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<td><strong>Supervisor:</strong></td>
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THE EFFECTS OF CONCURRENT STRENGTH AND ENDURANCE TRAINING ON INDICIES OF STRENGTH, POWER AND ENDURANCE PERFORMANCE

(Dissertation submitted under the discipline of SCRAM)

STEPHANIE MORRIS

ST20001437
THE EFFECTS OF CONCURRENT STRENGTH AND ENDURANCE TRAINING ON INDICIES OF STRENGTH, POWER AND ENDURANCE PERFORMANCE
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ACKNOWLEDGEMENTS

Firstly, I would like to thank my dissertation supervisor Rob Meyers for his continued support, effort and guidance throughout the duration of the present study. I would also like to thank all the participants who volunteered to take part within this project; without you this dissertation would not have been possible.
ABSTRACT

The purpose of this study was to investigate the effects of concurrent strength and endurance training on indices of strength power and endurance performance in female games players. Twelve female games athletes (age 19.6±0.9 years) were assigned to either strength training-only (ST – n=5) or concurrent strength and endurance training (SET – N=7). Strength training required the participants to complete two training sessions a week in the form of conventional resistance training. The participants in the SET group completed the same strength training as the ST group accompanied by two additional endurance training sessions in the form of interval training. Indices of strength, power and endurance were measured pre and post 6-week intervention period. Both ST and SET resulted in significant gains in strength and endurance (p < 0.05); with no significant difference between the ST and SET groups. Only the SET induced a significant increase in power post intervention (p < 0.05). The present results enable the rejection of the interference hypothesis for the case of female athletes participating in a regime of two strength training sessions and two interval training session’s per week. Results document an effective training protocol to improve strength, endurance and power for games players and support prescription of concurrent training under defined conditions, in which exercise intensity and training frequency are considered.
CHAPTER ONE

INTRODUCTION
1.1 Background

Adaptations to exercise are dependent on the specific type of training performed and limited to the physiological systems used and overloaded (Astrand et al, 2003). In order to optimise performance in competition, training must meet the numerous physiological demands required of the athlete, evoking a high degree of transfer from competition into a training regime (Bloomfield, Polman and O'Donoghue, 2004).

Despite the extreme contrast in training methods and adaptations, many sports require interaction between the aerobic and anaerobic metabolic systems, as well as combinations of both strength and endurance for optimal performance (Bell et al, 1991). Needs analysis of individuals in games sports therefore dictates the training of these multiple energy sources (Platanoua and Geladasb, 2006; Davidson and Trewartha, 2008; Matthewa and Delextrata, 2009; Lythe and Kilding, 2011). Endurance is required in order to sustain performance in repeated bouts of high-intensity work and repeated changes in direction and speed (Benjamin and Hangerman, 2008), whilst strength is essential for maximal force behind the movements. As such, it is inevitable that strength and endurance training will be performed concurrently at particular stages during a games players training cycle.

1.2 Rationale for the Study

The compatibility of concurrent strength and endurance training has been investigated for over 3 decades. It was first investigated in 1980 by Hickson, who suggested that combined strength and endurance training within the training regime will result in a reduced capacity to develop strength, but will not affect the magnitude of increase in endurance performance. This negative interaction between strength and endurance training has been termed the interference effect or phenomenon (Hickson, 1980). In support of the pioneering work of Hickson (1980), arguably the most consistent finding to since emerge from literature, is that concurrent strength and endurance training results in a compromised strength adaptation, compared with training for strength alone (Dudley and Djamil, 1985; Nelson et al, 1990; Sale et al, 1990; Hennessy and Watson, 1994; Bell et al, 2000;
Izquierdo et al, 2005; Hawley, 2009). Conflicting research exists however, suggesting a positive rather than negative effect of concurrent strength and endurance training on muscle strength and maximal aerobic capacity, supporting the concept of an additive effect (Gettman, Ward and Hagan, 1982; Vope et al, 1993; McCarthy et al, 1995; Balabinis et al, 2003; Shaw, Shaw and Brown, 2009).

The overall lack of clarity with regards to the existence of an additive or interference effect highlights the need for future research within this area. Despite concurrent training being frequently implemented in games players’ training regimes, there is limited research implementing a games specific training approach. The current research however observed no interference effect and suggested concurrent strength and endurance training results in considerable improvement of a players’ physical capacity (Balabinis et al, 2003; Helgerud et al, 2011). Further research in this area will help to further knowledge of concurrent training in games players and produce findings specific to this population. The study is novel in that it is the first study to investigate the effects of concurrent training on games players, concerning female participants.

1.3 Aims and objectives of the study

As suggested by (Balabinis et al, 2003), a well-designed concurrent strength and endurance training programme, which considers sports specific requirements and training principles, should show a reduced interference effect. Thus, through a precise and deliberate choice of training protocols, the purpose of this study was to examine the effects of concurrent interval training and maximal strength training, on indices of strength, power and endurance in female games players. An evidence-based training approach was adopted with the aim of preventing the incompatibility between strength and endurance training.
CHAPTER TWO

LITERATURE REVIEW
2.1 Strength

Strength is broadly defined as the ability of a given muscle or group of muscles to exert force (Siff, 2001). Deemed as essential in human performance, strength is therefore a main priority in physical preparation for the majority of sports and athletes (Almasbakk and Hoff, 1996; Gamble, 2003). Maximal strength is defined as the ability of a given muscle or group of muscles to produce a maximal voluntary contraction in response to optimal motivation (Sale, 1992). For the majority of sports is it suggested that athletes require optimal levels of strength as opposed to maximal strength in order to compete in their sports (Murray and Brown, 2006). Regardless of this, the superior playing performance of elite level players has often been attributed to the greater strength capacities of these athletes (Gabbett, 2005; Sheppard et al, 2008). Research by Baker (2002) supports this, finding differences among first-grade, second-grade, and third-grade players for measures of upper and lower-body strength and power. It can be concluded that skilful performance is constrained, at least in part, by strength limitations (Gabbett, Kelly, and Pezet, 2007; Burr et al, 2008), hence why strength training may be seen as an essential component of athletic development.

2.2 Endurance

Endurance is defined as the ability to maintain or repeat a given force or power output (Stone et al, 2006). Aerobic endurance performance is dependent on three elements: maximal volume of oxygen uptake (VO$_2$ max), anaerobic threshold, and work economy (Helgerud et al, 2001); however is most often measure by VO$_2$max, which represents the limit to which oxygen delivery and uptake within exercising muscles can occur (Levine, 2008). Research suggests that increased VO$_2$ max can lead to improved performance; substantiated as distance covered, level of work intensity, number of sprints and number of involvements with the ball during a match (Helgerud et al, 2001). Therefore, endurance has long been recognised as an important fundamental component of physical fitness; with endurance and strength often referenced as the foundation fitness attributes.
2.3 Power

Power is quantified by the product of force and velocity, therefore strength is an integral part of power production. As a result of this, increases in strength are often accompanied by increases in power and rate of force development (Aagaard et al., 2002). Furthermore, it has also been shown that endurance performance depends directly on maximal strength (Stone et al., 2002). Stronger athletes generally produce higher power outputs (Cronin, McNair and Marshall, 2000; Østerås, Helgerud, and Hoff, 2002) and express higher levels of muscular endurance (Green and Patla, 1992; Hoff, Helgerud and Wisloff, 1999).

