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Zengyuan Lin
Edith Cowan University

Author also known as Ryan Lin

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MASTER THESIS

NEUROMUSCULAR FATIGUE FOLLOWING A SINGLES BADMINTON MATCH

Zengyuan, Lin (Ryan)

Student ID: 10136520

Principle Supervisor: Prof. Ken Nosaka

Co-principle Supervisor: Dr. Chris Abbiss

Co-principle Supervisor: A/Prof. Anthony Blazevich

Co-principle Supervisor: Dr. Jodie Wilkie

School of Exercise and Health Science
Faculty of Health, Engineering and Science
EDITH COWAN UNIVERSITY

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ABSTRACT

A typical badminton singles match involves numerous intense and high impact movements. Lunges were accounted for approximately 15% of overall movements and were believed to presumably induce significant muscle damage following a match. However, no previous study has investigated changes in knee extensor muscle function after a badminton match. The present study investigated changes in knee extensor neuromuscular function and muscle soreness after a simulated 1-h badminton singles match in relation to the number of lunges performed in the match.

Ten state-level male badminton players were recruited (n=10), with each player played a total of eight simulated 1-h matches under the International Badminton World Federation rules. However, each participant was required to play against the same opponent twice and only one participant was fitted with the equipment at any one session, thus the total number of matches analysed was 40. The number of lunges performed by each player in a game was obtained from video analysis. Heart rate (HR) and core body temperature were recorded during the matches, and blood lactate (BL) was measured before and immediately post match. Both femoral nerve and muscle electrical stimulations were used in the present study. Maximal voluntary isometric contraction (MVC) torque of the knee extensors and flexors, voluntary activation during the knee extension MVC (VA), torque generated by a doublet (DT), and 20 Hz (T_{20}) and 80 Hz stimulation (T_{80}) and the ratio (T_{20}/T_{80}) for the knee extensors, and muscle soreness of knee extensor muscles by a 100-mm visual analog scale (VAS) were measured before, immediately (8 - 10 min post-match), 1-h and 24-h after a match. Pearson product-moment correlations were computed to examine relationships between variables using ANOVA.

Average (± SD) match HR was 162.0 ± 11.0 bpm, post-match BL was 7.2 ± 1.3 $mM \cdot L^{-1}$, and 194 ± 18 lunges were performed per match per player. Core body temperature increased from 36.5 ± 0.5 ^{o}C to 39.4 ± 0.5 ^{o}C immediately post match. Knee extension MVC torque was lower than baseline (278.4 ± 50.8 Nm) at immediately (-11%) and 1 h (-14%) post match ($P<0.05$), but returned to baseline at 24 hour post match. Knee flexion MVC torque was also lower than baseline (143.0 ± 36.2 Nm) at immediately (-18%) and 1 h (-16%) post match ($P<0.05$), but returned to baseline by 24 hour post-match. VA (baseline: 90.4 ± 1.9%) decreased 12% at immediately and 8% at 1 h post-match ($P<0.001$). DT was 13% lower than baseline (75.0 ± 5.6 Nm) only at immediately post-match ($P<0.001$). T_{20} and T_{80} decreased from baseline at immediately (31% and 25%, respectively) and 1 h post match (24% and 16%, respectively). There were no significant changes in T_{20}/T_{80} immediately post-match from baseline (0.66 ± 0.07), but a 10% decrease was observed at 1 h post-match ($P<0.05$). VAS at 24 hour post match was 53.8 ± 11.3 mm, which was significantly greater than baseline (2.4 ± 2.1 mm). Significant ($P<0.05$) correlations were observed between the number of lunges and BL ($r=0.61$, $P<0.001$), as well as the number of lunges and the magnitude of decrease in MVC torque ($r=0.68$, $P<0.001$) at immediately post-match and ($r=0.36$, $P<0.05$) at 1-h post match.

Moderate muscle soreness developed after 1-h simulated badminton matches, but muscle function returned to baseline by 24 hour post match, indicating moderate muscle fibre damage. Since VA was decreased without changes in T20/T80, and knee flexion MVC torque also showed similar changes to those of knee extension MVC torque that was thought to be affected by lunges, the decrease in MVC torque appeared to be associated with central rather than peripheral fatigue or muscle damage. With moderate muscle soreness developing after 1-h simulated badminton matches and muscle function returning to baseline by 24 hour post-game, suggesting minimal muscle fibre damage. It was concluded that both central and peripheral factors contributed to alterations in neuromuscular fatigue and that muscle damage was moderate after the singles matches in which the game intensity and physiological characteristics were close to those in competitive tournaments.

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CHAPTER ONE

1. INTRODUCTION

1.1. Background and Literature Review

1.1.1. Badminton

Badminton is an indoor racket sport that has gained popularity since its inclusion in the Olympic Games (Barcelona, 1992). Badminton is claimed to be the world's fastest racket sport with the shuttlecock reaching a maximum velocity of 100 $m \cdot s^{-1}$ (360 $km \cdot h^{-1}$) and an average velocity of 50 – 75 $m \cdot s^{-1}$ during a match (Gowitzke and Waddle, 1978). The activity pattern in a badminton match is intermittent with short duration movements interspersed with short rest periods (Lees, 2003). In the past, official matches were played over the best of 3 games of 15 points each. However, a new game scoring system of 21 points with a rally point system over the best of 3 games was introduced in 2006, with the intention of shortening the length of the game (Ooi et al., 2009; Chen and Chen, 2008).

Chen and Chen (2008) compared the characteristics of a badminton singles match between the old and new scoring systems which was achieved using the same players. The total match duration was longer for the old (2754.6 ± 178.9 s) than the new (1949.7 ± 147.6 s) scoring system. More specifically, the average duration of each game was 1184.7 ± 47.6 s versus 803.4 ± 34.7 s, the overall exercise period was 860.7 ± 60.0 s versus 667.0 ± 50.0 s and the rest interval was 1897.5 ± 123.2 versus 1282.1 ± 106.7 s for the old and new scoring systems, respectively. Therefore, the average play-to-rest ratio of 1:2.3 for the old scoring system compared to a ratio of 1:2 for the new scoring system. These results are consistent with those of Pearce (2002) and Faude et al. (2007), who reported the mean time to play a point in an international level badminton match to be 5.5 ± 4.0 s with a break between points of 11.4 ± 6.0 s (e.g. Play-to-rest ratio: 1:2). Collectively, these results indicate that rest periods are shorter and play: rest ratio is greater under the new scoring system. Although total match duration has been reduced, rally time and the number of shots per rally are greater under the new scoring system (number of shots per rally: 17.0 ± 0.7 vs 20.1 ± 1.2; rally time: 7.9 ± 0.2 s vs 8.2 ± 0.2 s). Additionally, it has also been found that a player's skill level also influences match characteristics. For example, the duration of a typical elite singles match is 54 min yet match time for sub-elite players is only 32 min (Tu, 2007).

Kuntze et al. (2010) assessed the movement patterns of 18 international and 16 national level male and female singles badminton players at international badminton matches using notational analysis. The authors identified different types of movements and classified them into six categories: running, crossover sidestepping, lunging, sidestepping, jumping and scrambling (for all other unclassified movements). It was reported that lunges were the most frequently performed movement of the six categories, accounting for approximately 15% of the overall movements performed during a badminton singles match. Two different types of lunges; full and half lunge, have been identified to impact neuromuscular characteristics and muscle functions differently. Thus, suggesting that different responses to strength loss and alterations to muscle function would also be highly associated to the frequency of different type of lunges executed during a singles badminton match (Cronin et al. 2003 and Jonhagen et al. 2009). It was also noted that lunge frequency was higher in international- (17.9 ± 4.9%) than national-level matches (14.3 ± 4.5%). Therefore, lunging movements, where large forces are rapidly produced at potentially long muscle lengths, are a common component of badminton singles matches. The ability to execute a lunge in badminton is important as it allows the player to rapidly halt the body's momentum, remain relatively stationary in preparation for effective stroke performance, and to return back to position in preparation for the following shot (Kuntze et al., 2010; Cronin et al., 2003). It has been documented that winning a point during intense rallies in an international-level singles badminton match is strongly associated with the ability to move rapidly around the court (Kuntze et al., 2010). Therefore, the ability for players to move rapidly and frequently perform lunge movements appears key to success in singles-match badminton and factors influencing this physical performance, such as neuromuscular fatigue, might be expected to negatively affect performance.

1.1.2. Movement, force production and aerobic characteristics of badminton players

Flexibility, muscular endurance, strength and power as well as specific factors including acceleration, agility, balance ability and reaction time have been described as important physiological factors in racket sports (Lees, 2003; Girard and Millet, 2008; Faude et al., 2007). At the elite level, effective stroke production requires rapid on-court movements and explosive force production. Consequently, success in decisive rallies at the end of a long and demanding match may be determined by the ability to repeatedly perform periods of high intensity exercise and effective generate high forces in order to perform powerful strokes (Girard and Millet 2008). As such, it is likely that success during competitive singles badminton is significantly influenced by an athlete's ability to minimise fatigue development, however little is known about the time course of, and factors influencing, fatigue in high-level badminton competition. A greater understanding of the factors responsible for fatigue during competitive singles badminton matches could assist coaches and sport scientists to improving the preparation of athletes through effective training, as well as game and exercise recovery strategies.

Girard and Millet (2008) compared the physiological profiles of athletes across four major racket sports (tennis, squash, table tennis and badminton) and reported that maximal oxygen consumption ($VO_{2\ max}$) was greater in squash players (> 60 $ml \cdot min^{-1} \cdot kg^{-1}$) than badminton (55 – 60 $ml \cdot min^{-1} \cdot kg^{-1}$), tennis and table tennis players (50 – 55 $ml \cdot min^{-1} \cdot kg^{-1}$). Interestingly, blood lactate concentrations during badminton were reported to be 3 to 6 $mMol \cdot l^{-1}$, which was reasonably low considering the intensity of match play. Faude et al. (2007) measured oxygen consumption in 12 internationally ranked badminton players during both a treadmill test and a simulated singles badminton match using a portable gas analysis system. Mean oxygen consumption during match play were 73% and 89% of VO_2 peak (i.e. 61.8 ± 5.9 $ml \cdot min^{-1} \cdot kg^{-1}$ and 50.3 ± 4.1 $ml \cdot min^{-1} \cdot kg^{-1}$) for men and women, respectively. Furthermore, the average heart rate during a simulated singles badminton match was reported to be 169 ± 9 bpm for both men and women. These results therefore indicate that the high intensity nature of competitive badminton results in a significant aerobic energy contribution therefore requiring players to have a high aerobic capacity.

1.1.3. Other physiological factors

Hydration status and core body temperature are important physiological factors that are known to be associated with fatigue and thus influence endurance performance (Chris and Laursen, 2005; Pearce, 2008). Abian-Vicen and colleagues (2012) examined the hydration level of 70 elite badminton players (46 men and 24 women) before and after singles badminton matches at a Spanish Championships played at an environmental temperature of 24 ± 3^{o}C, and reported sweat rates of 1.14 $l{\cdot}h^{-1}$ and 1.02 $l{\cdot}h^{-1}$ in men and women, respectively. Generally, sweat losses of less than 3% of body weight have little influence on performance. Furthermore, players were given many opportunities to rehydrate during play due to numerous intervals between sets. Therefore these results indicate that fluid loss and hydration status may not be a major factor influencing match performance. Several other studies in elite level indoor sports men and women, such as soccer (Maughan et al., 2005), volleyball and handball (Hamouti et al., 2010), played in environmental temperatures of 22 ± 3 ^{o}C, reported similar findings. Thus, suggesting that elevated core temperatures have been associated with reduced muscle activation (Racinais and Oksa, 2010). Badminton matches are generally played in an air-conditioned environment but in some cases environmental temperature can vary, affecting performance. In fact, most tournaments hosted in Asian countries are run in higher temperature and humidity conditions (e.g. 30^{o}C, 50%). Such environmental conditions are known to result in extremely high body temperatures (~40-42C) which are associated with fatigue (Chris and Laursen, 2005), even in sports such as cycling or running whereby convective wind movement provides considerable cooling. Since badminton is performed on a court with athletes travelling a relatively short distance, convective cooling is likely to be much lower and thus body temperature may significantly influence performance. To the best of the author's knowledge, there are currently no studies documenting changes in the core body temperature during a badminton match. It is important to monitor core temperature changes so as to identify the physiological profiles of badminton matches as hydration is possibly not a major factor, but it's unclear if this is the case when tournaments are played in the heat, and it's also not known if changes in core temperature might impact on player performance?

1.1.4. Muscle fatigue and damage during a match

Lunging movements require the activation of the quadriceps, hamstrings and gluteal muscles during eccentric contractions to produce the braking reaction force (Jonhagen et al., 2009 & Kuntze et al., 2010). A lunge can be grouped into five phases; initial impact (heel strike), secondary impact (loading), amortization (force reduction), and weight acceptance (loading) and drive off (Kuntze et al. 2010). A lunge is normally executed using the leg on the same side as the arm holding the racket and the impact loading will be solely placed on this leg. It is therefore assumed that neuromuscular fatigue profiles would differ between legs, although this has not been explicitly tested. With the high frequency of lunges executed during a badminton match it could be assumed that the movement itself significantly contributes to the accumulation of muscle fatigue. It may also be expected that lunges cause muscle stiffness, loss of muscle function, muscle pain and eventually impair performance as a result of muscle damage (Cronin et al., 2003; Jonhagen et al., 2009 & Kuntze et al., 2010). It is assumed that a greater frequency and intensity of lunges could result in greater neuromuscular fatigue and muscle damage to the knee extensor muscles. However, previous studies have not investigated the effects of lunges and other movements in relation to neuromuscular fatigue and muscle damage during badminton match. Additionally, with the movement patterns also involving actions related to knee flexion, therefore, suggesting that fatigue may be also experienced to the knee flexors. There are several different techniques which could be used to investigate on muscle damage or DOMS; (i.e. Range of motion, swelling or blood markers such as CK or myoglobin concentrations) apart from MVC torque and perceived muscle soreness. However, due to the time constraints, the current study focused only on MVC torque and perceived muscle soreness.

1.1.5. Changes in muscle function after a badminton match

An attempt to quantify the changes in muscle function using counter-movement jump (CMJ) and handgrip strength measures after singles badminton matches in the Spanish Championship was made by Abian-Vicen and colleagues (2012). The changes in jump height, mean power during the push off phase in a CMJ and the handgrip strength of both dominant and non-dominant hands were assessed before and after the exercise. The authors reported that the completion of one singles badminton match led to an increase in CMJ height (4.5 ± 7.3%, $p<0.05$), although they observed no change in handgrip strength in either hand. Given these data, it could be concluded that little fatigue is induced in well-trained players during a single competitive match. However, no other studies have been completed to validate these findings, and it is not known whether jump height and power might result from playing under different environmental conditions or against different opponents.

