training protocol on volume load, power output, electromyographic responses, and efficiency. *J Strength Cond Res 24*: 1782– 1789.

Santos, E.J.A.M., Janeir, M.A.A.S. (2008). Effects of complex training on explosive strength in adolescent male basketball players. *J Strength Cond Res 22*: 903–909.

Sotiropoulos, K., Smilios, I., Christou, M., Barzouka, K., Spaias, A., Douda, H., Tokmakidis, S.P. (2010). Effects of warm-up on countermovement jump performance and muscle electrical activity using half-squats at low and moderate intensity.(Research article)(Report). *Journal of Sports Science and Medicine, 9*(2), 326-31.

Tillin, N., Bishop, D. (2009). Factors Modulating Post-Activation Potentiation and its Effect on Performance of Subsequent Explosive Activities. *Sports Medicine, 39*(2), 147-66.

Weber, K.R., Brown, L.E., Coburn, J.W., Zinder, S.M. (2008). Acute effects of heavy-load squats on consecutive squat jump performance. *J Strength Cond Res 22*: 726–730.

Witmer, C.A., Davis, S.E., Moir, G.L. (2010). The acute effects of back squats on countermovement jump performance in men and women. (Research article)(Report). *Journal of Sports Science and Medicine, 9*(2), 206-13.

Young, W.B., Jenner, A., Griffiths, K. (1998). Acute enhancement of power performance from heavy load squats. *J Strength Cond Res 12*: 82–84.

Xenofondos, L., Kyranoudis, G., Bassa, K. (2010). POST-ACTIVATION POTENTIATION: FACTORS AFFECTING IT AND THE EFFECT ON PERFORMANCE. *Citius Altius Fortius 28:*(3), 32-38.

Appendix A: Warm-up Protocol

Warm-up Protocol

Dynamic Warm-up	
Movements	**Repetitions/side**
5 minutes on Cycle-Ergometer or Treadmill	--
Iron Cross	5 each
Scorpions	5 each
3-way heel-toe raise	8 each
Dynamic Knee Hugs	5 each
Lunge & Side Bend	5 each
Lateral Lunge	5 each
Quad Stretch	5 each
Leg Swing (front/back, side/side)	5 each
Arm Circles (forward/reverse)	5 each
Air Squats	8 each
Jumping Jacks	20 reps

Appendix B: Researcher-Created Back Squat Protocol Modified

Researcher-Created Back Squat Protocol

Researcher-Created Back Squat Protocol	
Repetitions	**% 1-RM**
10	Barbell only
10	30%
7	40%
5	50%
3	70%
3	80%
3	90%
3	93%

Appendix C: Technical Cues

Technical cues

Back Squat (High bar)

1. Keep your feet at hip width.
2. Feet slightly turned out.
3. Always push through your mid-foot and heel.
4. On the way down, push your hips back and your knees out. Knees should be aligned with feet.
5. Keep your back slightly arched/neutral and a proud chest at all times.
6. Position the bar on the upper portion of your back.
7. Grip the bar slightly wider than shoulder width.

Countermovement jump

1. Align feet even just inside the measuring slats.
2. Forcefully swings arms down and back, and drop hips into quarter-squat position.
3. Explosively extend hips, knees and ankles, and propel off balls of feet to jump straight up.
4. Continue extending dominant hip as you cock hips to the side. Extend dominant arm up and look at middle finger of dominant hand.
5. Land softly with bent knees.

Appendix D: ANOVA-Post HOC Analysis

Test of Homogeneity of Variances

VERTICAL IMPULSE (BW•S)

Levene Statistic	df1	df2	Sig.
1.841	3	108	0.144

ANOVA

VERTICAL IMPULSE (BW•S)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	10.056	3	3.352	3.823	0.012
Within Groups	94.688	108	0.877		
Total	104.744	111			

Robust Tests of Equality of Means

VERTICAL IMPULSE (BW•S)

	Statistica	df1	df2	Sig.
Welch	3.224	3	49.003	0.03
Brown-Forsythe	3.605	3	73.953	0.017

a Asymptotically F distributed.

POST HOC

Multiple Comparisons

Dependent Variable: VERTICAL IMPULSE (BW•S)

	(I) ICRI	(J) ICRI	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey HSD	Baseline	1-min	.94156*	0.2867	0.007	0.1934	1.6897
		2-min	.78906*	0.2867	0.035	0.0409	1.5372
		4-min	0.62625	0.2867	0.134	-0.1219	1.3744
	1-minute	B	-.94156*	0.2867	0.007	-1.6897	-0.1934
		2-min	-0.1525	0.23409	0.915	-0.7633	0.4583
		4-min	-0.31531	0.23409	0.535	-0.9262	0.2955
	2-minute	B	-.78906*	0.2867	0.035	-1.5372	-0.0409
		1-min	0.1525	0.23409	0.915	-0.4583	0.7633
		4-min	-0.16281	0.23409	0.899	-0.7737	0.448
	4-minute	B	-0.62625	0.2867	0.134	-1.3744	0.1219
		1-min	0.31531	0.23409	0.535	-0.2955	0.9262
		2-min	0.16281	0.23409	0.899	-0.448	0.7737
Games-Howell	Baseline	1-min	.94156*	0.30607	0.025	0.0949	1.7882
		2-min	0.78906	0.31137	0.079	-0.0687	1.6468
		4-min	0.62625	0.33101	0.253	-0.2748	1.5273
	1-minute	B	-.94156*	0.30607	0.025	-1.7882	-0.0949
		2-min	-0.1525	0.20533	0.879	-0.6947	0.3897
		4-min	-0.31531	0.23405	0.537	-0.9346	0.304
	2-minute	B	-0.78906	0.31137	0.079	-1.6468	0.0687
		1-min	0.1525	0.20533	0.879	-0.3897	0.6947

	4-min	-0.16281	0.24093	0.906	-0.7997	0.4741
4-minute	B	-0.62625	0.33101	0.253	-1.5273	0.2748
	1-min	0.31531	0.23405	0.537	-0.304	0.9346
	2-min	0.16281	0.24093	0.906	-0.4741	0.7997

** The mean difference is significant at the 0.05 level.*

Homogeneous Subsets

VERTICAL IMPULSE (BW•S)

	ICRI	N	Subset for alpha = 0.05	
			1	2
Tukey HSDa,b	1-min	32	3.2416	
	2-min	32	3.3941	
	4-min	32	3.5569	3.5569
	B	16		4.1831
	Sig.		0.625	0.085

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 25.600.

b The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.