2020

The Effect of Ballistic Training on Punch Kinetics and Endurance in Trained Boxers

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THE EFFECT OF BALLISTIC TRAINING
ON PUNCH KINETICS & ENDURANCE
IN TRAINED BOXERS

A Master's Thesis presented to the Faculty of the

Graduate Program in Exercise and Sport Sciences

Ithaca College

In partial fulfillment of the requirements

for the degree

Master of Science

By

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October 2020

Ithaca College

School of Health Sciences and Human Performance

Ithaca, New York

CERTIFCATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the thesis of

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submitted in partial fulfillment of the requirements for

the degree of Master of Science in the School of

Health Sciences and Human Performance

at Ithaca College has been approved.

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Date: 11.20.2020

ABSTRACT

Strength and conditioning coaches are becoming increasingly aware of the importance of sport-specific movements when designing and implementing training programs for power development. The use of ballistic training (BT) for combat athletes, such as boxers, is growing in popularity, however there is a paucity of research on the effect of this method on punching kinetics and endurance. This study examined changes in punch kinetics and endurance following a six-week BT intervention. Forty-five participants (male $n = 28$, female $n = 17$; mean age = 28 ± 6.0 years, height = 1.8 ± .1 m, mass = 83.4 ± 15.2 kg) with a mean boxing experience of 11.3 ± 7.9 months were recruited for the study. Participants were sorted by self-reported boxing experience and then randomly assigned to either a control (CONTR) or experimental (BT) group. Participants in the BT group completed supervised training involving loaded ballistic exercises twice per week for six weeks. CONTR group participants completed supervised training twice per week for six weeks, with unloaded exercises performed at a slow and controlled tempo. Participants' punch kinetics and endurance were examined before and after the 6-week training period using force plates. Results' showed a 30% increase in maximum punch force (PF_{max}; $p < 0.001$) and a 44% increase in rate of force development (RFD; $p < 0.001$) in the BT group, throughout the 6-week training period. In contrast, CONTR group participants showed no change in PF_{max} and RFD over the course of the study. Increases in PF_{max} occurred despite no significant change in lead and rear foot forces. Although $\overline{PF}_{max}$, the average of the PF_{max} across all punches within the first and third minutes, was shown to significantly increase in the BT group, a similar decrement in force output was observed between both groups post-intervention. Thus, BT

exhibited little effect on punching endurance. The ability to produce high power outputs has been identified as a key variable in boxing performance. Consequently, power development should be a priority for strength coaches working with combat athletes. These coaches should consider how punch kinematics relates to force transmission. A distinct advantage of BT is its versatility as a training stimulus, whereby exercises aim to enhance force characteristics while replicating the movement patterns of the sporting task. The present data supports this notion and the inclusion of BT within a speed-strength phase prior to competition should be considered by coaches working with combat athletes.

ACKNOWLEDGMENTS

I would like to acknowledge my thesis advisors Drs. Diggin and King whom without their support this research would not have been possible. I would also like to thank the coaching team, Jessica Hanshaw and Isabel Callen for their time and commitment to the study; coach, mentor, and friend, Patrick O’Connor, for his generosity in our use of his *Black Irish Boxing* gym, which was instrumental to the success of this study; Frank Micale and the *Robert R. Colbert Sr. Wellness Clinic* of Ithaca College; Drs. Swensen and Harenberg for piquing my interest in research; and my wife, Esther.

DEDICATION

This work is dedicated to the memory of my father and first person to lace up my boxing gloves, Robert George Crouch.

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Chapter 1

INTRODUCTION

The ability to produce high power outputs, defined here as high levels of force in a short period of time, is a characteristic which underpins successful performance in many sports (Haff & Nimphius, 2012). Various training methods have been used to develop power including heavy resistance training and explosive-type power training, such as plyometric and ballistic exercises. Strength and conditioning coaches are becoming increasingly aware of the importance of sport-specific movements when designing and implementing training programs for power development. To increase athletic performance, coaches are using a variety of training protocols to elicit power adaptations specific to a key skill or movement pattern within the sport. In boxing, the scoring of bouts is based on factors including: the number of quality punches, technical and tactical dominance, and infringement of rules. However, matches can be won at any point if a boxer knocks out their opponent, or if the referee stops the fight deeming it unsafe to continue.

Monitoring changes in punching force (PF) may be a useful diagnostic variable in the design and efficacy of strength and conditioning interventions (Lenetsky, Harris & Brughelli, 2013). Despite the importance of force / power to performance in boxers, there is a paucity of research examining the impact of training methods on PF. A variety of training methods are used to develop these characteristics in athletes. Movements performed with maximal velocity are usually considered to be ballistic actions (Desmedt & Godaux 1977), where-by the term ballistic is used to describe an exercise that is an "accelerative, high-velocity movement with actual projection of a body (e.g. athlete /

medicine ball) into free space" (Newton & Kraemer, 1994, p. 25). Ballistic training (BT) is a versatile training method found to increase the rate of force development (RFD) and power output in trained athletes (Newton, Kraemer & Häkkinen, 1999). Rate of force development is defined as the rate at which the contractile elements of the muscle can develop force (Aagaard, Simonsen, Andersen, Magnusson & Dyhre-Poulsen, 2002). Ballistic training performed at high speeds with low to moderate loads (e.g. body weight & medicine balls) can be used to target the velocity component of power. Ballistic training exercises can be sport-specific, ensuring RFD is trained across functional movement patterns. Ballistic training can also involve plyometric movements that exploit the stretch-shortening cycle (SSC). Many studies have implemented plyometric training (PT) to elicit power adaptations however, the majority have focused exclusively on the lower body exercises.

Statement of Purpose

The purpose of this study was to examine the impact of BT on punch kinetics and endurance, in recreationally-trained boxers.

Hypotheses

It was hypothesized that:

(1) PF_{max} and RFD will increase in the BT group, while CONTR group participants will show little change.

(2) Decrements in $\overline{PF}_{max}$ will decrease in the BT group across a 3-minute period relative to the CONTR group post-intervention.

(3) Ground reaction force’s; Resultant (F_{max}-lead, F_{max}-rear), horizontal (Fx_{max}-$_{lead}$, Fx_{max}-$_{rear}$), and vertical (Fz_{max}-$_{lead}$, Fz_{max}-$_{rear}$) will increase in the BT group post-intervention, while the CONTR group will show little change.

Scope of the Problem

Winning by knockout is considered the greatest performance outcome for a combat athlete, so much so that it is the primary statistic recorded in professional boxers’ profiles, along with the number of wins and losses. Pierce, Reinbold, Lyngard, Goldman and Pastore (2006) examined punching forces generated during six professional boxing matches. Data showed that when the outcome of the competition was determined by the judges, the boxer who delivered the greatest cumulative force and the greatest number of punches won by unanimous decision. This implies that the ability to generate large impact forces, as well as a high volume of forceful punches, is a key performance variable in boxing. Subsequently, increasing the force of a punch is critical to combat athletes.

Delimitations of Study

The selection criteria for the study required participants to possess a minimum of three months of boxing experience. Participants were recruited from local boxing clubs however, many had never boxed competitively. The rationale behind the three-month boxing experience inclusion criteria was to increase the participant sample size whilst recruiting participants who could demonstrate basic competence in boxing movement patterns and punch delivery.

Limitations of Study

Participants recruited for the study were engaged in boxing at a recreational or competitive amateur level. The data collected is therefore not representative of elite fighters.

Assumptions of Study

An assumption has been made that participants recruited to both the CONTR and BT groups did not increase their boxing training load during the training intervention period. Furthermore, it was assumed that participants adhered to the requirements of the study by maintaining their level of activity and not engaging in training interventions outside of those that implemented within the current study.