Although no studies have investigated neuromuscular function following badminton, two other racket-sport studies (tennis and squash) have examined changes in neuromuscular function. In a study by Girard and colleagues (2006), changes in maximal voluntary isometric contraction (MVC) strength, multi-rebound jump test performance (hopping) and peak in squat (SJ) and CMJ power were measured before, every 30 min during (i.e. 30, 60, 90, 120, 150 and 180 min) and 30 min after a simulated 3-h tennis match in 12 well-trained regional- to national-level male tennis players. Knee extensor muscle soreness and rate of perceived exertion (RPE) were also assessed at each time point. The authors reported a decrease in MVC strength (-12%) progressively during the game that reached statistical significance by 150 min, however leg stiffness did not change. No change in peak SJ and CMJ power was observed during the match but a significant decrease (-5%) was present 30 min post-match. Muscle soreness and RPE increased progressively during the match. These findings suggest that a functional decrement may be induced by competitive tennis play, and such changes might speculatively occur in similar sports such as badminton.

In another subsequence study (Girard et al., 2011), changes in MVC strength, electrically-induced contractile capacity (peak torque, time to peak torque and half-relaxation time) and EMG activity in the knee extensors of the right leg were assessed before, during (30, 60, 90, 120, 150 and 180 min), immediately after and 30 min following a 3-h simulated tennis match. Quadriceps peak torque elicited by low- and high-frequency muscle stimulation (20 Hz and 80 Hz; i.e. P20 and P80) was used in 12 regional- to national-level male tennis players. MVC strength was found to decrease by 9% immediately post-match with no sign of recovery by 30 min post-match, while a decrease of 16% in MVC/P80 ratio was observed immediately after the match. There was no significant change in P80; however P20 decreased by 12% and therefore the P20/P80 ratio was 12% lower in the fatigued state. It was therefore concluded that the impairment of neuromuscular function during a prolonged tennis game resulted from both central activation failure and alterations in excitation-contraction coupling. These data strongly indicate that sports requiring frequent changes of direction and lunging to hit balls may elicit significant central and peripheral fatigue. Nonetheless, it is not known whether similar results are obtained in well-trained badminton players.

Girard and colleagues (2010) also investigated the changes in MVC strength, voluntary activation level, EMG activity and motor unit activation of the knee extensor muscle group by applying twitch interpolation technique and measuring handgrip strength of the non-dominant hand after a simulated 1-h squash match played by 10 competitive regional- to national-level male squash players. It was reported that MVC strength of the knee extensors decreased by 16%

immediately post-match, which was associated with a decrease in knee extensor voluntary activation and raw EMG activity (7% and 17%, respectively). Although there was no significant change in handgrip strength after the match, it appeared that the magnitude of neuromuscular fatigue was comparable between 1-h of simulated squash and 3-h of simulated tennis. The results from both studies suggest that the neuromuscular fatigue may be induced in racket sports such as tennis and squash, which is suggestive that similar changes might be seen in badminton players. The approaches mentioned above in the investigations of tennis and squash could therefore also be applied to assess neuromuscular fatigue in badminton. Furthermore, studies could also more clearly monitor the recovery of muscle force and neuromuscular function by measuring not only immediately after match but also at least one day after a match to determine any possible effect on muscle damage or changes in muscle function after a badminton match.

1.1.6. Areas not examined in previous research

There is limited research quantifying the effects of a high level singles badminton match on neuromuscular fatigue and other physiological changes. Further studies are necessary to investigate these physiological factors in order to better understand physiological requirements, including oxygen consumption, heart rate, blood lactate and core temperature changes during and after badminton matches played by high-level players. Furthermore, it would also provide a better understanding between the physiological requirements which could lead to the neuromuscular fatigue. In addition, determining the relationship between the occurrence of lunges and neuromuscular fatigue (e.g. muscle soreness and muscle damage) in badminton matches is also of great scientific and practical interest. Further researches are required to identify how a specific movement (lunge) is related to fatigue characteristic as that could assist in developing appropriate strategies to best prepare training and post-match recovery strategies, thus improving performance during the competitions.

1.2. Purposes of Study

The purpose of this study is to: 1) determine the metabolic demand, 2) identify the frequency of full/half lunges performed using video analysis, 3) examine knee extensor neuromuscular fatigue, and 4) investigate the relationships between: i) movement patterns (e.g. the number and intensity of lunges) and metabolic demands, ii) movement patterns and muscle function changes/muscle damage, and iii) metabolic demands and muscle function changes/muscle damage; imposed by a badminton game during a 1-h simulated singles badminton match.

1.3. Significance of the study

To date, there is a lack of data describing the effects of neuromuscular fatigue imposed during a singles badminton match, despite its growing popularity and significance within the sporting community. Further researches determining which movements (e.g. lunges) are most strongly related to fatigue could assist in developing appropriate strategies to best prepare training and post-match recovery strategies, thus improving performance during the competitions.

1.4. Research Questions and Hypothesis

1. What is the average oxygen consumption and heart rate (relative to VO_{2max} and HR_{max}) recorded during 1-h simulated badminton?

   The average oxygen consumption and heart rate will be 60 – 70% of VO_{2max} and HR_{max}, but will often peak at 95 - 100%.

2. What core temperature change will be observed during a badminton match?

   The core temperature will increase 2 to 3°C during a badminton match, but the magnitude of increase will vary depending on the intensity of the game.

3. How frequently are lunges performed during a badminton match and are there any different types of lunges being performed?

   More than 15% of movements will consist of lunges. Half lunges will be the most frequent performed lunge.

4. Does knee extensor strength decrease after a simulated badminton match?

   Knee extensor strength will decrease more than 10% for the leg that is on the same side of the arm holding the racket, and will last for at least one day; the decrease will be negligible for the other leg.

5. Do knee extensor voluntary activation and EMG activity decrease after a simulated badminton match?

   Voluntary activation and EMG activity will decrease approximately by 10% and 15%, respectively, and last for at least one day.

6. Is there a correlation between movement patterns (e.g., the number and intensity of lunges) and metabolic demands; between movement patterns and muscle function changes/muscle damage; and between metabolic demands and muscle function changes/muscle damage?

   There will be a strong correlation between all variables.

CHAPTER TWO

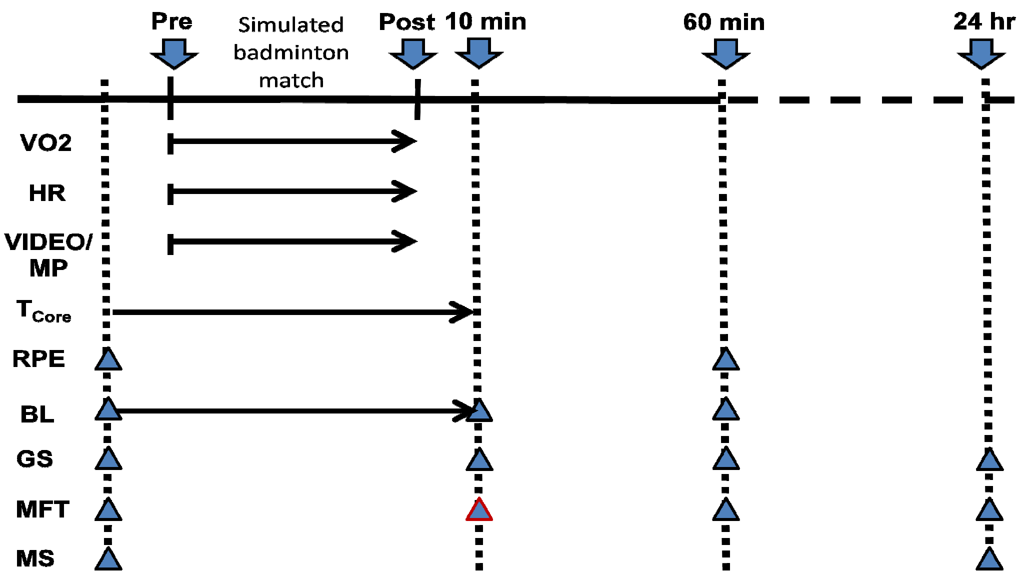
2. METHODS

2.1. Participants

Ten competitive singles male badminton participants with at least 5 years of senior state level playing experience were recruited from the Western Australia badminton team to perform in this study. The present study focused only on male participants as it has been noted that significant differences exist in the physiological characteristics (Lewis et al. 1986; Faude et al. 2007) and exercise demands of badminton (i.e. number and speed of movements) between male and female participants (Faude et al. 2007). Participants were requested to abstain from taking caffeine for at least 6 hours and alcohol for at least 24 hour prior to testing. Before participating in the study, each participant was informed of the risks and procedures of the study and the Physical Activity Readiness Questionnaire (PAR-Q) was used to assess the participants' risks for participation in the study. Prior to the participation, informed consent was obtained from each participant. Ethical clearance was obtained from the Edith Cowan University Human Research Ethics Committee before commencement of the study.

2.2. Experimental Procedure

Elite badminton singles matches were reported to complete in approximately 54 minutes (Tu, 2007). Therefore, it was assumed that the 1 h simulated matches would represent physiological changes occurring during actual competitive badminton singles matches. During the remaining 8 visits participants performed a simulated 1 h badminton match with standardised rules applied (International Badminton World Federation rules). Participants were requested to report to the laboratory on 10 separate occasions across 10 weeks. Sessions included a familiarisation trial, an incremental exercise test and 8 sessions of simulated badminton match play. During the first visit, participants were familiarised with the muscle function measurements and the portable gas analyser used for oxygen consumption measurement (described below in 2.3.1). In the subsequent visit participants performed an incremental exercise test. This was based on the study by Girard et al. (2010) who investigated changes in mean peak torque of knee extensors after 1 h simulated squash match.



Key: Refers to measurement at time point.

Figure 1: Time points of dependent variable measurements, which consisted of oxygen consumption (VO_2), heart rate (HR), movement patterns (video/MP), core body temperature (T_{core}), rate of perceived exertion (RPE), blood lactate (BL), handgrip strength (GS), muscle function test (MFT) and muscle soreness (MS) in relation to a 1-h simulated badminton singles match. The MFT at 8 - 10 min post match after a match was carried out for the dominant leg only.

The dependent variables for the study consisted of oxygen consumption, heart rate, core temperature, which was measured throughout the trials. Rate of perceived exertion (RPE), blood lactate (BL), maximal voluntary isometric contraction (MVC) torque of the knee extensors and flexors, voluntary activation (VA), doublet torque (DT), and 20 Hz (T_{20}) and 80 Hz stimulation (T_{80}), hand grip strength, muscle soreness of knee extensor muscles and on-court movements were measured pre and post-match. However oxygen consumption and muscle function measures were limited to one of the participants in every match, due to the limitation of equipment and time constraint (refer to Figure 1). All trials were performed in an environmental temperature of 24 ± 3°C in the Exercise Physiology laboratory and sport centre. It should be noted that this was close to the temperature in the gymnasium where the badminton matches are normally performed. The portable gas analyser used to measure the oxygen consumption, was calibrated before use prior to every test session. Gas and flow meter calibrations was performed using the software – MetaSoft (MetaSoft®, Germany), with a 3-L calibration syringe (Hans Rudolph) for flowmeter calibration and a digital thermo-barometer and certified calibration/reference gas was used for gas calibration.

2.2.1. Familiarisation (Session 1)

Participants were asked to undertake a familiarisation session for the MVC torque and electrical stimulation procedures. During the session, participants were introduced to the study procedures and were requested to perform three MVCs (4 s duration) of knee extensors (KE) with a rest interval of 1 min. Subsequently, participants were required to get accustomed with several sub-maximal and maximal electrical stimulations. In addition to the muscle function testing procedures, participants were instructed to run on a treadmill for 10 min with a portable gas analyser unit. They were given an opportunity to perform the grip strength, and other measures (e.g. blood lactate and core temperature) were demonstrated to them.

2.2.2. Maximal Aerobic Capacity Test (Session 2)

The test was performed on a treadmill (TrackMaster, USA) in a standard room. During the maximal aerobic capacity test, participants began running at 10 $km \cdot h^{-1}$ for 5 min with 0% gradient. Subsequently, the speed was increased by 2 $km \cdot h^{-1}$ every minute until 16 $km \cdot h^{-1}$. If participants reached a running speed of 16 $km \cdot h^{-1}$ the gradient was subsequently increased by $1\% \cdot min^{-1}$ until volitional exhaustion was reached (Buchfuhrer et al. 1983, Faude et al. 2007). Participants were verbally encouraged throughout the session. Expired gas was measured breath-by-breath throughout the test with the use of a portable metabolic gas analyser (MetaMax® 3B, Germany) and averaged over every 30 s. Raw gas exchange data was stored on the data logger of the metabolic system and downloaded onto a computer following the test. VO_{2max} was determined as the point where: (a) Breath-by-breath of VO2 consumption plateau over a 30 s period and/or declined with an increase in workload, (b) a respiratory exchange ratio (RER) of >1.1 was achieved, (c) HR reached within 10 $beats \cdot min^{-1}$ of age predicted maximum HR, and (d) volitional fatigue was attained (Dupont et al. 2003). HR was recorded averaged over 5 s continuously, using a Polar heart rate monitor (S610, Polar, Finland) and the data was transferred to a computer for further analysis.

2.2.3. Badminton Match Play (Sessions 3 to 10)

The simulated matches were all standardised competitive badminton match, but played for 1 hour regardless of the final scores, under the rules of the International Badminton World Federation. A 5 min warm up period was performed prior to commencement of the simulated badminton match play. Participants were permitted to rest for a maximum of 120 s between sets, after which, there had a changeover of sides. During the 1 h simulated match, participants were permitted and encouraged to consume a maximum of 250 ml water every 30 min.

Participants were assigned into two separate groups based on their national ranking. Within each group, participants played against each other twice. Therefore, a total of 40 simulated badminton matches were played among the 10 participants, with each participant playing a total of 8 matches. All the simulated badminton matches were held in an indoor sports centre and played with an average environmental temperature of 24 ± 3 ^{o}C and were scheduled to be on the same time of the day throughout the trials. Participants were permitted to rest for a maximum of 120 s between sets, after which, there had a changeover of sides. During the 1 h simulated match, participants were permitted and encouraged to consume a maximum of 250 ml water every 30 min (Abian-Vicen et al. 2012; Faude et al. 2007).