When using master endurance athletes, strength training was finalized to optimize endurance performance, resulting in increased running economy, also accompanied by an increase in power performance (Piacentini et al., 2013). It is possible that the increase in power and rate of force development may have been a causable factor in the increase in endurance, by reducing the relative force (percentage of maximum) applied at similar loads (Østerås et al., 2002, Hoff, Gran and Hergerud, 2002). Thus increases in power and rate of force development, rather than the increased 1RM per se, might be accountable for improvements in endurance performance (Østerås et al., 2002). In contrast, Guglielmo, Greco, and Denadai (2009) found that whilst explosive strength training resulted in improvements in Counter Movement Jump (CMJ) height, no significant modification in running economy was evident. Thus it could be suggested the neuromuscular mechanisms that determine increase of CMJ height can be different from those which improve running economy. Contrasting evidence therefore suggests a need to monitor power performance when measuring indices of strength and endurance performance.
2.4 Concurrent Training
When developing several physical and fitness attributes, athletes ideally use a periodised approach to training allowing sequential development of the fitness requirements (Bompa and Haff, 2009). However, time constraints and demands of competitive schedules mean a periodised approach is not always possible. Consequently, athletes are often required to train different physiological systems simultaneously, during the same training cycle. This approach is particularly true for the development of strength and endurance, dictating the inclusion of both strength and endurance training methods within the training regime. Additionally, sports medicine and exercises science organisations, including the American College of Sports Medicine (ACSM) (Riebe, 2014), recommend concurrent training in order to maximize the benefits of exercise at all levels. Despite delivering scientifically based standards on exercise prescription, the organisation fails to consider the possibility of a negative interaction between strength and endurance training, which could lead to compromises in program outcomes.

2.5 Training Methods to Improve Endurance
In 1990, Nelson et al reported that improvements in VO₂ max during the second half of a 20-week training programme were compromised during concurrent strength and endurance training when compared with endurance training alone. Hickson, Rosenkoetter and Brown (1980) and Dudley and Djamil (1985) in contrast found concurrent torque training and endurance training had no effect on aerobic adaptation when compared to endurance training alone. The diluted aerobic adaptation evident in the study by Nelson et al (1990) may have been as a result of testing protocols; despite cycling on an ergometer for endurance training, VO₂ was measured on a treadmill.

Further reasoning for the compromise in endurance performance may however be a function of the endurance training intensity. Improvements in endurance are directly related to the intensity of training (Helgerud et al, 2007). It has been suggested that training at higher intensities elicits a higher training response (Wenger and Bell, 1986; Gormley et al, 2008); more specifically, it has been
concluded that interval training may benefit aerobic capacity more so than continuous running (Thomas, Adeniran and Etheridge, 1984; Gormley et al, 2008). This is supported in a study, by Helgerud and colleagues (2007), who found high-intensity aerobic interval training, resulted in significantly increased VO$_2$ max compared with long, slow distance and lactate-threshold training intensities. Although, contrasting research has found similar increases in VO$_2$ max in subjects who trained at markedly different exercise intensities, this is likely due to the high baseline fitness of the subjects (Poole and Gaesser, 1985).

The study by Nelson et al (1990) incorporated an endurance program of continuous cycling at 75% to 85% of Maximum Heart Rate. In comparison, the previous two studies (Hickson et al, 1980; Dudley and Djamil 1985) used an interval program requiring near-maximal effort during each work interval. Whilst these results support the conclusions that interval training may benefit aerobic capacity more so than continuous running, it could be further suggested the extent of the interference effect is highly dependent on the intensity of the training program as a result of the distinct adaptations elicited (Nelson et al, 1990). Submaximal endurance training is suggested to result in neurological alterations which cause a reduction in central drive (Abbis and Laursen, 2005). It has been suggested that the central nervous system fatigue slows the speed of excitation, particularly within fast-twitch fibres, therefore having a counter-productive effect on power and strength development (Eloranta, 2003).

In support, Cunningham, McCrimmon and Vlach (1979) compared the effects of low intensity, continuous and high intensity, interval training in untrained female participants. Results found the interval group demonstrated greater increases in the oxygen difference between the arterial and mixed venous blood than the continuous group, reflecting greater peripheral adaptation. On the other hand, authors suggest improvements elicited by the continuous group would have been more centrally mediated, although not evidenced. Furthermore, Henriksson and Reitman (1976) investigated the effect of eight weeks of physical training on oxidative and glycolytic enzyme activities in type I and type II fibres of human quadriceps femoris muscle. Participants were trained at the same total work-load
on a bicycle ergometer 3 days per week using interval exercise with maximal intensity or continuous exercise with submaximal intensity. Research found the interval training and continuous training to recruit different muscle fibre types and therefore to elicit different aerobic adaptations. Regardless of the small number of participants used in the study, this research is in support with more recent literature which suggests that up to the level of maximum aerobic velocity, it is the intensity of training that determines the training response and physiological adaptations.

Whilst it has been suggested that continuous aerobic training would have minimal interference on strength development (Docherty and Sporer, 2000), this method of endurance training is less specific to games sport athletes when compared to interval training. Interestingly, the studies which have implemented interval training provide contrasting evidence with regards to the interference effect (Hennessy and Watson, 1994; Dudley and Djamil, 1985; Bell et al, 2000; Balabinis et al, 2003).

In the study by Dudley and Djamil, (1985) interval sessions completed, consisted of 5 sets of 5 minute cycles. Whilst these sessions were designed to elicit peak cycle ergometer VO$_2$ max, exercise intensity was evaluated with consistent values of 180 beats per min or greater during minute 4 or 5. Taking into consideration the subject’s age, this suggests a training intensity of only approximately 80% VO$_2$ max was implemented (Swain et al, 1994). Results demonstrated significant increases in strength, in both the strength only and concurrent training groups.

More recently, when investing the effects of concurrent strength and endurance training Bell et al (2000) prescribed endurance training which consisted of a combination of continuous and aerobic training. Endurance training entailed two continuous sessions and one interval session per week. The interval training consisted of running at a work-to-rest ratio of 1:1, working for 3 minutes at a time, at the equivalent of 90% VO$_2$ Max. In contrast to Dudley and Djamil, (1985), results showed increases in knee extension strength were greater for that of the strength only group in comparison to the concurrent training, therefore concluding some interference with the development of strength; confined to concurrently
trained limbs. The variance in endurance training protocols, including training intensity and rest, may be causable for the differences in findings between the two studies. Furthermore, a work-to-rest ratio of 1:2 would be likely to show increased benefits for aerobic capacity and economy, more specific to games players (Fernandez, Mendez-Villanueva and Pluim, 2006; Davidson and Trewartha, 2008).

Hennessy and Watson (1994) invested the effects of three pre-season training regimes on endurance, strength, power and speed performance. Participants were split into a strength-only training group, endurance-only training group and concurrent strength and endurance training group. Whilst the concurrent training yeilded improvements in endurance and upper body strength, the results found strength gains were compromised in squat performance. Additionally, the concurrent training did not lead to vertical jump or speed gains. Whilst a sports specific training approach was adopted, overtraining was not considered. The concurrently trained group performed strength training three times a week and endurance training four times a week, having only one day of rest. In contrast, when comparing regimens of concurrent strength and endurance training in male basketball players, no interference effect was evident (Balabinis et al, 2003). Balabinis et al (2003) took into consideration the sport-specific requirements and the importance of adequate rest periods, in order for overtraining to be avoided. Although strength and endurance training was completed on the same day, participants then had three rest days throughout the week. Therefore, this may suggest when adopting a sports specific approach, training frequency also needs to be considered.

2.6 Training Methods to Improve Strength

Training-induced adaptations in the neuromuscular system are known to differ according to the specific mode of exercise used for strength training. Resistance training may be utilised to develop all components of strength, power, hypertrophy and muscular endurance, however varying the training volume and time under tension may determine which aspect is developed most (Bean, 2001). Several studies have shown the superiority of heavy resistance loadings for the development of maximum strength (Harris et al, 2008; Cormie, McGuigan and
Newton, 2010; Smilios et al, 2013). Contrasting strength training protocols are however evident when examining the concurrent training literature. The variation in these protocols therefore elicits distinct neuromuscular adaptations, resulting in equivocal findings. In contrast to the founding work of Hickson (1980), in the majority of studies, strength training is of low load, and high volume (Sale et al, 1990; Bell et al, 2000; Hakkinen et al, 2003; Shaw, Shaw and Brown, 2009). The increased volume and time under tension that can be achieved through lower intensity lifts employed in these studies, is however associated with a greater increase in muscle size due to increases in the muscle's cross-sectional area (Folland and Williams, 2007). This adaptation may be detrimental to a games player, where muscle forces are generated to support the body mass against gravity. Gains in body mass are therefore undesirable because they are believed to impede optimal endurance performance (Aagaard et al, 2011). Furthermore, body mass is found to be a strong predictor of linear speed, suggesting an increase in body mass may impede optimal speed and agility performance (Xu et al, 2011).