Chapter 2

REVIEW OF LITERATURE

Boxing

Boxing, historically known as pugilism, dates to 3000 BC in Egypt and was first accepted as an Olympic sport in 688 BC, according to the International Boxing Association (AIBA). The AIBA is the world governing body for amateur boxing with 196 affiliated nations and territories ("AIBA Boxing History," n.d.). Professional boxing contests are fought for a purse and can often include monetary incentives for winning by knockout. Amateur boxing on the other hand may involve the use of head protection during novice competitions and is based on scoring points against your opponent. The goal for boxers competing in both disciplines is to beat their opponent. Winning is achieved via 'decision', the accumulation of points, or 'stoppage' by forcing an opponent to retire via knockout (KO) or technical knockout (TKO). Since revenue in professional boxing is influenced by the level of entertainment, the primary goal of the professional boxer is to inflict maximum damage to their opponent. In addition to scoring criteria, key differences between amateur and professional boxing include the number and duration of rounds. In professional boxing, bouts typically range from six-to-twelve three-minute rounds. In contrast, amateur boxing is comprised of three two-to-three-minute rounds. To ensure 'equity' between competitors, weight classifications were introduced to boxing in 1897 (Prior, 1995). Today, senior weight categories are found in both professional and amateur boxing. Categories can differ marginally between sexes.

The Physiological Profile of a Boxer

The duration and intermittent nature of a bout requires competitive boxers to exhibit a range of characteristics. Specifically, competition requires frequent high-intensity efforts, during which re-synthesis of adenosine triphosphate is provided by anaerobic metabolism, involving an increase in lactate production (Zuliani, Bonetti, Serventi, Ugolotti & Varacca, 1985). Post competition blood lactate levels have been shown to reach averages of 17.1 mmol/l in elite boxers, illustrating the extreme anaerobic nature of the sport (Hubner-Wozniak, Kosmol, Glaz & Kusior, 2006). In addition to anaerobic requirements, a well-developed aerobic capacity is important (Smith & Draper, 2006). This is supported by Smith (2006) who recorded $VO_{2\ max}$ values of 63.8 ± 4.8 $ml \cdot kg^{-1} \cdot min^{-1}$ in elite amateur boxers.

In addition to specific metabolic requirements, local muscular endurance is important to maintain a fighting stance, defensive hand positions and to execute repetitive punching actions. Furthermore, speed is essential to ensure offensive and defensive success. By being evasive and beating an opponent to the punch, a boxer can minimize the damage they receive whilst increasing their chances of contacting their opponent. Smith (2006) noted that the ability to throw repeated punches with sufficient force to be a key component for success in boxing. This is supported by Loturco et al. (2016) who showed correlations ($r = .67 – .85$) between strength/power variables and punching force in amateur boxers from the Brazilian national team.

Pierce et al. (2006) examined the relationship between boxing performance and punching using a proprietary system (*bestshot* system™). The authors measured the punching force of 12 professional boxers during live boxing matches across five different weight classes. Results showed that when a fight went to the judges' scorecards, the victor was the athlete who had landed the greatest total force to their opponent. These findings suggest cumulative force and the volume of punches are powerful indicators of performance in professional competitions. It is worth noting that forces reported by Pierce et al. (2006) were lower than those recorded previously in laboratory tests (Atha & Sandover, 1985; Smith, Dyson, Hale & Janaway, 2000; Walilko, Viano & Bir, 2005), with ranges from 867 N (Super Middleweight) to 1149 N (Light Middleweight) across the fights. This is possibly due to the differences between a stationary and moving target. Furthermore, the two boxers who delivered the highest forces (5033 & 5358 N) weighed 62.3 kg and 80.5 kg (were not Heavyweights). In contrast, a laboratory study by Walilko et al. (2005) comparing punching force of elite amateur boxers across weight classes, revealed that the forces were higher in the heavier weight categories. The authors reported maximum rear hand punch forces of 3336 N (559) in Flyweight boxers and 4345 N (280) in Super Heavyweight boxers. The authors attributed this to a greater effective mass of the punch due primarily to greater body mass. Given the significant differences in forces produced between elite, intermediate and novice boxers (Appendix B), it is clear that experience plays a role in force generation (Smith et al., 2000). Variability in levels of force between studies are likely due to differences in data collection (both the equipment and protocols used), testing environment (laboratory vs. competition), and technical proficiency. Consequently, there are several factors that influence punching force.

The Kinetic Chain: From Foot to Fist

The rear hand punch is one of the most renowned strikes within combat sports and although it may not be the fastest, it is likely the hardest punch in a boxer's arsenal (Turner, Baker & Miller, 2011). Punching is a kinetic chain action where the force generated is initiated and influenced by the legs and transmitted through the mid-section of the body to the punching hand. Filimonov, Koptsev, Husyanov, and Nazarov (1985) used biomechanical observations and force dynamometry to analyze 120 boxers of varying ability. The authors suggested that force generated in the rear hand punch is influenced by: (i) the drive off the ground by the legs, (ii) the rotation of the trunk, and (iii) contributions from the arm musculature. The data collected indicated that boxers with more experience had a significantly greater contribution from their legs to the punch when compared with the other contributors (arms and trunk). The authors suggested that, leg contribution accounted for 38.6% of total punching force in experienced boxers, compared with 32.2% for intermediate and 16.5% for the novice boxers. This study demonstrates that the efficiency of the punching movement sequence plays an important role in the summation of force.

These findings are supported by Dyson, Smith, Martin and Fenn (2007) who used electromyography to evaluate the muscular recruitment sequences used by six male amateur boxers while they delivered punches to a dynamometer. The authors showed that punches delivered for maximum force to the head began with recruitment of the gastrocnemius as plantar flexion of the rear foot occurred. This was then followed by recruitment of the rectus femoris and biceps femoris which resulted in extension of the rear knee and hip, respectively. This linear model continued with successive recruitment of the upper body (trapezius and anterior deltoid) and subsequent arm muscles (biceps brachii and triceps brachii) for arm flexion and extension. This suggests that force is generated from the floor and transferred via the kinetic chain from the foot through to the fist and target.

Training Methods to Develop Punching Force

Considering the importance of force to boxing performance, it stands to reason that power is an important component of fitness for a boxer to possess. Power is an expression of strength and based on contemporary literature, stronger athletes are reported to generate higher power outputs (Haff et al., 2012). Theoretically, the use of low-load high-velocity movements can impact the high-velocity area of the force-velocity relationship, while heavier loads enhance the high-force portion of this relationship (Haff et al., 2012). Thus, power can be enhanced by increasing the force or the velocity of movement using slow-moving resistance exercises that target improvements in force, or high velocity training methods such as plyometrics or ballistics.

Aagaard et al. (2002) examined the effect of heavy resistance training on RFD under isometric testing conditions and reported significant increases (17–26%) in contractile RFD after 14 weeks of heavy-resistance training. Similarly, participants in a 24-week progressive lower body ballistic training program using loaded and unloaded jumping exercises, showed improvements (21%) in vertical jump performance (Häkkinen, Komi, and Alén, 1985). Increases in jump performance following BT have also been shown following shorter training periods. Newton et al. (1999) examined the effects of an eight-week BT program on elite volleyball players and reported significant increases in jump height (6 ± 3% in standing vertical jump & reach; 6 ± 5% in jump & reach from a three step), which the authors attributed to an increase in overall force output and RFD. Similarly, Carter, Kaminski, Douex Jr, Knight & Richards (2007) investigated the effects of high-volume upper body plyometric training on throwing velocity in collegiate baseball players. The authors reported a significant increase ($p < .05$) in throwing velocity following eight weeks of upper body plyometric training, when compared to a control group.

Medicine balls can be an effective tool for loading ballistic exercises. Significant improvements in medicine ball test throwing distances as well as improved peak power output during bench and shoulder press at 30 and 50% of 1RM, were reported in female handball players following 12-weeks of resistance training with medicine balls (Ignjatovic, Markovic & Radovanovic, 2012). Participants assigned to the experimental group were required to perform a variety of medicine ball exercises (shot put, overhead throw, and side throw) from four different positions (standing, sitting, lying, and jumping). As both the throwing athlete and the boxer’s rear hand punch utilize the same muscle groups and movement sequence, these results hold important implications for punching forces.

Mechanisms of Increasing Punching Force

Muscle is said to adapt its contractile properties specifically to the type of exercise training employed (Duchateau & Hainaut, 2003). Thus, sport specificity should be a consideration when designing training methods to enhance power. Turner et al. (2011) examined the movement pattern of the rear hand punch and identified the following variables as likely contributors to overall punching force: (i) leg drive and rigid landing, (ii) stretch-shortening cycle (SSC) and core function, and (iii) velocity and effective mass.