For every match, one of the participants was assigned to either oxygen consumption or muscle function measurements. During the subsequent match against the same participant these measurements were swapped. Thus, these data were obtained from a total of four matches for each participant. Core body temperature was measured only for two matches per participant randomly. All matches were video recorded for game and motion analysis. Participants had a hand grip strength test for both arms before the muscle function measurements of the knee extensors. The muscle function measures were performed for the leg that correspond to the same side of the arm holding the racket first (dominant leg), followed by the opposite leg (non-dominant leg) before, and 1 hour and 24 hours after a match. At approximately 10 min after a match, the muscle function measures were performed only from the dominant leg. Blood lactate was assessed before and 10 min post-match and RPE was obtained before and immediately post-match.

All the settings of the portable metabolic gas analyser (MetaMax® 3B, Germany) for oxygen consumption measurement were consistent with the set up during maximal aerobic capacity test. Participants were informed to keep activities to the minimum for 24 h to reduce any influence to the post match and to rehydrate as much as possible.

2.3. Measurements

2.3.1. Oxygen Consumption Measurements

The portable metabolic gas analyser (MetaMax® 3B, Cortex, Germany) was used to measure oxygen consumption during a match. The device consisting of two housing units and battery, weighed roughly 650g, was strapped across the chest (Figure 2). The participant breathed through a Hans-Rudolph face mask that was connected to the analyser. Raw data was stored on the data logger of the metabolic system and transferred to a computer after the matches for further analysis. Markers were set at the beginning, during rest interval of the matches; end of all matches and at the end of the 1 h testing period to denote the playing period. VO_2 was collected breath-by-breath and averaged over 5 s and only within the markers of the entire 1 h period as demonstrated in Figure 3 according to a previous study (Faude et al. 2007).

Figure 2: A participant wearing the portable gas analyser during 1 h simulated badminton match.

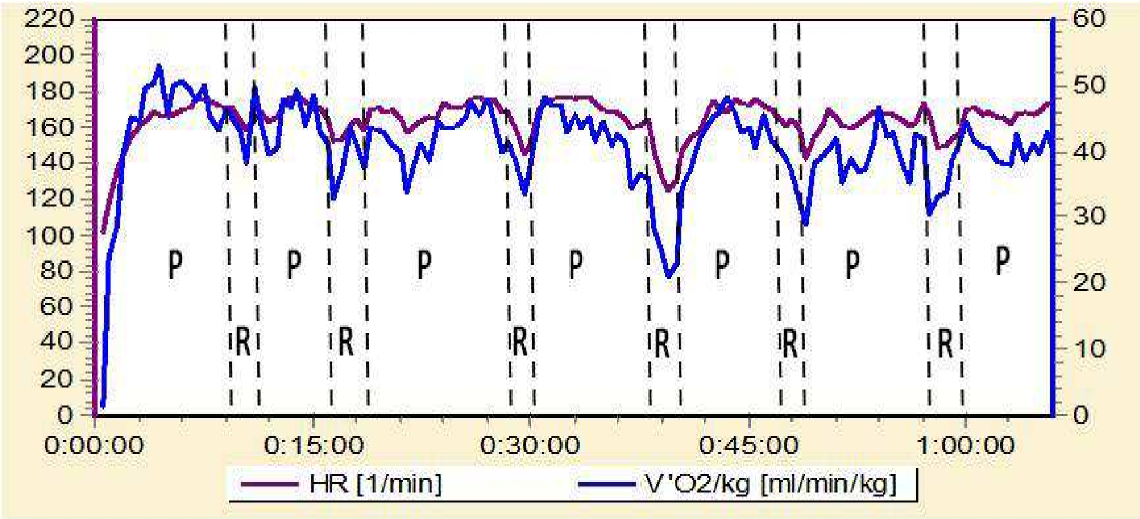


Figure 3: A typical data of the oxygen consumption and heart rate during 1 h of simulated badminton match where the in-play region is denoted as [P] and the rest interval region is denoted as [R].

2.3.2. Core Temperature

Core body temperature was measured with the use of an ingestible thermometer (CorTemp™, HQInc, FL) which was instructed to the participants to be ingested at least 6 hours prior to testing session. The data was recorded at a frequency of 262 kHz by a data recorder (CorTemp™, HQInc, FL). Core temperature data was averaged over the 30 s immediately prior to after warm-up and following end of exercise. The data was eventually transferred from the data recorder to a computer for further analysis.

2.3.3. Heart Rate (HR)

HR was recorded every 5 s during the badminton match using a heart rate monitor (S610, Polar, Finland) which was configured to connect wirelessly to the portable gas analyser. The average HR calculation was based on the markers of the entire 1 h period similarly to that demonstrated in Figure 2. The average heart rate was analysed and computed for the play time period while excluding the resting time period.

2.3.4. Blood Lactate

Blood lactate was measured from a finger prick blood sample (Unistik 2 Normal: Owen Mumford, Oxford, UK) obtained from the non-racket holding hand prior to exercise and immediately after exercise. The required amount of blood was 5 μl and was loaded on to a lactate strip (Lactate Pro Test Strips, Australia) to measure blood lactate concentration using a portable blood lactate analyser (Lactate Pro, Australia).

2.3.5. Rate of Perceived Exertion

The rating of perceived exertion was recorded using a modified rating of perceived exertion scale (Category Ratio 10 scale). The participants were required to indicate a scale of between 0 (Nothing at all) and 10 (Maximal) by answering the question, "What is your overall perceived exertion?" immediately post-match (Borg, 1998) as illustrated in appendix F.

2.3.6. Video Recording

All simulated badminton matches were video recorded. The videos were analysed for the following parameters: (i) the total number of lunges performed during each match, and (ii) the different type of lunges (e.g. full lunge or half lunge) as outlined in the below section (2.3.9).

2.3.7. Muscle Function Measurements

2.3.7.1. Set up

The measurement of the muscle function of the knee extensors required the participant to sit on an isokinetic dynamometer (Biodex System 3 Pro, NY), with their leg strapped to the dynamometer's chair and the ankle fixed to the dynamometer lever arm (Figure 4). The trunk-thigh angle was positioned at 90^o and the lateral femoral epicondyle was aligned to the axis of rotation of the dynamometer with the knee fixed at 60^o of flexion (0^o corresponding to full knee extension) as 60^o was the optimum angle to produce highest torque (Brughelli et al. 2010). The movement of the upper body was restricted by two crossover shoulder harnesses and a belt across the abdomen. Both femoral nerve and muscle electrical stimulations were used in the present study.

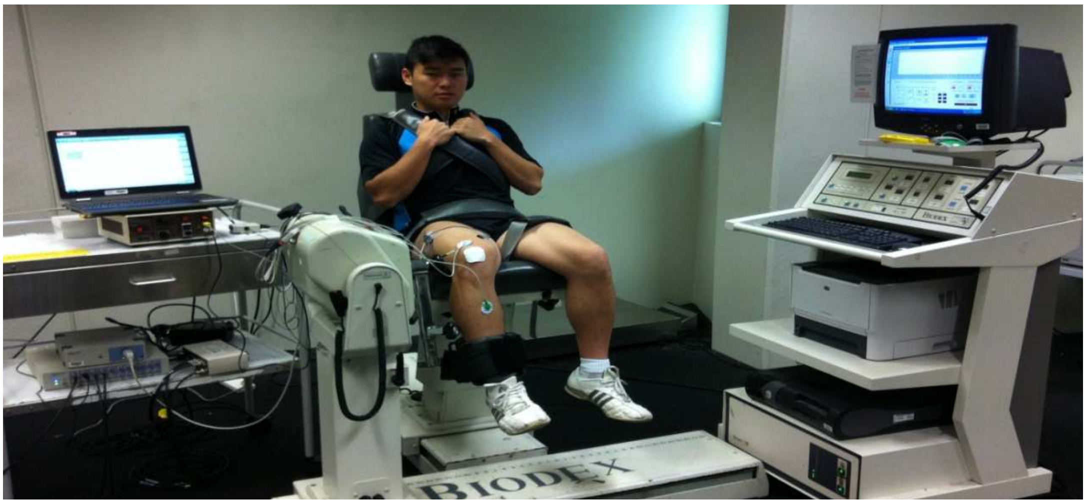


Figure 4: Set up for the muscle function measurements.

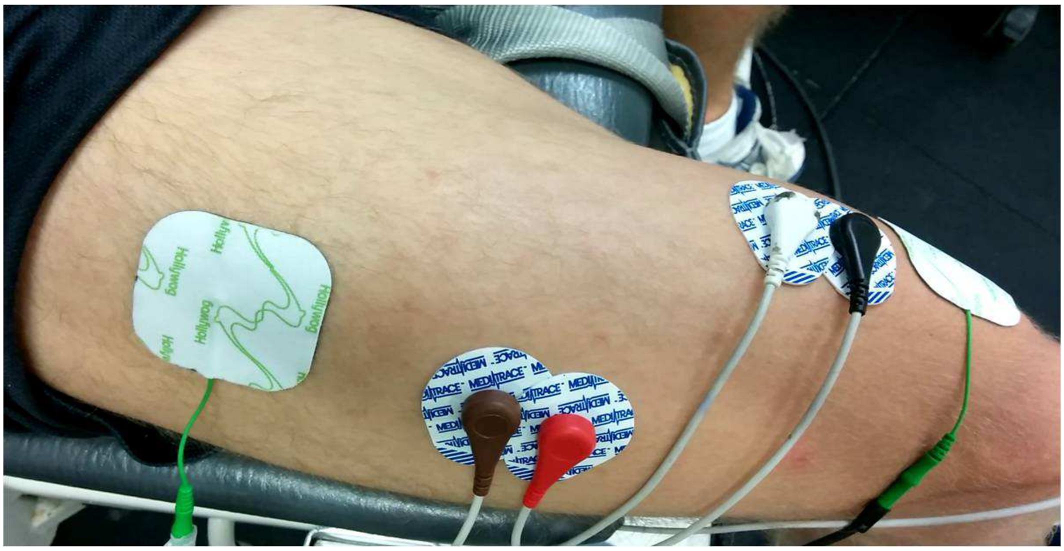


Figure 5: Location of electrodes for electrical muscle stimulation of the knee extensors.

Prior to the testing, stimulation electrode placement was based on the study by Girard et al. (2007) and Verges et al. (2009). Briefly, for the muscle stimulation, the electrode for cathode electrode was positioned on the belly of the VL and the anode electrode on the end of VM (Figure 5). Furthermore, for femoral nerve stimulation the cathode electrode was positioned 5 cm below the inguinal ligament and the anode electrode located 10 cm lateral to the cathode (around the greater trochanter). The electrodes were secured onto the subject throughout the badminton match. Before placing all the electrodes, the skin was shaved, abraded and cleaned with alcohol. Each participant performed three isometric knee extensions at 30, 60 and 80% of the perceived maximal voluntary contraction (MVC) at the knee angle of 60° with 30-s rest between contractions. Participant was instructed to perform 1 maximal trial of two MVCs before the commencement of the actual measurements.

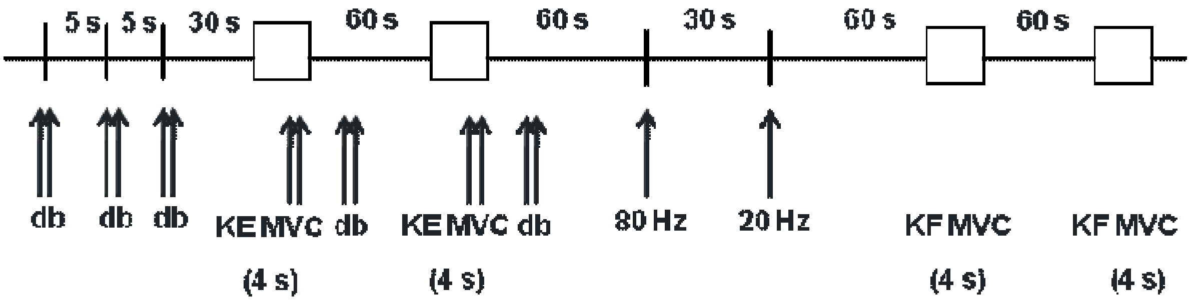


Figure 6: Measurement protocol of muscle function of the knee extensors (KE), which includes controlled doublets (db) being given 5 s prior and after KE MVC, knee flexors (KF), 20 Hz and 80 Hz frequency stimulation.

2.3.7.2. MVC Torque and Muscle Activation

Following the warm up contractions as described above, two maximum isometric voluntary contractions were performed as ‘fast and hard as possible’ twice over 4 s with 60 s rest between contractions. From the torque data, peak torque was calculated from each contraction, and the higher value of the two was identified and was used for further analysis. During the MVC torque measures, maximal voluntary activation was estimated by using interpolated-doublet technique with two sets of electrically evoked stimuli (10 ms apart) being superimposed when the torque reaches a plateau, with the aid of a constant current stimulator (DS7, Digitimer Ltd., Welwyn Garden City, UK). Control doublet was given 5 s after the end of each MVC for the calculation of voluntary activation (Girard et. al, 2006). The voluntary muscle activation level had been estimated according to the following formula (Allen et. al, 1995):

$$Voluntary\ activation = [1 - (superimposed\ doublet/potentiated\ doublet)] \times 100$$

In addition to the knee extensor MVC measures, MVC torque of the knee flexors was measured at the same setting as that of the knee extensors without electrical stimulation following the muscle function measurements of the knee extensors as illustrated in Figure 6. Muscle function measurements for the non-dominant leg consisted of knee extensions and knee flexions without the electrical stimulation as illustrated in Figure 6.

2.3.7.3. Electrically Evoked Contractions

The femoral nerve of the dominant leg was electrically stimulated using a stimulator (DS7, Digitimer Ltd., Welwyn Garden City, UK) to assess the twitch contractile properties of the knee extensors muscle. Before commencing the test, square-wave paired pulse electrical stimulations (width of 200 µs) were evoked progressively (10 mA increment) until a plateau for the doublet twitch amplitude was observed. The intensity was then further increased by 20% and maintained throughout the testing session. A doublet stimulus was delivered prior to the execution of the MVC. Peak doublet torque (DT) was assessed following a doublet stimulation during the execution of the MVC (Girard et al. 2010). To understand the catch- vs. non-catch-induced trains of stimuli which might be presented to the subjects; the 20:80 Hz stimulation ratio was included with the use of a high-frequency (80-Hz) 0.75 s and low-frequency 0.75 s (20-Hz) stimulation (Girard et al. 2008). The intensity set for all muscle stimulations were 50% of MVC as suggested by Gabriel (2013); which appears to be more bearable and still being able to obtain a good reading to study the E-C coupling effect.

2.3.8. Hand Grip Strength Test

To measure the hand grip strength, a manual handheld dynamometer (Lafayette Hand Dynamometer, USA) was used. The measurement is carried out before the muscle function of the knee extensors. Each participant was required to grip as hard as possible using the dominant arm followed by the non-dominant arm. Participants performed two efforts for each hand with a rest interval of 1 min between attempts. During the test, the elbow joint was extended straight out with the arm parallel to the body and the wrist in neutral position. The distance from the handle to the base of the dynamometer was set based on participant comfort and kept consistent between trials. The higher value of the two measurements was used for analysis (Abian-Vicen et al. 2012).

