NORTHUMBRIA UNIVERSITY

ENDURANCE TRAINING NEGATIVELY IMPACTS FORCE RESPONSES IN RUGBY UNION PLAYERS.

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A MASTERS DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS IN STRENGTH AND CONDITIONING

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TITLE: Endurance Exercise Negatively Impacts Force Responses in Academy Rugby Players

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ABSTRACT

The primary objective of this study was to investigate acute force responses in team sport athletes following different volumes of endurance training. Evidence supports an incompatibility between aerobic and strength training when performed concurrently that is subsequently detrimental to strength outcomes, colloquially referred to as the interference effect. Eleven academy rugby players (n=11) completed 3 submaximal cycling interventions of 20, 40, and 60 minutes, respectively. To assess the impact of the cycling interventions on acute force production, subjects performed two 5x5 back squat protocols at 85% of their 1RM, one trial prior to the cycling intervention, and one trial immediately following the cycling intervention. The difference in force production between the two trials was collected for analysis. A one-way repeated measures ANOVA was used to assess a significant impact ($p < .05$) of the cycling interventions on mean force production. A multi-variate repeated measures ANOVA was used to determine a significant impact on peak force production ($p < .05$) in response to either the cycling intervention or across working sets. Endurance volumes elicited decrements in peak force production of 8%, 10%, and 5%, for the 20, 40, and 60 minute conditions, respectively. However, none of these decreases managed to attain statistical significance ($p > .05$). No effect of sets was observed on peak force production, furthermore, cycling interventions did not have any statistically significant effect on mean force production ($p > .05$). Lack of statistical power likely contributed to the lack of statistical significance. Future research should implement similar protocols to assess the magnitude of acute force reductions in response to preceding endurance in a larger cohort of team sport athletes.

KEYWORDS: Interference Effect, Concurrent Training, Rugby, Force Production, Strength Development

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List of Abbreviations

AMPK- adenosine monophosphate-activated protein kinase

ANOVA- analysis of variance

CMJ- Countermovement Jump

CSA- Cross Sectional Area

DOMS- Delayed Onset Muscle Soreness

EMG- Electromyography

mTORC1- Mammalian Target of Rapamycin Complex 1

MVC- Maximal Voluntary Contraction

N-Newtons

N/kg-Newtons per kilogram of body weight

NSCA- National Strength and Conditioning Association

RFD- Rate of Force Development

RM- Repetition Maximum

RPM- Revolutions per minute

VO_{2max}- Maximal Oxygen Uptake

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1.0 Introduction

Athletic development in team sports is a multidimensional practice which demands an integrated and cohesive approach from a variety of disciplines. While technical coaches primarily oversee the development of game skills, it is the responsibility of the strength and conditioning coach to develop physical traits like size, speed, aerobic capacity, and strength (Kilduff, Finn, Baker, Cook, & West, 2013). The development of these specific phenotypes is reached through a variety of means, most commonly a combination of strength training and endurance training. Both strength and endurance training elicit a host of acute physiological responses beneficial to athletic performance. Performing either strength or endurance training for an extended period of time further augments these physiological adaptations frequently resulting in superior sport performance (Myer, Ford, Palumbo, & Hewett, 2005).

In some circumstances, athletes and coaches may hope to develop strength and endurance simultaneously as high capacity in both qualities is necessary for success. This practice is colloquially referred to as concurrent training (Jones, Howatson, Russell, & French, 2013). Athletes performing concurrent training will frequently follow up strength training immediately with endurance training, practice, or *vice versa.* Similarly, athletes training concurrently may also choose to perform strength and endurance sessions on separate days or within the same micro-cycle (Jones et al., 2013). It has become apparent though, that when performing strength and endurance training simultaneously, in comparison to solely strength training, attenuated gains in strength and power often occur (Hickson, 1980; Dudley & Djimal, 1985; Sale, Jacobs, Madougall, & Garner, 1990; Collins & Snow, 1993). This phenomenon was initially discovered by Hickson (1980) and appropriately named the "interference effect," a title still used in scientific literature today. In the 40 years since this discovery a plethora of research has tried to elucidate the underlying mechanisms behind the interference effect, the extent of this attenuation given different training conditions, and how interference can ultimately be mitigated. As such, various hypotheses exist surrounding concurrent training and the interference effect.

Some of the most frequently cited mechanisms underpinning interference include residual fatigue from a prior bout of exercise (Hakkinen et al., 2003), molecular incompatibility of strength and endurance training (Baar, 2006), inhibition of type II muscle fibres (Ellefsen &

Baar, 2019), and increased training stress from improper manipulation of training variables (Fyfe, Bartlett, Hanson, Stepto, & Bishop, 2016). It stands to reason that neuromuscular fatigue from endurance training performed in close temporal proximity to strength training would result in interference. Previous findings show support for this hypothesis given qualities such as RFD are impaired following concurrent training but not strength training (Hakkinen et al., 2003). Molecular incompatibly behind interference has been a prominent area of research for 20 years (Baar & Esser, 1999) and provides a theoretical mechanism by which endurance training attenuates strength performance, despite limited evidence in human subjects. It is well known that endurance training results in greater hypertrophy of type I muscle fibres and a simultaneous hypertrophic inhibition of type II muscle fibres, potentially limiting muscle strength and power, in spite of simultaneous resistance training (Kazior et al., 2016). The inappropriate manipulation of training variables leading to a potential state of overtraining and subsequent interference has received much attention in concurrent literature, but has yet to produce definitive results (Bishop, Batlett, Fyfe, & Lee, 2019). A variety of methodologies have been used in concurrent studies showing support for (Hickson, 1980; Kraemer et al., 1995; Coffey & Hawley, 2016; Berryman, Mujika, & Bosquet, 2019), and against (McCarthy, Pozniak, & Agre, 2002; Balabinis, Psarakis, Moukas, Vassiliou, & Behrakis, 2003; Hakkinen et al., 2003) interference. All relevant hypotheses considered, no individual mechanism appears to be solely responsible for the interference effect. As a result, the field remains highly debated and contentious in spite of much scientific investigation.

The primary aim of this paper was to add to the current breadth of information surrounding interference following combined strength and aerobic training. As very few studies have compared force responses to concurrent exercise (Schumann, 2019), the purpose of this dissertation was to examine the impact of three separate volumes of endurance training on force production in an acute setting in rugby players.

2.0 Literature Review

2.1 Background

It has long been established that exercise adaptations occur specifically as a result of the demand of an external stimulus. Heavy, explosive resistance training for example results in muscle cell hypertrophy, increased bone mineral density, increased connective tissue strength, increased anaerobic enzymes, and occasionally decreased mitochondrial density (Kraemer, Deschenes, & Fleck, 1988). Conversely, endurance training results in increased mitochondrial density and volume, increased aerobic capacity, and increased muscle myoglobin (Astrand & Rodah, 1986). In addition, both strength and endurance training elicit morphological changes in muscle fibre type towards their specific phenotypes following exercise. Endurance training causes a shift towards type I "slow" oxidative fibre type, hypertrophy of type I muscle fibres and a simultaneous inhibition of hypertrophy in type II "fast" twitch muscle. Though it appears that all fibre types shift toward a "slower" oxidative phenotype following activity (Ciciliot, Rossi, Dyar, Blaauw, & Schiaffino, 2013), strength and power training show a much higher preservation of type II muscle fibres, including improvement in and maintenance of strength and velocity specific qualities (Farup et al., 2012). The abovementioned list of adaptations is not exhaustive, in addition, different adaptations occur under acute and chronic exercise, further augmenting the resulting muscular profile.

Both strength and endurance training are commonly used during athletic development to elicit a certain phenotype that is advantageous for a specific sport. In a variety of sports strength and endurance training are performed concurrently with the hopes of developing both divergent qualities (Waldron & Highton, 2014). Evidence suggests however that this may not be possible under various conditions. Seminal research by Hickson (1980) was the first scientific study to outline this potential incompatibility of concurrent aerobic and strength training. Hickson's research consisted of three treatment groups: a strength, endurance, and concurrent condition. The strength condition lifted 5x/week for 30-40 minutes a session, the endurance condition performed treadmill running 6x/week for 40 min a session, and the concurrent condition performed both the strength and endurance protocols. Following 10 weeks of training the strength and endurance group both improved significantly in their respective qualities. The concurrent training group saw similar improvements in VO_2 max as the endurance group over 10 weeks, however, the concurrent training group only saw similar strength improvements up until week 7 of the training intervention. After 7 weeks of concurrent training improvements in strength were significantly less than strength training alone and concurrent training actually appeared to decrease strength from weeks 8-10. Hickson goes on to state in his discussion that "these results provide suggestive evidence that at the upper limits in the development of strength, aerobic training inhibits or interferes with further increases in strength" (Hickson, 1980, p 281). As a result, this attenuated strength response in the presence of simultaneous strength and endurance training has been aptly referred to as the "interference effect" in subsequent literature.

2.2 Previous Work

In the following years the interference effect was confirmed by other authors. Hunter, Demment, and Miller (1987) showed decreased force development through decreased countermovement jump height following 12 weeks of concurrent training in both novice and advanced endurance athletes. Craig, Lucas, Pohlman, and Stelling (1991) investigated the effects of endurance, strength, and concurrent training on growth hormone release and found, despite no significant difference in growth hormone release, decreased lower body strength compared to resistance training alone in the concurrent training condition. Kraemer et al., (1995) observed no strength attenuation when upper body strength training was combined with running over a 12-week study but did report interference in lower body strength and power following concurrent training. These findings were in accordance with Craig et al., (1991) who similarly reported no strength attenuation in upper body strength when concurrent training was performed. Though the interference effect has been corroborated over the past 40 years, research does not support the notion of a universal interference effect. Rather it appears the presence and magnitude of interference depends upon a host of program variables namely the part of body being trained, frequency, volume, exercise sequence, rest period, intensity, and modality (Murach & Bagley, 2016).