Leg Drive & Rigid Landing

Production of force via the kinetic chain requires an effective motor pattern involving technique and mobility dependent sequential muscle recruitment. This begins with the drive off the ground by the legs, a fundamental contributor to the summation of force in the action of punching (Filimonov et al., 1985). During a rear hand punch an anterior-posterior breaking force is said to involve landing with a rigid lead foot (Turner et al., 2011). To increase leg drive, Turner et al., (2011) suggests the use of axial loaded movements such as squats, weightlifting variations and vertical jumps. However, these movements only occur bilaterally and in the vertical direction whereas leg drive during punching requires ground reaction force (GRF) to be developed in the vertical and horizontal directions (Lenetsky et al., 2013). One distinct advantage of ballistic exercises is that they can be sport-specific, ensuring RFD is trained across functional movement patterns.

SSC & Core Function

The SSC is any muscle action where the preactivated muscle is first stretched (eccentric action) followed immediately by shortening (concentric action) (Nicol, Avela & Komi, 2006). Considering the sequential nature of the punching action it is important to consider the role of SSC actions in the generation of PF. Cavagna, Dusman, & Margaria, (1968) attributed the SSC phenomenon to elastic and contractile components of the muscle. The authors suggested that part of the work done by the muscle-tendon unit during the eccentric phase is recovered as elastic energy, which enhances the force generated by the contractile component during concentric shortening. This force potentiation is dependent on both the amplitude and velocity of the imposed stretch (Komi & Nicol, 2010). Two important functions of the SSC action in movement have been previously identified; firstly, to reduce any unnecessary delays in the force-time relationship, and secondly to make the final concentric muscle action more powerful and/or generate greater force economically (Komi et al., 2010).

The SSC is a key muscle action involved in producing a forceful punch, however this cycle is subject to fatigue, characterized by a progressive increase in movement time and decreases in force output (Nicol & Komi, 2011). For a boxer, this SSC fatigue could decrease the likelihood of making contact with the target and increases the boxer's vulnerability to punches. An important consideration when selecting training exercises is the role of the trunk musculature in rotation to transfer force from the lower body to the fist (Filimonov et al., 1985; Turner et al., 2011). The stretching of the trunk muscles during the rotation away, allows for a more powerful rotation forward via the combination of a transmission of breaking force through the body and employment of the SSC within the trunk musculature (McGill, 2010). Core strength and range of motion will likely affect a boxer's ability to rotate their hips and torso into a punch, and consequently transfer force via the kinetic chain. A recent study by Tong-Iam, Rachanavy & Lawsirirat (2017) used video analysis and force plates to assess the kinematic and kinetic action of throwing a straight punch in three professional boxers who competed regularly in Muay Thai and boxing. Their findings suggested that boxers use trunk rotation to transform vertical GRF to horizontal punch force.

When designing strength programs for throwing athletes, Stodden, Campbell & Moyer (2008) advocate incorporating trunk training exercises that demonstrate sport-specific trunk ranges of motion and velocities, as this may help to increase ball velocity and/or decrease the risk of injury. Similar principles likely apply to boxers.

Velocity & Effective Mass

In addition to the trunk musculature, the contractile elements of lower body skeletal muscle may influence the resultant hand velocity and consequent momentum (mass × velocity) up the kinetic chain. Muscle activity leading up to the hand's point of contact with a target may also affect subsequent force production. "Stiffening' the body prior to impact, by increasing all muscle activity i.e. agonists, antagonists, and stabilizers, has been shown to increase the effective mass, allowing for a greater impulse (force × time) to be conveyed (MacWilliams, Choi, Perezous, Chao & McFarland, 1998; Turner et al., 2011). Earlier research investigating recruitment patterns of single motor units (Desmedt et al., 1977) reported muscular and neural adaptations in response to training with small loads at maximal movement velocity. The intervention involved a series of fast, low-load dorsiflexion's performed five days a week for 12-weeks. The authors categorized this training method as 'dynamic or explosive', involving ballistic contractions characterized by short times to peak tension, high rates of tension development and high single motor unit discharge frequencies. At the muscular level, these adaptations are speculated to be primarily controlled by changes in muscle compliance and intracellular mechanisms such as enhanced myosin ATPase activity and/or intensified phasic ionized calcium movements (Duchateau et al., 2003). These physiological adaptations would likely result in increases in the rate of excitation-contraction coupling (ECC). ECC includes the sequence of events triggered by the membrane action potential responsible for regulating contractile protein interactions (Sandow, 1965).

Summary

The current literature suggests strength training methods that promote PF, the impact force generated from a punching action, should consider the role of the SSC muscle action and kinetic chain sequencing from foot to fist. Use of power training methods, such as BT has been shown to target the velocity component of power, however, to date there is a lack of research examining its impact on punch kinetics and endurance. The aim of this study was to examine the impact of upper body BT on punch kinetics and endurance, in recreationally-trained boxers. It was hypothesized that punch kinetics (PF_{max}, RFD and GRF) would increase in the BT group post-intervention, while CONTR group participants would show little change and that improvements in punch endurance would be observed relative to the CONTR group post-intervention.

Chapter 3

METHODS

This chapter describes the methods of data collection and analysis for examining the effect of ballistic training on punch kinetics and endurance. The methods section identifies participant characteristics along with experimental procedures and the statistical analysis procedures employed.

Participant Characteristics

Forty-five participants (CONTR: male n = 16, female n = 6, mean age = 27.4 ± 7.4 years, height = 1.9 ± .1 m, mass = 87.1 ± 13.8 kg; BT: male n = 12, female n = 11, mean age = 26.2 ± 4.0 years, height = 1.7 ± .1 m, mass = 72.1 ± 13.3 kg) with a mean boxing experience ≈ 11.3 ± 7.9 months were recruited. Participants were required to be free from cardiovascular and neuromuscular conditions that would increase their risk of injury during high-intensity training, and free from current injury. Participants were required to have a minimum of three months experience in boxing from a qualified coach or instructor and had no involvement in BT in the three-month period prior to data collection.

Study Procedure

Participants attended familiarization prior to testing which took place in the Ithaca College Biomechanics Laboratory. During the familiarization session, participants were informed of the nature of the study and provided written consent. Participants then completed a screening protocol that required them to demonstrate appropriate technique by performing one-minute of shadow boxing. Aspects of technique that were evaluated included body position and punching movement sequence. Following screening, participants were familiarized with testing procedures.

Punching is a complex skill requiring coordination of multiple body segments. Research has shown that adults are very amenable to motor control development, if given practice (Voelcker-Rehage, 2008). Using functional magnetic resonance imaging, Kami, Meyer, Jezzard, Adams, Turner, & Ungerleider (1995) demonstrated motor cortex plasticity, and vast improvement in speed and accuracy, in six adult males that were asked to practice specific rapid finger movement sequences daily for several weeks. These results are in line with other studies that have shown specific neurologic adaptations following motor control development exercises (Doyon & Benali, 2005; Isaacs, Anderson, Alcantara, Black, & Greenough, 1992; Wang, Conner, Rickert, & Tuszynski, 2011).

To mitigate the effect of individual differences in pre-existing motor control ability, participants were matched based on recent boxing experience. Thus, after familiarization, participants were categorized based on self-reported experience (> 3 months; > 6 months; >12 months). Within these categories, participants were randomly assigned to either a CONTR group with sham treatment, or BT group. Participants were also required to maintain their pre-existing volume of boxing training throughout the intervention period to limit extraneous punch-specific motor control development during the study.

Data Collection

Two punching protocols were administered to assess participant punching performance, Protocol 1: assessment of rear hand punch kinetics and Protocol 2: assessment of punching endurance. Ground reaction forces (GRF) from the lead and rear legs were also collected to assess leg involvement in punching.

Punch Kinetics

Prior to warming up participants had their hands wrapped and completed two minutes of shadow boxing. Once warm-up was complete, participants placed 10 oz. AIBA approved boxing gloves on both hands (the same gloves were used at pre- and post-tests). Participants then performed five maximum effort ("as hard as possible") rear-hand punches to a wall mounted force plate (Bertec, Model 4060-NC) positioned at a height of 1.12 m from the floor. The wall mounted force plate was covered by a 5 cm thick strike shield to prevent impact injuries to participants. The center of the shield was positioned in line with participants' shoulder height. Participants received 60-seconds recovery between efforts. All punches were performed with participants standing on two force plates (AMTI, Model OPT464508-2000) positioned side-by-side (Figure 1). Data was collected using Vicon Nexus (Vicon, Centennial, CO). All ground and wall-mounted force plates were synchronized within Vicon Nexus.