Despite an increase in muscle strength and muscle thickness in strength-trained muscles, there is not always a change in total body mass (Rønnestad et al, 2012). Concurrent strength and endurance is an example of this, in which training may result in increased maximal muscle strength in the absence of muscle fibre hypertrophy (Hickson et al, 1988; Aagaard et al, 2011). The potential gain in maximal muscle force in the absence of muscle hypertrophy is likely to result in an enhanced exercise performance in games players, thus promoting concurrent training for games athletes. The absence of muscle fibre hypertrophy found by Hickson et al (1988) and later by Aagaard et al (2011) may however be due to the low volume and high intensity strength training prescribed; associated with predominantly neural adaptations (Docherty and Sporer, 2000).

It has however been suggested that the attenuated improvements in strength during concurrent training may be due to a lack of hypertrophic adaptation (Jones et al, 2013). In support, Nelson et al (1990) also reported that concurrent strength and endurance training produces different fibre hypertrophy patterns than strength training. Significant hypertrophy occurred in response to both endurance and
concurrent training in all fibre type areas (I, IIA, IIb). However, the strength training only group, induced hypertrophy in Type IIb fibres only. Regardless of these findings, there was no impairment in strength development when the endurance training was added to the strength training. These findings therefore might suggest increased interference when strength gains are achieved through predominately hypertrophic adaptations.

2.7 Training Frequency and Monitoring

In the majority of concurrent training studies, the concurrent training group perform the same amount of strength training as the strength only training groups, with additional endurance training. As a result, the concurrent training group participants are subject to double the dose of training load in comparison to the single mode of training. Therefore, it is considered that overtraining or overreaching may account for the inability to attain optimal strength gains when strength and endurance training are concurrently performed, as a result of excess fatigue (Dudley and Fleck, 1987; Docherty and Sporer, 2000; Nader, 2006). In support, in the study by Hickson (1980) strength gains achieved during the first six to seven weeks, plateaued, followed by a decrease during the last two weeks of the training program. This depression in performance continued for weeks, typical of overtraining (Kreider, Fry and O’Toole, 1998). This suggests the imbalance between training and recovery may have impairment strength (O’Toole, 1998), especially as the athletes were subject to high volumes of training, completing five strength training sessions per week and six endurance training sessions per week.

Additionally, Sale et al. (1990) found strength and endurance training, on the same day twice a week, impaired strength development when compared with training four times a week, on different days. This supports the theory that increasing the recovery periods in between strength and endurance workouts will reduce the chances of overtraining and may decrease the incompatibility of concurrent training. Findings thus highlight the need to account for sufficient rest periods and monitor for the potential of overtraining in future studies in this area. Despite the possibility of fatigue being accountable for the interference effect, previous concurrent training studies have failed to report any indicators of training status. In order to evaluate training status and accumulative fatigue, monitoring
internal training is considered the most relevant method (Meeusen et al, 2006). Whilst a number of methods are available for coaches to quantify internal training loads, the practicalities of such techniques do not easily lend themselves to team sports. The use of Training Impulse (TRIMP) originally developed by Banister (1991) for example is unreliable when monitoring discrete bouts of activity, as present in sports specific training (Akubat and Abt, 2011). On the other hand, Session Rating of Perceived Exertion (RPE) first introduced by Foster et al (2001), has been shown to accurately represent internal training load of several different training modalities (Kelly and Couts, 2007; Clarke et al, 2013). Thus Session RPE provides a subjective intensity rating of the training sessions, useful for comparison when monitoring fatigue state.

2.8 Methods of Testing

2.8.1 Testing of Strength Performance

Despite similar training protocols, the findings of concurrent studies are often in contrast, potentially due to variation in strength testing protocols (Bell et al, 2000; Dudley and Djamil, 1985); supporting the notion that various strength indices do not monitor similar events (Abernethy, Wilson and Logan, 1995).

Maximum muscle force and maximum muscle torque have previous been measured by isometric, isoinertial and isokinetic dynamometry, all of which have acceptable reliability as evidenced by Abernathy et al (1985). In order to best assess improvements in strength relative to athletic performance, testing should however be of a functional nature. Functional training intentionally incorporates balance and proprioception (Boyle, 2003). Thus, most machine-based systems are not deemed functional because the load is stabilised by the machine, not by the athlete. Furthermore, functional movements are characterized by multi-joint movements such as squatting and lunging or pushing or pulling (Boyle, 2003). Unlike dynamometry, in which the recorded force predominantly represents the results of action of a single muscle group, testing the maximum weight lifted in standard lifting tasks provides strength scores based on the contraction of several muscle groups of a particular kinetic chain. Involving these movements, the lifting of maximal weights has therefore been considered a functional movement task,
specific to sports performance. Thus, although isokinetic dynamometry is considered the gold standard for the assessment of muscle strength (Dvir, 2004), one repetition maximum (1RM) testing performed on training-specific equipment is more commonly applied in sporting assessment.

It has been suggested that novice lifters should not perform a 1RM strength assessment, as lifting maximal weight by individuals not accustomed to weight training may induce muscle soreness and increase the risk of more serious muscular injury (Welday, 1988). Furthermore, the reliability of 1RM testing is reduced respectively in accordance with the previous resistance training experience of the athletes (Ritti-Dias et al., 2011). Therefore, in order to minimize the risk of strength assessment and improve reliability, regression equations have been developed to predict 1RM strength. Research by Dohoney et al. (2002) concluded that the 4-6 RM submaximal strength test improved the predictive accuracy of 1RM strength when compared to the 7-10 RM submaximal strength assessment, suggesting a reduced number of repetitions in submaximal strength testing is likely to increase the reliability.

2.8.2 Testing of Endurance Performance

In the literature, an increase in VO$_2$ max is the most common method of demonstrating training effect on endurance performance (Bassett and Howley, 2000). Furthermore, it can be argued that VO$_2$ max is the most important factor in determining success in aerobic endurance sports (Di Prampero, 2003).

Whilst VO$_2$ max values obtained in laboratory testing are considered the ‘gold standard’ for the measurement of aerobic fitness, the procedures are time consuming and require trained personal and expensive equipment. Moreover, VO$_2$ max is not the endurance indicator of importance, as other indices such as sport-specific economy and anaerobic capacity will contribute to endurance performance (Di Prampero, 2003; Joyner and Coyle, 2008). This is supported by research which found variation in work economy in athletes with similar VO$_2$ max results (Helgerud, Ingjer and Strømme, 1990). Individual peak oxygen uptake is specific of that given activity, therefore when measuring endurance performance emphasis is placed on testing in sport-specific activities (Strømme, Ingjer and
Meen, 1977). A sport specific test provides a general evaluation of endurance performance as opposed a measurement of only one contributing factor.

Testing with a practical alternative of the Yo-Yo 1R1 test allows testing of all participants to occur simultaneously. Research shows the Yo-Yo 1R1 test elicits physiological demands similar to those during competition, mimicking the intermittent nature of sports, therefore suggesting ecological validity. Scores have been further found to significantly correlate with VO$_2$ Maximum assessed in laboratory, confirming validity when providing a measurement of endurance performance (Kurstrup et al, 2003; Castagna et al, 2006; Castagna et al, 2008).