2.3.9. Muscle Soreness

The level of muscle soreness was quantified using a 100-mm visual analogue scale (VAS) in which 0 indicated no pain and 100 represented the worst pain imaginable from both legs. Level of perceived pain of the quadriceps femoris, hamstring and gluteus muscles were assessed during a single leg forward lunge using each leg. The participant was required to mark the level of perceived pain on the VAS taking the above mentioned muscles as a whole (Jönhagen et al. 2009).

2.3.10. Video Analysis

Each match was recorded with a recording frequency of 25Hz for data analysis of the on-court movements. Two video recorders (Sony HD 1080i, Japan) were placed at 2 positions of the court. The first recorder was placed at the side of the court, centre of one half of the court at a distance of 8.5 m which is perpendicular to the court and at a height of 1.2 m. The second recorder was placed on the opposite side of the court, facing the back of the participant, to capture lunge actions performed on the opposite side of the first recorder, for the purpose of checking back during data analysis. The video was analysed to quantify the number of lunges by two separate investigators using Sports Code Pro (Sportstec, USA). Lunges, were classified into either a half lunge (the forward movement of the knee which does not exceed the position of the toe) or full lunge (the forward movement of the knee which goes beyond the toe) as outlined by Jonhagen et al. (2009).

2.4. Statistical Analysis

A one-way analysis of variance (ANOVA) with repeated measures was used to assess changes in the variables measured during matches (HR, VO_2, core temperature), and before and after the matches (CR10, muscle soreness, MVC torque and other neuromuscular parameters). A two-way analysis variance (ANOVA) with repeated measures was used to compare the magnitude of changes of the MVC torque and neuromuscular parameters over time between dominant and non dominant legs (using absolute values), and between knee extensors and knee flexors (using normalised values). Where significant interaction effects were detected, Bonferroni post-hoc tests were performed. Pearson product-moment correlations were used to examine relationships between the number of lunges (total, full) and changes in MVC torque and some other parameters (HR, T_{core}, BL and VAS), and heart rate and other parameters (T_{core}, BL and VAS); with a strong correlation of $r < 0.75$ was considered poor, $r=0.75 - 0.9$ was considered a moderate correlation and $r > 0.9$ was considered as a strong correlation (Cornin et al. 2003). Statistical significance was set at $P<0.05$, and all values are reported as means and standard deviations being conducted using SPSS.

CHAPTER THREE

3. RESULTS

3.1. Participant's Characteristics

The participant's physical characteristics are presented in Table 1 with the report of age, height, body mass, total training hours weekly (include strength and conditioning, recovery), oxygen consumption and max heart rate.

Table 1: Physical characteristics of the participants.

	Mean	SD	Range
Age (years)	26.4	5.3	19 - 33
Height (cm)	174.4	8.6	165 - 191
Body Mass (kg)	69.7	8.5	59.5 - 83
Total Training Hours Weekly (h)	7.1	1.0	6 - 9
VO_2 peak ($ml \cdot kg^{-1} \cdot min^{-1}$)	57.0	7.3	50 - 70
Max Heart Rate @ VO_2 peak (bpm)	187.6	8.7	173 - 195

3.2. Physiological Characteristics of Simulated Badminton Match

Table 2 shows the characteristics of the simulated singles badminton match and Table 3 shows the relative VO_2 and HR during the simulated badminton match in comparison to VO_2 max and HR max obtained during the VO_2 max test. The VO_2 during simulated badminton match represents an approximately 80% of the VO_2 max test. The heart rate during simulated badminton match represents 84% of the heart rate max.

Table 2: VO_2, heart Rate and RPE of simulated singles badminton match.

	Mean	SD	Range
VO_2 (ml·kg^{-1}·min^{-1})	44.3	8.6	37 – 56
Heart Rate (bpm)	162.0	10.6	140 - 176
RPE	7.0	2.0	5 - 9

Table 3: Oxygen consumption (VO_2) and heart rate during simulated badminton match.

Relative Value to VO_{2max} and Heart Rate Max (%)

	Mean	SD	Range
VO_2 (ml·kg^{-1}·min^{-1})	80.0	10.4	70 – 89
Heart Rate (bpm)	84.0	6.8	72 – 91

The baseline core body temperate was 36.5 ± 0.5 ^{o}C and increased 8% ($p<0.05$) significantly to 39.4 ± 0.5 ^{o}C post-match (Figure 7). The highest core temperature recorded at immediately after simulated match was 40.3 ^{o}C.

The baseline of blood lactate concentration was 1.8 ± 0.3 mM.L^{-1} at pre-match and increased 36.5% ($p<0.05$) significantly to 7.2 ± 1.3 mM.L^{-1} at immediately after simulated match (Figure 8) with the highest value recorded was 9.3 mM.L^{-1}.

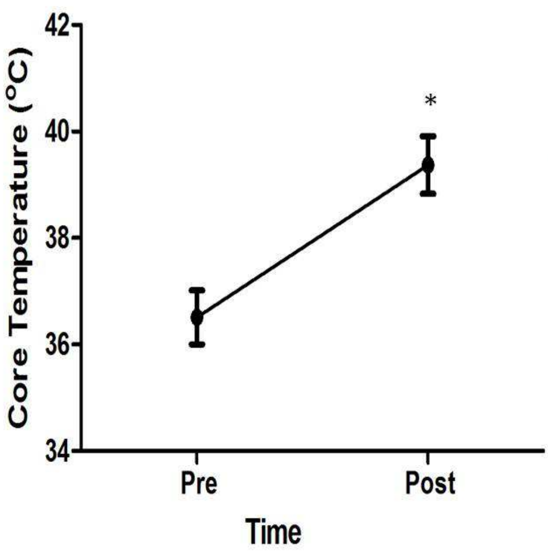


Figure 7: Changes (mean ± SD) in core body temperature prior to match (pre) to immediately after a simulated match (Post).

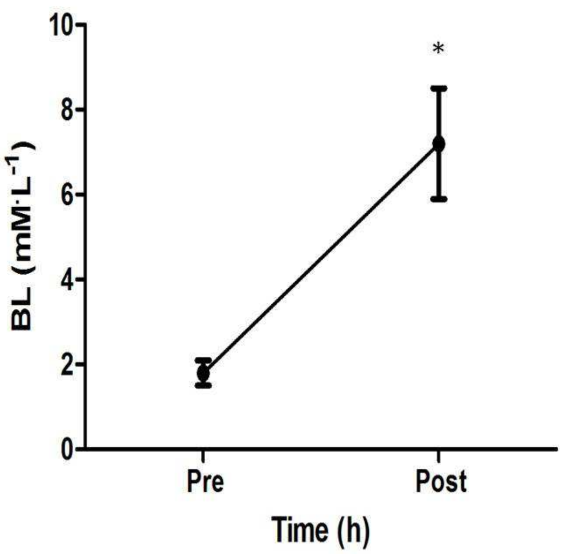


Figure 8: Changes (mean ± SD) in blood lactate (BL) from prior to match (pre) to immediately after a simulated match (Post).

3.3. Video Analysis

The average number of lunges performed during a match was 194 ± 18 with a range from 160 – 240. Out of the total lunges, 153 ± 12 were half lunges (the forward movement of the knee which does not exceed the position of the toe) and 41 ± 15 were full lunge (the forward movement of the knee which goes beyond the toe).

3.4. Maximal Voluntary Isometric Contraction (MVC) Torque

The knee extension MVC torque for the dominant leg was 278.4 ± 50.8 Nm at pre exercise. MVC torque decreased 11% ($P<0.05$) immediately post-match and 14% ($P<0.001$) 1 h post-match, but recovered to baseline at 24 hour post-match (Figure 9a). The pre exercise knee flexion MVC torque for the dominant leg was 143.0 ± 36.2 Nm, and decreased 18% ($P<0.05$) immediately post-match and 16% ($P<0.05$) 1 h post-match, but returned to the pre exercise at 24 hour post-match (Figure 9b).

Figure 10 shows changes in knee extension MVC torque for the non-dominant leg. The torque was 237.6 ± 41.7 Nm at pre exercise and decreased 12% ($P<0.05$) 1 h post-match but recovered to pre exercise by 24 hour post-match. The knee flexion MVC torque for the non-dominant leg was 122.0 ± 29.7 Nm, with no significant changes observed after match. There was no significant interaction effect for the changes between the difference in the magnitude of change between extension and flexion for all time point.

A significant interaction effect ($p < 0.05$) was found for changes in MVC torque of the dominant leg between extensors and flexors. A post-hoc test showed a significant difference at immediately post-match such that the magnitude of decrease was greater for flexors (17.9 ± 8.1%) than extensors (10.6 ± 2.5%).

When changes in MVC torque of knee extensors and flexors were compared between dominant and non-dominant legs, a significant interaction effect ($p < 0.05$) was found for both. A post-hoc test showed that a significant difference at 1 h post-match occurred such that the magnitude of decrease was greater for the dominant leg (14.6 ± 3.2 %) than the non-dominant leg (12.4 ± 4.1%) for the knee extensor torque, and for the dominant leg (16.0 ± 7.4 %) than the non-dominant leg (12.5 ± 6.2%) for the knee flexor torque.

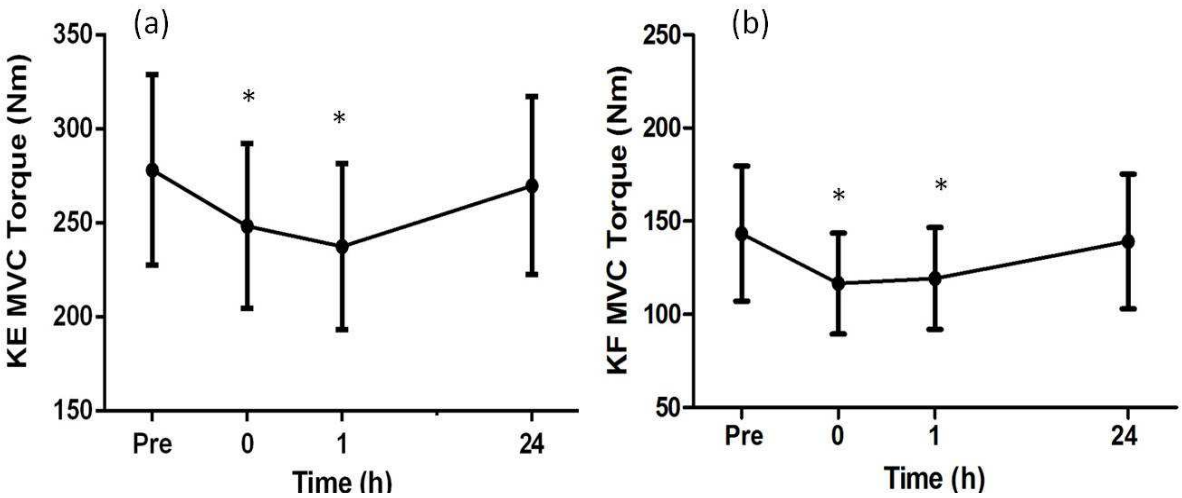


Figure 9: Changes (mean ± SD) in maximal voluntary isometric contraction (MVC) torque of the knee extensors-KE (a) and the knee flexors-KF (b) for the dominant leg prior to match (Pre), within 10 min after match (0), 1 h post-match and 24 hour post-match. * Significantly different from Pre.

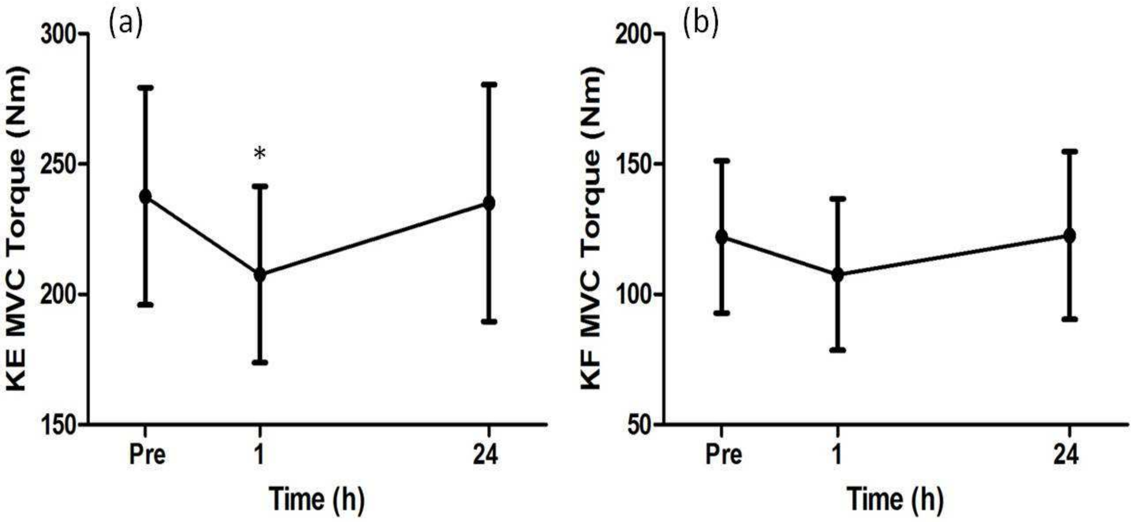


Figure 10: Changes (mean ± SD) in maximal voluntary isometric contraction (MVC) torque of the knee extensors-KE (a) and the knee flexors-KF (b) for the non-dominant leg prior to match (Pre), 1 h post-match and 24 hour post-match. * Significantly different from Pre.

3.5. Voluntary Activation (VA)

As shown in Figure 11, voluntary activation (VA) of the dominant leg was 90.4% at pre exercise, and decreased (P<0.001) 12% at immediately post-match and 8% at 1 h post-match respectively, but recovered to pre exercise by 24 hour post-match.