2.2.1 Upper vs Lower Body

Limited interference has been observed in upper body musculature, as a result it has been suggested that interference may be body part specific (Jones & Howaston, 2019). Some studies indicate that adaptations of the upper and lower body to resistance training differ due to different muscle fibre type distributions and metabolic capacities (Calbet et al. 2005; Helge, 2010; Van Hall et al. 2003). Upper body musculature tends to present with larger volumes of type II muscle fibres and a greater affinity for anaerobic adaptations. In contrast, lower body musculature presents with a greater volume of type I muscle fibres, greater mitochondrial density, and is more inclined to shift towards "slow" oxidative phenotypes (Helge., 2010). It appears as though skeletal muscle displays an inverted parabolic relationship with training volume and subsequent hypertrophy. However, lower body musculature shows greater resilience to high training volumes. Essentially, it appears as though a higher training volume is required to induce the same relative hypertrophic response in the lower body compared to the upper body (Wernbom, Augustsson, & Thome, 2007). A recent review of concurrent training on upper body musculature concluded a positive effect on muscle strength under concurrent training conditions in 7 out of 8 viable studies and a positive effect on aerobic capacity in 5 out of 8 studies (Hansson, 2017). These results and that of other authors demonstrate the potential that interference is muscle type specific and dependent on the muscle architecture's ability to adapt to the different training stimuli (Wilson et al., 2012). Further research is warranted to investigate the underlying mechanism.

2.2.2 Frequency & Volume

Hickson's (1980) principal research on concurrent training implemented both a high training frequency and high training volume, 11 training sessions over the course of 6 days in the concurrent training group, leading to a very high training density. Interference in this study could arguably then be a result of overtraining and subsequent catabolic state (Kraemer et al., 1995; (Bell, Syrotuik, Martin, Burnham, & Quinney, 2000). Previous literature supports the notion that lower training frequencies may mitigate interference (McCarthy et al., 2002; Hakkinen et al., 2003; Glowacki et al., 2004). For example, Hakkinen et al., (2003) investigated the neuromuscular adaptations between concurrent training and strength training over 21 weeks with the use bilateral and unilateral leg machine exercises. In contrast to previous literature at the time, nearly identically adaptations in the strength and concurrent training conditions occurred over 21 weeks. The authors suggested that this may be a result of a lower training frequency over a longer study. The strength group trained only 2x/week and the concurrent group only 4x/week leading to decreased training density over the course of the study. Similarly, other authors also observed no interference in lower training frequencies <4x/week (McCarthy, Agre, Graf, Pozniak, & Vailas, 1995; McCarthy et al., 2002; Millet, Jaouen, Borrani, & Candau 2002; Balabinis et al., 2003, Jones et al., 2013). Previous research indicates that to avoid interference when the primary outcome is strength, endurance training should be performed at a frequency of less than 3 times per week. Furthermore, strength training sessions should be performed at least 4 times per week to ensure a greater resistance exercise stimulus (Methenitas, 2018).

2.2.3 Exercise Sequence

Manipulation of intra-session exercise order has been frequently investigated in accordance with the appearance of interference. Data published by Craig et al., (1991) was one of the first to propose that inappropriate exercise sequence was the mechanism for interference. It was proposed that endurance training that preceded strength training limited strength and hypertrophy via residual fatigue from a preceding endurance session. This hypothesis was subsequently supported by various studies (Collins & Snow, 1993; Enright, Morton, Iga, & Drust, 2015; Panissa et al., 2015; Murach & bagley, 2016; Murlasists, Kneffel, & Thalib, 2017). Yet, other studies found no significant impact on strength or hypertrophy development when endurance training preceded strength training (Leveritt, MacLaughlin, & Abernethy, 2000; Goto, Higashiyama, Ishii, & Takamatsu, 2005). Interestingly, a small amount of evidence exists that suggests than in highly trained endurance athletes, an endurance session may actually enhance subsequent strength performance (García-Pinillos, Soto-Hermoso, & Latorre-Román, 2015). However, in strength based or team sport athletes, this does not appear to be the case. Therefore, when strength is the primary outcome measure, it is recommended to perform strength training first to avoid potential strength decrements from residual fatigue (Eddens, van Someren, & Howatson, 2017; Murlasists et al., 2017).

2.2.4 Rest Period

Of all the investigated training variables, the relief period allowed between strength and endurance sessions has been highlighted as potentially the most important modulator in the appearance of interference. Current literature suggests that rest periods of less than 60 minutes inhibit acute strength performance (Jones & Howaston, 2019). Studies which have utilized a rest period of at least 8 hours have reported no impairment of strength performance (Schumman et al., 2014; Panissa et al., 2012; Sporer & Wenger 2003; Bentley, Smith, Davie, & Zhou, 2000). Therefore, it is currently recommended that a relief period of at least 8-hours separate endurance and strength if endurance sessions must precede strength sessions (Jones & Howaston, 2019). The improtnace of inter-session rest period has been further corroborated by authors who have shown that interference is less likely when strength and endurance sessions are performed on separate days (Sale et al., 1990). However, interference may still occur with rest periods up to 72 hours if the endurance stimulus is of high enough intensity and duration (Thomas et al., 2015).

2.2.5 Intensity

Intensity of endurance training has been hypothesized to mediate the appearance of interference based on the divergent molecular signalling involved in high intensity interval training (HIIT) and moderate intensity continuous training (Fyfe et al., 2016). Furthermore, due to the greater neuromuscular demand involved in HIIT it is possible that interval training represents a more similar stimulus to strength training than continuous training (Jones et al., 2013). As such, it stands to reason that HIIT represents a form of endurance training that would not interfere with the development of strength. Some authors have observed that HIIT and resistance training concurrently does not hinder strength development or hypertrophy (de Souza et al., 2012; Cantrell, Schilling, Paquette, & Murlasits, 2014; Laird et al., 2016), while other studies indicate the contrary (Fyfe et al., 2016; Kikuchi, Yoshida, Okuyama, & Nakazato, 2016; Gentil et al., 2017). A recent systematic review and meta-analysis (Sabag et al., 2018) compared HIIT and resistance training to resistance training alone on outcomes of strength and hypertrophy and concluded that HIIT can interfere with lower body strength, but not hypertrophy (Sabag et al., 2018). As such, it appears that intensity of the endurance exercise is not a primary determinant of interference.

2.2.6 Modality

Past concurrent training literature has most typically prescribed either running (Taipale et al., 2014; Panissa et al., 2015; Jones, Howaston, Russell, & French, 2016) or cycling (Leveritt & Abernathy 1999; Thomas et al., 2015; Eklund et al., 2016) as the endurance modality. Due to the lack of interference present in upper body musculature and the notion that interference is body part specific (Wilson et al., 2012; Murlasits et al., 2017), avoiding lower body interference when performing cycling or running is most relevant. Wilson et al., (2012) reported in a previous meta analysis that concurrent running resulted in significant decrements in strength and hypertrophy, greater than that present with cycling. Conversely, a more recent meta-analysis (Sabag et al.,

2018) concluded that strength interference was more likely to appear with concurrent HIIT cycling rather than running. As previously discussed, the intensity of endurance exercise may impact the appearance of interference. As such, it is possible the different conclusions between authors is a result of the intensity of endurance exercise analysed. It is therefore difficult to make general conclusions on the superior modality choice based on current literature. Practitioners should instead select a modality that closely resembles the demands of their sport and is appropriate for the given point in time in the periodized program (Bishop et al., 2019).

2.3 Explaining the Interference Effect

Evidence discussed in this review highlights the ambiguity surrounding the appearance and mitigation of interference via manipulation of training variables. As such, it is appropriate that the mechanisms underpinning interference are equally as equivocal. Currently, two main hypotheses exist to explain interference: the chronic hypothesis, and the acute hypothesis (Ellefsen & Baar, 2019; Jones & Howaston, 2019).

2.3.1 Chronic Interference

The chronic interference effect occurs as a result of performing endurance and strength training in the same training program over an extended period of time, potentially resulting in decreased mass, strength, and power (Wilson et al., 2012). This attenuation in strength development is frequently attributed to the highly divergent molecular, neurological, and morphological changes that occur following extended strength and endurance training, respectively (Jones et al., 2013).

In regards to muscle hypertrophy, it was previously thought that interference may be a result of a molecular blockade. mTORC1 is one of the key molecular signals to muscle hypertrophy and was directly inhibited by AMPK in animal muscle (Baar & Esser, 1999; Inoki, Zhu, & Guan, 2003). AMPK is a protein activated by endurance exercise (Winder & Hardie, 1996). Logically, it was hypothesized that AMPK functioned similarly, if not identically in human muscle, however, that is not the case. Instead, it appears that in humans multiple signalling molecules are involved in the activation of AMPK isoforms and subsequent inhibition of mTORC1 (Ellefsen & Baar, 2019). Furthermore, it is unknown if the relationship between AMPK and mTORC1 is causal or merely a correlation. Therefore, it would be ill advised to make sweeping conclusions on AMPK and mTORC1 as the primary regulatory molecules underpinning chronic interference in humans. Regulation of both AMPK and mTORC1 in human muscle require a cascade of molecular pathways and gene suppressors that are beyond the scope of this review. What is most relevant though, is the awareness that concurrent training of too high a workload performed longitudinally impact these molecular pathways negatively, inducing greater metabolic stress, and thus a greater interference effect (Bartlett et al., 2012; Ellefsen & Baar, 2019).