2.9 Purpose of the Study

Studies investigating the interaction of concurrent strength and endurance training, provide overall strong evidence that concurrent training does not impair endurance development (Hickson, 1980; Kraemer et al, 1997; Balabinis et al, 2003). Thus it appears the major consideration with concurrent training is that of endurance training possibly interfering with the neuromuscular system’s ability to generate maximal force.

Arguably, research suggests high intensity strength training and interval training are the most effective methods for strength and endurance development in sport athletes. Research also proposes less interference is evident when combining interval training with high load strength training because the training stimulus for increasing strength would be mainly directed at the neural system, whilst the adaptations for increasing maximal aerobic power will mainly induce peripheral adaptations (Docherty and Sporer, 2000).

Understanding of the interference effect between strength and endurance is crucial to exercise physiologists, coaches, strength and conditioning coaches and athletes, who invest substantial time and resources to maximize training adaptations and competitive efficiency. Understanding of concurrent training is therefore essential, as an interference effect could impede optimal development. In contrast an addictive effect could lead to more efficient athletic training
protocols. Specific to recreational athletes, the possibility of interference has also created ambiguity in exercise prescription.

Previous studies differ markedly in programme design factors, including the methods of training, exercises, frequency, sequencing, volume of training and training history of participants. The majority of concurrent research has used male athletes to draw definitive conclusions on the effects of concurrent training. Findings by Bell et al, (2000) however provide some support for a differential response in males and females. Authors concluded concurrent strength and endurance training can lead to an elevated catabolic state in women compared to performing the same strength or endurance training separately, or in comparison to men. Findings therefore highlight the need to further investigate the interference effect on female participants, providing findings specific to females.

Overall, it is apparent that research demonstrates a lack of systematic approach to investigating the interference phenomenon, with particular reference to the compatibility of the intensity of strength and endurance training. The benefits or effects of a concurrent training regime for female sports players is therefore an unresolved issue, that may be addressed with further research on the effects of concurrent, high intensity strength training to sport-specific interval training.
CHAPTER THREE

METHOD
3.1 Experimental Overview

The study used a quantitative, controlled experimental design to assess the effects of concurrent strength and endurance training on indices of strength, power and endurance, in female games players. Each dependent variable (strength, power and endurance) was measured pre and post 6-week intervention period for both of the groups in the study: Strength training-only (ST) and Concurrent Strength and Endurance training (SET). A ST group was utilised in the present study in order to provide a comparison for the effects of the additional endurance training sessions in the SET group, against a single mode, strength training programme.

3.2 Participants

Twelve female athletes from Cardiff Metropolitan University volunteered to participate in the study. Participants were all games athletes (Hockey (n=3), Netball (n=8), Water polo (n=1) with limited resistance training experience prior to the study. The average (SD) age, height, and mass of the group was 19.6 (+0.9) years, 167.0 (+5.3) cm, and 66.4 (+ 8.4) kg, respectively. Initial characteristics of the experimental groups are presented in Table 1.

All participants were notified of the study requirements, benefits and potential risks via a background information sheet (see Appendix A) prior to the start of the study. Self-administered physical activity readiness questionnaires (see Appendix B) ensured participants were all free of cardiovascular, musculoskeletal and metabolic diseases. Ethical approval for this study was obtained from the Cardiff Metropolitan University Ethics Committee.
Table 1. Initial characteristics of the experimental groups (mean ± SD)*

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (y)</th>
<th>Height (cm)</th>
<th>Body Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST</td>
<td>19 ± 0.7</td>
<td>166.5 ± 4</td>
<td>65.3 ± 5.1</td>
</tr>
<tr>
<td>SET</td>
<td>19.9 ± 0.7</td>
<td>168.9 ± 4.6</td>
<td>68.2 ± 9.9</td>
</tr>
</tbody>
</table>

*ST= Strength training-only group; SET= Strength and Endurance Training group

3.3 Procedure

Participants were randomly assigned to an intervention group; ST group (n=5) or SET group (n=7). All participants (both the ST group and SET group) were required to attend one familiarisation session and two testing sessions in the week preceding the 6-week intervention period. The familiarisation session prior to 3RM strength testing ensured participants were familiar with the testing protocols and improved test reliability, minimizing the learning effect and systematic bias (Hopkins, 2000). One testing session consisted of Three Repetition Maximum (3RM) Strength Tests and the other of a Counter Movement Jump (CMJ) Test followed by a Yo-Yo Test. The testing procedures were then repeated for all participants within 7 days of the 6-week training intervention ending. All tests were conducted by the same investigator. Participants were asked to refrain from any vigorous exercise in the 24 hours prior to each of the testing sessions.

3.4 Three Repetition Maximum (3RM) Strength Tests

Maximal strength was tested in 3RM tests in bench press, squat and prone pull. Strength was determined by measuring the maximum load that could be lifted for 3 successful repetitions. All participants completed a generalised warm-up prior to strength testing consisting of: a 200 m low-intensity jog, 10 body weight squats and lunges and 10 disk jumps. The 3RM testing procedure required the participants to complete a maximum of 5 sets of lifts to obtain a final 3RM score (Welday, 1988). Participants completed 5-10 repetitions using light weight on the first set. Following a one-minute rest, 10-20% of weight was added and 5 repetitions completed. Successive rest was then increased to 3-5 minute rest between sets. After increasing the weight by 20-30%, the 3RM was attempted in
the third set. 10-20% of weight was then added for each successful set or subtracted if unsuccessful (Welday, 1988). Using a 3RM test prevented induced fatigue and reduced the high potential for injury which occurs in 1RM testing (Welday, 1988). The results of the pre-intervention 3RM tests were also used to predict the participant’s 1RM results in order to calculate training load for strength training sessions. The 1RM prediction equation by Wathen was used, producing the most accurate results when predicting bench press and squat (LeSuer et al, 1997).

3.4.1 Bench Press

The participants were positioned supine on the bench with an overhand-pronated grip on the bar. The bar was to be controlled by the participant, down to touch the chest before beginning the concentric phase. The back of the head, upper back and sacral area/buttocks were to remain in contact with the bench and both feet were to remain in contact with the floor, throughout. A repetition was considered successful if the participant performed a press of the bar back to full arm extension, having lowered the bar to the required depth in contact with the chest.

3.4.2 Squat

The participants were to perform a back squat to a parallel depth of knee flexion, squatting to a depth at which the buttocks made contact with a medicine ball, performed with a free-weight Olympic-style barbell. A repetition was considered successful if the participant performed a squat to the required depth, in contact with the ball and raised the body back into the erect position.

3.4.3 Prone Pull

The participants were positioned in a prone position on the bench with a shoulder-wide, overhand-pronated grip on the bar. The bar was to be pulled up until it made contact with the bottom of the bench. The chest was to remain in contact with the bench and the head, trunk and legs to remain still throughout. The bar was lowered back to the starting hang position in a controlled manner. A repetition was considered successful if the participant performed a pull to the height required, making contact with the bench and controlling the bar back to the hang position.
3.5 Yo-Yo Test

In order to test endurance performance, the participants completed the Yo-Yo 1R1 Test, a test shown to be a sensitive measure of changes in endurance performance in games athletes (Bangsbo et al, 2008). The Yo-Yo test was performed on the indoor athletics track at the National Indoor Athletics Centre (NIAC), Cyncoed Campus, Cardiff. The test consisted of 20-m shuttle runs performed at increasing velocities with 10 secs of active recovery between runs, until exhaustion. When the participant twice failed to reach the front or back line of cones in time (objective evaluation) or felt they were unable to complete another shuttle (subjective evaluation) the test was terminated and the final score recorded. The total distance covered during the Yo-Yo (including the last incomplete shuttle) was considered as the test score. From the Yo-Yo test score, each of the participants VO$_2$ Max was later estimated and used for subsequent data analysis. VO$_2$ Max was calculated using the following equation by Bangsbo et al (2008):

$$\text{VO}_2\text{max (mL/min/kg)} = \text{Distance (m)} \times 0.0084 + 36.4$$

The estimation of VO$_2$ max from the Yo-Yo test has shown to be unreliable (Bangsbo et al, 2008) however the Yo-Yo test has been previously identified to produce reliable, valid and repeatable results (Krustrup et al, 2003; Bangsbo et al, 2008) Therefore VO$_2$ max values were calculated solely for the purpose of comparison against previous studies.