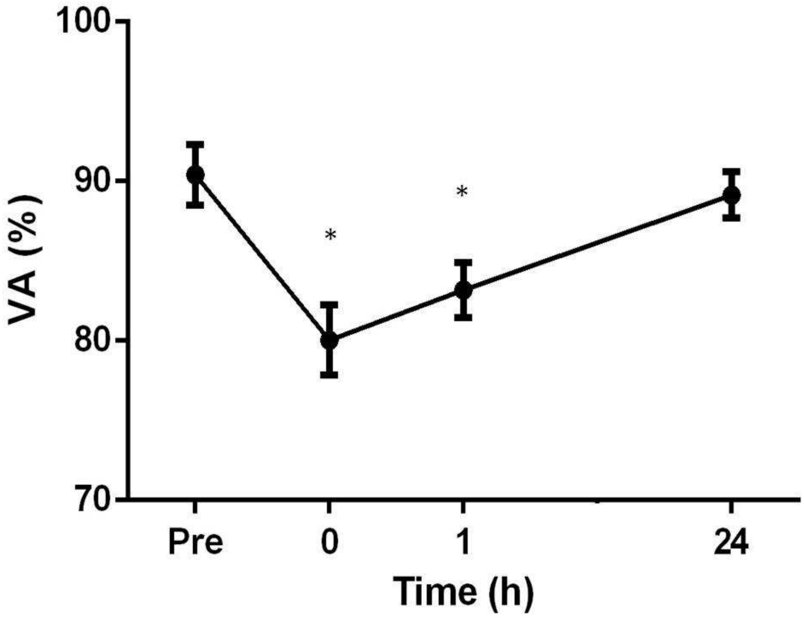


Figure 11: Changes (mean ± SD) in voluntary activation (VA) of the dominant leg prior to match (Pre), within 10 min after match (0), 1 h post-match and 24 hour post-match. * Significantly different from Pre.

3.6. Doublet Torque (DT)

Doublet Torque (DT) for the dominant leg was 75.0 ± 5.6 Nm at pre exercise, which was 28 ± 7 % of MVC torque of KE for the same leg. DT decreased 13% at immediately post-match ($P<0.001$), but interestingly recovered to baseline at 1 h post-match (Figure 12).

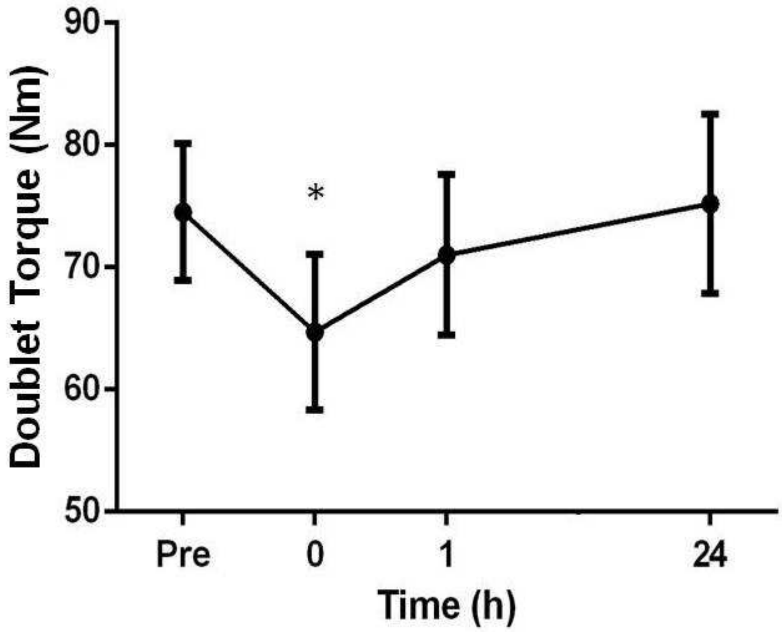


Figure 12: Changes (mean ± SD) in doublet torque (DT) for the dominant leg prior to match (Pre), within 10 min after match (0), 1 h post-match and 24 hour post-match. * Significantly different from Pre.

3.7. Low and High Frequency Stimulation

As shown in Figure 13, both the torque induced by the low (20 Hz) frequency (T20) and high (80 Hz) frequency (T80) electrical stimulation decreased from baseline (92.5 ± 18.1 Nm for T20 and 142.8 ± 31.6 Nm for T80, respectively) by 31% and 25%, respectively at immediately post-match, and 24% and 16%, respectively at 1 h post-match. Interestingly, both recovered to baseline by 24 hour post-match ($P<0.05$).

A significant interaction effect was found for changes in torque between T_{20} and T_{80}, and a post-hoc test showed a significantly greater decrease in torque was greater for T_{20} (31.1 ± 12.3%) than T_{80} (25.5 ± 7.9%) at immediately post-match, and T_{20} (24.3 ± 14.6%) than T_{80} (15.8 ± 8.0%) at 1 h post-match.

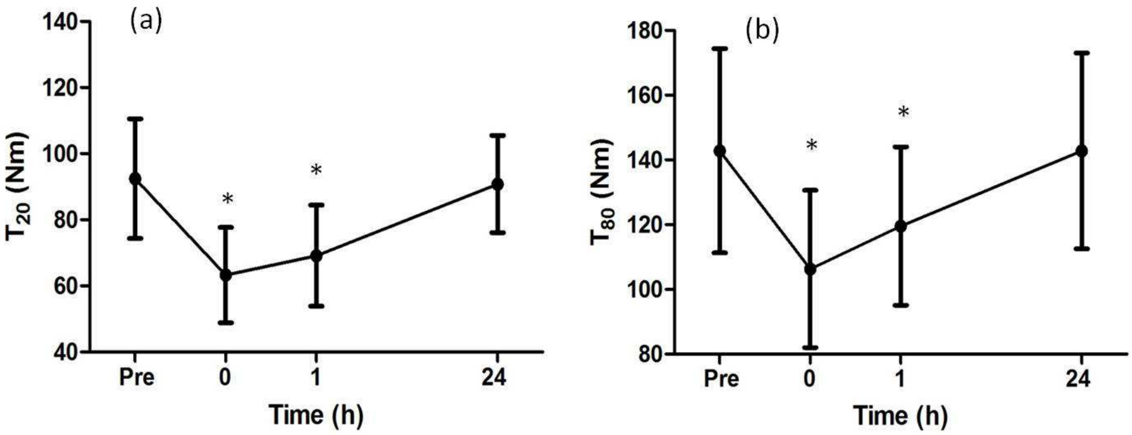


Figure 13: Changes (mean ± SD) in knee extension torque induced by 20 Hz stimulation (a) and 80 Hz stimulation (b) for the dominant leg prior to match (Pre), within 10 min after match (0), 1 h post-match and 24 hour post-match. * Significantly different from Pre.

Figure 14 show the ratio between T_{20} and T_{80}. The pre exercise ratio was 0.66 ± 0.07, and no significant changes in T_{20}/T_{80} was evident at immediately post-match, but a 10% decrease ($P<0.05$) was observed at 1 h post-match, and returned to pre exercise at 24 hour post-match.

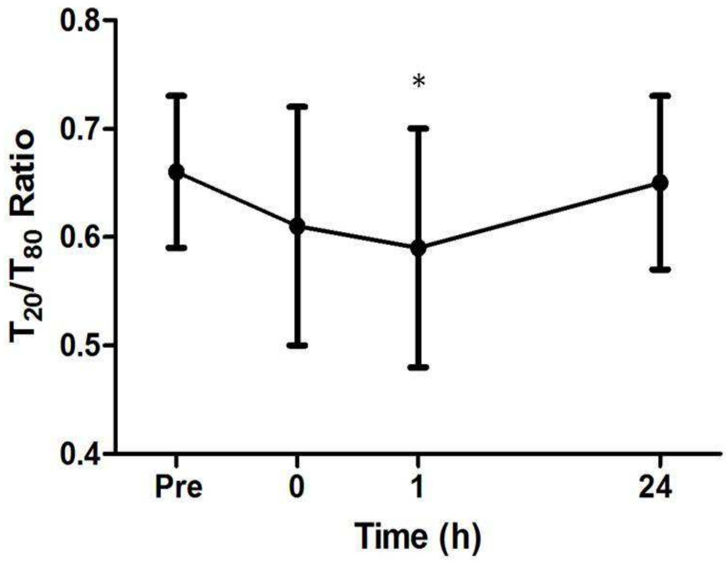


Figure 14: Changes (mean ± SD) in T_{20}/T_{80} ratio for the dominant leg prior to match (Pre), within 10 min after match (0), 1 h post-match and 24 hour post-match.

* Significantly different from Pre.

3.8. Visual Analog Scale (VAS)

As shown in Figure 15a, the VAS for the dominant leg was 2.4 ± 2.1 mm at baseline, and increased to 34.4 ± 11.2 mm immediately post-match (P<0.001) and further increased to 51.5 ± 11.6 mm at 24 hour post-match (P<0.001). Interestingly, VAS for the non-dominant leg was 1.9 ± 1.5 mm at baseline, and increased to 18.8 ± 8.6 mm at immediate post-match (P<0.001). However, it recovered to baseline to 8.3 ± 6.1 mm at 24 hour post-match (P<0.001) as shown in Figure 15b, which was opposite for the dominant leg.

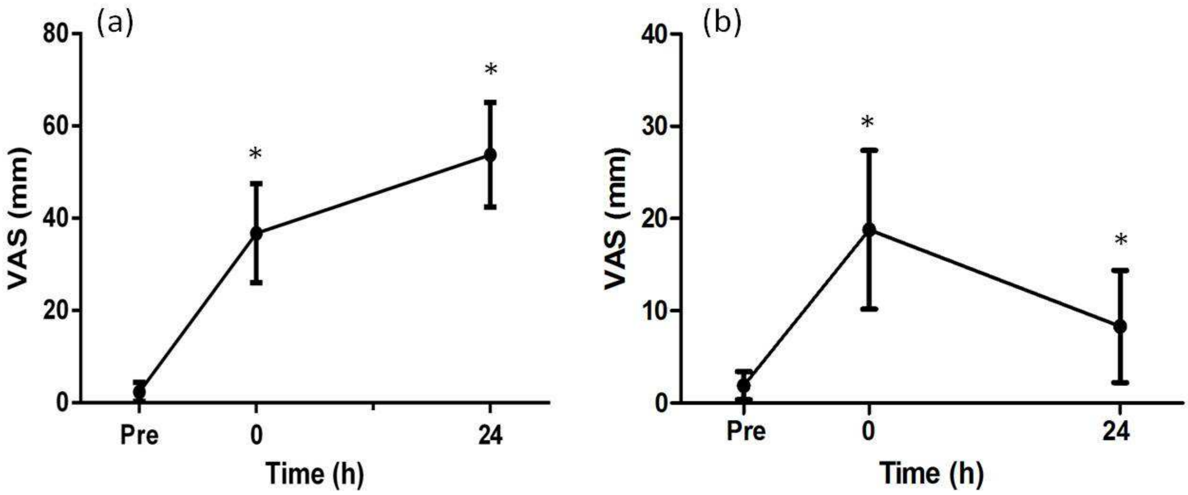


Figure 15: Changes (mean ± SD) in visual analog scale for muscle pain for the dominant leg (a) and the non-dominant leg (b) prior to match (Pre), within 10 min after match (0), and 24 hour post-match. * Significantly different from Pre.

3.9. Hand Grip Strength

As shown in Table 4, no significant changes in the hand grip strength were evident before and after a simulated match.

Table 4: Changes (mean ± SD) in hand grip strength of dominant and non-dominant hand before (Pre-match), immediately after (Post-match) and 24 hour after match (24 hour Post-match).

Variable	Pre match (kg)	Post-match (kg)	24 hour Post-match (kg)
Dominant Hand	56.7 ± 12.9	56.6 ± 11.4	57.7 ± 11.5
Non-Dominant Hand	49.7 ± 9.6	50.3 ± 8.8	51.4 ± 8.6

3.10. Correlation between Variables

As shown in Figure 16a, the number of total lunges and the magnitude of change in knee extensor MVC torque from pre- to immediately post-match were correlated (r = 0.64, p<0.001). Figure 16b shows a poor significant correlation between the number of total lunges and the magnitude of change in knee extensor MVC torque from pre- to 1 h post-match (r = 0.36, p<0.05). No possible correlation was found to be associated between the number of (total/full) lunge and knee flexor strength.

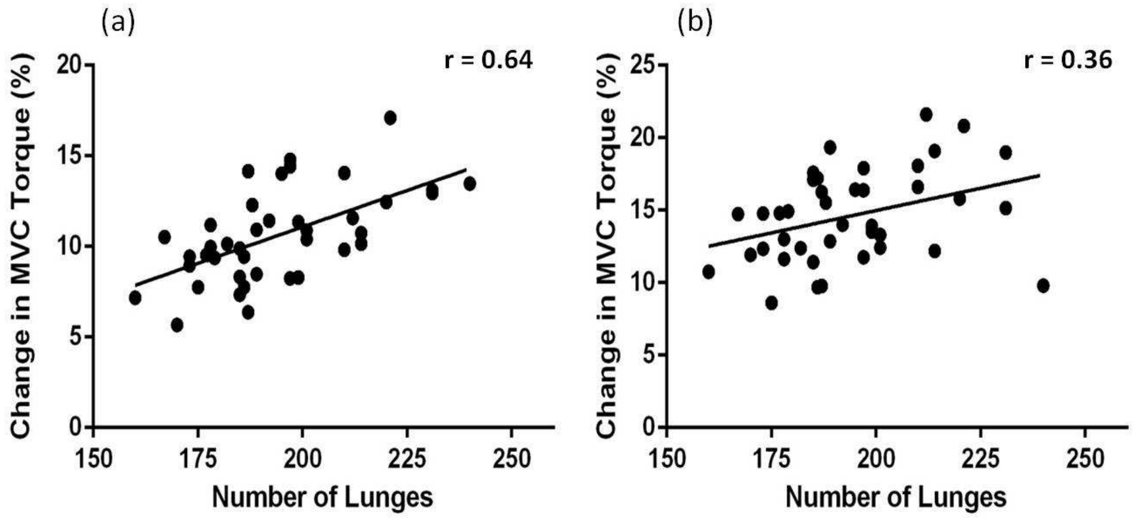


Figure 16 : Correlation between the number of lunges and the magnitude of change in maximal voluntary isometric contraction (MVC) torque of the knee extensors of the dominant leg (%) from pre- to immediately post-match (a), and pre- to 1 h post-match (b).

As shown in Figure 17, a significant correlation was found between the number of full lunges and the magnitude of change in MVC torque of the knee extensor of the dominant leg from pre- to immediate post-match (a, $r = 0.68$, $p<0.001$) and from pre- to 1 h post-match (b, $r = 0.39$, $p<0.05$).