Interference of muscle strength and power is impacted by multiple variables, including physiological CSA (previously discussed), neurological activation, muscle fibre type, and technical application of force. Various studies (Hakinnen et al., 2003; Eklund et al., 2016) have shown that neural adaptations can be negatively impacted by concurrent training with decreases in EMG activity, voluntary activation, and rate of force development compared to strength training alone. Other studies show that chronic concurrent training elicits greater hypertrophy in Type I muscle fibres and an inhibition of Type II fiber growth (Kraemer et al., 1995; Kazior et al., 2016). To date, no studies have examined the effects of concurrent training on the technical ability to produce force, as such this may be an area of future research. Interference of strength and power could then potentially be a result of any of the aforementioned variables.

2.3.2 Acute Interference

In contrast to chronic interference, the acute interference effect refers to the effect of preceding endurance training on subsequent strength performance (Jones & Howaston, 2019). The acute hypothesis, initially proposed by Craig et al., (1991), proposed that interference was a result of improper exercise sequence causing residual fatigue, and thereby inhibiting strength performance. The authors initially observed that endurance training that preceded strength training led to decreased strength gains and lower body mass. They therefore postulated that performing strength training prior to endurance training would mitigate interference.

The effects of exercise sequence and other program variables on the appearance of interference have been extensively studied and previously discussed in this review. Given that the relief period between endurance and strength sessions appears to be the primary determinant of acute interference (Jones & Howaston, 2019), it stands to reason that the initial hypothesis of residual fatigue proposed by Craig et al., (1991) was correct. However, fatigue is an exceptionally broad term with multiple orchestrating mechanisms, many of which are not well understood (Thomas et al., 2015). As such, mitigating strength decrements that occur as a result of residual fatigue is a challenge. Furthermore, the challenge for strength and conditioning practitioners is not in elucidating central and peripheral mechanisms of fatigue but rather managing the appearance of interference under modern logistical constraints (Coffey & Hawley, 2016).

Central and peripheral fatigue are well documented and both play potentially significant roles as mechanisms for acute interference (Leveritt & Abernathy, 1999; Lepers, Hausswirth, Maffiuliti, Brisswalter, & Van Hoecke, 2000; Sporer & Wenger, 2003; Panissa et al., 2015). It is generally accepted that preceding endurance training has a negative impact on strength performance. Though it appears as though the volume and intensity of endurance training dictates the relative contribution of peripheral and central mechanisms. During intermittent high intensity activity, such as interval sprints, it appears that peripheral mechanisms of fatigue dominate. Conversely, central mechanisms appear to be more significant as exercise duration increases (Bigland-Ritchie, Furbush, & Woods, 1986; Sahlin & Seger, 1995; Thomas et al., 2015).

2.4 Gaps in current Research

Despite the large existing body of literature surrounding concurrent training, ambiguity remains around the interference effect. Perioidzed programs which consider acute interference may potentially eliminate chronic interference via appropriate prescription protocols. Currently, no such periodization model exists and no longitudinal studies on modern concurrent training recommendations have been performed. An aim of future research should be directed at developing concurrent periodization models that consider the current body of literature and are adaptable to the demands of various athletic events, primarily team sports (Robineau, 2019).

Surprisingly, very few studies have specifically investigated force responses following acute strength loading (Schumann, 2019). Expectedly, these studies have shown decreased force production (Taipale et al., 2014; Schumann et al., 2013; Eklund et al., 2016). While acute reductions in strength performance following endurance training are expected and well documented, it should be noted that the vast majority of this research has occurred in cyclists (Thomas et al., 2015; Bentley et al., 2000; Lepers et al., 2000), runners (García-Pinillos, Molina-Molina, & Latorre-Román, 2016; Latorre-Román, García-Pinillos, Martínez-López, &

Soto-Hermoso, 2014; Taipale et al., 2014) or non-athlete cohorts (Jones et al., 2017; Eklund et al., 2016; Jones et al., 2016; Panissa et al., 2015). Of 31 research designs which have investigated the acute effects of endurance loading on subsequent strength performance, only 1 (Thomas et al., 2015) used specifically a team sport, athletic subject group, semi-professional soccer players. The endurance loading in this study was also a 90-minute simulated soccer match, which the authors hypothesized the duration, and intensity of, contributed to the observed interference effect. Evidently, a gap in the literature exists investigating team sport athletes using conventional endurance modalities. As touched on throughout this review, the impact of the interference effect is most significant in the context of team sport athletes who require high capacity in both strength and endurance qualities (Robineau, 2019).

Though not addressed in this review, nutritional interventions should be investigated as a method to prevent the hypothesized "molecular blockade" frequently attributed to chronic interference. The metabolic demands of strength and aerobic training differ significantly (Gastin, 2001) and drive many of the cellular and molecular (e.g. AMPK, mTORC1) responses to exercise (Egan & Ziereth, 2013). It is well established that certain nutrition strategies and nutraceuticals can instigate muscle repair, drive aerobic adaptations, and promote an anabolic state (Jensen & Richter, 2012). Further investigations on the impact of nutritional interventions and supplementation on molecular adaptations following concurrent training are therefore warranted.

2.5 Aims of Proposed Research

Given the current body of literature surrounding concurrent training, the aim of the present study is to measure acute force responses to concurrent aerobic and strength training in rugby union players. Rugby is a multidimensional team sport which puts a high demand on both the neuromuscular and cardiovascular system (Duthie, Pyne, & Hooper 2003; Deutsch, Kearney, & Rehrer 2007). As research on both force responses related to interference, and team sport athletes is lacking, the purpose of this research is to measure these force responses in an acute setting in elite rugby players.

2.6 Practical Applications

The research in this study will provide practitioners information to more effectively anticipate the responses of their athletes to differing volumes of endurance training and will provide further information to inform a potential concurrent training periodization model. The demands of team sport athletes are numerous, and interference may not be avoided given the logistical constraints of team sport athletes (Mujika, Halson, Burke, Balagué, & Farrow, 2018). If this is the case, then the strength and conditioning coach's periodization program should consider the decrease in force as a result of acute interference as a program variable and prescribe accordingly. Research into the acceptable force loss given different volumes, intensities, and modalities of endurance training is then necessary.

3.0 Methodology

3.1 Subjects

Eleven healthy males (Age 18.67 ± 1.67; Stature 178.67.17 ± 9.15 cm; Mass 83.76 ± 12.53kg) whom were playing for a local rugby union club were recruited to participate in this study. Participants were selected because of their extensive experience in rugby, a sport which puts a high demand on both aerobic fitness and strength. During the course of testing, 2 subjects dropped out, leading to a final testing pool of 9 subjects. One subject did not show up to their final testing session, as such, only 8 subjects are included under the 40-minute condition. All subjects agreed to participate in this experiment after being informed of the testing protocol and extensive conversation with the lead investigator (Appendix 1). Coaches were aware of the research and consented to participation (Appendix 2). Any questions players had prior to testing were answered, following which subjects signed informed consent forms (Appendix 3). At the time of testing subjects were all participating in concurrent training programs, were competent in the back squat exercise, and had at least 2 years of strength and conditioning experience. Subjects had no matches during the course of testing. Participants were required to refrain from any exercise supplements (caffeine, creatine, etc) or alcohol during the testing period. Subjects were each provided with a participant code that was used to identify their results and maintain anonymity.

3.2 Design

An experimental cross over design was implemented to test the impact of varying volumes of endurance training on the appearance and magnitude of interference, defined as a decrease in force production. Testing was performed over 3 days, at the same time of day, each session separated by at least 24 hours. Subjects performed a standardized warm up prior to testing each day. All visits followed the same testing protocol: warm up, the first 5x5 back squat trial at 85% 1RM, either 20, 40, or 60 minutes of low intensity continuous cycling at a self selected pace, then finally the second 5x5 back squat trial at 85% 1RM. As part of the subject's strength and conditioning programs for their rugby club, 1RM was routinely tested. As such, retesting 1RM was deemed unnecessary and values provided by the rugby club were used as baseline data to estimate 1RM and prescribe 85% of 1RM.

In between the two separate squat bouts, subjects performed varying volumes of endurance training: 20, 40, or, 60 minutes of continuous cycling at a self selected low intensity pace. A self selected pace was chosen as subjects had no experience with VO_2 Max testing protocols and were unable to go through familiarization due to subject scheduling restrictions. All squats were performed on a Type 9281E standard Kitsler Force Plate via which data on force production was collected for analysis.

3.3 Experimental Procedures

3.3.1 Warm Up Protocol

Upon arrival subjects were greeted and began 5 minutes of continuous cycling on a Wattbike Pro (Wilford Ind Est, Nottingham, NG11 7HQ) at a self selected pace. Subjects were instructed to keep the intensity "light to moderate." Following the 5 minutes of cycling subjects performed a battery of 5 mobility exercises to prepare them for the exercise protocol that followed. Mobility exercises included: 10 repetitions of overhead squat with a wooden dowel, 10 bilateral glute bridge, 5 unilateral Romanian dead lift on each leg, 5 reverse lunge on each leg, and 5 counter movement jumps.

3.3.2 Back Squat Protocol

Upon completion of the warm up participants began their first 5x5 back squat trial at 85% of their 1RM. For the pre-endurance squat bout subjects were given two progressive warm up sets with increasing load, in accordance with lifting recommendations provided by the NSCA: one warm up set of 8 squats at 60% of 1RM and a second set of 5 repetitions at 80% 1RM. Sixty to ninety second rest was provided between warm up sets. Upon completion of the second warm up set, subjects were given 2 minutes' rest and then performed the first working set of 5. Two minutes' rest was provided in between each working set of 5. No warm up sets were allowed prior to the second squat bout. Subjects were closely supervised and spotted by an NSCA certified strength and conditioning practitioner. If the subject was unable to complete all the repetitions or reached technical failure prior to the 5 repetitions the spotter assisted them in completing their final rep and the set was terminated.