3.6 Counter Movement Jump (CMJ) Test

Power was determined by measuring the participant’s peak Counter Movement Jump (CMJ) height. All participants completed a generalised warm-up prior to power testing consisting of: a 200m low-intensity jog, 10 body weight squats and lunges, 10 disk jumps and a minimum of 5 practice CMJ’s. Participants then performed 3 CMJ tests on a force platform (Smartspeed Jump Mat, Smartjump Brisbane, Australia) with a minimum of 1 minute recovery between each jump (Markovic et al, 2007). Participants were instructed to jump for maximal height and
no restriction on the degree of knee flexion was enforced during the eccentric phase of the CMJ. On completion of the 3 CMJ’s, the best jump height was recorded for analysis (Markovic et al, 2007). CMJ test is the most reliable and valid field test for the estimation of explosive power of the lower limbs, when compared with other jump tests (Markovic et al, 2007). Participants were given a 15 minute rest period before the subsequent Yo-Yo Test.

3.7 Training Interventions

3.7.1 Strength Training-only

Participants in the strength training-only group were required to complete two training sessions a week in the form of conventional resistance training. Exercises were free-weight variations of lower and upper body, unilateral and bilateral exercises, an example session is shown in Table 2 (see Appendix E for full Strength Training Programme Outline). 1-5 repetitions of each exercise and 2-6 sets were completed. A moderate lifting velocity (2-secs CON: 2-secs ECC) was implemented with rest intervals of 2-3 minutes. Load lifted progressed from 70% of 1RM and increased by 5% of 1RM each week. Strength training protocols across the 6 week training programme are outlined in Table 2. RPE monitoring in the strength training sessions improved the accuracy of the estimated training load, identifying when the load should be adjusted in accordance (Day et al, 2004; Ritti-Dias et al, 2011).

Table 2. Strength Training Programme: Week-1 example.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Session 1</th>
<th>Load (%1RM)</th>
<th>Reps</th>
<th>Sets</th>
<th>Rest (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back Squat</td>
<td>Deadlift</td>
<td>70</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bench Press</td>
<td>Bench Press</td>
<td>70</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Prone Pull</td>
<td>Prone Pull</td>
<td>70</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>
3.7.2 Concurrent Strength and Endurance Training

The participants in the SET group completed the same strength training as the ST group accompanied by two additional endurance training sessions. A minimum of 24 hours separated the two types of training. Endurance training was in the form of interval training. The training was performed on the indoor athletics track at the National Indoor Athletics Centre (NIAC), Cyncoed Campus, Cardiff. Training required the subjects to run at maximum effort with a 1:2 work-to-rest ratio. This was applied for 10-20 second work bouts, with passive rest intervals of 20-40 seconds between reps and 2 minute rest intervals between sets. Interval training protocols across the 6 week training programme are outlined in Table 4.

Table 3. Strength Training Protocols.

<table>
<thead>
<tr>
<th>Week</th>
<th>% 1RM</th>
<th>Reps</th>
<th>Sets</th>
<th>Rest (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70</td>
<td>6</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>75</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>85</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>95</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 4. Interval Training Protocols.

<table>
<thead>
<tr>
<th>Week</th>
<th>Duration (min)</th>
<th>Reps</th>
<th>Sprint (sec)</th>
<th>Recovery (sec)</th>
<th>Sets</th>
<th>Rest (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>8</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>8</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>8</td>
<td>15</td>
<td>30</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>8</td>
<td>15</td>
<td>30</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>20</td>
<td>8</td>
<td>20</td>
<td>40</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>8</td>
<td>20</td>
<td>40</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
3.8 Monitoring

To evaluate training status and accumulative fatigue session RPE and duration was recorded throughout the 6 week training programme (see Appendix F for Participant Weekly Monitoring sheet). Participants were required to perform physical activity as part of their university degree requirements and sporting commitments outside of the training interventions. Therefore, after completing any training session (within the training intervention and outside of the training intervention), participants were asked to indicate training intensity and duration. Training intensity was representative of the entire training session, indicated by referring to a numerical value on the Foster's Modified Borg (FMB) (Borg, Hassmén and Lagerström, 1987; Foster et al, 2001). A single arbitrary unit for global internal training intensity was then calculated by multiplying the training duration (in minutes) by the RPE intensity value provided retrospectively by the athlete. The global internal training intensity for training outside of the intervention was later used for statistical analysis, providing a comparison between the two groups in order to improve the validity of the findings. RPE data recorded for the strength training sessions was later used for statistical analysis, providing a comparison between the two groups in order to identify any variance in fatigue status.

3.9 Statistical Analysis

All data analysis was conducted through the Statistical Package for the Social Sciences (SPSS for Windows (version 20.0, SPSS, Inc., Chicago, IL, USA). The Two-way Mixed Model Analysis of Variances (ANOVA) was used to examine for differences across the groups (ST, SET) in 3RM Strength (Bench Press, Prone Pull and Squat), CMJ and Yo-Yo (distance travelled and VO₂ max) test results. This reduced the high familywise error rate which would occur in separate t-tests (Field, 2000). When the underlying assumption of sphericity associated with repeated measures ANOVA was not met, the Greenhouse-Geisser adjustment was used as the determinant of statistical significance. The independent T-test was used to examine for differences across the groups (ST, SET) in the Strength training RPE (StrT RPE) and Training Load Index outside (outside TLI) of the training programme. Data was presented as mean ± SD for each group (SE, SET).
or percent change. For all statistical analyses, a p value of 0.05 was accepted as the level of statistical significance.
CHAPTER FOUR

RESULTS
4.1 Three Repetition Maximum (3RM) Strength

4.1.1 Bench Press

As shown in figure 1, there was no significant different between the ST and SET groups in 3RM Bench Press in the pre-testing results (p>0.05). Bench Press strength (3RM) increased significantly for both groups; ST (+21.2%, p<0.05) and SET (+28.6%, p< 0.05). No significant (group × time) interaction effects were observed (p > 0.05).

![Figure 1](image)

**Figure 1.** Bench Press 3RM (mean ± SD) for the strength training-only group (ST) and concurrent strength and endurance training group (SET), Pre and Post 6-week training period ; * = significant difference within group from the pre-test results (p < 0.05).

4.1.2 Squat

As shown in figure 2, there was no significant different between the ST and SET groups in 3RM Squat in the pre-testing results (p>0.05). Squat strength (3RM) increased significantly for both groups; ST (+50.5%, p< 0.05) and SET (+32.9%, p<0.05). No significant (group × time) interaction effects were observed (p > 0.05).
Figure 2. Squat 3RM (mean ± SD) for the strength training-only group (ST) and concurrent strength and endurance training group (SET), Pre and Post 6-week training period; * = significant difference within group from the pre-test results (p < 0.05).

4.1.3 Prone Pull

As shown in figure 3, there was no significant different between the ST and SET groups in 3RM Prone Pull in the pre-testing results (p>0.05). Prone Pull strength (3RM) increased significantly for both groups; ST (+24.4%, p< 0.05) and SET (+12.4%, p< 0.05). No significant (group × time) interaction effects were observed (p > 0.05).
Figure 3. Prone Pull 3RM (mean ± SD) for the strength training-only group (ST) and concurrent strength and endurance training group (SET), Pre and Post 6-week training period; * = significant difference within group from the pre-test results (p < 0.05).