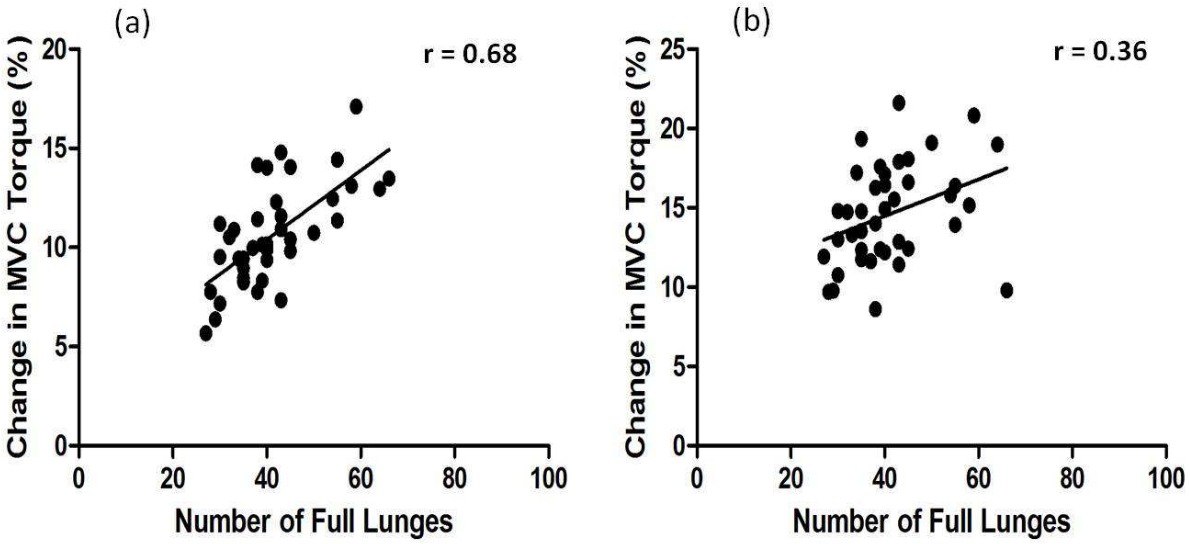


Figure 17: Correlation between the number of full lunges and the magnitude of change in maximal voluntary isometric contraction (MVC) torque of the knee extensors of the dominant leg (%) from (a) pre- to immediate post-match, and (b) from pre- to 1 h post-match.

As shown in Table 5, a significant correlation was observed between the total number of lunges and core body temperature (r = 0.41, p<0.001), and blood lactate (r = 0.61, P<0.001), as well as, the number of full lunges and core body temperature (r = 0.54, p<0.001), and blood lactate (r = 0.75, p<0.001). However, no significant association were observed for heart rate and VAS for the dominant leg.

Table 5: Correlation between number of total and full lunges and heart rate (HR), core temperature (T_{core}), blood lactate (BL) and visual analog scale (VAS) for muscle soreness of the dominant leg. * Significant (P<0.05) correlation.

	HR	T_{core}	BL	VAS
# Lunges (Total)	r = 0.03	r = 0.41 (P<0.001)*	r = 0.61 (P<0.001)*	r = 0.17
# Lunges (Full)	r = 0.17	r = 0.54 (P<0.001)*	r = 0.75 (P<0.001)*	r = 0.17

As shown in Figure 18, the average heart rate during badminton match was correlated with the magnitude of change in knee extensor MVC torque of the dominant leg from pre- to immediate post-match (a, r = 0.57, p<0.01), pre- to 1 h post-match (b, r = 0.47, p<0.01).

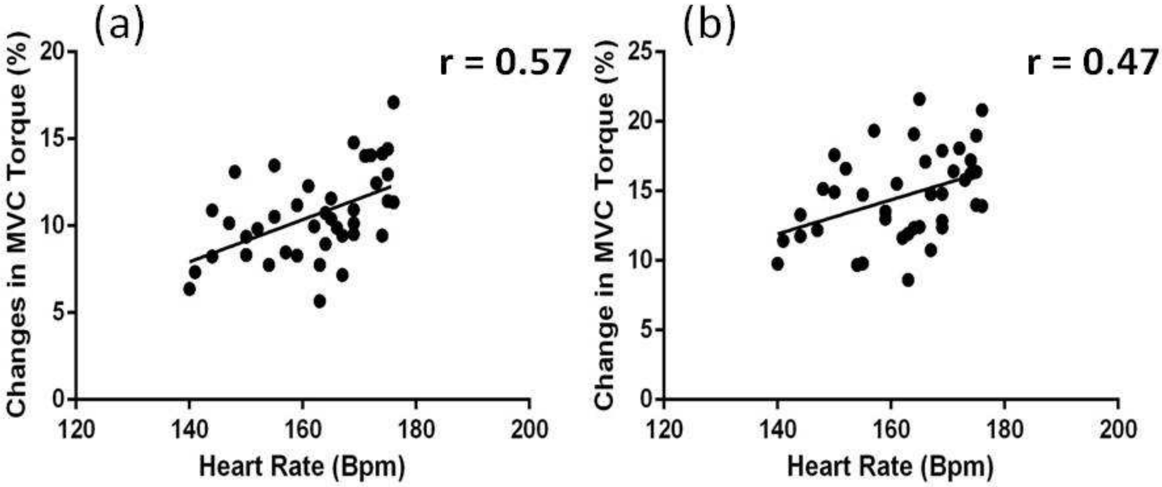


Figure 18: Correlation between heart rate and the change in maximal voluntary isometric contraction (MVC) torque of the knee extensors of the dominant leg (%) from (a) pre- to immediate post-match, (b) pre- to 1 h post-match.

HR was also correlated with core body temperature (r = 0.42, p<0.005), blood lactate (r = 0.4, P<0.001) and muscle soreness (VAS) of the dominant (r = 0.5, p<0.001) and non-dominant leg (r = 0.42, p<0.05).

CHAPTER FOUR

4. DISCUSSION

The purpose of this study was to examine changes in neuromuscular function after 1-h simulated singles badminton matches played by high-level players in relation to physiological characteristics and movements (i.e. the number of lunges) performed during the games. The main findings were as follows: (i) average VO_2 consumption during matches was ~80% of each player's maximal oxygen consumption, with an average heart rate of 84% of their maximum heart rate (observed during the match) and a 3°C increase in core temperature (observed post-match); (ii) both knee extensor and flexor MVC torque of the dominant leg (i.e. on the racket side) decreased immediately (-11% and -18%, respectively) and 1 h (-14% and -16%, respectively) post-match, which was accompanied by significant reductions in voluntary activation of the knee extensors, T20 and T80 torque. Peak doublet torque was observed to only decreased at immediate post-match while T20/T80 ratio only decreased at 1 h post-match; (iii) knee extensor MVC torque of the non-dominant leg also decreased (-12%) at 1 h post-match. This was accompanied by decreases in voluntary activation (immediately: -12%, 1 h: -8%) and peak doublet torque (-13%, -4%) of the knee extensors immediately post-match, respectively for the dominant leg, but knee flexor MVC torque of the non-dominant leg was unaffected and handgrip strength did not change in either both arms; (iv) muscle soreness increased in both legs immediately post-match with a further increase being observed for the dominant leg at 24 hour post-match, but the level of pain was moderate; and (v) the number of lunges and full lunges performed during the match was significantly correlated with the magnitude of decrease in knee extensor and knee flexor MVC torque immediately and 1 h post-match. These findings suggest that the 1-h simulated badminton match, which appears to well represent matches that players perform in competitions, induced neuromuscular fatigue, although muscle soreness was moderate, and that the number of lunges especially full lunges contributed to the fatigue.

In the sections below, (i) the metabolic demand and the movement patterns of players during the simulated singles badminton match, and (ii) neuromuscular fatigue following a simulated singles badminton match in relation to movement patterns and metabolic demands, are discussed.

4.1. Metabolic Demand and Lunges

Previous studies have described badminton as a high-intensity and intermittent sport, which requires the players to be aerobically fit (Faude et al., 2007; Girard and Millet, 2008). It has also previously been reported that absolute strength recorded by 1-RM squat was 143.2 ± 17.3 kg and lower body power during countermovement jump was 3977 ± 385 W (Lees, 2003; Ooi et al., 2009) indicating that players can produce significant lower body force and power. Faude et al. (2007) reported that the average VO_{2peak} of 12 internationally ranked players was 61 $ml \cdot min^{-1} \cdot kg^{-1}$ with an average heart rate of 190 bpm during the VO_2 max test. In the present study, the average VO_{2max} was 57 $ml \cdot min^{-1} \cdot kg^{-1}$ and maximum heart rate was 188 bpm. Thus, the players used in the present study appear to be comparable to internationally ranked players. Cabello et al. (2003) also showed that the average heart rate was 89% of the heart rate max during a match, which was consistent with the current study, although Faude et al. (2007) showed that average oxygen uptake during a singles badminton match was 73% of VO_{2max} and heart rate was 89% of heart rate max, which were lower than those found in the present study (Table 3). It should be noted that the oxygen consumption for matches in the present study was calculated based on the playing period only (Figure 3), but it was not clearly described whether this was also the case for the studies by Faude et al. (2007) and Cabello et al. (2003). CR-10 increased to 7 ± 2 at the end of the match, indicating that the 1-h simulated badminton match was ‘hard’ to ‘very hard’.

Core body temperature increased to 39.4^{o}C immediately after simulated matches. No previous study has reported changes in core temperature after a badminton match, furthermore, the increase (approximately 3^{o}C) appears to be large, considering the oxygen consumption and heart rate during the game, and the high-intensity intermittent nature of the sport (Glaister, 2005). It is noteworthy that some players’ core temperatures exceeded 40^{o}C. The simulated matches were performed in a temperature of 24^{o}C with a relative humidity of 50%, but it is possible that some matches in tournaments are held in higher temperature and humidity conditions. In addition, Racinais et al. (2011) found that hyperthermia subjects were unable to maintain their maximal muscle drive to the muscle, which may limit the force generating capacity. Thus, strategies to minimise the large increases in body temperature like wearing cooling vest during longer rest interval or consuming of cold beverages are necessary, since it has been documented that body temperature significantly affects performance (Abbiss and Laursen, 2005). In the present study, the blood lactate concentration increased to 7.2 $mM^{.}L^{-1}$ post-match. Faude et al. (2007) reported that blood lactate concentration after badminton match was 3 to 6 $mM^{.}L^{-1}$, which is comparable to that found in the present study. These data indicate a reasonable contribution of the anaerobic energy system to the total energy contribution of singles badminton play and is suggestive that specific conditioning may be required to improve this capacity in players.

In the present study, the total of lunges ranged between 160 and 240, and approximately 20% of them were full lunges. Kuntze et al. (2010) reported that the frequency of lunges accounted for 15% of overall movements that include jumping, side-stepping, shuffling, and lunging; however, no actual number of lunges performed was documented in their study. Other movements were not examined in the present study but it seems likely that the simulated matches consisted of similar movements to those used by subjects in the study of Kuntze et al. (2010). Kuntze et al. (2010) stated that lunges were the most frequently performed movement in a typical badminton match. Cornin et al. (2003) and Kuntze et al. (2010) pointed out that the eccentric contractions were performed during the impact loading phase (e.g. Gluteus, quadriceps and calf muscles), and the ground reaction force required to halt the body's horizontal and vertical momentum during forward lunges was greater than that during the drive off phase. Higher level athletes tend to execute full lunges more frequently as they tend to stretch further and attaint a lower position with greater knee flexion and extension angles (Andersen et al., 2007; Lees, 2003), thus placing more stress on the quadriceps muscle group, which in turn could result in greater impairment in muscle function. It seems possible that lunges are the main cause of the decreases in MVC torque after matches as discussed below.

4.2. Neuromuscular Fatigue and Muscle Damage

MVC peak torque of both the knee extensors and flexors of the dominant leg decreased 11% and 14%, respectively, immediately post-match and no recovery was evident after 1 h. This was accompanied by decreases in voluntary activation (immediately: -12%, 1 h: -8%) and peak doublet torque (-13%, -4%) of the knee extensors immediately post-match, respectively for the dominant leg. Interestingly, peak MVC knee extensor torque in the non-dominant leg also decreased (-12%) at 1 h after the match, although the magnitude of decrease was significantly smaller than that in the dominant leg. This was likely related to the execution of lunges in which the knee extensors of the dominant leg were mainly used, as other movements seemed to be equally performed by both legs. It should be noted that MVC torque and other muscle function variables returned to baseline at 24 hour post-exercise. Although muscle soreness was present in the dominant leg at 24 hour after the match, it seems likely that muscle damage was minimal.

Girard et al. (2006) reported gradual decreases in knee extensor MVC torque over a 3-h simulated tennis match, resulting in a 13% decrease at the end of the matches that did not recover in the 30 min after the match. Girard et al. (2010) also reported a 16% decrease in knee extensor MVC torque immediately after a 1-h simulated squash match played by elite players. It appears that the magnitude of decrease in the MVC torque in the present study was comparable to those after play in other racket sports (Girard et al., 2006 and 2010).

It should be noted that MVC knee extensor torque decreased further from immediately post- to 1 h post-match, and this was accompanied by greater decreases in T_{20} than T_{80}, suggesting low frequency fatigue and thus E-C coupling failure (Girard and Millet, 2008). Interestingly, knee extensor MVC torque did not recover even after 1 h, which could have resulted from a decrease in motor neurone excitability. Despite the fact that voluntary activation was reported to have reduced significantly across post-match and 1 h post match, which reflected that there were some signs of development of central fatigue, we have no possible distinction between spinal and supraspinal components. In addition, motoneuron pool excitability modulations have been evidenced from the plantar flexors (Girard et al. 2010), thus suggesting that different muscle groups may have contributed differently to the development of central fatigue.

It should also be noted that muscle pain developed immediately after match for the dominant leg only, and the pain increased further at 24 hour post-match. It might be that muscle pain was associated with the decreases in MVC torque, as neuromuscular fatigue could be related to a modulation of gain in the spinal loop, which could involve the group III and IV afferents (Gandevia, 2001) which in turn contributed to the cause of central fatigue along with reduction of voluntary activation. Furthermore, Girard and Millet (2008) stated that a decrease in motor neurone excitability in response to metabolic disruption could remain as a potential fatigue factor which would affect the ability to perform the activation of synergistic musculature.

However, if central fatigue was mainly responsible for the MVC torque decrease after match, the handgrip strength of both hands might be speculated to also decrease post-match, but this was not this case, which was consistent with previous studies (Girard et al., 2010 and Abian-Vicen et al., 2012). Girard et al. (2010) found no changes in handgrip strength after a squash match, and concluded that the loss of cortical excitability intrinsically was probably not the only cause of the central fatigue. Therefore, it appears that the loss of MVC more than 1 hour and decrease in T_{20}:T_{80} indicates a peripheral fatigue most likely associated with a reduced activation of the dihydropyridine-ryanodine receptor complex or sensitivity of calcium within the actomyosin complex.

Furthermore, the number of lunges and full lunges was significantly correlated with the magnitude of decrease in knee extensor MVC torque of the dominant leg at immediately and 1-h after match. This suggests that the execution of lunges, especially the full lunges, was an important cause of the fatigue leading to the decreases in the MVC torque. Although there was no significant correlation between the number of lunges and the magnitude of decrease in knee flexor MVC torque in the dominant leg, the reduction of MVC torque for knee flexion was evident. Lees (2003) stated that the braking action when applied in recovery to base after each stroke, apart from the application of lunge could have also contributed in the overall muscle function loss. This could explain the decrease in the knee flexor MVC torque.