Of the five maximal punch efforts, the punch recording the highest peak normal force (N) was used for subsequent statistical analysis. The primary data identified to be of interest for the punch kinetics protocol was the punch force (PF_{max}), rate of force development (RFD), contact time (CT) and maximum lead and rear foot GRF's. Force onset and offset was determined with a 20 N threshold. All calculations were performed in LabVIEW (2016 National Instruments Austin Texas).

- PF_{max} (N) was determined as the maximum normal force (N) recorded from the wall-mounted force plate.
- RFD (N/s) was calculated as the average RFD by dividing the magnitude of the peak normal force by the time to peak force. In punches with a double peak, average RFD was calculated as the magnitude of the first peak of the normal force divided by the time to the first peak.
- CT (s) was calculated from the normal force by subtracting force onset from force offset.
- Maximum lead and rear foot GRF (N) were determined from the floor-mounted force plates. Resultant ($F_{max\text{-}Lead}$, $F_{max\text{-}Rear}$), horizontal ($Fx_{max\text{-}Lead}$, $Fx_{max\text{-}Rear}$), and vertical ($Fz_{max\text{-}Lead}$, $Fz_{max\text{-}Rear}$) were selected for analysis.

Punching Endurance

In addition to measuring punch kinetics, the impact of BT on punch endurance was evaluated. After a 2-minute recovery from the punch kinetics protocol, participants performed nine all-out 10-second punching efforts against the wall mounted force plate (Bertec, Model 4060-NC) over a 3-minute period (10 seconds of rest after each 10 seconds of punching). Participants were instructed to throw consecutive lead and rear hand (jab and cross) punches as hard and as fast as possible for each 10-second period. Participants were required to maintain a 'high guard' hand position during rest periods. To analyze the impact of the six-week intervention on punching endurance the average PF, RFD, CT and punch count for the first and third minutes were calculated. Force onset and offset was determined with a 20 N threshold. All calculations were in LabVIEW (2016 National Instruments Austin Texas).

- Mean PF_{max} ($\overline{PF}_{max}$) was calculated as the average of the PF_{max} across all punches within the first ($\overline{PF}_{max\text{- min 1}}$) and third minutes ($\overline{PF}_{max\text{- min 3}}$).
- Mean RFD ($\overline{RFD}$) was calculated as the mean of the average RFD across all punches within the first ($\overline{RFD}_{\text{min 1}}$) and third minutes ($\overline{RFD}_{\text{min 3}}$).
- Mean CT ($\overline{CT}$) was calculated as the mean CT across all punches within the first ($\overline{CT}_{\text{min 1}}$) and third ($\overline{CT}_{\text{min 3}}$) minutes.
- Total punch count was also determined for first ($Punch\ Count_{\text{min 1}}$), and third ($Punch\ Count_{\text{min 3}}$) minutes.

Figure 1. Image showing participant during data collection.

Training Protocol

Participants were required to attend supervised training sessions twice per week for 6-weeks. The BT group completed a series of loaded upper body ballistic resistance exercises (Appendix A). Exercises used in the BT program were chosen to reflect the kinematic action of a boxer's punch, promote leg contribution, and enhance efficiency of the SSC action of the trunk musculature. The following three parameters, suggested by Duchateau & Baudry (2011) were considered when designing the training protocol: (i) movement pattern and position, (ii) contraction type and (iii) the magnitude of the load and the speed of contraction.

The training protocol began with a standardized dynamic warm-up involving 2-minutes of shadow boxing and a band resisted shoulder preparation exercise. This was followed by six low-to-moderate load, high velocity exercises. Exercises were performed with an emphasis on exploiting the SSC. A high intensity of effort for each repetition was encouraged. In accordance with the NSCA's power training recommendations for multiple effort events, five repetitions were performed per set with three sets performed per exercise (Haff, & Triplett, 2016). Horizontal and vertical exercises were paired and performed as super-sets to increase time efficiency. Participants received a 2-minute recovery between sets (Baechle, Earle, & Wathen, 2008). Exercises performed remained the same for all 12 training sessions, however there was a progression in the medicine ball load after the halfway point of the treatment (six sessions) from 4 lb (1.8kg) to 7 lb (3.15 kg) for one-handed exercises, and from 7 lb (3.15 kg) to 11 lb (4.95 kg) for two-handed exercises. A standardized cool-down consisted of core exercises and static stretching. Training sessions were performed a minimum of 48-hours apart to aid recovery from microtrauma and inflammatory responses.

The CONTR group completed a sham treatment that consisted of the same exercises and repetitions detailed in the BT training protocol. CONTR group participants performed each exercise in a slow and controlled manner, without load. All training sessions were supervised by a coach.

a.

b.

Figure's 2a & *2b.* Showing participant performing two of the six ballistic exercises implemented in the BT intervention protocol.

Statistical Analysis

Data was imported into Microsoft Excel 2010 from LabVIEW and analyzed in JASP (version 0.10.2) statistical software. All continuous variables were assessed for normality using z-scores for skewness and kurtosis with values between -2 and +2 deemed acceptable (George & Mallery, 2010). Data was then checked for normality and the outliers deleted as appropriate.

Two-by-two mixed-measures analysis of variance (ANOVA) with two independent variables (time & group) was used to analyze changes in PF_{max}, RFD, CT and GRF recorded following the punch kinetics protocol.

To analyze the impact of the six-week intervention on punching endurance the average PF ($\overline{PF}_{max}$), RFD ($\overline{RFD}$), CT ($\overline{CT}$) and total number of punches for the first ($Punch\ Count_{\min 1}$), and third ($Punch\ Count_{\min 3}$) minutes were analyzed by using mixed measures ANOVAs with three independent variable's (time, duration and group). All independent variables had two levels (time: pre & post training intervention, duration: min1 & min3, group: CONTR & BT). For all analyses, alpha equaled .05.

For all variables, the magnitude of changes in means from pre- to post-training were calculated using Cohen's (*d*) effect sizes. These effect sizes were interpreted using the suggested magnitudes of *d* = .2 (small), .5 (medium) and .8 (large) (Cohen, 1992).

Chapter 4

RESULTS

Punch Kinetics

Statistical analysis revealed a significant main effect for time ($F_{(1, 43)} = 61.9$; $p < .001$). Post hoc analysis showed PF_{max} increased from pre- to post-training across CONTR and BT groups ($t = 5.25$; $p < .001$; $d = .78$). Examination of between-subject effects showed no significant difference in PF_{max} between CONTR and BT groups throughout the study ($F_{(1, 43)} = .63$; $p > .05$). Subsequently, interaction effects showed a significant increase (30.3 %) in PF_{max} in the BT group over time ($F_{(1,43)} = 60.2$; $p < .001$). In contrast, PF_{max} did not change in CONTR group participants over the course of the study (< 1 % change) (Figure 3).

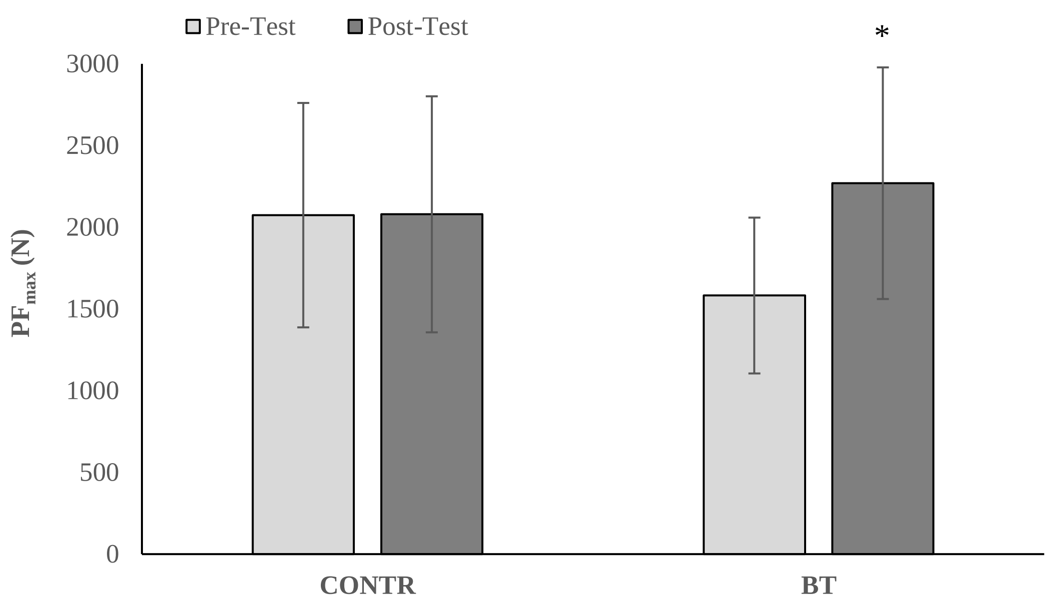

Figure 3. Changes in PF_{max} (in Newtons, N) over time for CONTR & BT groups (* significantly different from pre-test $p < .001$).