4.2 Yo-Yo Test

As shown in figure 4, there was no significant different between the ST and SET groups in the Yo-Yo Distance Travelled in the pre-testing results (p>0.05). Distance travelled increased significantly for both groups; ST (+ 21.6%, p< 0.05) and SET (+59.1%, p>0.05). No significant (group × time) interaction effects were observed (p>0.05).
Figure 4. Distance travelled in Yo-Yo Test for the strength training-only group (ST) and concurrent strength and endurance training group (SET), Pre and Post 6-week training period; * = significant difference within group from the pre-test results (p < 0.05).

Table 5. Change in Yo-Yo test performance as an effect of training measured by VO2 Max

<table>
<thead>
<tr>
<th>Group</th>
<th>VO2 max (mL/min/kg)</th>
<th>Performance Change (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>ST</td>
<td>43.9 ± 2.4</td>
<td>45.5 ± 3.3*</td>
</tr>
<tr>
<td>SET</td>
<td>41.92 ± 1.8</td>
<td>45.2 ± 1.7*</td>
</tr>
</tbody>
</table>

* = significant difference within group from the pre-test results (p < 0.05).

4.3 Counter Movement Jump (CMJ)

As shown in figure 5, there was no significant different between the ST and SET groups in peak height jumped in the pre-testing results (p>0.05). Peak jump height increased significantly in SET group only (+8.3%, p>0.05). Peak jump height increased in ST group, but no significance was observed (+6%, p>0.05). No significant (group x time) interaction effects were observed (p > 0.05)
Figure 5. Counter Movement Jump (CMJ) peak height (mean ± SD) for the strength training-only group (ST) and concurrent strength and endurance training group (SET), Pre and Post 6-week training period; * = significant differences within group from the pre-test results (p < 0.05).

4.4 Monitoring

As shown in table 6, there was no significant difference between the Rate of Perceived Exertion (RPE) for the Strength Training sessions between the ST group and SET group (p>0.05). There was no significant difference between the overall Training Load Index (TLI) of sessions performed outside of the training programme between the ST group and SET group (p>0.05).

Table 6. Strength Training Rate of Perceived Exertion (StrT RPE; mean ± SD) and Training Load Index for sessions performed outside of the training programme (Outside TLI; mean ± SD), across the 6-week training period

<table>
<thead>
<tr>
<th></th>
<th>ST</th>
<th>SET</th>
</tr>
</thead>
<tbody>
<tr>
<td>StrT RPE</td>
<td>7.4 ± 0.2</td>
<td>7.5 ± 0.2</td>
</tr>
<tr>
<td>Outside TLI</td>
<td>8939 ± 3031</td>
<td>8723 ± 2171</td>
</tr>
</tbody>
</table>

*ST= Strength training-only group; SET= Strength and Endurance Training group
CHAPTER FIVE

DISCUSSION
5.1 Findings

The primary focus of this study was to investigate the effects of concurrent strength and endurance training on indices of strength, power and endurance, in female games players. The primary findings of this investigation were that concurrent strength and endurance training resulted in significant gains in maximal strength and endurance. The SET group showed a further significant increase in power performance. In comparison, the ST group on the other hand showed no significant increase in power performance. Overall however, there was no significant difference between ST and SET groups when examining the effects on indices of strength, power and endurance performance. Despite an inability to control the training load outside of the study, the overall training was monitored and no significant difference between the ST and SET groups was observed in the training load index of training performed outside of the study (Outside TLI). This prevents a confounding variable which has the potential to affect comparisons made (Punch, 2009). Results indicate that in female games players, a training regime incorporating sports specific methods of strength and endurance training 4 days a week, on different days, will induce substantial increases in strength, endurance and power.

5.2 Strength

The present 6 week training period led to large increases of 51% and 33% in 3RM squat strength in groups ST and SET, respectively. Increases in upper body strength were of a smaller magnitude; namely 21% and 29% in Bench Press and 24% and 12% in prone pull in the ST and SET groups, respectively. Despite a difference in the magnitude of increase, there was no significant difference between strength gains in the ST and SET groups. In general, the magnitudes of the present strength gains are within similar ranges to the strength gains reported to take place during combined strength and endurance training in previously untrained athletes (McCarthy et al, 1995; Häkkinen et al, 2003). Findings are in support of conclusions made by Häkkinen et al (2003), in that the frequency of strength training in amateur athletes can be as low as twice a week when the loading intensity of training is sufficient and increased progressively. It is important to note however the large standard deviation seen within the groups. Since
sample size is one of the factors directly influencing the power of detecting the real and meaningful effect in treatment studies (Thomas et al, 1997), it could be suggested a larger sample size would increase the reliability of these findings.

Findings of the present study are in contrast to research that has shown some attenuation in muscle strength adaptations, after concurrent strength and endurance training compared to a single mode of training (Hickson, 1980; Sale et al, 1990; Kraemer et al. 1995; Bell et al, 2000;). Research suggests the attenuation in muscle strength seen in the previous studies may be related to a lack of change of some aspects of skeletal muscle morphology, with evidence to support a lack of change in skeletal muscle cross-sectional area after performing combined strength and endurance training (Esser and White 1990; Bell et al, 1991). Bell et al, (2000) and Kraemer et al (1995) both report some type of impairment in strength development with concurrent training compared with strength training- only, and both implicate an underlying factor may be a limitation in hypertrophy of Type I fibres. As the reduced gains in strength with concurrent training are partially due to a suppressed hypertrophic response in the muscle, differences in these physiological responses to strength training can be as a result of training protocol variations; with regards to intensity and volume of strength training eliciting distinct neuromuscular adaptations.

High load, low volume strength training employed in this study may be more dependent on neural factors for strength gains, being an inadequate stimulus for muscle tissue growth (Kraemer, Fleck and Evans, 1996). This therefore suggests that the contributing role of the nervous system to maximal strength development during the present training period in both groups may have been greatly important. The strength improvements may have been essentially as a result of changes in co-ordination and learning that facilitate improved recruitment and activation of the involved muscles during a specific task (Sale, 1992; Häkkinen et al, 2003; Folland and Williams, 2007). Training programs of high volume and lower load may however diminish the contribution of the initial neural adaptations, promoting muscle tissue growth (Kraemer et al, 1996). A reduced gain in skeletal muscle hypertrophy is a possible explanation for the compromise in strength gains during concurrent training in previous studies (Kraemer et al, 1995; Sale et al, 1990; Bell
et al, 2000) as a result of the high volume, low load strength training protocols. Thus, the present results might not indicate a lack of interference for the SET group as the strength training volume was not enough to elicit hypertrophic adaptations in either the SET or ST group; therefore no interference effect was evident as strength gains were dependent on neural adaptation. At present no research exists investigating neural activation changes due to endurance training in support of this contention.

There are several different lines of evidence that indicate increases in maximal strength observed during the initial weeks of strength training can be attributed largely to neural factors and motor learning; an attribution which appears to be more obvious in the early phases of training (Moritani, 1979, Häkkinen et al, 2003). As the duration of training increases, muscle hypertrophy eventually takes place and contributes more than neural adaptations to strength and power gains observed. As evidence by Hickson (1980), a training programme of longer duration may show evidence of interference, as strength gains are less attributable to neural factors following the initial early stages of training.

5.3 Endurance

Since the focus of the present research was to examine the impact of additional endurance training on the neuromuscular system’s ability to generate maximal force, a design limitation of this study was the absence of a control group for endurance training alone. As a consequence of this limitation, the present results bear more on the interference effect of strength gains with additional endurance training and less on comparing concurrent training adaptations with single-mode endurance training adaptations. Findings however show concurrent training improved endurance performance. The slightly elevated increase in the endurance performance of SET group over the ST group may suggest interval training as prescribed in the present study is effective at improving endurance performance, although this remains to be tested by appropriate internal controls for interval training alone.
The gains in VO$_2$ max in the SET group were lower than those observed in previous concurrent training studies that have focussed upon continuous endurance training as opposed to interval training (Hickson, 1980; Sale et al, 1990). Whilst research has identified sprint interval training be a time-efficient strategy to induce rapid adaptations in endurance performance (Gibala et al, 2006), findings of the present study may support of conclusions by Franch et al (1998); who suggested continuous training at sufficient intensities and long duration interval training, may be superior to short duration interval training for improving VO$_2$ max. On the other hand, in order to prevent a small effect size, the participants selected were sensitive to the strength training protocols, having a limited previous strength training history (Thomas et al, 1997). In contrast, participant’s demonstrated increased levels of endurance training history prior to the study; therefore, participants may less sensitive the endurance training protocol as a result of the higher performance levels prior to the study (Poole and Gaesser, 1985). The current literature is lacking in a clear consensus when comparing the effectiveness of interval training at improving VO$_2$ max, therefore the principle of training specificity may be of greater importance to training decisions.