3.3.3 Cycling Protocol

Subjects were randomly assigned their endurance volume at the beginning of the session. Following the first squat session subjects received 2 minutes' rest, after which they began cycling. Subjects were instructed to maintain a low to moderate intensity for the entirety of the prescribed volume and were allowed to select their resistance. To ensure a low to moderate intensity, subjects were closely monitored throughout the duration of their cycling intervention to maintain an RPM below 70.

3.4 Outcome Measures

Total peak force (N) and relative peak force (N/kg) from each of the 5 sets of the pre and post squat bouts were recorded. The difference between pre and post values were analysed. Analysis across sets was included to observe if either the volume or set had a significant effect on force production. Mean total force (N) and mean relative force (N/kg) across all 25 repetitions for pre and post squats were collected. Difference in mean force from pre to post protocols was used for analysis. Mean values were included with peak values to see if a greater volume of endurance training impacts ability to produce force throughout an exercise bout. As majority of team sports require repeated bouts of maximal or close to maximal effort (Johnson & Gabbett, 2011), mean values across a host of repetitions represents a potentially more practical measure than peak values.

3.5 Statistical Analysis

A one-way repeated measures ANOVA was used to assess a significant difference between the various volumes of endurance training for mean values. Any significant of set or volume on peak was assessed via repeated measures mixed model ANOVA. If the P-Value indicated a significant difference between the three conditions, then confidence intervals were used to quantify the magnitude of the effect. Tukey's post hoc test was used for both peak and mean force to determine which variable had the most significant impact on force production.

4.0 Results

None of the primary outcome measures analysed showed a statistically significant ($P<.05$) decrease in response to the cycling interventions. Total peak force production decreased in response to the cycling interventions, however, the decrease did not reach statistical significance ($p = .092$). Total peak force following the 60-minute intervention was, on average, 130N and 80N greater than that of the 40 minute, and 20 minute interventions, respectively. However, these differences were also not statistically significant ($p = .079$, $p = .37$) (Appendix 4). Change in averaged total peak force can be seen in Figure 1. A greater decrease in relative peak force production was observed following the cycling interventions than in total peak force ($p = .058$). Despite greater decreases in relative peak force, the force decrement failed to reach statistical significance (Appendix 5). The greatest decrease was present in the 40-minute condition, approximately 1.63 N/kg lower than 60 minutes ($p =.053$), and .53 N/kg lower than 20 minutes ($p=.719$). Collated relative peak force changes can be seen in Figure 2. No significant interactions were observed between total or relative peak force and working sets ($p = .066\text{-}1.000$). The greatest effect of sets was observed in the first set of total peak force, during which subjects produced, on average, 153-194N more force than the following sets ($p = .086\text{-}0.26$) (Appendix 4). Neither total or relative mean force production showed any significant change in response to the endurance interventions ($p = .959$; $p = .906$) (Appendix 6). Change in total and relative mean force is displayed in Figure 3.

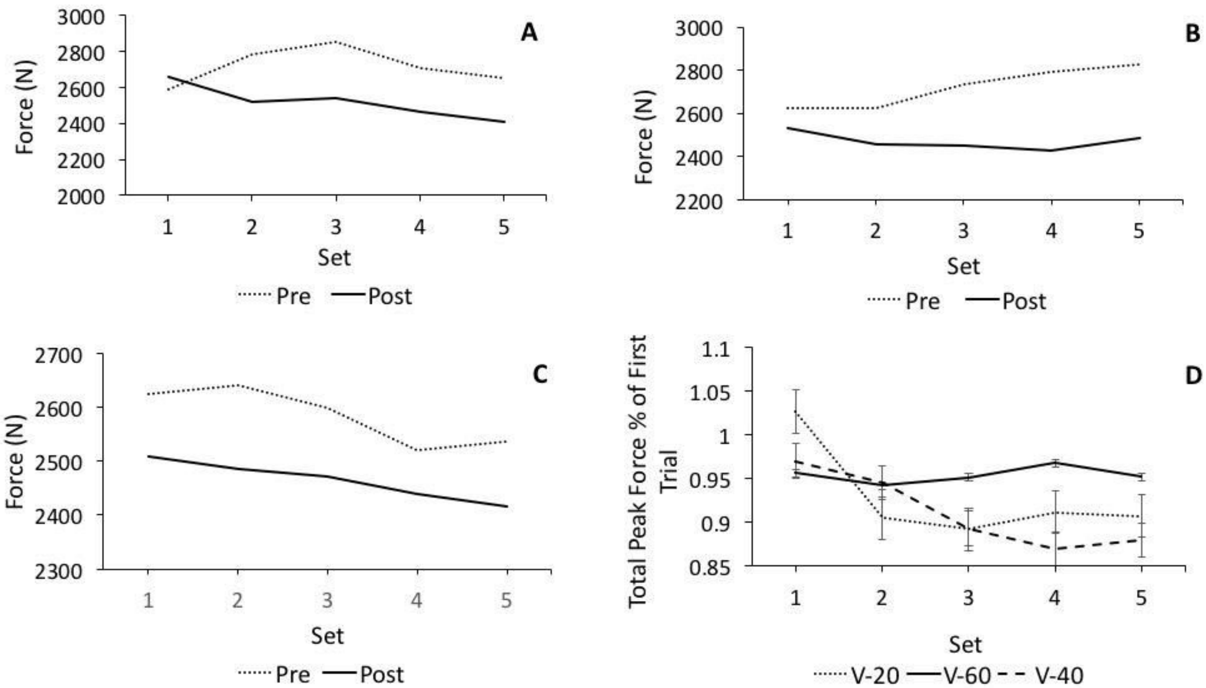

Figure 1: Average pre and post total peak force production for (A) 20-minute condition, (B) 40-minute condition, and (C) 60-minute condition. (D) Difference in total peak force for 20, 40, and 60 minutes displayed as percentage of first trial.

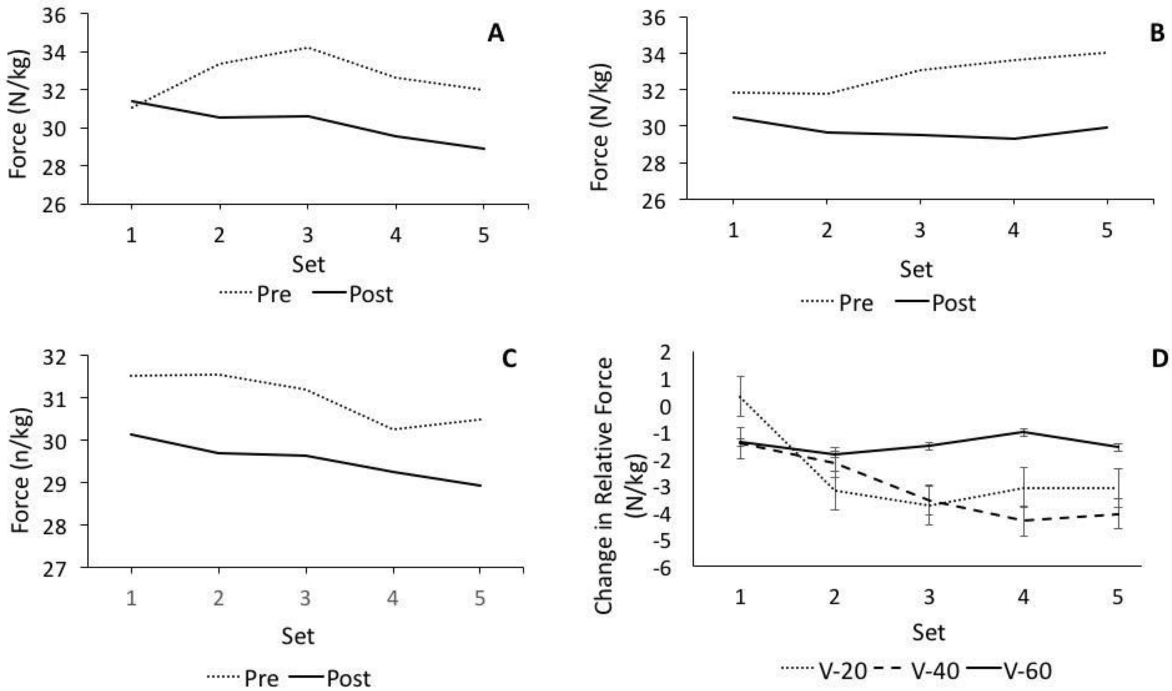

Figure 2: Average pre and post relative peak force production for (A) 20-minute condition, (B) 40-minute condition, and (C) 60-minute condition. (D) Difference in total peak force for 20, 40, and 60 minutes displayed as change in newtons/kg.