Results showed that changes in PF_{max} occurred despite no significant change in lead and rear foot forces. Statistical analysis revealed the main effect for time for F_{max}-Lead ($F_{(1, 42)} = 3.21$; $p > .05$) and F_{max}-Rear foot resultant forces ($F_{(1,38)} = 2.74$: $p > .05$) was not significant. Examination of between subject effects showed no difference in F_{max}-Lead ($F_{(1,42)} = 1.43$; $p > .05$) and F_{max}-Rear ($F_{(1,38)} = .97$; $p > .05$) foot resultant force between CONTR and BT groups throughout the study. Subsequently, interaction effects showed no change in F_{max}-Lead ($F_{(1,42)} = .51$; $p > .05$) and F_{max}-Rear ($F_{(1,38)} = 2.20$; $p > .05$) foot resultant forces in the CONTR or BT groups from pre- to post-training. When the forces were resolved to their horizontal and vertical components no significant change was observed. However, a comparison of percentage changes in resultant forces between the CONTR and BT groups pre- and post-training, revealed a trend towards increasing force within the experimental group (8.21%), with little change evident in the CONTR group (.41%).

Table 1

Lead & Rear Foot Force Data

	CONTR			**BT**		
	Pre-Test	**Post-Test**		**Pre-Test**	**Post-Test**	
	M (SD)	*M (SD)*	%Δ	*M (SD)*	*M (SD)*	%Δ
F_{max}-Lead (N)	822 (175)	844 (195)	2.69	744 (195)	795 (185)	6.89
Fx_{max}-Lead (N)	60 (45)	62 (36)	4.26	54 (41)	58 (38)	7.34
Fz_{max}-Lead (N)	809 (172)	829 (188)	2.38	754 (171)	777 (184)	3.06
F_{max}-Rear (N)	861 (167)	864 (210)	.41	774 (201)	838 (185)	8.21
Fx_{max}-Rear (N)	212 (61)	218 (65)	2.56	197 (62)	221 (59)	11.06
Fz_{max}-Rear (N)	839 (161)	842 (205)	.26	729 (154)	801 (174)	9.82

Figure 4 shows changes in RFD for CONTR and BT groups over the course of the study. Statistical analysis revealed a significant main effect for time ($F_{(1,43)} = 27.75$; $p < .001$) with an increase in RFD from pre- to post-training. Examination of between-subject effects showed no difference in RFD between CONTR and BT groups throughout the study ($F_{(1,43)} = .37$: $p > .05$). Subsequently, interaction effects showed a significant increase (44%) in RFD in the BT group over time ($F_{(1,43)} = 18.8$; $p < .001$). In contrast there was no significant change in RFD in CONTR group participants over the course of the study (5% change).

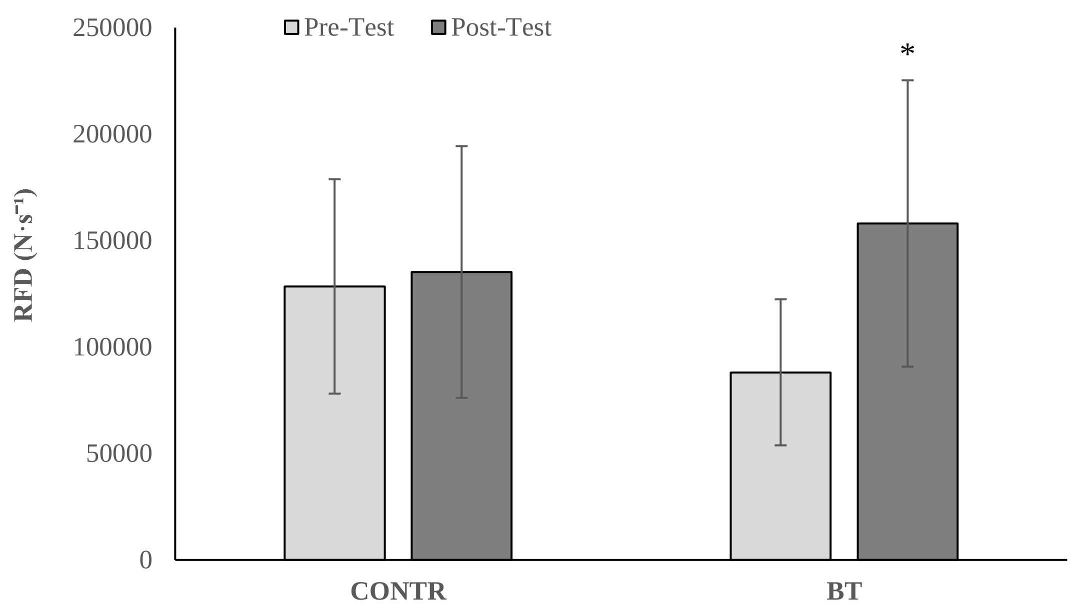

Figure 4. Comparison of changes in RFD (in Newtons per second squared, $N \cdot s^{-1}$) over time between CONTR & BT groups (* significantly different from pre-test $p < .001$**)**.

Changes in RFD occurred despite no corresponding changes in CT. Statistical analysis revealed no significant main effect for time ($F_{(1,35)} = 2.16$; $p > .05$). Examination of between subject effects showed no difference in CT in CONTR and BT groups throughout the study ($F_{(1,35)} = 0.00$; $p > .05$). Furthermore, interaction effects showed no significant difference in CONTR or BT groups over time ($F_{(1,35)} = .12$; $p > .05$).

Punching Endurance

Mixed-measures ANOVA results showed that $\overline{PF}_{\text{max}}$ increased significantly ($F_{(1, 39)} = 7.27$; $p < .05$) from pre- to post-training ($d = 0.39$). Analysis of time*group interactions showed that $\overline{PF}_{\text{max}}$ increased in the BT group from pre- to post-training ($F_{(1, 39)} = 7.77$; $p < .05$) with little change in the CONTR group. Further, analysis of mixed-measures ANOVA results also showed $\overline{PF}_{\text{max}}$ deteriorated from Min_1 (762.8 N) to Min_3 (677.7 N; $F_{(1, 39)} = 50.66$; $p < .001$; $d = 0.43$). Examination of duration*group interactions showed that the deterioration in $\overline{PF}_{\text{max}}$ from Min_1 to Min_3 was similar for both groups ($F_{(1, 39)} = 2.15$; $p > .05$). In addition, analysis of time*duration interactions showed that deterioration in $\overline{PF}_{\text{max}}$ from Min_1 to Min_3 was consistent from pre- to post-training for both groups ($F_{(1, 39)} = .723$; $p > .05$). Subsequently, analysis of time*duration*group interactions suggests that while the training group were producing more force relative to the CONTR group at post-training, the level of deterioration between groups from Min_1 to Min_3 was similar for the BT and CONTR groups ($F_{(1, 39)} = 1.17$; $p > .05$) following the training period (Figures 5 & 6).