Regarding muscle soreness, it is noteworthy that players reported muscle soreness already immediately after the match, and it further increased at 24 hour after match. The magnitude of muscle soreness was greater for the dominant leg than non-dominant leg even though the non-dominant leg show significant difference in muscle soreness at 24 hour post-match but has shown to have recovered close to baseline. This may have resulted from non-dominant leg muscles remaining relatively uninvolved in the lunge movements, at least relative to the dominant leg. Most other movement patterns were performed by both leg and therefore indicate the fact that lunges might indeed prove to be the movement which leaded to decrease of knee extensor muscle strength. As discussed above, the recovery of muscle function by 24 hour post-match suggests that muscle damage was moderate, probably due to the protective effect that was conferred by regular training and matches. However, it is interesting to note that the players still experienced moderate muscle soreness at 24 hour after match, which is a symptom of muscle damage. It may be that connective tissue surrounding muscle fibres and fascicles (i.e. endomysium, perimysium) was damaged and inflamed during matches, which evoked pain but was not sufficient to cause a prolonged loss of muscle force production (Rampinini et al., 2011). Further study is necessary to investigate the cause of the muscle pain after matches.

4.3. Conclusion

This was the first study to show the core body temperature change after matches, and the average temperature immediately post-match was over 39°C (and 40°C being observed in some players). The matches consisted of many lunges with a range of 160 – 240, which appeared to be roughly 15% of the overall movement patterns.

MVC knee extensor and flexor torque decreased (10-20%) immediately and 1 h after the match, but recovered by 24 hour post-match for the dominant and non-dominant legs. Decreases in voluntary activation, doublet torque, torque induced by 20 Hz and 80 Hz stimulation, and T_{20}/T_{80} ratio was also evident after match, but all returned to the baseline at 24 hour post-match. These changes appeared to be associated with the number of lunges, especially full lunges performed in the matches and indicate that peripheral mechanisms at least partly underpinned the loss of force generating capacity. The magnitude of muscle soreness was greater for the dominant leg than non-dominant leg even though the non-dominant leg show significant difference in muscle soreness at 24 hour post-match but has shown to have recovered close to baseline. Although mild muscle soreness was evident 24 hour after matches, it appears that muscle damage induced by the matches was moderate since the loss of muscle function was not observed at 24 hour post-match. This was likely due to the protective effect that the players obtained from their regular training and experiences in matches. In addition, the results of the present study confirmed that badminton singles matches are high intensity intermittent events as indicated by the average oxygen consumption of 80% of VO_2 maximum and a heart rate of 84% of heart rate maximum during play. In conclusion, both central and peripheral factors contribute to alterations in neuromuscular fatigue following a 1 h simulated singles badminton match.

4.4. Practical Application

The findings of the present study indicate several important applications to players and coaches. Firstly, players and coaches need to consider strategies to attenuate increases in body temperature. It has been clearly shown that an increase in body temperature is an important factor limiting exercise capacity (Abbiss and Laursen, 2005). In the present study, the average core temperature increased to a mean of 39°C, and increased to > 40°C in some of the players. It is assumed that greater increases in body temperature are induced if matches are held in hotter and more humid conditions than that of the present study (24°C, 50%), and/or higher intensity and longer duration matches are performed. Therefore, cooling strategies (i.e. wearing cooling vest and consumption of adequate cold fluid) could be adopted to limit core temperature increase during interval of match play. Secondly, it may be necessary for coaches and players to focus on resistance training to strengthen leg muscles especially knee extensors and flexors. The results of the present study revealed an association between the number and type of lunges performed in the matches and decreases in knee extensor strength. It is possible that a large number of full lunges results in a greater loss of knee extensor strength. It may be that the eccentric contractions performed in the lunges induce greater muscle soreness that lasts several days, and might induce muscle damage lasting more than 24 hour. Thus, resistance training incorporating eccentric contractions should be prescribed to improve knee extensor and flexor muscle strength and thus fatigue resistance. However, without any detailed report of match structure (point duration), no specific analysis of the energy requirement (time spent above a given intensity) or movement patterns (only lunges) it is felt that the main novelty is more about neuromuscular fatigue characteristics. Thirdly, a possible use of a handheld dynamometer (force chair) could be considered as it is reliable and valid in field (Crow et al., 2010).

4.5. Future Research Directions

Future studies should include (i) a more detailed oxygen consumption analysis in relation to movement patterns by isolating movement patterns and oxygen consumption region and determining the trend of change in oxygen consumption, and (ii) examination of whether resistance training of the lower extremities (e.g., knee extensors and flexors) helps to prevent DOMS and loss of muscle function. It is also necessary to (iii) establish a simple method to assess changes in muscle function in relation to fatigue and muscle damage as in the present study, MVC torque was measured using an isokinetic dynamometer which this methodology cannot usually be performed in a practical situation. Thus, measurements that could be performed easily but are reliable and valid should be established. Lastly, it is necessary to (iv) identify the difference between other time points in reference to the nature of the game could provide further information of recovery of muscle activity.

4.6 Limitations

Limitations to the current study include (i) time point (10 min) between exercise cessation and the start of the neuromuscular assessment may have allowed a substantial recovery, (ii) measuring of blood lactate concentration, RPE and core temperature at match end of presenting match-averaged VO_2, HR and core temperature values were not likely to accurately reflect match demand, (iii) no hydration or pre-body weight measurements were taken, (iv) VAS for muscle soreness was subjective and not using a previously published technique, (v) the nature of the game (being based on playing time) rather than playing to win could influence the effort of the players, and the fact these were simulated games and not matches within a competitive environment (such as a tournament), (vi) strength and significance of a relationship provide no insight into whether the relationship between two variables is causal.

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APPENDIXA:
Informed Consent Document

Title of the project

Physiological and movement characteristics of singles badminton matches

Researchers and Contact details

Ryan Lin,
School of Exercise and Health Sciences
Edith Cowan University
270 Joondalup Drive, Joondalup, WA 6027
Mob: 0420871848
Email: z.lin@ecu.edu.au

Statement indicating consent to participate

I, ____________________________, have read the information letter provided. Any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I confirm the following:

- I have been provided with a copy of the Information Letter, explaining the research study
- I have read and understood the information provided
- I have been given the opportunity to ask questions and I have had any questions answered to my satisfaction
- I am aware that if I have any additional questions I can contact the research team
- I understand that participation in the research project will involve:
    - A total of 16 testing sessions including an incremental running test, a familiarisation session, eight sessions of simulated badminton match play with muscle function testing and only muscle function testing 24 hours after each simulated badminton match play.
    - Measurements of heart rate, oxygen consumption, core body temperature, perceived exertion stress, muscle soreness, electromyography, hand grip strength and on-court movements.
    - All sessions of simulated badminton match play will be video recorded and used for future data analyses.
    - A small sample of blood drawn from my finger on a number of occasions during the simulated badminton matches.
    - Performing of maximal isometric knee extensions; kicking outward like action and knee flexions; kicking inward like action while sitting on the strength dynamometer.
    - The delivery of electrical stimulations to the femoral nerve.

- I understand that my information provided will be kept confidential, and that my identity will not be disclosed without consent
- I understand that the information provided will only be used for the purposes of this research project, and I understand how the information is to be used
- I understand that I am free to withdraw from further participation at any time, without explanation or penalty
- I understand that if I choose to withdraw part way through the study, the researchers may be unable to remove my data from the project
- I freely agree to participate in the project
- Emergency Contact Details
- Please provide at least 1 point of contact in case of any emergency.

Name:	______________________	Name:	______________________
Relationship:	______________________	Relationship:	______________________
Contact:	______________________	Contact:	______________________

-
-
- **Signed** ……………………………………………… **Name**………………………………………. **Date**……………
-
- **Signed by member of research team** ………………………………………………….

APPENDIX B: INFORMATION LETTER TO PARTICIPANT

Information Letter to Participants

Title of the project

Physiological and movement characteristics of singles badminton matches

Researchers and Contact details

Ryan Lin

School of Exercise and Health Sciences

Edith Cowan University

270 Joondalup Drive, Joondalup, WA 6027

Mob: 0420871848

Email: z.lin@ecu.edu.au

DESCRIPTION OF THE RESEARCH PROJECT

This study aims are to understand physiological and movement characteristics of badminton singles matches from a simulated match scenario to provide better post-match recovery, game and training strategies.

You have been asked to participant in this project because of your excellent playing experience. If you were to participate in this study, you will be asked to be involved in 18 sessions which comprise of: one familiarisation session, one maximal aerobic capacity test, eight exercise test sessions and follow-up of muscle function test session 24 hours after each exercise test session. The details of the testing procedures can be found below. Laboratory testing for the muscle function testing will be conducted at the Exercise Physiology Laboratory (Building 19, Room 19.150) at Edith Cowan University (Joondalup) while the simulated badminton match play will be performed at the Sports Centre (Building 22) at Edith Cowan University (Joondalup). Each exercise test session comprises of one hour of simulated singles badminton match with a pre and post muscle function measurement testing and the session will last for approximately 2 - 3 hours. For the follow-up of muscle function test session, it will last for approximately 1 hour.

Prior to the commencement of all laboratory testing, you will be required to complete a set of medical questionnaire, just so in the event of any medical conditions being indicated by you, the researcher will be able to take note of that so as to minimise any form of incidents that may occur during laboratory testing.

This study has been approved by the ECU Human Research Ethics Committee.

TESTING PROCEDURES

Familiarisation session: During the first laboratory visit, you will undergo an anthropometric assessment (height and weight) and be familiarised with muscle function and oxygen consumption measurements. This session will last for approximately one hour.

Maximal aerobic capacity test session: You will be asked to perform an incremental exercise test for the determination of aerobic capacity (VO_{2max}). The incremental running test will start at a relatively light intensity of 10 $km \cdot h^{-1}$ and every 1 minute the intensity will be increased by 2 $km \cdot h^{-1}$ until you have reached the fastest running speed possible (i.e. your maximal aerobic capacity). During this test, your expired gases will be monitored via a portable metabolic gas analyser. This test typically lasts 20-30 minutes but will depend on your fitness.

Exercise test session: You will be required to perform the muscle function measurements before you proceed to one hour of simulated singles badminton match play. After the match play, you will be required to perform the muscle function measurements at 10 minutes and 60 minutes after the match play. As such, the details of the muscle function measurements and simulated singles badminton match play can be found below.

Simulated singles badminton match play: You will be required to complete a total of eight singles matches over 30 days with a minimum of 2 days and maximum of 4 days rest between matches. Matches will be played under the rules of the Badminton World Federation however they will be played over one hour regardless of the scores. You will be allowed to rest for a maximum of 120 s between sets, after which, there will be a changeover of sides.

During each simulated badminton match play testing session, all matches will be recorded using three seperate digital video cameras and you will be asked about your rate of perceived exertion immediately at the end of the match play session. The following measurements will be made:

- *Heart Rate* - Your heart rate will be monitored continuously with a personal monitor
- *Core Body Temperature* - Your body temperature will be measured using a telemetric pill ingested 6 – 8 hours prior to testing throughout the simulated badminton match
- *Oxygen Consumption* - Expired gases during the simulated badminton match will be monitored via a portable metabolic gas analyser
- *Blood Lactate* - A small amount of capillary blood sample (<0.5mL) will be taken from a finger prick before the start of the simulated badminton match play, during changeover of each set of game and ten minutes after following each session.

Muscle function measurements: You will performed the muscle function test first with the leg that is corresponding to you holding the racket (dominant side) followed by the opposite leg. However, at 10 minutes after the simulated badminton match play, you will only be required to perform the muscle function measures to the dominant leg due to time constraint.

- *Knee Extensor Muscle Strength* - You will be required to perform 2 maximal voluntary isometric contraction with electrical stimulation to the knee extensors; 2 maximal voluntary isometric contraction of the knee flexors without the electrical stimulation for both limbs

For the electrical stimulation procedure, a small electrical current will be applied to the femoral nerve. The stimulation will be initiated at very low intensities and progressively increased until your muscle is maximally activated or you feel discomfort; at maximal intensities the electrical stimulation might be slightly uncomfortable. The time points of the electrical stimulation administered will be as follow:

- 3 electrical stimulations separated with a 5 seconds interval, will be administered before the commencement of the contraction of knee extensors
- 1 electrical stimulation will be administered 5 seconds after the execution of each contraction
- 2 separate electrical stimulations (80Hz and 20Hz) separated with a 30 seconds interval, will be

administered after the completion of the 2 contractions of knee extensors

- *Electromyography (EMG)* - You will be monitored continuously with small self-adhesive skin-mounted electrodes which will record the electrical signals emanating from your quadriceps muscles during the knee extensor muscle contractions
- *Handgrip Strength* - You will be asked to perform handgrip test using a manual handheld dynamometer for both hands
- *Muscle Soreness* - You will be assessed via a 100-mm Visual analogue scale (VAS) through single leg forward lunge for each leg

Post 24 hour muscle function test session: You will be required to come back 24 hours after the exercise test session to complete a set of muscle function measurements with the details of the test as explained above.

Risks and Benefits

During both the simulated badminton matches and laboratory testing sessions it is possible that you may experience fatigue and muscle soreness. It is also possible that injury may occur (albeit unlikely) however a person with first aid training will be present at testing sessions.
As with all tests of maximal muscle force production, there is the chance for muscle or tendon strain. This risk is low given that proper warm-up and familiarisation will be performed; the tests will be conducted by a researcher who is experienced in the procedures. Electrical stimulation procedures can be uncomfortable, but SHOULD NOT be painful; the researcher will ask for continuous feedback from you. You will benefit from participating in this study by gaining fitness from the exercise and through a better understanding of your own activity, physiological stress and performance during a singles badminton match. This information may assist in improving your game, training and post-match recovery strategies

Confidentiality of information

The information collected in this study will be used to prepare a scientific report to be published in an academic journal and masters thesis. The information will only be available to Ryan Lin and supervisors. Your personal data will be assigned an identification code, such that only those people directly involved in collecting information for the study will be able to recognise which person the information pertains to. The information collected in this study will be stored under file in the School of Exercise and Sport Sciences for a period of 5 years. After this 5 year period the information collected during the course of the study will be destroyed.

Results of the research study

The data collected in this study will be summarised as average data for all participants. There will be no individual data presented, which means that your personal information cannot be identified. The data will be presented at conferences and as a scientific report to be published in an academic journal. If you request it, you will receive a summary of your own personal information and a group summary explaining the findings of the study.

Voluntary participation

Your participation in this study is entirely voluntary. No explanation or justification is needed if you choose not to participate.