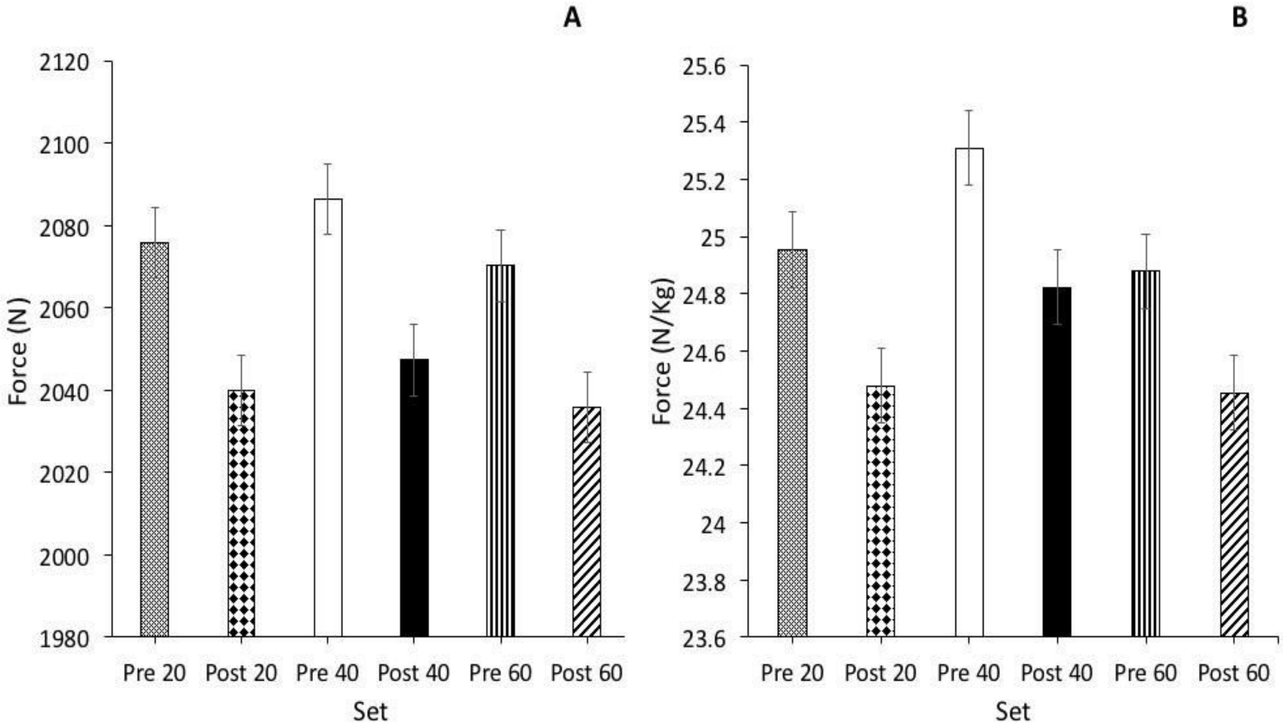

Figure 3: Average (A) total mean force production and (B) relative mean force production for pre and post cycling interventions.

5.0 Discussion

The purpose of this study was to assess the impact of differing volumes of endurance training on force production during a back squat protocol. The primary findings of this study were that low intensity, continuous endurance training had a greater negative impact on peak force than mean force production. Furthermore, the cycling interventions impacted relative peak force production slightly more than total peak force production. Interestingly, the greatest force attenuation was observed under the 40, and 20-minute conditions, but not 60. Mean force production remained relatively unchanged following all cycling conditions. Finally, no significant change in force was observed across sets.

Similar to the findings of the present study, previous research has observed attenuated strength performance following volumes of endurance training ranging from 15-150 minutes (Abernathy & Quigley, 1993; Lemos et al., 2009; Taipale et al., 2014; Panissa et al., 2015; Jones et al., 2017). Despite large variations in the methodology across these studies, interference still occurs. As such, this acute strength decrement appears to occur independent of endurance training intensity or modality. Interestingly, outside of the rest period separating endurance and strength training, no other program variable appears to be a significant determinant of acute interference. Considering the time and logistical constraints of modern strength and conditioning practice, adopting an 8-hour rest period in between sessions, as recommended (Jones & Howaston, 2019), is not always feasible. The limitations of current evidence-based recommendations in a practical team setting necessitate more research into acute interference to develop superior concurrent training strategies. Specifically, in regards to the management and understanding of the effects of acute interference. Therefore, an acute concurrent training protocol was designed to elicit interference.

5.1 Relevance of Outcome Measures

A large body of literature has outlined the importance of both total and relative force production in team sport's performance (McGuigan, Wright, & Fleck, 2012; Kawamori, Nosaka, & Newton, 2013; Morin et al., 2015), as such, strength training has become an almost universal practice in modern sport (McGuian et al., 2012). An athlete's ability to produce force has been examined in previous research which showed force production in both a vertical and horizontal manner (Randell, Cronin, Keogh, & Gill, 2010) can effectively predict performance in athletic movements (Stone et al., 2003; Wisloff, 2004; Shepard et al., 2008) and also differentiate elite level athletes from amateurs (Fry & Kraemer, 1991; Young et al., 2005; Baker, 2002; Gabbett, Kelly, & Pezet, 2007). The ability to produce higher ground reaction forces has also been linked with increased running velocity (Weyand, Sternlight, Bellizzi, & Wright, 2000; Morin, Edouard, & Samozino 2011), relevant due to the finding that higher running velocities are associated with successful performance in the majority of team sports (Morin et al., 2015). Further reinforcing the importance of maintaining force production and strength in the presence of concurrent aerobic training.

5.2 Impact of Interference on Force Production

Much strength and conditioning research has focused on concurrent training, yet, limited research has looked specifically at force responses to acute concurrent protocols. Taipale & Hakkinen (2013) tested the order effect and found that RFD and MVC both significantly decreased when endurance training preceded strength training. Schumann et al., (2013) also tested the order effect on explosive force production, however, the authors chose to use CMJ height as an outcome measure, rather than a force response. Interestingly, one study indicates that over the course of a 24-week concurrent training protocol, no acute force reductions were observed (Schumann et al., 2014). However, acute force measurements were only taken at the 0 week and 24-week mark. As such it is possible no acute reductions in force were present at those time points, but force production was negatively impacted throughout the training program. From the relatively limited research that exists, it appears as though a 10% drop in maximal force production is standard if aerobic training precedes strength training (Schumann, 2019). This is in accordance with the findings from this study. Maximal force production for the 20, 40, and 60 minute conditions decreased by 8%, 10%, and 5%, respectively. The use of relative peak force in the present study represents a novel outcome measure in concurrent literature. This is of interest as relative peak force production may constitute a superior performance metric than total peak force in multidimensional athletic activities (Hansen, Cronin, Pickering, & Douglas, 2011). The current findings indicate that while relative peak force may be slightly more susceptible to interference than total peak force, that decrease is not significant. However, the impact of volume on relative peak force was very close to reaching statistical significance ($p = .058$), which may still have practical performance implications, as such, further research is warranted on the impact of interference on relative force production.

Neither peak, nor mean force had any significant interaction across working sets. However, force production across sets did come close to reaching statistical significance in the first set (*p = .086-0.26)*, indicating significantly greater force production in the first set than subsequent sets. Interestingly, mean force showed no significant decrease across the cycling interventions. All 3 cycling conditions elicited decreases of approximately 2% in total and relative mean force. Given these findings in association with those of peak force, it is evident that interference occurred following the cycling interventions, but evidently had no significant impact on mean force production. Force production is not a direct parallel to strength development, however, the ability to produce greater force does equate to higher strength levels (Suchomel, Nimphius, Bellon, & Stone, 2018). If force production were to be used synonymously with strength development, then the current study indicates that peak force (i.e maximal strength) may be more susceptible to interference than mean force (general strength/hypertrophy), as peak force dropped more dramatically under all three conditions. This appears to be consistent with longitudinal concurrent training studies examining interference on strength development. The effects of preceding endurance training on maximal strength measured via 1RM is generally negative. 1RM measured via Leg Press (Eklund et al., 2016), Bench Press (De Salles Painelli et al., 2014), and Back Squat (Reed, Schilling, & Murlasits, 2013), all show attenuated strength with preceding endurance training. However, the effect of preceding endurance training on hypertrophy is more ambiguous. Of 23 concurrent training studies that have measured hypertrophy, 8 of which reported hypertrophic interference (Craig et al., 1991; Kraemer et al., 1995; Bell et al., 2000; Ahtianen et al., 2009; Karavirta et al., 2009; de Souza et al., 2013; Jones et al., 2013; Tervis et al., 2016), as such it appears the general effect of endurance loading on hypertrophy is less than that of maximal strength (Lundberg, 2019). These previous findings, together with our current results, provide more support for the notion that peak strength is more susceptible to interference than hypertrophy, and perhaps suggest an acute mechanism by which peak force development is more impaired than average force production.

As previously mentioned, the present study fills a gap in the breadth of concurrent literature as one of the only to investigate force responses in team sport athletes. Previous research in team sports have investigated the effects of different interval programs on power and speed in water polo (Botonis, Toubekis, & Platanou, 2016), shoulder strength in college football players (Legg & Burhamm, 1999), and maintenance of strength and power during a competitive rugby season (Baker, 2001). As athletes have further developed aerobic and neuromuscular systems than the general population (Koceja, Davison, & Robertson, 2004), it stands to reason that athletes whom are in superior physical condition may better tolerate low intensity/short duration endurance interventions and maintain force production. However, this study contradicts that hypothesis. Despite their training status of at least 2 years in high level strength and conditioning environments, and the concurrent nature of their training program, elite academy rugby players still displayed interference with volumes as low as 20 minutes. Similar to interference that is present in recreationally active males (Panissa et al., 2015), physically active elderly women (Lemos et al., 2009), and male cyclists (Bentley et al., 2000). Beyond 20 minutes, both volumes of 40 and 60 minutes elicited decreases in peak force production during the second squat protocol. Similar results have been observed by previous authors, with volumes of 36 minutes (Sporer & Wenger, 2003), 45 minutes (Reed et al., 2013), and 60 minutes (Taipale et al., 2014; Taipale & Hakkinen, 2013) all eliciting interference. Contrary to the abovementioned hypothesis, it appears as though interference is actually more likely in well trained athletes. This is largely due to the demand for more focused and specialized training in individuals with a high training age. In these instances, a greater training stimulus is required to elicit a smaller performance change (Berthelot et al., 2008), as such, any level of conflicting molecular signals, decreased neuromuscular drive, or fatigue as a result of endurance training will negatively impact subsequent force production and strength development.