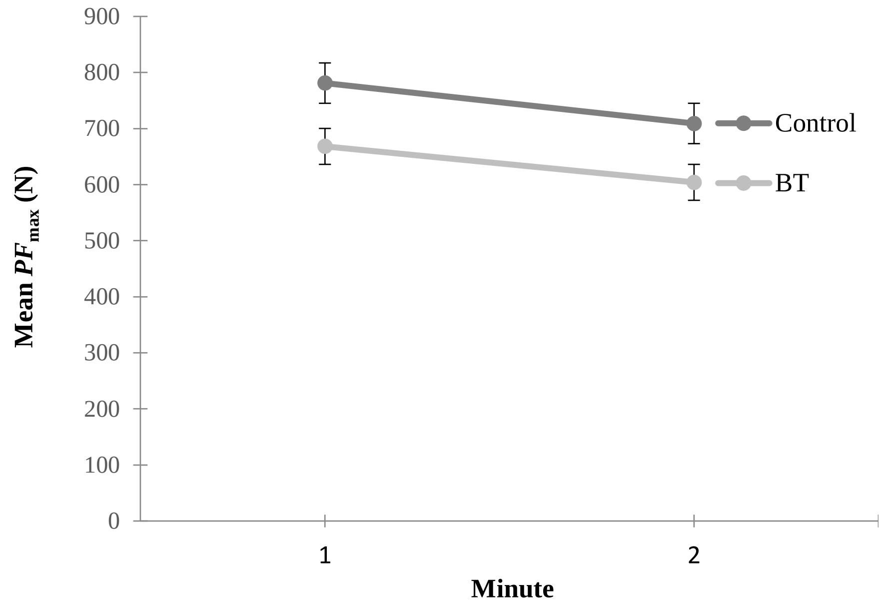

Figure 5. Changes in $\overline{PF}$max- min 1 & $\overline{PF}$max- min 3 for CONTR & BT groups at pre-test.

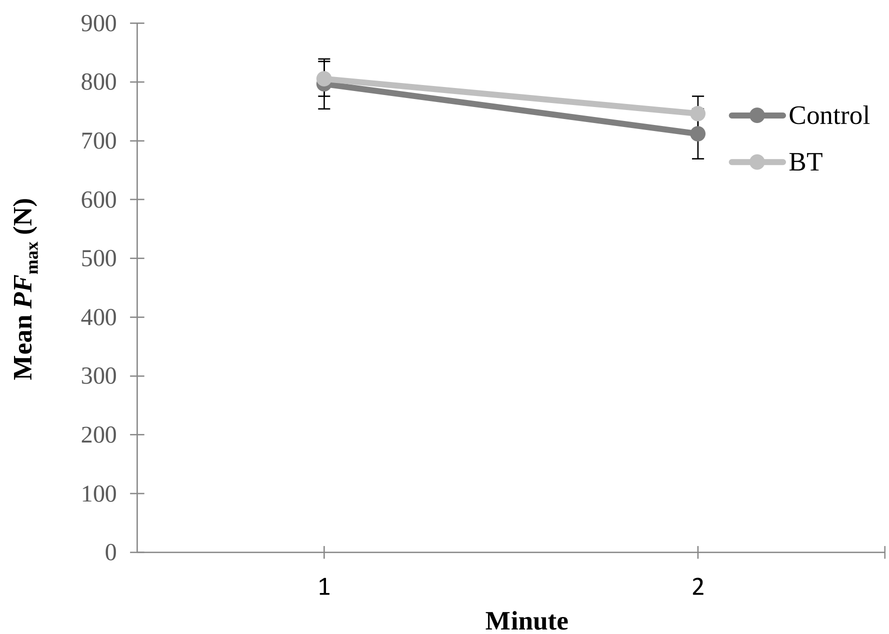

Figure 6. Changes in $\overline{PF}$max- min 1 & $\overline{PF}$max- min 3 for CONTR & BT groups at post-test.

Similarly, as with protocol 1 (punch kinetics) results, changes in $\overline{PF}_{\max}$ were accompanied by increases in $\overline{RFD}$ ($F_{(1, 35)} = 15.89$; $p < .001$) from pre-post training. Analysis of time*group interactions showed no difference in $\overline{RFD}$ between BT and CONTR groups at pre- or post-training ($F_{(1, 35)} = 3.17$; $p > .05$). Further, data showed $\overline{RFD}$ deteriorated from Min_1 to Min_3 ($F_{(1, 35)} = 91.10$; $p < .001$). Examination of duration*group interactions showed that the deteriorations in $\overline{RFD}$ from Min_1 to Min_3 were similar for both groups ($F_{(1, 35)} = 0.12$; $p > .05$). Subsequently, time*duration interactions showed deteriorations in $\overline{RFD}$ from Min_1 to Min_3 were consistent from pre- to post-training for both groups ($F_{(1, 35)} = 3.35$; $p > .05$). This is supported by analysis of time*duration*group interactions ($F_{(1, 35)} = .00$; $p > .05$) which showed that deteriorations in $\overline{RFD}$ were similar between BT and CONTR groups.

Mixed-measures ANOVA results showed that the punch count did not change significantly ($F_{(1, 43)} = .18$; $p > .05$) from pre-post training. Thus time*group interactions showed no change in punch count in the BT relative to the CONTR group from pre- to post-training ($F_{(1, 43)} = 2.52$; $p > .05$). Further, analysis of mixed-measures ANOVA results also showed that the punch count did not decrease from Min_1 to Min_3 ($F_{(1, 43)} = 3.36$; $p > .05$). Examination of duration*group interactions showed that the total punch count determined from first ($Punch\ Count_{\min 1}$), and third ($Punch\ Count_{\min 3}$) minutes was similar for both groups across the duration of the study ($F_{(1, 43)} = .30$; $p > .05$). Analysis of time*duration interactions showed a significant decrease in the number of punches thrown from Min_1 to Min_3 ($F_{(1, 43)} = 4.17$; $p < .05$). Although examination of time*duration*group interactions revealed that the punch count decreased from Min_1 to

Min_3 to a similar extent in CONTR and BT participants before and after the training period ($F_{(1, 43)}$ = .25; p > .05).

Table 2

Total Punch Count Recorded for First, Second & Third Minutes Before & After the Intervention Period

	CONTR		BT	
	Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**
	Mean (± SD)	*Mean (± SD)*	*Mean (± SD)*	*Mean (± SD)*
$Punch\ Count_{\min 1}$	34 (± 7)	35 (± 8)	40 (± 9)	38 (± 10)
$Punch\ Count_{\min 2}$	33 (± 7)	34 (± 8)	39 (± 9)	38 (± 9)
$Punch\ Count_{\min 3}$	32 (± 7)	34 (± 9)	38 (± 10)	38 (± 10)

Analysis of $\overline{CT}$ results showed no change from pre-post training intervention ($F_{(1, 30)}$ = 1.00; p > .05). Thus, time*group interactions showed no difference in $\overline{CT}$ between the BT or CONTR groups at pre- or post-training ($F_{(1, 30)}$ = .01; p > .05). Data also showed no difference in $\overline{CT}$ from Min_1 to Min_3 ($F_{(1, 30)}$ = 2.79; p > .05). Thus duration*group interactions showed that $\overline{CT}_{\min 1}$ and $\overline{CT}_{\min 3}$ was similar for both groups ($F_{(1, 30)}$ = .08; p > .05). Analysis of time*duration interactions showed that $\overline{CT}_{\min 1}$ and $\overline{CT}_{\min 3}$ was consistent from pre- to post-training for both groups ($F_{(1, 30)}$ = .23; p > .05). Subsequently, time*duration*group interactions suggest that the $\overline{CT}$ was similar for the BT and CONTR groups ($F_{(1, 30)}$ = .18; p > .05).

Chapter 5

DISCUSSION

The ability to generate large punching forces and a high volume of forceful punches is the cornerstone to boxing performance. The rear-hand punch has been identified as one of the most forceful punches in a boxer's arsenal (Turner et al., 2011). Considering the importance of force to boxing performance, it stands to reason that power is an important component of training. Historically, resistance training programs included exercises that focused on improving the force component of power as opposed to velocity, such as squats, however these force gains were restricted to the exercises' movement patterns (Lenetsky et al., 2013). In contrast, BT in athletes has been shown to increase RFD in a sport-specific manner, ensuring RFD is trained across functional movement patterns, such as punching (Newton et al., 1999). Additionally, BT involve plyometric movements that exploit the SSC muscle action. This is the first study to examine the effects of BT on punch kinetics and endurance.

In the present study, average rear-hand PF_{max} of the total sample was recorded to be 2024 ± 294 N. These values are similar to previous research assessing the biomechanics of boxers (Appendix, Table 2). Smith (2006) reported average rear-hand punch forces of 2643 ± 1273 N in 29 male English international amateur boxers. In an earlier study by Smith (2000), average rear-hand punch forces of 2381 ± 116 N were observed in eight novice level competitive boxers. Research suggests there is a correlation between punching force and boxing experience (Atha et al., 1985; Smith et al., 2000; Smith et al., 2006; Viano et al., 2005; Waliko et al., 2005). Other variables that may account for comparative differences in forces between studies include the method of data collection, participant weight class, and participant gender. Rear-hand punch force values collected during this study suggests that the population of trained boxers recruited is most representative of recreational to amateur novice level.