Whilst endurance performance can be increased after both continuous and endurance training, it can be suggested the mechanisms behind the improvement are different. Therefore, research suggests as a result of the high and fluctuating workload during interval training employed in the present study, both central and peripheral adaptations may be accountable for the improvements in endurance performance (Daussin et al, 2008). However, the constant workload during continuous training employed in previous studies may have predominately resulted in peripheral adaptations in skeletal muscles (Daussin et al, 2008). Endurance performance is limited by the complex interaction of VO$_2$ max, economy, and lactate threshold. Therefore, divergent adaptations of interval and continuous training may alter the contribution of each endurance component, affecting the sensitivity of the dependant variable selection.
In addition endurance performance also significantly improved in the ST group. These findings are in support with the majority of research which suggests strength training can be associated with improvements in running endurance performance (Hickson et al, 1980; Paavolainen et al, 1999; Hoff, Gran and Helgerud, 2002; 1985; Piacentini et al, 2013).

The magnitude of cardiorespiratory adaptation depends primarily on the intensity, duration, and frequency of the exercise (Wenger and Bell, 1986). Evidence suggests strength training protocols employed in the present study do not fulfil the acknowledged requirements of duration and intensity to cause cardiorespiratory adaptation, therefore improvements in Yo-Yo performance may be as a result of increased economy (Hoff et al, 1999).

In support, Millet et al (2002) found that heavy-strength training yielded a positive influence on running economy, with no alteration in VO$_2$ kinetics. Since the increase in running economy in the study by Hoff et al (2002) was moderately correlated to a change of hopping power, it could be suggested that the larger improvement in power in the SET group may be accountable for the larger improvement in endurance. Hoff et al (1999) suggested that the rate of force development may be more important to improvements in running economy than an increase in maximal muscle strength. In contrast however a non-significant power increase was paralleled with a significant increase in endurance performance. This therefore suggests the heavy weight training may have contributed to improvement in running mainly through neural factors such as increased activation, more efficient recruitment, and motor unit synchronization (Paavolainen et al, 1999).

Furthermore the participants continued to perform physical activity as part of their university degree requirements and sporting commitments alongside the training intervention. Therefore, a benefit in endurance performance may have been as a result of training outside of the study, as opposed to the training intervention.
5.4 Power

Power, as measured by CMJ height, increased significantly in the SET group only. The non significant improvement in CMJ in ST group denotes that improvements in 1RM alone are not sufficient to elicit improvements in jump performance. Findings are in support of previous research, which also suggests heavy weight training to be ineffective at eliciting improvements in jump performance (Guglielmo et al, 2009). The velocity specific response to training, in that adaptations following training are maximized at or near the velocity of movement used during training, may account for improvements seen in SET group but not ST group (Cormie, McGuigan, and Newton, 2011). The low velocity strength training employed in the present study may have increased power predominately at low movement velocities (Kawamori, and Newton, 2006; Cormie et al, 2011). Thus countermovement jump, described a high velocity movement against low external load (Cormie et al, 2011), was not significantly increased.

The ability to generate maximal power in dynamic, multi-joint movements is dependent on the nature of the movement involved (Cormie et al, 2011). Therefore, the characteristics of the sprint interval training programme may have contributed to the significant improvement in jump performance in SET group. Full speed sprinting, requires the rapid release of muscular energy to propel the athlete forward, with maximal attainable velocity (Ross and Leveritt, 2001), determined mainly by the action of the hip extensors and ankle extensors (Wiemann and Tidow, 1995). In particular, it appears that the improvements in jumping performance seen as a result of the sprint interval training could be partly the result of improved leg extensor strength and power (Markovic et al, 2007).

Furthermore, it has been demonstrated that peak vertical ground reaction forces during foot contact in maximal sprinting can be higher than 5 times body weight (Mero, Komi and Gregor, 1992), advocating the importance of both high force and high power production. These data suggest that sprinting represents a multidimensional movement that activates great proportion of the leg musculature and requires both concentric and Strength Shortening Cycle (SSC) explosive force production. For comparison, heavy resistance training employed in the present
In addition, the integrated training approach employed in the concurrent training group may have been accountable for the observed increases in power. Heavy load resistance training may have developed strength at slow velocities (Kraemer and Ratamess, 2004), whilst the sprint interval training may have enhanced high velocity strength and improve SSC performance (Markovic et al, 2007). Improvements in power output following such concurrent training are hypothesized to be due to improved high velocity performance rather than being primarily driven by increased maximal strength (Markovic et al, 2007). These results suggest that the velocity of movement may be proportionally more important than strength level maintained during training when aiming to develop power. Furthermore, the neuromuscular adaptations resulting from an integrated approach to training are theorized to result in greater improvements in maximal power production than any of these modalities used in isolation (Newton and Kraemer, 1994), hence the higher increase seen in SET group to ST group. It is important to note however such interval training alone may not have provided an adequate stimulus for adaptation in either the force or velocity requirements (Newton and Kraemer, 1994); however no endurance training-only group was used in the present study to confirm this.

In contrast to the findings of the present study, Häkkinen et al. (2003) showed that individuals who performed strength training alone showed increases in rapid force production of the trained leg extensors and a significant improvement in rapid neural activation, whereas the concurrent strength and endurance training groups showed no significant changes, despite a significant increase in strength. These results lead authors to suggest that concurrent strength and endurance training lead to interferences in explosive strength development, due to a reduced improvement in rapid voluntary neural activation (Häkkinen et al. 2003). Endurance training in the study by Hakkinen et al (2003) consisted of continuous training protocols, an insufficient training stimulus for power production (Newton and Kraemer, 1994). Therefore, these findings support the concept of an
integrated training response being accountable for the improvements in power seen in the present study.

5.5 Fatigue Status

Both the ST and SET groups had an equal effort perception of the strength training sessions throughout the training period. Effort perception involves the integration of multiple afferent signals from a variety of perceptual cues (Hampson et al., 2001). Since the circumstances under which the strength training was conducted were equal between groups, (i.e. exercise modality, exercise intensity, duration), any variations in RPE would predominately be mediated by a physiological cue, such as fatigue (Pandolf, 1981). Research suggests fatigue results in an increase in the perceived effort necessary to exert a desired force output (Davis and Bailey, 1997). Since no variation were seen in RPE we could assume fatigue state between the groups were equal. It is important to note however, this form of fatigue is predominantly associated with specific alterations in CNS function that cannot be reasonably accounted for by peripheral dysfunction within the muscle itself (Davis and Bailey, 1997).

This finding is however unsurprising due low training frequency and large recovery periods between sessions in both groups. Research has found no major difference between the effectiveness of two or three strength training sessions per week (Graves et al., 2008). Therefore, by selecting only two sessions per week, a rest interval of two days between sessions was applied; found to be significantly more effective in ensuring recovery than a rest interval of one day (Hickson, Hidaka and Foster, 1994: Reed, Schilling and Murlasits, 2013).