5.3 Mechanisms to Explain Acute Interference

As touched on previously in this paper, the exact underpinnings behind interference remain unknown, and multiple hypotheses exist to explain both chronic, and acute interference. The most readily cited mechanism for acute interference is residual fatigue from a prior bout of exercise. Current concurrent training recommendations suggest a period of at least 8 hours between same-day endurance and strength training, during which a high carbohydrate meal is consumed, to mitigate residual fatigue (Jones & Howaston, 2019). As no more than 5 minutes' rest was provided between cycling and squatting in the current study, fatigue was expected to play a role in any interference. It is likely that both peripheral and central mechanisms play a role in the residual fatigue that prompts acute interference, to what extent each ultimately contributes to the observed force decrement though, is unknown. Therefore, multiple hypotheses could be made regarding potential underlying central and peripheral mechanisms.

Various biological mechanisms have been hypothesized to underpin central nervous system fatigue. Some of these include but are not limited to: cortico-spinal excitability, neurotransmitter levels, and afferent nerve firing frequency (Jones & Howaston, 2019). Regardless of the biological underpinnings, the mechanisms ultimately manifest in the same way, an unwillingness, or difficulty developing and sustaining neurological drive to the active muscle (Davis & Bailey, 1997). The various volumes of endurance training in the present study were selected to elicit some level of fatigue and accordingly impact subsequent strength performance. Central mechanisms appear to play a greater role with increased exercise duration (Thomas et al., 2015). As such, it can be hypothesized that the volumes of greater duration in the present study (40 and 60 minutes) led to decreased neurological drive in the lower limbs, therefore attenuating force production in the following back squat protocol. Of interest is the threshold at which low intensity prolonged endurance training ultimately elicits this decrease in neurological drive and contractile strength. It is common practice for athletes to engage in a warm up that usually involves a "raise" period of continuous low intensity cycling or running prior to strength training or technical practices (Safran, Seaber, & Garrett, 1989; Fradkin, Zazryn, & Smoliga, 2010). Considering various reviews have concluded that warm-ups generally improve physical performance (Fradkin et al., 2010; McCrary, Ackermann, & Halaki, 2015) it can be assumed that the practice of engaging in some form of endurance training prior to exercise has a positive potentiation effect on force production given the endurance training is below a certain volume. However, the exact volume at which endurance training elicits decreases in contractile strength is unknown.

In contrast to central fatigue, peripheral fatigue is defined by activity at or distal to the neuromuscular junction and disturbances in muscle homeostasis (Zając, Chalimoniuk, Gołaś, Lngfort, & Maszczyk, 2015; Jones & Howaston, 2019). Peripheral fatigue impacts strength performance to a greater degree when endurance intensity is high and of a shorter duration (Thomas et al., 2015). Concurrent training studies which incorporate intermittent high intensity aerobic exercise reinforce these findings (De Souza et al., 2007; Painelli et al., 2014). The intramuscular consequences of peripheral fatigue following exercise, e.g. substrate depletion, are well documented (Lambert, 2005), as are considerations to mitigate these consequences e.g. manipulation of training variables, nutrition (Allen, Higham, & Duffield, 2019). A plethora of concurrent training studies have focused on the manipulation of training variables, yet, almost no concurrent training studies consider nutritional methods (Perez-Schindler, Hamilton, Moore, Baar, & Philp, 2014), and no studies have investigated substrate utilization during either prolonged or acute concurrent loading. This is significant as substrate availability is one of the driving factors behind the molecular adaptations to exercise, and is also a commonly cited mechanism for peripheral fatigue (Zajac et al., 2015). Considerable theoretical evidence exists to suggest that various nutraceuticals and nutritional strategies may assist in mitigating the interference effect via increased substrate availability (Allen et al., 2019; Etherdige & Atherton, 2019). Only one such study currently exists which concluded that creatine supplementation is capable of potentially counteracting acute interference (Painelli et al., 2014). The authors postulated that creatine supplementation mitigated interference via increases in phosphorylcreatine content and maintenance of ATP/AMP ratio, providing credence to the notion that peripheral fatigue is the primary mechanism for acute interference. Increases in energy substrate availability have long been associated with increases in, and maintenance of physical performance, in addition to the attenuation of the perception of fatigue (Beelen, Burke, Gibala, & van Loon, 2010). Furthermore, numerous studies on concurrent training have employed protocols which conducted training in a fasted state (Coffey, Pilegaard, Garnham, O'Brien, & Hawley, 2009; Lundberg, Fernandez-Gonzalo, Gustafsson, & Tesch, 2012; Wang, Mascher, Psilander, Blomstrand, & Sahlin, 2011), a methodology which is not representative of athletic practices. As such, further studies examining substrate utilization and the effects of nutritional strategies on muscle homeostasis following acute and chronic concurrent loading are warranted.

Given the nature of concurrent research and the interference effect, the mechanisms behind these findings are appropriately equivocal. Considering the volume and intensity of the cycling protocol in this study, and that testing was done in a fed-state, it is likely that central mechanisms were the primary determinant behind the observed force decrement. However, the prevalence of both intermittent high intensity aerobic exercise and low intensity continuous exercise in modern strength and conditioning practices necessitates the awareness of both central and peripheral mechanisms of fatigue, what modes of exercise elicit each, and methods to mitigate them.

5.4 Practical Applications

The findings of this research provide valuable insight to strength and conditioning professionals in team sport environments whom routinely use concurrent training to develop their athletes. The primary program variable manipulated in this research was volume of endurance training. However, exercise sequence could also be mentioned as this was the first study to present an acute force decrement relative to force values which preceded endurance training.

As expected, interference was present under all three conditions to some degree. Higher volumes of endurance training tend to to result in greater decreases in force (Wilson et al., 2012), though not what was observed in the current study. Coaches programming for strength or power should still anticipate that greater volumes or intensities of endurance training will elicit greater interference. Given the means to measure force responses in a practical setting, coaches or sports scientists may use the observed force decrement seen in this study and from previous research, approximately 10%, as a feedback tool. If decreases in force fall within 90-100% of baseline values, then coaches can attribute this to an expected interference effect. However, if force decreases are at 15-20% then perhaps an athlete is not adequately prepared for training and intervention on behalf of the coaching staff is required.

As the pursuit for concurrent training periodization models continue, this information can be used to help exercise prescription during parts of the annual calendar. A recent survey polled professional rugby union coaches around the world and found that 77% of coaches consider the interference effect in their training (Jones, Smith, Macnaughton, & French, 2016). Furthermore, coaches believe that appropriate periodization is best method to alleviate any mitigation in strength. Avoiding interference is not always the goal of a training plan, nor should it be. However, given the time of year, if interference is likely to occur, then coaches should be aware of how much force may be reduced, and adjust goals, expectations, and training accordingly.

5.5 Limitations

The primary limitations in this study were the sample size and the time provided between testing sessions. The original sample size of 11 subsequently dropped to 9 after two drop outs, and one missed testing session led to only 8 subjects during the 40-minute condition. Given P-values of .092 and .058 for the interactions of total peak force and relative peak with volume, it is possible the failure to reach statistical significance resulted from a lack of statistical power. In addition, Tukey's post hoc test was used, a considerably more conservative post hoc than Bonferroni or least significant difference test (Abdi & Williams, 2010). As such, it is possible that a different statistical analysis would have yielded a significant difference between volumes. Furthermore, twenty-four hours' rest was provided between each testing session, however, DOMS may last for up to 72 hours (MacIntyre, Reid, & McKenzie, 1995). As rugby players actively involved in strength and conditioning, the chosen subjects were well trained in the testing protocol. However, compounding fatigue from previous testing sessions could have occurred and effected force production in subsequent testing sessions.

Contrary to previous findings, 60 minutes of endurance training elicited the smallest decrease in force production. This disparity may have occurred as a result of pacing during the endurance stimulus. A self selected pace was prescribed for the continuous cycling protocols. Subjects were instructed to ride at an easy to moderate pace at which they could hold a conversation. Though self selected pace has been used frequently in previous literature (Abbiss & Laursen, 2008), prescribing endurance training via this method introduces potential error from pacing issues. Subjects were not blinded to the cycling duration, and they may have unintentionally cycled at a lower intensity than during the shorter interventions, leading to less fatigue and superior force production despite the longest cycling intervention. In addition, cycle ergometer resistance was also self-selected. In which case, subjects may have selected a lower resistance for the longest duration, compounding a potential decrease in effort.

5.6 Future Research

More research into the magnitude of acute force reductions following concurrent loading is warranted, primarily in team sport athletes. As referenced throughout, the demands of team sport athletes are multidimensional, and the constraints placed in practical settings on strength and conditioning coaches may not accommodate separating sessions by 8 hours to eliminate interference. As such, future research should focus on developing practical strategies to manage potential interference. Recommendations to prevent interference do currently exist (Jones & Howaston, 2019). However, no longitudinal studies have been conducted to test the efficacy of these recommendations, as such, further research must be done to corroborate current suggestions. The aim of practitioners should be to develop pragmatic periodization models for concurrent strength and aerobic training.

Though this paper has focused on the acute reductions in contractile strength and force production following concurrent training, further efforts should be focused on areas such as the efficacy of nutritional strategies on concurrent adaptations (Etherdige & Atherton, 2019), the role and efficacy of recovery strategies within concurrent training (Allen et al., 2019), mechanisms underpinning the acute and chronic interference effect (Bishop et al., 2019), longitudinal impact of concurrent training on hypertrophy (Lundberg, 2019), and the implications of the immune system on concurrent training adaptations (Goh, Lim, & Suzuki 2019).