An important finding of the current work is that kinetic variables; PF_{max} and RFD significantly increased, 30.3% and 44.0% respectively, in the BT group. These changes occurred without a statistically significant change in GRFs, although there was a notable trend towards increased leg contribution in BT group participants (Table 1). The transfer of force during a rear-hand punch, via the kinetic chain from foot to fist, is influenced by leg contribution as well as several other kinematic variables including; the effective strike mass, following the step forward, and landing with a rigid leg to increase braking and transmission of forces (Turner et al., 2011). It is speculated that the ballistic exercises, where force was initiated from the ground with subsequent core rotation, may have led to an improvement in force transmission. This is potentially attributed to the SSC muscle action employed in the rotation of the trunk, and the contribution of the arm musculature through the target on the force plate. Furthermore, the inclusion of exercises within the training intervention that focused on increasing core strength and range of motion, would have likely contributed to improvements in the participants' ability to rotate their hips and torso into a punch, and consequently improve the transfer of force via the kinetic chain.

Of note was the difference recorded in pre-test PF_{max} values between groups. While PF_{max} did not change in CONTR group participants over the course of the study ($<$ 1 % change), their average pre-test PF_{max} values were significantly higher than BT group participants (Figure 3). A probable cause for this contrast in pre-test PF_{max} values was the difference in collective participant mass between groups. To mitigate the effect of individual differences in pre-existing motor control ability, participants were matched based on recent boxing experience then randomly assigned to either group. This assignment resulted in an overall heavier CONTR group (87.1 ± 13.8 kg), relative to the BT group (72.1 ± 13.3 kg). An increase in participant mass would account for these initial disparities in punch force seen between groups.

Improvements in PF_{max} and RFD seen in the BT group suggest that the participants' muscle contractile kinetics may have been intrinsically modified by the training intervention. Skeletal muscle may adapt its contractile properties specifically to the type of exercise training endured (Duchateau et al., 2003; Van Cutsem, Duchateau, & Hainaut, 1998). Contractile RFD has been shown to be influenced by the level of neural activation, muscle size, and fiber-type composition (Aagaard et al., 2002). The lack of improvement in punch kinetics in the control group is speculated to be due to the absence of external load, and the slow and controlled (non-ballistic) manner in which the sham treatment was carried out. In addition to the speed of contraction, the BT exercises were performed with low to moderate loads targeting the velocity component of the power equation. Improvements in rear-hand punch kinetics after the six-week training program may have been attributed to increases in the velocity of the punch. These findings are consistent with results from Carter et al. (2007), who reported significant improvements in throwing velocity in baseballers subjected to an eight-week, upper extremity plyometric training intervention.

Increases in force output and RFD have been documented following lower body BT. One such study reported marked improvements in various jump tests after eight weeks of ballistic training (Newton et al., 1999). The authors suggested that the ability of the neuromuscular system to maintain tension while the muscles are rapidly shortening may have been enhanced (Newton et al., 1999). Neural adaptations integral to explosive power training were reviewed by Duchateau et al., (2003). Dynamic training using small loads were found to evoke neural and muscular adaptations that increased the maximal rate of tension development. It is speculated that punch kinetic changes in the BT group occurred as a result of this type of neuromuscular conditioning. Proposed mechanisms of muscle and motor unit adaptation to power training include selective activation of fast high-threshold motor units, enhanced synchronization between motor units, and an increase in the rate at which motor units are discharged. Intracellular mechanisms such as enhanced myosin ATPase activity and/or intensified phasic ionized calcium movements, also appear to underlie muscular adaptation to training (Duchateau et al., 2003). These adaptations likely contributed to an increased rate of ECC and contract-relax mechanisms, that may account for the significant increases in PF_{max} and RFD observed in the BT group.

Although the main outcome variable for punching endurance, $\overline{PF}_{max}$, was shown to significantly increase in the BT group, a similar decrement in force output was observed between both groups post-intervention. This suggests the intervention had no significant effect on punching endurance. Alternatively, it is possible that results were confounded due to participants pacing themselves during the endurance protocol. Boxers, in particular those who regularly perform bag drills similar to that employed for the endurance protocol, are likely familiar with pacing. Analysis of the mixed-measures ANOVA results was consistent with pacing, which showed that the punch count did not decrease from Min_1 to Min_3, implying that participants appeared to sacrifice punching force for punching volume. This suggests that while the number of punches thrown by participants remained unchanged, the force output decreased. From an applied standpoint, a boxer may be able to keep the volume of punches high, but the effect of this will deteriorate over the duration of a round as the force decreases. To mitigate the potential for a 'pacing effect' in future studies, the experimental design could be altered to have participants perform an all-out 30 second maximal punching effort, similar to that of an anaerobic Wingate test, so as to better reflect a measure of punch endurance.

The amount of time the glove made contact with the force place, CT, was deemed an important variable for both protocols, as it had the potential to influence force measurements. In both the punch force and endurance protocols, improvements in PF_{max}, RFD and $\overline{PF}_{max}$ were observed in BT group participants despite no corresponding changes in CT. These findings suggest BT has little effect on punch CT, and that PF_{max} and RFD increases in the treatment group post-intervention were unrelated to the participants CT on the force plate.

Chapter 6

SUMMARY, CONCLUSIONS AND RECCOMMENDATIONS

Summary

This study indicates that short-term punch-specific BT may increase the PF_{max} and RFD produced by a rear-hand punch in recreationally-trained boxers, although more research is required to fully characterize its utility. Greater understanding of the effects of manipulating the duration, frequency, and volume on punching kinetics and endurance is needed. Based on this study, it seems appropriate to convert strength training for boxers from slow-moving to fast-moving. The focus of the training stimulus (increasing force or velocity of movement) should be considered when programming, as manipulation of these two variables will determine the development of physical characteristics, such as muscle-tendon size, neural drive and motor unit recruitment, all of which are shown to contribute to power output (Aagaard et al., 2002). Although these physical characteristics were not measured in this study, it is speculated based on previous literature that BT increased efficiency of the contractile components of the muscle due to an enhanced rate of ECC and contract-relax mechanisms, increasing punch PF_{max} and RFD. Future research should examine the precise neuromuscular adaptations to BT. In addition to neuromuscular properties, the kinematics of a boxer's punch will influence the subsequent forces produced, therefore technique is a fundamental variable in force production. Thus, additional research in professional or elite-level amateur boxer populations is required, in order to affirm whether a similar response to the training intervention would occur.

Conclusions

Strength and conditioning coaches are becoming increasingly aware of the importance of sport-specific movements when designing and implementing training programs for power development. Accordingly, the use of BT for combat athletes, such as boxers, has gained popularity, despite limited evidence supporting its efficacy. To the best of the author's knowledge, this work represents the first study to examine the impact of BT on punch kinetics in boxers, and demonstrates significant increases in PF_{max} and RFD following a six-week BT intervention. In contrast, BT had little effect on punching endurance. Thus, ballistic exercises involving punch-specific functional movement patterns, are appropriate to develop punch kinetics.

Recommendations

These findings support the inclusion of a BT program within a speed-strength phase prior to competition, to convert slow-strength to fast/speed-strength within the combat athlete paradigm (e.g. in the pre-competition phase). This study highlights the importance of punch kinematics in force transmission, and the necessity for strength coaches working with combat athletes to incorporate this into training exercises.