Withdrawing consent to participate
You are free to withdraw your consent to further involvement in the research project at any time. If you choose to withdraw, you have the right to request that any personal information collected up to that point in the study is returned to you without question.

Questions and/or further information
For inquiries or additional information, please do not hesitate to contact us.

Investigator: Zengyuan (Ryan) Lin, BSc
Tel: 63042264/ 2242
Mob: 0420871848
Email: z.lin@ecu.edu.au

Supervisors: Prof Ken Nosaka, PhD
Tel: 6304 5655
Email: k.nosaka@ecu.edu.au

Dr Chris Abbiss, PhD
Tel: 6304 5740
Email: c.abbiss@ecu.edu.au

A/P Anthony Blazevich, PhD
Tel: 6304 5742
Email: a.blazevich@ecu.edu.au

Dr Jodie Wilkie, PhD

Tel: 6304 5860

Email: j.wilkie@ecu.edu.au

Independent contact person
If you have any concerns or complaints about the research project and wish to talk to an independent person, you may contact:
Research Ethics Officer
Human Research Ethics Committee
Edith Cowan University

270 Joondalup Drive
JOONDALUP WA 6027
Phone: (08) 6304 2170
Email: research.ethics@ecu.edu.au

The Human Research Ethics Committee at Edith Cowan University requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Human Ethics Research Officer, Human Ethics Research Committee, Edith Cowan University, 270 Joondalup Drive, Joondalup, WA 6027 (Tel: 6304 2170, Email: research.ethics@ecu.edu.au). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

APPENDIX C – TRAINING WORKLOAD QUESTIONNAIRE

PHYSIOLOGICAL AND MOVEMENT CHARACTERISTICS OF SINGLES BADMINTON MATCHES

SCHOOL OF EXERCISE AND HEALTH SCIENCES

EXERCISE LOAD QUESTIONNAIRE

How often do you train for badminton?

____

How long do your badminton training sessions last?

____

Briefly describe the type and amount of any other exercise you may do.

____

Do you engage in any resistance training exercises? YES / NO

If YES please provide details (i.e. type, duration, frequency)

____

____

Have you engage in any lower limb strength training exercise in the past 12 months? YES / NO

If YES please provide details

____

____

Signature : ______________________________ ( )

Date: ______________________________

APPENDIX D - MEDICAL QUESTIONNAIRE

PHYSIOLOGICAL AND MOVEMENT CHARACTERISTICS OF SINGLES BADMINTON MATCHES

SCHOOL OF EXERCISE AND HEALTH SCIENCES

MEDICAL QUESTIONNAIRE

Name: ___________________________ DOB: _____ Weight: ____kg Height: ___cm

Do you smoke? YES / NO

Have you ever been diagnosed with –

being overweight? YES / NO

high blood pressure? YES / NO

diabetes? YES / NO

asthma? YES / NO

any bleeding disorders? YES / NO

Do you have any reason to believe that you are more at risk of cardiovascular disease than a normal member of the population of the same age and sex?

YES / NO

If YES please provide details

____

____

Is there anything that you are aware of that may limit your capacity to exercise? (e.g., Chronic back pain and/or other joint pain, severe headaches?)

YES / NO

If YES please provide details

____

____

Do you have any allergies?

YES / NO

If YES please provide details

____

____

Are you currently on any prescribed or non-prescribed medications?

YES / NO

If YES please provide details

____

____

Do you have any other complaint or any other reason that you know of which you think may prevent you from participating in and completing this experiment?

YES / NO

If YES please provide details

____

____

I believe that the information that I have supplied is true and correct.

Signature : ________________________________ **(** **)**

Date: ________________________________

APPENDIX E - RESEARCH GRANT APPLICATION

Application Form / Proposal
Research Grant 2013/2014

Please use as much space as you wish on the form below. Attach additional background information if you wish. Ensure that all the Evaluation Criteria in the Request for Proposal guidelines are addressed.
Applications close 26 July 2013. *Email to Ian Wright, Development Director i.wright@bwfbadminton.org*

a) Institution / Researcher

Institution's Name	EDITH COWAN UNIVERSITY

Researcher's Name	RYAN LIN ZENGYUAN PROF KEN NOSAKA DR CHRIS ABBISS A/PROF ANTHONY BLAZEVICH DR JODIE COCHRANE

Researcher's Qualifications	RYAN LIN ZENGYUAN: MASTERS CANDIDATE, EDITH COWAN UNIVERSITY. PROF KEN NOSAKA: PHD, PROFESSOR, SCHOOL OF EXERCISE AND HEALTH SCIENCES, EDITH COWAN UNIVERSITY, FORMER DIRECTOR OF CENTRE FOR EXERCISE AND SPORTS SCIENCE RESEARCH (CESSR), POSTGRADUATE COURSE COORDINATOR FOR EXERCISE AND SPORTS SCIENCE. DR CHRIS ABBISS: PhD, LECTURER (EXERCISE PHYSIOLOGY), EDITH COWAN UNIVERSITY. A/PROF ANTHONY BLAZEVICH: PhD, A/PROF (BIOMECHANICS), EDITH COWAN UNIVERSITY. DR JODIE COCHRANE: PhD, LECTURER (BIOMECHANICS), EDITH COWAN UNIVERSITY, HIGH PERFORMANCE MANAGEMENT AND SPORTS SCIENCE CONSULTANT TO BADMINTON AUSTRALIA.

Institutional application **<u>or</u>** ****Individual*** application?	INSTITUTIONAL

** Individual applicants must submit a letter of endorsement / support letter from a university / institution stating the research is being undertaken with the oversight of the university / institution's academic programme.*

Is this study connected to a longer term study through an institution – or as part of post graduate degree work (as part of a Masters or PhD for example). Provide details.	POST GRADUATE DEGREE WORK (MASTERS)

Address	270 Joondalup Drive, Joondalup WA 6027
Mobile Phone	+61 4 20871 848
Phone	+61 6304 2264
Fax	
Email Address	z.lin@ecu.edu.au

b) Research Focus / Scope / Relevance / Outcomes

Description - Research Focus & Scope	Physiology and movement characteristics of men's singles badminton matches
Paradigm / Area (physiology / biomechanics / psychology etc)	Physiology, Biomechanics and Performance Analysis
Originality **–** is this a new area or a follow up focus area that adds value to existing research – if so – how?	This research will build on previous research, using a novel research design to improve our understanding of the fatigue process and metabolic cost during performance in badminton competition. The mean oxygen consumption during simulated singles badminton matches has been

	documented previously (ref). However, the contributions of specific player movements to the energy cost of badminton play is not known, so it is unclear how different match strategies might influence this cost. Indeed, the development of fatigue during badminton will be largely influenced by the player movement patterns and the physiological responses to these movements. Also, while a number of studies have provided strong evidence for a relatively linear increase in fatigue during racquet sports, no study has yet examined the mechanisms of fatigue following competitive badminton matches. Therefore, it is not yet possible to apply specific fatigue management strategies during training or match play. Numerous physiological factors may influence the development of fatigue during exercise, including neuromuscular alterations, muscle damage, dehydration and elevated body temperature. Previous studies have shown significant changes in neuromuscular function, the accumulation of muscle damage and significant dehydration; however these were only assessed from different racquet sports (tennis and squash) and so it is not known whether would there be other factors contributing to this model, and no data are available regarding changes in body temperature. A greater understanding of the factors that are responsible for fatigue during competitive singles badminton matches will allow coaches and sport scientists to improve athlete preparation through effective training, game and recovery strategies.
Research Question(s)	7. Are there relationships between decrements in muscle function and markers of muscle damage following a badminton match and the movement patterns used and metabolic demands imposed during the match? 8. Do measures of voluntary muscle activation percentage and EMG activity (considered to represent central neural drive magnitude) of the knee extensor muscle group decrease after a simulated badminton match? 9. Do maximal knee extensor strength and rate of force development decrease after a simulated badminton match? 10. How often are lunges performed during a simulated badminton match, and is its prevalence associated with markers of fatigue? 11. Does core body temperature increase during a simulated badminton match, and is its magnitude of rise associated with markers of fatigue? 12. What is the average relative intensity (i.e. anaerobic power and heart rate) during a simulated badminton match?
Relevance - to badminton	This research would greatly increase the knowledge towards badminton as it is based on singles badminton match.
Outcomes - how will the outcomes benefit badminton	An improved understanding of the physical (i.e. movement and total work) and physiological loads (i.e. energy cost, heart rate, blood lactate concentration and core

coaches, players and/or members of the entourage.	temperature) of competitive badminton matches is important in the development of training programs used by coaches and athletes. Understanding the mechanisms underpinning the fatigue induced by match-specific badminton play will also assist coaches and athletes to select appropriate training/preparation and recovery strategies that may reduce fatigue and improve overall athlete performance. This knowldege may also assist in talent identification and talent development of singles players.
Immediate Impact – how can the result be applied / used for practice in coaching / talent development / other areas.	This research will provide a greater understanding of physical demands of badminton, which will allow for the development of better address game, training and post-match recovery strategies used to improve badminton performance. This could lead to changes in coaching, training and recovery procedures. Tests to monitor the physical loads and movements of players could be developed to assist the coaches in the identification and/or development of athletes, and these can be trialled to assess their effectiveness in the short-term.
Additional information on the research focus relevant to your application.	From this research, knowing more on fatigue and physical demands of the sport will improve our understanding (and result in future research examining) of the effectiveness of various training interventions, pre-match preparation strategies and post-match recovery strategies that have been shown to be successful in other sports/settings. The researchers involved in this research have also been involved in i.e. High Intensity Training (HIT), CHO supplementation, resistance training, cooling strategies, supplements etc.

c) Research Grant and Estimated Costs

Methodology – brief overview	Ten male players from the Western Australia State badminton team will be recruited for the study. Participants will peform an incremental exercise test on a treadmill for determination of their maximum aerobic capacity. Over 30 days, each participant will play a total of 8 matches against four players of a similar skill/performance level with each match lasting for an hour. Throughout the matches heart rate, oxygen consumption and core body temperature will be continuously monitored. Before each match, in-between sets, and 10 min after the match, blood lactate concentration will be measured. Neuromuscular function of both legs will be assessed by the assessment of maximal voluntary isometric contraction (MVC) torque, and electrical stimulation of the knee extensors will be done before, 10 min, 60 min and 24 hours after each match to assess the level of central (i.e. central nervous system) and peripheral (i.e. muscle) fatigue; peak

	Doublet Torque, H-reflex amplitude, M-wave amplitude and voluntary muscle activation percentage will be assessed with these stimulation procedures. EMG activity of vastus lateralis and vastus medialis will be recorded during the MVC torque measures as an additional measure of central and peripheral function. Handgrip strength from both arms will be measured before and after match to provide a measure of central fatigue. A category ratio 10 (CR10) scale will be used to assess perceived exertion immediately post-match, and a visual analogue scale (100-mm line) will be used to assess delayed onset muscle soreness of the knee extensors before and 24 hour post-match. Notational analysis of the matches (recorded by video) will be conducted using Sports Code software to quantify the total number of specific movements (list some here?) performed by players during match play. The changes in dependent variables over time will be analysed by a one-way and/or two-way repeated measures ANOVA. After testing for the assumption of liinearity of the data, Pearson's product moment correlation coefficients will be computed to quantify the relationships between the variables (e.g. heart rate, core temperature, oxygen consumption, MVC torque); non-linear relationships will be quantified if necessary. From these data, the physiological and movement characteristics of singles badminton matches will be determined, which will provide valuable information for training program design of badminton players.

d) Describe the broad staging of the research – 2013 / 2014

Broad Stages – and time frames	Data collection: August 2013 – November 2013 Data Analysis (First batch): September 2013 – October 2013 Data Analysis (Second batch): November 2013 – December 2013 Complete Data Report: December 2013 Journal Manuscript writing: August 2013 – December 2013 Thesis preparation and submission: February 2014

e) Research Grant and Estimated Costs

Total expected cost of this research project $	Consumables Stimulation electrodes 5X5 cm (20 units) Tape Transpore 3M (1 box) Alcohol wipes (200 units) Razor blades (12 units) Abrasive (4 units) Surgical skin marker MEDI Trace 200 (Kendall) ECG Electrodes	
	Badminton Shuttlecocks	
	Ingestible CoreTemp Thermometer Pill	
	Blood Lactate Strips	
	External Hard Disk and Video Tapes	
	Total Amount:	$5300
Total $ for this Application	$2500	
Other sources of funding and estimated amounts	Edith Cowan University Research Fund. $2800	
Has other sources of funding been secured?	Yes.	

f) What makes this research important for badminton now

Context of the Research for world badminton. Describe how this research is	To date, no studies have examined the physiological characteristics of competitive singles badminton matches under the current scoring system. Thus, the physiological costs of badminton play, and the relative influences of different movement patterns, are currently not known. This lack of knowledge makes it difficult to implement specific strategies to minimise fatigue accumulation, and to tailor strategies to individual players who might use different movement patterns or have varying fatigue responses to such patterns. An

important to conduct just now for world badminton.	understanding of this would immediately improve our ability to develop player-specific training, preparation and recovery routines.

g) Point of Difference / Add Value

Why do you think this research has 'an edge' over other grant applications – what is your point of difference / significant 'add value'.	To date, little research is available quantifying the physical demands and fatigue induced by competitive badminton. But, more specifically, the mechanisms of fatigue have not been detailed and the effects of specific badminton movement patterns have not been defined. Thus, player-specific training routines are impossible to implement, and strategies to delay or overcome 'fatigue' cannot be designed. This detailed analysis, completed in match conditions, will be the first to provide this information and will therefore have immediate impact on training and recovery program design. In the longer term, such information should also be attained in female and youth players as their fatigue profiles (and movement patterns during play) may differ significantly from male players. In addition, the research will provide an edge on talent identification and development for men's singles and that it may also have applications for women's singles. Furthermore, this research could later be developed to assess doubles.

h) Declaration: ***I the undersigned……..***

- ✓ *have read the Request for Proposal guidelines and understand the intent of the BWF Research Grants Programme and the criteria for evaluating applications;*
- ✓ *understand that if I my project is selected for a grant, an MOU / agreement will need to be signed between the BWF and myself / my institution;*
- ✓ *understand that BWF has the right to publish on the BWF website and other communications platforms the names of successful applicants and to provide a synopsis of the focus and scope of the research in order to promote the research project and research in badminton;*
- ✓ *understand that the research findings, methodology and details of the study will be made available to practitioners in the field and published by the BWF on its website or through other BWF communication channels at the conclusion of the research.*
- ✓ *declare that the information in this document is accurate.*

	Signature
Position	
Name / Title	
Signature	
Date	

APPENDIX F – BORG CR-10

rating	description
0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)

for more information see http://www.topendsports.com/testing/rpe.htm