Previous concurrent training research has failed to use RPE values to provide a psychological marker of overtraining, instead using the values in order to regulate progression during resistance training (Davis and Bailey, 2008). This use of RPE data may have negatively affected the validity of findings; varying progressions between groups, as opposed to an interference effect, may have been accountable for differences between groups. The similar strength gains seen in both ST and SET in the present 4-day-per-week training regime are in sharp contrast to concurrent training that takes place at higher frequencies (Hickson,
1980; Dudley and Djamil, 1985; Sale et al, 1990; Hennessy and Watson, 1994; Bell et al, 2000) with substantial impairments in strength development being evident. Findings from these earlier investigations may suggest that the combined, high exercise loads of performing both training regimes may account for the inability to attain optimal strength gains when strength and endurance training are concurrently performed (Dudley and Fleck, 1987; Docherty and Sporer, 2000; Nader, 2006). Since it has been suggested that the conflicting findings in the current literature might be reconciled based on different training frequencies (McCarthy et al, 1995), it could be possible training at higher frequencies, in comparison to the present study, may increase the possibility of interference (Dudley and Fleck, 1987). Findings cannot therefore be generalized to training at a higher frequency.

5.6 Limitations & Future Research

In reference to external validity, it important to emphasize the extent of generalization of the findings. Evidently, findings cannot be generalized to highly trained athletes as it is well recognised that training status may influence adaptations to concurrent training (Leveritt et al, 1999). Strong evidence however suggests that interference is associated with poor physical condition and that synergy is associated with good physical condition (Davis et al, 2008). Thus, it could be suggested a training programme similar to that used in the present study, appropriately matched in training volume and frequency would elicit a synergic training response.

Furthermore, findings by Bell et al, (2000) suggest a differential response in men and woman to concurrent training. Therefore it could further be suggested the findings of this study cannot be generalized to male athletes. Research has previous suggested females may have a greater capacity for neural adaptations over males, reflected by greater gains in strength of females in comparison to males, but smaller increases in muscle cross sectional area (Hubal et al, 2005). This supports the suggestion that differential adaptations to concurrent training in males and females may be apparent, as a result of adaptation capacity. Therefore,
a comparative study of males and females performing concurrent training for a training period of over 6 weeks may provide further information into the causable factors of the interference on strength training adaptations.

Since no interference effect was evident in the present study, it could be suggested that adaptations associated with strength and endurance training protocols employed did not markedly differ for one another. Further research investigating the neural activation during concurrent training would provide physiological evidence to support this. In approximately the first six weeks of a strength training program, the steady rate of strength increase is almost wholly due to neural adaptation. Whilst research strongly advocates strength gains in the early stages of strength training can be largely attributed to neurogenic factors, numerous morphological changes could also account for this increase; including changes in the architecture of muscle fibres, fibre type and preferential hypertrophy (Sale, 1992; Folland and Williams, 2007). Since the contribution of these hypertrophic processes increases after these initial weeks of training (Folland and Williams, 2007) it was also be interesting to observe the changes over a longer duration of time.
6.1 Conclusion

Athletes often have limited time assigned for conditioning, and, as such, it is essential that training elicits the necessary responses to maximize adaptations and performance. At present, little guidance exists for practitioners and athletes involved in sports that require both strength and endurance capabilities, when designing concurrent training programs to minimize interference. The present results enable the rejection of the interference hypothesis for the case of female athletes participating in a regime of two strength training sessions and two intervals training session’s week. This study validates the rationale for prescribing concurrent training for games athletes in order to improve indices of strength, power and endurance, providing exercise intensity and training frequency are considered. Intensity should be specific to the sporting requirements in order to elicit an integrated training response, and prevent any reduction in the capability of the neuromuscular systems ability to rapidly generate force. The frequency of training, whilst being appropriately to the participants training status, should ensure sufficient recovery between strength and endurance training sessions.
REFERENCES


APPENDICES
APPENDIX A

PARTICIPANT INFORMATION SHEET

The effects of concurrent strength and endurance training on indices of strength, power and endurance performance.

Background
This research project aims to compare the physiological effects of a combined running and strength training program with a strength training-only program. As a member of a Cardiff Metropolitan sports team you are a perfect candidate for the study. Participation in the study is entirely voluntary, however you are being invited to be involved in the project because it is thought that you will benefit as a result.

Your participation in the research project
Power, strength and endurance performance will be tested at the beginning of a six week period and then reassessed at the end of this period. After the initial testing, you will then be randomly assigned to either a combined running and strength training group or a strength training-only group.

Strength training -only
You will undergo a six-week strength training program on top of normal training. These sessions will run twice a week and will last for around 30-45 minutes. The training will be conventional resistance training programme. The exercises will allow for a total body workout, alternating stress on all major muscles groups developing upper and lower body strength.

Combined running and strength training group
You will undergo a six week strength and endurance training program on top of normal training. You will complete resistance training two times a week but will also complete endurance training twice a week on alternate days. Interval training will consist of work at 100% of VO2 max with a 1:2 work-to-rest ratio. This is applied for 10-20 second work bouts, with passive rest intervals of 20-40 seconds between reps and 2 min rest intervals between sets. These sessions will last for around 20-30 minutes.

Unfortunately if you answer 'yes' to any or the PAR-Q you will be unable to participate in the study to prevent putting you at risk.

Are there any risks?
We do not think there are any significant risks to you taking part in the study. You won’t be expected to do anything you don’t want to. The training may actually reduce your risks of injury in the future.
The Benefits
These sessions not only offer you an opportunity to develop your performance in terms of developing your physical fitness but they also allow you to gain valuable coaching. As a third year SCRAM student I will be coaching you throughout the programme helping you correct and improve your lifting techniques.

See it as an experience to improve your gym competencies and enhance your sports performance, requiring less self-motivation than attending the gym twice a week by yourself.

How we protect your privacy
Invasion of privacy and breach of confidentiality will not occur within the project. Your test results will be held for analysis to latter be presented in a report. There will be no description that would identify individuals. Information will be kept if a safe place and remain strictly confidential and handled in accordance with the provisions of the Data Protection Act 1998.2.

Submission of a completed consent form implies consent to participate in the project.

Further information
If you have any questions about the research project, please contact me.

Stephanie Morris
✉️ st20001437@outlook.uwic.ac.uk

Supervisor Contact Details
Rob Meyers
☎️ 02920 416505
✉️ rwmeyers@cardiffmet.ac.uk
APPENDIX B

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

Please answer the following questions YES or NO.

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
2. Do you feel pain in your chest when you do physical activity?
3. In the past month, have you had chest pain when you were not doing physical activity?
4. Do you lose your balance because of dizziness or do you ever lose consciousness?
5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?
6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
7. Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more of the above, talk to your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can engage in physical activity.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

_________________________  __________________
Signature of Participant                  Date

Resistance Training Experience

How often do you currently partake in resistance Training?
Date: 18/03/14

To: Steph Morris

Project reference number: 13/05/264U

Your project was recommended for approval by myself as supervisor and formally approved at the Cardiff School of Sport Research Ethics Committee meeting of 29th May 2013.

Yours sincerely

[Signature]

Rob Meyers
Supervisor
APPENDIX D

PARTICIPANT CONSENT FORM

PARTICIPANT CONSENT FORM

Participant name:

__________________________________________________________

Participant to complete this section: Please initial each box.

I confirm that I have read and understand the information sheet for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason.

I agree to take part in the above study.

_______________________________  ___________________
Signature of Participant Date

_______________________________  ___________________
Name of person taking consent Date

__________________________________________________________
Signature of person taking consent

* When completed, 1 copy for participant & 1 copy for researcher site file
## APPENDIX E

### STRENGTH TRAINING PROGRAMME OUTLINE

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<th>Session 1</th>
<th>Session 2</th>
<th>Load (%1RM)</th>
<th>Reps</th>
<th>Sets</th>
<th>Rest (min)</th>
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# APPENDIX F

## PARTICIPANT WEEKLY MONITORING SHEET

### RPE Scale
- 0: Rest
- 1: Very, very easy
- 2: Very easy
- 3: Easy
- 4: Somewhat hard
- 5: Hard
- 6: Very hard
- 7: Very, very hard
- 8: Close to max
- 9: Maximal

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