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APPENDIX A

BT Training Protocol

APPENDIX B

Table 3

Comparison of Rear-Hand Punch Forces

Source	Method	Type	Level	Weight Class/Body Mass (kg)	n	Force (N)
Atha et al. (1985)	Single punches to instrumented target mass	Professional		Heavy	1	4096
Smith et al. (2000)	Single punches to "head" of pear-shaped bag	Amateur	Elite		7	4800 (227)
			Intermediate		8	3722 (133)
			Novice		8	2381 (116)
Viano et al. (2005)	Single punches to Hybrid III ATD head (with neck/torso)	Amateur	Elite (Olympic)	76.2 (22.1)	11	Forehead: 3419 (1381) Jaw: 2349 (962)
Waliko et al. (2005)	Single punches to Hybrid III ATD head (with neck/torso)	Amateur	Elite (Olympic)	Fly	3	3336 (559)
				Light welter	1	2910 (835)
				Middle	1	2625 (543)
				Super Heavy	2	4345 (280)
Smith et al. (2006)	Single punches to "head" of pear-shaped bag	Amateur	Elite		29	2643 (1273)
Dyson et al. (2008)	Subjects given 30secs to punch dynamometer manikin	Amateur	'Competitive amateurs'	73.3 (19.0)	6	
Loturco et al. (2016)	Force platform covered by a body shield was mounted on the wall at a height of 1m	Amateur	Elite (National team)	54-91	15 (9 male & 6 female)	

APPENDIX C

Informed Consent

ITHACA COLLEGE

Department of Exercise and Sport Sciences

Informed Consent Form

Thesis Title: THE EFFECT OF BALLISTIC TRAINING ON PUNCH KINETICS & ENDURANCE IN TRAINED BOXERS

1) Purpose of the study?

The ability to generate forceful punches is a key performance variable in combat sports. Many examples of 'combat conditioning' exercises can be found on social media, however, whether or not there is a significant effect on the punching impact force remains unknown. This study intends to examine if ballistic training (BT) exercises can increase punching forces. BT is a method of power training which has been shown to increase the rate at which an athlete can develop force. BT typically involves exercises performed at high speeds using body weight, or medicine balls.

2) Benefits of the study?

Participant Benefits: As a participant in this study you will receive testing that may be used to inform your training practices. Upon request and completion of all testing, you will receive a feedback report showing your pre and post test measurements.

Researcher Benefits: Following project completion, data will be presented to scientific and coaching communities in the form of journal articles and / or conference presentations. Members of the research team will also improve their research and applied coaching experiences in the field of strength and conditioning.

Scientific Community Benefits: On publication of our research findings it is expected that the data collected will enhance knowledge in the field of biomechanics and strength and conditioning.

3) What are you asked to do?

In agreeing to participate, you will be asked to attend the Ithaca College Biomechanics lab (CHS 308) at three time-points (i.e. weeks 1, 2 & 7) to undergo testing. Each testing session will take place at the same time of day. Testing will take approximately 20-mins.

Initials________

Week 1 Testing (20 mins):

Testing procedures completed here are designed to familiarize you with all future testing procedures (detailed within this section). This session will give you the opportunity to ask any questions you may have and to become comfortable with the testing environment. Data collected during these procedures will not be included in analysis.

Week 2 and 7 Testing (~ 20 mins):

On arriving at the biomechanics lab your height and weight will be measured. You will be required to wrap your hands with boxing wraps (we can do this for you) and wear 10oz boxing gloves, both of which will be provided. After a standardized warm up of two minutes shadow boxing you will complete two protocols to assess punching performance.

Protocol 1 (Punch Dynamics): You will be required to perform five rear hand punches to a padded target with 60 second recovery between efforts.

Protocol 2 (Punch Endurance): You will be required to perform nine all-out punching efforts with both lead and/or dominant hand for the duration of 180 seconds with 10 second intervals of effort and recovery (10 second maximal effort with 10 second recovery). You will be required to maintain your boxing stance as well as hand (guard) position during recovery periods. Data will be used to measure force and endurance.

Training Intervention:

Following week 2 testing you will be randomly assigned to one of two training groups as follows;

a) *Low Intensity* – If assigned here you will complete a supervised low intensity training program at the Wellness Clinic or Black Irish Boxing. This program should be performed twice per week for six weeks.
b) *High Intensity* – If assigned here you will complete a supervised high intensity training program at the Wellness Clinic or Black Irish Boxing. This program should be performed twice per week for six weeks.

Initials________

4) What is the total time commitment associated with participating in this study?

In agreeing to participate, the total time commitment is as follows;

Low Intensity Training Group	High Intensity Training Group
Testing = 1 hour	Testing = 1 hour
Training = ~10 hours	Training = ~10 hours
Total = ~11 hours	**Total** = ~11 hours

5) Risks?

There is minimal risk of injury during testing and training. Risks will be reduced as you will be familiarized with all testing equipment and protocols before testing. You will also be instructed on correct training technique by a fitness coach and your performance will be carefully monitored throughout each exercise session.

Note: There may also be a risk of developing Delayed Onset of Muscle Soreness (DOMS) after testing / training. The discomfort and stiffness associated with DOMS are harmless and usually goes away within 2-3 days.

6) Compensation for Injury?

If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost for such care will be charged to you. If you have insurance, you may bill your insurance company. You will be responsible to pay all costs not covered by your insurance. Ithaca College will not pay for any care, lost wages, or provide other financial compensation.

7) If you would like more information about the study.

If you would like more information about the study feel free to contact the principal investigator, George Crouch: **Email:** gcrouch@ithaca.edu. **Phone:** 607 379 3690.

8) Withdrawal from the study.

You are not obliged to take part in this study. Also, please be aware that as the participant, you reserve the right to withdraw from the study at any stage (without explanation) and completely without prejudice towards you.

Initials________

9) How will the data be maintained in confidence?

All recorded information will be treated with the strictest confidence and will not be disclosed to any party other than the investigator, supervisor or yourself (if desired). Your results will also remain completely anonymous at all times and will be stored on the investigators password protected personal computer. Data on the computers will be coded by participant number. Only members of the research team will have access to the names associated with the code, and the code will be kept separate from data files in a secure location (faculty advisor's office: CHS 321). Data files will be kept for at least 5 years.

I have read the above and I understand its contents. I agree to participate in the study. I acknowledge that I am 18 years of age or older.

Participant's Name (Please print): ....

Participant's Signature: .... **Date:** ..../......../.............

Investigator's Signature: .... **Date:** ..../......../.............

This study has been approved by the Institutional Review Board (IRB) of Ithaca College. If you have any concerns about this study and wish to contact someone independent, you may contact the IRB at:

Tel: (607) 274 3113 Email: irb@ithaca.edu

(IRB 1218-10)

Initials__________

APPENDIX D

Health Screening Questionnaire

Department of Exercise and Sport Sciences

Health Screening Questionnaire

As you agreed to participate in this study, you are required to complete the following questionnaire. Please be assured that any information contained herein will remain completely confidential. Your cooperation in this is greatly appreciated.

Participant's Name: .... ***Date of Birth:*** ....

Age: ....

Height: .... **Weight:** ....

Boxing Experience: □ Greater than 3 months

□ Greater than 6 months

□ Greater than 12 months

If greater than 12 months please indicate the number of years: ....

Persons to contact in case of emergency:

Name: .... ***Phone Number:*** ....

Physician's Name: .... ***Physician's Phn:*** ....

Have you had to consult your doctor within the last six weeks? Yes □ No□

If 'yes' please give details:

....

....

....

Have you currently or ever had:

□ Diabetes □ Asthma □ Bronchitis □ Heart complaints

Initials_____

If so, please give details:

....

....

....

Injury History:

Have you experienced an injury within the last six weeks that has resulted in the termination of your normal exercise activities and has forced you to consult a sports medicine professional (e.g. Physical Therapist / Athletic Trainer)? Yes □ No □

If yes please provide details of:

- Type of injury; ....
- How it occurred; ....
- When it occurred; ....

Could these injuries prevent / limit your performance in the forthcoming exercise testing?

Yes □ No □

If you have answered **NO** to all questions, then you can be reasonably sure that you can take part in the physical activity requirements of the testing procedures.

I .... declare that the above information is correct at the time of completing this questionnaire **Date** ..../........./.........

Participant's signature .... **Date** ..../........./.........

Investigator's signature .... **Date** ..../........./.........

Please Note: If your health changes so that you can then answer YES to any of the above questions, please inform the experimenter / laboratory supervisor. You should also consult with your doctor regarding the level of physical activity you can conduct.

If you have answered **YES** to one or more questions:

Please consult your doctor and discuss with him / her, those questions you answered yes. Ask your doctor if you are able to conduct the physical activity requirements.

Investigator's signature .... **Date** ..../......../............

Doctor's signature .... **Date** ..../......../..............

This study has been approved by the Institutional Review Board (IRB) of Ithaca College. If you have any concerns about this study and wish to contact someone independent, you may contact the IRB at:
Tel: (607) 274 3113 Email: irb@ithaca.edu

(IRB 1218-10)