6.0 Conclusion

The findings from the present study indicate that when low intensity prolonged endurance training is performed prior to, and in close temporal proximity to strength training, maximal force production may decrease anywhere between 5 and 10%. Furthermore, it appears as though relative and total peak force are affected similarly by preceding endurance training. These findings also suggest that mean force production may better tolerate the acute interference effect, as reductions in force of only 2% were observed. An awareness of how much force may be lost given preceding endurance training provides practitioners with pragmatic information regarding a potential interference effect that can be used to better guide training protocols. Future research should further explore the impact of preceding endurance training on force production in a larger cohort of team sport athletes.

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Appendix A - Participant Information Sheet

Faculty of Health and Life Sciences

Northumbria University NEWCASTLE

Participant Code:

PARTICIPANT INFORMATION SHEET

Study Title: Impact of Various Volumes of Moderate Intensity Continuous Cycling on Force Decrement in Rugby Union Players

Investigator: Jared Perez

Supervisor: Dr. Thomas Jones

Chair of Ethics Committee: Dr. Nick Neave

You are being invited to take part in a research study. It is important for you to understand why the following research is being completed and what it entails before you decide. Please take the time to read over the following information provided carefully and discuss with others if you so please. If there is anything that is not clear or if further information is needed, please ask. Take time in deciding whether or not you wish to be a participant. Thank you for reading.

What is the Purpose of the Study?

The purpose of this study is to examine how different volumes of continuous cycling (20, 40, 60 minutes) impact an athlete's ability to produce force.

Why have I been Invited?

You have been invited to take part as you are injury free, a rugby player, have been involved in strength training for at least 2 years, and are familiar with the methodology that will be employed during the study.

Do I have to take part?

No, participation in this study is based on your own decision. This sheet of information has been given to you in order to help you make that decision. You are able to withdraw from the study at any point if you decide to take part. Leaving the study before its completion is also okay. If you choose to not participate or want to leave before it is complete, those decisions will not affect you in any way.

What will happen if I do take part?

You will be asked to read over the participant information sheet, then read and sign the consent form provided. After your consent has been given, a date and time of convenience will be determined in order to collect baseline aerobic data on a WattBike, baseline jump data, and perform a back squat 3 repetition maximum test (3RM). The Wattbike is a cycle modality that provides real time information on force production, as such, it has been chosen for this study. The baseline testing on the Wattbike will include a 3 min maximal aerobic test which will provide estimated maximal heart rate, with this information the subsequent cycling sessions can be prescribed at 60% of your maximum heart rate (low-moderate intensity). The jump data will provide a baseline of how high you can jump prior to the study, in the event anything drastically impacts your jump ability during the course of the study, we can evaluate what may have happened. The 3RM test will test your maximum ability to produce force over 3 reps. This will be used to calculate your predicted 1 repetition maximum (1RM). Once again, this information will be used for prescription purposes.

The next three sessions will be scheduled on this day. During the data collection of days 2, 3, and 4 you will be required to perform 2 separate maximal counter movement jump protocols on a jump mat, 2 separate back squat protocols: 5 sets of 5 repetition back squat at 85% of your predicted 1RM on a force plate (to collect force data), and cycling bouts of either 20, 40, or 60 minutes. Cycling bouts will be completed in-between the two jump/squat sessions and will require no external software or apparatus.

Please note that in order to ensure quality assurance and equity this project may be selected for audit by a designated member of the ethics committee. This means that a request can be made to see the signed consent forms. However, if this is the case your signed consent form will only be accessed by the designate auditor or member of the audit team.

Will I have to provide any bodily samples (i.e. blood/saliva/urine)?

No bodily samples will be required

What are the possible disadvantages of taking part?

Possible disadvantages include musculoskeletal damage or soreness, mental or physical fatigue, and muscle strains.

Appropriate risk assessments have been conducted for all procedures that will be carried out during the period in which the study occurs.

What are the possible benefits of taking part?

We hope that your participation in this study will help you. However, that is not completely guaranteed. The information we collect from this study will help us to see how much your ability to generate force is affected by continuous endurance training. This will help inform coaches how much endurance training is appropriate as to not impact performance in subsequent lifting sessions. Hopefully this study will allow further research to be done on impacts of concurrent training programs and how to avoid fatigue or negative effects.

Will my taking part in this study be kept confidential?

Yes; there have been a number of procedures put into place to protect the confidentiality of the participant's information. You will be given a participant code that will always be used in order to identify any data you provide. Your name and other personal details will never be associated with your data, for example, the consent form that you have signed will be kept completely separate from the data that will be collected from you during the study. Any paper records will be stored in a safe binder and only accessible by the research team, while all electronic data will be stored on a password protected computer. All information that is provided by you will be treated in accordance with the UK Data Protection Act.

How will my data be stored?

Information from you will be stored in a secure binder or on a password protected computer. All information will only be used for the purpose of this study. Any personal data will be destroyed after 3 years.

What will happen to the results of the study?

The results of this study will be used as part of my dissertation and thesis write-up. The data may be used to present at conferences. It will only be used by members of the research team and at no point will your information be revealed.

Who has reviewed the study?

The study has received full ethical approval from the Northumbria ethics committee who reviewed the study.

Contact for further information

If you required any further information, have any questions or concerns, or would like to withdraw your data please contact:

Jared Perez--jaredaperez1995@gmail.com

Supervisor: Thomas Jones-- thomas2.jones@northumbria.ac.uk

Chair of Research Ethics Committee—nick.neave@northumbria.ac.uk

Thank you for taking part in this study. Please keep this participant information sheet as it contains your participant code, important information, and the research teams contact details.

Appendix B – Academy Consent Form

NEWCASTLE FALCONS

NEWCASTLE RUGBY LIMITED
KINGSTON PARK
BRUNTON ROAD
KENTON BANK FOOT
NEWCASTLE UPON TYNE
NE13 8AF

To whom it may concern,

I'm writing to grant Jared Perez approval to lead his current masters dissertation at the club, using some of our AASE scheme (school of sport) athletes as subjects for it. It has been discussed in-depth both with me and the subjects who will take part and the subjects and I are happy for it to go ahead.

Yours sincerely,

Michael Ferguson
Academy Strength & Conditioning Coach
Newcastle Falcons

Appendix C – Informed Consent Form

Participant code:

Project Title: Impact of Various Volumes of Moderate Intensity Continuous Cycling on Force Decrement in Academy Rugby Union Players

Principal Investigator: Jared Perez

Supervisor: Dr. Tomas Jones

	please tick or initial where applicable
I have carefully read and understood the Participant Information Sheet.	☐
I have had an opportunity to ask questions and discuss this study and I have received satisfactory answers.	☐
I understand I am free to withdraw from the study at any time, without having to give a reason for withdrawing, and without prejudice.	☐
I agree to take part in this study.	☐

Signature of participant... Date.....………………..   (NAME IN BLOCK LETTERS)...……………………….
Signature of researcher.. Date.....………………..   (NAME IN BLOCK LETTERS)...……………………….

Appendix D – Total Peak Force Statistical Handouts

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F
Corrected Model	Force	1058793.430[a]	6	176465.572	2.344
	Subject	6.923[b]	6	1.154	.175
Intercept	Force	4631472.862	1	4631472.862	61.528
	Subject	3027.600	1	3027.600	459.747
Volume	Force	366574.557	2	183287.279	2.435
	Subject	6.923	2	3.462	.526
set	Force	692218.873	4	173054.718	2.299
	Subject	.000	4	.000	.000
Error	Force	9258778.708	123	75274.624	
	Subject	810.000	123	6.585	
Total	Force	14849694.877	130		
	Subject	3870.000	130		
Corrected Total	Force	10317572.138	129		
	Subject	816.923	129		

Tests of Between-Subjects Effects

Source	Dependent Variable	Sig.
Corrected Model	Force	.035
	Subject	.983
Intercept	Force	.000
	Subject	.000
Volume	Force	.092
	Subject	.592
set	Force	.063
	Subject	1.000
Error	Force	
	Subject	
Total	Force	
	Subject	
Corrected Total	Force	

Subject	

a. R Squared = .103 (Adjusted R Squared = .059)
b. R Squared = .008 (Adjusted R Squared = -.040)

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) set	(J) set	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Force	1.00	2.00	-153.9821	76.09439	.261	-364.6616	56.6975
		3.00	-194.2979	76.09439	.086	-404.9775	16.3816
		4.00	-179.7113	76.09439	.133	-390.3908	30.9683
		5.00	-188.5575	76.09439	.102	-399.2370	22.1221
	2.00	1.00	153.9821	76.09439	.261	-56.6975	364.6616
		3.00	-40.3158	76.09439	.984	-250.9954	170.3637
		4.00	-25.7292	76.09439	.997	-236.4087	184.9504
		5.00	-34.5754	76.09439	.991	-245.2549	176.1042
	3.00	1.00	194.2979	76.09439	.086	-16.3816	404.9775
		2.00	40.3158	76.09439	.984	-170.3637	250.9954
		4.00	14.5867	76.09439	1.000	-196.0929	225.2662
		5.00	5.7405	76.09439	1.000	-204.9391	216.4200
	4.00	1.00	179.7113	76.09439	.133	-30.9683	390.3908
		2.00	25.7292	76.09439	.997	-184.9504	236.4087
		3.00	-14.5867	76.09439	1.000	-225.2662	196.0929
		5.00	-8.8462	76.09439	1.000	-219.5257	201.8334

	5.00	1.00	188.5575	76.09439	.102	-22.1221	399.2370
		2.00	34.5754	76.09439	.991	-176.1042	245.2549
		3.00	-5.7405	76.09439	1.000	-216.4200	204.9391
		4.00	8.8462	76.09439	1.000	-201.8334	219.5257
Subject	1.00	2.00	.0000	.71173	1.000	-1.9706	1.9706
		3.00	.0000	.71173	1.000	-1.9706	1.9706
		4.00	.0000	.71173	1.000	-1.9706	1.9706
		5.00	.0000	.71173	1.000	-1.9706	1.9706
	2.00	1.00	.0000	.71173	1.000	-1.9706	1.9706
		3.00	.0000	.71173	1.000	-1.9706	1.9706
		4.00	.0000	.71173	1.000	-1.9706	1.9706
		5.00	.0000	.71173	1.000	-1.9706	1.9706
	3.00	1.00	.0000	.71173	1.000	-1.9706	1.9706
		2.00	.0000	.71173	1.000	-1.9706	1.9706
		4.00	.0000	.71173	1.000	-1.9706	1.9706
		5.00	.0000	.71173	1.000	-1.9706	1.9706
	4.00	1.00	.0000	.71173	1.000	-1.9706	1.9706
		2.00	.0000	.71173	1.000	-1.9706	1.9706
		3.00	.0000	.71173	1.000	-1.9706	1.9706
		5.00	.0000	.71173	1.000	-1.9706	1.9706
	5.00	1.00	.0000	.71173	1.000	-1.9706	1.9706
		2.00	.0000	.71173	1.000	-1.9706	1.9706
		3.00	.0000	.71173	1.000	-1.9706	1.9706
		4.00	.0000	.71173	1.000	-1.9706	1.9706

Based on observed means.
The error term is Mean Square(Error) = 6.585.

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Volume	(J) Volume	Mean Difference (I-J)	Std. Error	Sig.
Force	20.00	40.00	-51.4901	59.62076	.664
		60.00	78.4854	57.84063	.367
	40.00	20.00	51.4901	59.62076	.664
		60.00	129.9755	59.62076	.079
	60.00	20.00	-78.4854	57.84063	.367
		40.00	-129.9755	59.62076	.079
Subject	20.00	40.00	.5000	.55765	.643
		60.00	.0000	.54100	1.000
	40.00	20.00	-.5000	.55765	.643
		60.00	-.5000	.55765	.643
	60.00	20.00	.0000	.54100	1.000
		40.00	.5000	.55765	.643

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Volume	(J) Volume	95% Confidence Interval Lower Bound	Upper Bound
Force	20.00	40.00	-192.9357	89.9556
		60.00	-58.7370	215.7079
	40.00	20.00	-89.9556	192.9357
		60.00	-11.4701	271.4212
	60.00	20.00	-215.7079	58.7370
		40.00	-271.4212	11.4701
Subject	20.00	40.00	-.8230	1.8230
		60.00	-1.2835	1.2835
	40.00	20.00	-1.8230	.8230
		60.00	-1.8230	.8230
	60.00	20.00	-1.2835	1.2835
		40.00	-.8230	1.8230

Based on observed means.
The error term is Mean Square(Error) = 6.585.

Appendix E – Relative Peak Force Statistical Handouts

Tests of Between-Subjects Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F
Corrected Model	Force	140.219[a]	6	23.370	2.302
	Subject	6.923[b]	6	1.154	.175
Intercept	Force	733.446	1	733.446	72.262
	Subject	3027.600	1	3027.600	459.747
Volume	Force	59.226	2	29.613	2.918
	Subject	6.923	2	3.462	.526
set	Force	80.993	4	20.248	1.995
	Subject	.000	4	.000	.000
Error	Force	1248.435	123	10.150	
	Subject	810.000	123	6.585	
Total	Force	2107.297	130		
	Subject	3870.000	130		
Corrected Total	Force	1388.654	129		
	Subject	816.923	129		

Tests of Between-Subjects Effects

Source	Dependent Variable	Sig.
Corrected Model	Force	.038
	Subject	.983
Intercept	Force	.000
	Subject	.000
Volume	Force	.058
	Subject	.592
set	Force	.099
	Subject	1.000
Error	Force	
	Subject	
Total	Force	
	Subject	
Corrected Total	Force	
	Subject	

a. R Squared = .101 (Adjusted R Squared = .057)

b. R Squared = .008 (Adjusted R Squared = -.040)

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) set	(J) set	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Force	1.00	2.00	-1.5920	.88361	.377	-4.0384	.8544
		3.00	-2.1092	.88361	.126	-4.5557	.3372
		4.00	-1.9325	.88361	.192	-4.3789	.5139
		5.00	-2.0526	.88361	.145	-4.4990	.3938
	2.00	1.00	1.5920	.88361	.377	-.8544	4.0384
		3.00	-.5173	.88361	.977	-2.9637	1.9291
		4.00	-.3405	.88361	.995	-2.7869	2.1059
		5.00	-.4607	.88361	.985	-2.9071	1.9857
	3.00	1.00	2.1092	.88361	.126	-.3372	4.5557
		2.00	.5173	.88361	.977	-1.9291	2.9637
		4.00	.1768	.88361	1.000	-2.2696	2.6232
		5.00	.0566	.88361	1.000	-2.3898	2.5030
	4.00	1.00	1.9325	.88361	.192	-.5139	4.3789
		2.00	.3405	.88361	.995	-2.1059	2.7869
		3.00	-.1768	.88361	1.000	-2.6232	2.2696
		5.00	-.1202	.88361	1.000	-2.5666	2.3262
	5.00	1.00	2.0526	.88361	.145	-.3938	4.4990
		2.00	.4607	.88361	.985	-1.9857	2.9071
		3.00	-.0566	.88361	1.000	-2.5030	2.3898
		4.00	.1202	.88361	1.000	-2.3262	2.5666
Subject	1.00	2.00	.0000	.71173	1.000	-1.9706	1.9706
		3.00	.0000	.71173	1.000	-1.9706	1.9706
		4.00	.0000	.71173	1.000	-1.9706	1.9706
		5.00	.0000	.71173	1.000	-1.9706	1.9706
	2.00	1.00	.0000	.71173	1.000	-1.9706	1.9706
		3.00	.0000	.71173	1.000	-1.9706	1.9706
		4.00	.0000	.71173	1.000	-1.9706	1.9706
		5.00	.0000	.71173	1.000	-1.9706	1.9706
	3.00	1.00	.0000	.71173	1.000	-1.9706	1.9706
		2.00	.0000	.71173	1.000	-1.9706	1.9706
		4.00	.0000	.71173	1.000	-1.9706	1.9706
		5.00	.0000	.71173	1.000	-1.9706	1.9706
	4.00	1.00	.0000	.71173	1.000	-1.9706	1.9706
		2.00	.0000	.71173	1.000	-1.9706	1.9706
		3.00	.0000	.71173	1.000	-1.9706	1.9706
		5.00	.0000	.71173	1.000	-1.9706	1.9706
	5.00	1.00	.0000	.71173	1.000	-1.9706	1.9706

	2.00	.0000	.71173	1.000	-1.9706	1.9706
	3.00	.0000	.71173	1.000	-1.9706	1.9706
	4.00	.0000	.71173	1.000	-1.9706	1.9706

Based on observed means.
The error term is Mean Square(Error) = 6.585.

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Volume	(J) Volume	Mean Difference (I-J)	Std. Error	Sig.
Force	20.00	40.00	-.5369	.69231	.719
		60.00	1.0910	.67164	.239
	40.00	20.00	.5369	.69231	.719
		60.00	1.6279	.69231	.053
	60.00	20.00	-1.0910	.67164	.239
		40.00	-1.6279	.69231	.053
Subject	20.00	40.00	.5000	.55765	.643
		60.00	.0000	.54100	1.000
	40.00	20.00	-.5000	.55765	.643
		60.00	-.5000	.55765	.643
	60.00	20.00	.0000	.54100	1.000
		40.00	.5000	.55765	.643

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Volume	(J) Volume	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Force	20.00	40.00	-2.1794	1.1056
		60.00	-.5024	2.6844
	40.00	20.00	-1.1056	2.1794
		60.00	-.0146	3.2704
	60.00	20.00	-2.6844	.5024
		40.00	-3.2704	.0146
Subject	20.00	40.00	-.8230	1.8230
		60.00	-1.2835	1.2835
	40.00	20.00	-1.8230	.8230
		60.00	-1.8230	.8230
	60.00	20.00	-1.2835	1.2835
		40.00	-.8230	1.8230

Based on observed means.
The error term is Mean Square(Error) = 6.585.

Appendix F – Total and Relative Mean Force Statistical Handouts

Tests of Between-Subjects Effects

Dependent Variable: Relative Force

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	5.194	1	5.194	24.232	.001
	Error	1.732	8.082	.214[a]		
Volume	Hypothesis	.012	2	.006	.099	.906
	Error	.914	15	.061[b]		
Subject	Hypothesis	1.737	8	.217	3.564	.016
	Error	.914	15	.061[b]		

a. .982 MS(Subject) + .018 MS(Error)
b. MS(Error)

Tests of Between-Subjects Effects

Dependent Variable: Total Force

Source		Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Hypothesis	32697.170	1	32697.170	32.745	.000
	Error	8087.394	8.099	998.542[a]		
Volume	Hypothesis	28.561	2	14.281	.042	.959
	Error	5148.154	15	343.210[b]		
Subject	Hypothesis	8083.902	8	1010.488	2.944	.034
	Error	5148.154	15	343.210[b]		

a. .982 MS(Subject) + .018 MS(Error)
b. MS(Error)